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# Pharmaceutical Wastewater Treatment using Advanced Oxidation Processes (AOPs)

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**Abstract**: *The treatment of pharmaceutical wastewater containing recalcitrant organic pollutants is a significant challenge in modern wastewater management. Conventional treatment methods often fall short in removing stable chemical compounds. Advanced Oxidation Processes (AOPs), which generate powerful radicals such as hydroxyl (•OH) and sulfate radicals ($SO_4$•⁻), offer an effective alternative. In this study, oxidants including Oxone, Sodium Persulfate, Thiosulfate, and Air ($O_2$) were employed to enhance the degradation of pharmaceutical pollutants. This paper discusses the properties of each oxidant, their effects on wastewater treatment, experimental observations, and comparative analysis. AOPs demonstrated promising results and high potential for sustainable wastewater treatment.*

**Keywords**: Advanced Oxidation Process, Pharmaceutical Wastewater, Hydroxyl Radical, Sulfate Radical, COD Reduction, Oxone, Sodium Persulfate, Sodium Thiosulfate

## I. INTRODUCTION

### 1.1 Wastewater Hazards

Water is one of the most critical natural resources for sustaining life. However, in recent decades, rapid industrialization, particularly in the pharmaceutical sector, has significantly contributed to the deterioration of water quality worldwide. Pharmaceutical wastewater typically contains
persistent organic pollutants, heavy metals, pathogenic microorganisms, and emerging contaminants like endocrine-disruption compounds. If untreated, such effluents can cause ecological imbalance, disrupt aquatic ecosystems, and pose serious health risks to humans and wildlife. These contaminants are characterized by their stability, persistence, and potential bioaccumulation in aquatic environments.
The untreated discharge of such wastewater into natural water bodies poses serious environmental and health hazards. The presence of pharmaceutical residues can disturb the microbial balance of aquatic ecosystems, cause endocrine disruption in aquatic organisms, and lead to the development of antibiotic-resistant bacteria, posing a direct threat to human health. Thus, effective treatment of pharmaceutical wastewater is essential for environmental protection and public health.

### 1.2 Treatment Methods

Over the years, several treatment technologies have been employed to address wastewater contamination:

- Physical Treatments such as sedimentation, flotation, and filtration, which primarily remove suspended solids but are ineffective against dissolved organic pollutants.
- Chemical Treatments like coagulation, precipitation, and chlorination, which target specific contaminants but often generate large amounts of chemical sludge and secondary pollutants.
- Biological Treatments like activated sludge processes and anaerobic digestion, which degrade biodegradable organic matter but fail to break down persistent pharmaceutical compounds due to their complex molecular


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structures.

Despite significant advancements, traditional treatment methods often fall short when dealing with the complex and recalcitrant nature of pharmaceutical contaminants. These limitations have fueled the need for more robust, efficient, and environmentally sustainable technologies.

### 1.3 Introduction to Advanced Oxidation Processes (AOP)

Advanced Oxidation Processes (AOPs) have emerged as promising solutions to overcome the drawbacks of conventional treatments. AOPs are based on the in-situ generation of highly reactive radical species, primarily hydroxyl radicals (•OH) and sulfate radicals ($SO_4•^-$), which possess very high oxidation potentials.

The hydroxyl radical (•OH), with an oxidation potential of 2.80 V, is one of the most potent oxidizing agents known and reacts non-selectively with a wide range of organic compounds,

leading to their complete mineralization into carbon dioxide, water, and inorganic ions. Similarly, sulfate radicals ($SO_4•^-$) generated from persulfate activation exhibit strong oxidizing capabilities, especially in acidic to neutral pH conditions.

The key advantage of AOPs lies in their ability to degrade not only biodegradable pollutants but also stable, toxic, and bio-refractory pharmaceutical compounds that resist conventional treatment methods. By using oxidants like Oxone, Sodium Persulfate, and Air (oxygen), AOPs can efficiently initiate oxidation pathways that result in substantial COD (Chemical Oxygen

Demand) reduction and detoxification of wastewater.

Hence, this study focuses on evaluating the effectiveness of various oxidants under AOP mechanisms for treating pharmaceutical wastewater, with the aim of achieving higher pollutant removal efficiencies and promoting environmentally sustainable practices.

## II. USE OF OXIDANTS IN AOP TO TREAT WASTEWATER

### 2.1 Oxone (Potassium Monopersulfate - $KHSO_5$)

**Properties and Mechanism:**

Oxone is a powerful oxidizing agent composed of potassium monopersulfate. Upon activation (by heat, UV light, or catalysts), Oxone generates both sulfate radicals ($SO_4•^-$) and hydroxyl radicals (•OH), offering a dual pathway for pollutant degradation.

$$HSO_5^- \rightarrow SO_4^{\bullet -} + OH^{\bullet}$$

**Effect on Wastewater Treatment:**

The simultaneous generation of two types of radicals makes Oxone highly efficient for breaking down stable pharmaceutical molecules. It works effectively across a wide pH range (4–8), which makes it suitable for treating complex effluents without strict pH control.

### 2.2 Sodium Persulfate ($Na_2S_2O_8$)

**Properties and Mechanism:**

Sodium Persulfate is a stable oxidant that can be activated thermally, chemically (with iron or base), or by UV radiation to generate sulfate radicals ($SO_4•^-$).

$$S_2O_8^{2-} \rightarrow 2SO_4^{\bullet -}$$

**Effect on Wastewater Treatment:**

The sulfate radicals produced by Persulfate activation are strong oxidants capable of mineralizing pharmaceutical contaminants into carbon dioxide and water. Persulfate is particularly advantageous because of its stability, long shelf life, and effectiveness at moderate temperatures and pH.


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### 2.3 Sodium Thiosulfate ($Na_2S_2O_3$)

**Properties and Mechanism:**

Unlike Oxone and Persulfate, Sodium Thiosulfate is not an oxidant but a quenching agent. It is used after the oxidation process to neutralize any excess radicals, ensuring that no secondary oxidation reactions continue uncontrolled.

$$S_2O_3^{2-} + 4OH^\bullet \rightarrow 2SO_4^{2-} + 2H_2O$$

**Effect on Wastewater Treatment:**

By quenching residual radicals, Sodium Thiosulfate stabilizes the treated wastewater, making it ready for safe COD analysis and preventing further unintended chemical reactions. This step ensures accurate monitoring and evaluation of treatment efficiency.

### 2.4 Air (Oxygen, $O_2$)

**Properties and Mechanism:**

Air provides a readily available and sustainable source of dissolved oxygen. In AOPs, oxygen can participate in radical generation pathways, especially under UV activation or catalytic conditions.

$$O_2 + e^- \rightarrow O_2^{\bullet -}$$

**Effect on Wastewater Treatment:**

Although oxygen alone has limited oxidative power compared to radicals like •OH and $SO_4^{\bullet-}$, it enhances overall treatment by supporting radical reactions and improving mass transfer in the solution. When combined with other oxidants like Persulfate and Oxone, air helps maximize the oxidation potential and pollutant degradation.

## III. COMPARISON OF OXIDANTS PERFORMANCE

| Oxidant | Maximum Effectiveness | Minimum Effectiveness | Optimized Condition |
|---|---|---|---|
| Sodium Persulfate | High removal at 50–80°C with $Fe^{2+}$ or UV activation | Poor at room temp without activation | 30–50°C, pH 3–5 |
| Oxone | Excellent at 0.5–1 g/L dosage with UV/heat | Ineffective at <0.1 g/L without activation | 0.25–0.5 g/L, pH 4–7 |
| Air ($O_2$) | Effective with UV or catalyst support | Limited by itself | Aeration + UV/$TiO_2$ catalyst |
| Sodium Thiosulfate | Effective neutralization of radicals | Not applicable (not an oxidant) | 0.5–1 g/L post- treatment |

## IV. CONCLUSION

This study highlights the effectiveness of Advanced Oxidation Processes using oxidants such as Sodium Persulfate, Oxone, and Air for treating pharmaceutical wastewater. The use of these oxidants results in the generation of powerful radicals that successfully degrade complex pharmaceutical contaminants. Oxone and Persulfate showed superior performance under optimized conditions. Sodium Thiosulfate was effectively used for quenching post-treatment.

AOPs provide a strong, eco-friendly, and efficient method for achieving higher levels of wastewater purification, thus offering promising solutions for sustainable environmental management.

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