

# From Coagulation to Disinfection: Key Steps and Challenges in Wastewater Treatment

Shengyuan Wang<sup>1\*</sup>

<sup>1</sup>University of Southern California, Los Angeles, USA

**Abstract.** Wastewater treatment is a critical process to ensure the safe management of water for domestic, industrial and municipal use. The importance of wastewater treatment has become more pronounced as water consumption increases and environmental regulations become more stringent. Wastewater treatment plants remove harmful contaminants from wastewater and produce clean discharges that meet regulatory standards through a series of mechanical, biological, and chemical processes such as coagulation, sedimentation, filtration, and disinfection. This paper explores the advantages and disadvantages of each wastewater treatment stage and evaluates the wastewater treatment infrastructure in the United States and China. The U.S. has better wastewater treatment systems, while China still has inadequate wastewater treatment facilities in rural areas. Wastewater reuse is an important part of achieving a sustainable future, and further development and implementation of these systems can help improve global water management.

## 1 Introduction

Wastewater treatment is a critical process that ensures the safe and efficient management of water used in households, industries, and municipalities. As water consumption increases and environmental regulations tighten, the importance of treating wastewater before releasing it back into natural bodies of water becomes paramount. Wastewater contains a wide range of contaminants, including organic matter, pathogens, heavy metals, and nutrients, all of which can harm ecosystems and public health if left untreated. Through a series of mechanical, biological, and chemical processes, wastewater treatment plants (WWTPs) are designed to remove these pollutants and produce clean effluent that meets regulatory standards. This paper explores the various stages of the wastewater treatment process—coagulation, sedimentation, filtration, and disinfection—and evaluates each stage’s benefits and detriments. Further, this paper also examines the wastewater treatment infrastructure in the United States and China, two of the biggest and most influential countries in the world.

## 2 Wastewater treatment method

---

\* Corresponding author: [twang417@usc.edu](mailto:twang417@usc.edu),

## 2.1 Coagulation

The first step in treating wastewater is coagulation, which seeks to clump fine, negatively charged suspended solids in the wastewater so that they can be easily removed later in the wastewater treatment process. This is achieved through the addition of positively charged coagulants, usually metal ions or pre-polymerized inorganic compounds, to the wastewater. The coagulants then neutralize the negatively charged solids, which allows for them to bind together to form floccules—aggregates of material in suspension. After the reaction concludes, the wastewater will become less turbid and clearer—one step closer to becoming potable.

Commonly used metal ion coagulants include aluminum sulfate, ferric sulfate, and ferric chloride. Aluminum sulfate is the preferred coagulant by wastewater treatment plants worldwide due to its availability, affordability, and efficiency; ferric sulfate and ferric chloride work well but have downsides in the heavier floccules formed and the chloride's potential to increase the treated water's corrosivity, respectively. Metal ion coagulants, while effective, can also be extremely sensitive to the pH and the temperature of the water, which detracts from their overall versatility. As such, scientists have developed pre-polymerized inorganic compounds, such as aluminum chlorohydrate and polyaluminum chloride, which can function efficiently over wider ranges of pH and water temperatures. Further, testing has shown that pre-polymerized inorganic compounds produce less residual material overall through the coagulation process than metal ions, which makes the treatment and disposal of the residuals easier and reduces the possibility of toxic material leaking into the environment. Natural biopolymer coagulants also exist as a versatile option, but overall, the coagulant used for treating wastewater depends on the resources and needs of the wastewater treatment plant.

## 2.2 Sedimentation

After the wastewater undergoes coagulation, it will undergo the process of sedimentation, where gravity will separate the suspended floccules from the wastewater. During sedimentation, the floccules sink to the bottom of the sedimentation tanks, after which they are removed from the solution by a trough or a vacuum and properly disposed. The remaining water is then transported to the next stage, filtration.

Though sedimentation appears to be a simple process, there are still some obstacles to it, namely costs and time. Industrial sedimentation tanks, often circular, are large—they must be able to accommodate tens of thousands of gallons of wastewater and there are often several sedimentation tanks at a wastewater treatment plant [1]. As such, the tanks require sufficient funding, resources, and land to construct and maintain smooth operation. The second factor is time. First, less dense floccules take more time to settle to the bottom of the container because of fundamentals of flotation [2]. Second, according to sedimentation theory and Stoke's Law, warm water, due to its decreased viscosity, allows for the floccules to settle faster than cold water [3]. Therefore, the temperature of the wastewater must be carefully regulated, which can further increase the operational costs of sedimentation. While some of sedimentation's obstacles have clear workarounds and others are unavoidable, sedimentation remains a crucial part of the wastewater treatment process.

### 2.2.1 Disposal of sediments

External to the main wastewater treatment process is the treatment and disposal of the sediments generated by sedimentation. Such sediments often come in high amounts due to the volume of wastewater treated by a wastewater treatment plant. For example, after coagulation and sedimentation are applied, 1000 gallons of water can produce 5 gallons of

sediment [4]. Scaling the amount of wastewater by 40 or 50 times to account for industrial levels of wastewater treatment, the amount of sediment produced increases greatly. The method of treating and disposing the sediment depends on the type of coagulant used.

Metal ion coagulants result in the most complex treatment and disposal process for the sediments, as they often contain hazardous metal hydroxides and can sometimes be corrosive. As such, wastewater treatment companies must acquire the necessary equipment to ensure the proper treatment of the sediments, which can cost more than coagulation and sedimentation process. On the other hand, the sediments created by natural coagulants can be recycled and reused as soil conditioners and fertilizers, among other applications [4].

## **2.3 Filtration**

### **2.3.1 Slow sand filtration**

Wastewater then undergoes filtration to remove any solids and particles that remain after coagulation and sedimentation. The filters have varying pore sizes and are made of materials such as sand, gravel, and charcoal to ensure that all the particles are removed from the water, no matter the size. A common wastewater filtration method is slow sand filtration, which features layers of biofilm, sand, and gravel. The biofilm is made of a combination of particulate and organic matter and dense biomass growth, which further breaks down the particles in the water. Next, the water travels through the permeable sand and gravel layers. As the water seeps through the layer, the particles become trapped within the sand and gravel; the water becomes cleaner as a result.

Overall, slow sand filtration is a simple step in the wastewater treatment process. It is relatively inexpensive, as the materials used are mostly natural, and does not require specialized equipment or chemicals. Slow sand filtration is also energy efficient due to its reliance on gravity for filtering the wastewater. While industrial sand filters require regular maintenance and cleaning every four weeks, it still is one of the most efficient filtration methods.

### **2.3.2 Activated carbon filtration**

Another filtration method is activated carbon, typically made from carbon-rich materials such as coal, wood, or coconut shells that are treated at high temperatures to create a porous structure. This takes advantage of the adsorption process, during which contaminants stick to the surface of the carbon. The porous structure also increases the surface area of the activated carbon, thereby increasing the effectiveness of adsorption and in turn, filtration.

There are two primary types of activated carbon: granular activated carbon (GAC) and powdered activated carbon (PAC). GAC is commonly used in fixed-bed filter systems where water flows through a bed of carbon granules, whereas PAC is often used as a dosing agent in water treatment plants, where it is mixed with water and later filtered out. Both types of activated carbon are highly effective at removing organic and inorganic contaminants through adsorption.

The main advantage of activated carbon filtration is its ability to remove a wide range of contaminants, including those that are not easily eliminated by other treatment methods. It is especially effective at targeting organic compounds, chlorine, volatile organic compounds, and toxic heavy metals such as arsenic, copper, and lead in the wastewater [5]. Just like slow sand filtration, activated carbon filtration is also energy efficient as it relies solely on gravity for filtering the wastewater. However, over time, the activated carbon becomes saturated with

contaminants and must be replaced or regenerated, which increases operational costs, especially with carbon regeneration, as it relies on chemical and heating methods.

### 2.3.3 Reverse osmosis

Reverse osmosis (RO), widespread and effective, is another method of filtration in the wastewater treatment process, though it has certain niches to it—mainly in desalination. RO relies on the principles of osmosis and the use of a semi-permeable membrane to filter out contaminants from water, resulting in clean, purified water. It is especially valuable in regions where fresh water is scarce and the reuse of water or desalination of seawater is necessary to meet demand.

Osmosis is a natural process in which water molecules pass through a semi-permeable membrane from a region of low solute concentration (pure water) to a region of high solute concentration (contaminated water). The goal of this process is to balance the concentrations of solutes on both sides of the membrane. Reverse osmosis works by reversing this natural flow. By applying pressure to the contaminated water, it forces water molecules to move from the side with higher solute concentration to the side with lower solute concentration. This pressure needs to exceed the osmotic pressure of the water for the process to occur effectively. In addition, the semi-permeable membrane used in reverse osmosis is highly specialized. Its pores are incredibly small, typically around 0.0001 microns, which allows only water molecules and some minuscule molecules to pass through.

During reverse osmosis in a specialized unit, high pressure is applied to the water on the feed side of the membrane, forcing the water through. As the water is forced through the membrane, the water molecules and other small substances pass through the semi-permeable membrane. Remaining large contaminants from coagulation and sedimentation are left behind on the feed side of the membrane and are subsequently removed from the RO unit for disposal. The clean water that passes through is called permeate, while the concentrated contaminants that remain on the feed side are known as concentrate or reject. Afterwards, the permeate can proceed to disinfection.

Reverse osmosis has several significant advantages, the most notable being its ability to remove up to 99% of dissolved salts, organic matter, bacteria, and other contaminants from water [6]. This makes it an extremely effective method for producing clean water for drinking, industrial processes, and environmental discharge. Furthermore, reverse osmosis systems can be scaled to meet different needs of each community, from small towns to industrial wastewater treatment plants.

However, reverse osmosis also presents some challenges. One of the primary drawbacks is the high energy consumption required to generate the pressure needed to force water through the membrane, which makes RO unfeasible in areas that lack the necessary infrastructure and resources. Additionally, membrane fouling, which occurs when contaminants accumulate on the surface of the membrane, can reduce the system's efficiency and increase maintenance costs. To mitigate this, regular cleaning and maintenance are essential. Lastly, the disposal of concentrate or reject water, which contains high concentrations of contaminants, can be a challenge, especially in areas with strict environmental regulations. There are still many hurdles to overcome with reverse osmosis, but it shows promise as a filtration method.

## 2.4 Disinfection

The wastewater is now mostly contaminant-free, but it is crucial to disinfect the water to remove any remaining bacteria, as well as reduce the possibility of future bacteria growth in the water and the containers that store it. If disinfection does not occur, bacteria such as *E.*

coli and salmonella can enter the water systems of a city and cause mass disease outbreaks. Annually, waterborne pathogens in the United States cause approximately 7.15 million illnesses and 6630 deaths [7]; this number rises dramatically in third-world countries. There are three common methods of wastewater disinfection: ozone, ultraviolet (UV) radiation, and chlorine.

#### *2.4.1 Ozone disinfection*

Ozone disinfection uses ozone's chemical properties to clean the water. Ozone, generated from air or pure oxygen in an ozone generator, is pumped into a chamber with the filtered wastewater. Next, the ozone decomposes in the water and forms the free radicals hydroperoxyl and hydroxyl, both of which are powerful oxidizing agents. The free radicals then make contact with the cell walls of the bacteria in the wastewater, which induces protoplasmic oxidation and in turn, cell lysis, destroying the bacteria. The water is then discharged from the chamber to be converted into drinking water or released into the environment. Ozone is one of the most effective wastewater disinfection methods; however, it requires significant monetary and technological investments to ensure its effectiveness and safety [8].

#### *2.4.2 Ultraviolet disinfection*

Ultraviolet radiation disinfection relies on a system of high-intensity UV lamps, which are powered by a reaction of mercury and electricity. When shone into the wastewater, the UV rays penetrate through the cell walls of the bacteria in the water and destroy their essential biological functions, rendering them harmless. The water is then discharged from the container. UV disinfection is advantageous due to its avoidance of chemicals and large machinery. As such, it is a safer and more space-efficient method of wastewater disinfection compared to ozone or chlorine. UV disinfection becomes ineffective when there are low intensity UV rays or highly turbid wastewater, but these are minor issues.

#### *2.4.3 Chlorine disinfection*

Chlorine is the most widely used water disinfectant due to its oxidizing properties. Like ozone disinfection, chlorine gas is pumped into a chamber with the wastewater. The chlorine then damages the cell membranes of the bacteria, destroys their essential biological functions, and renders the bacteria harmless. However, while the water is now free from the bacteria, it is still full of chlorine residuals, which can last in the water for many hours. As such, the water is unsafe for release and must be dechlorinated. To dechlorinate the water, sulfur dioxide is added to the water, where it reacts with the chlorine residuals and renders them harmless. Overall, chlorine is an effective method of wastewater disinfection, but it also requires extensive safety measures due to the explosive nature of chlorine. Additionally, while chlorination itself is cost-effective, dechlorination is not.

### **3 Applications and usage in the United States and China**

In the United States, many states, especially those in the Sun Belt region, routinely suffer from high temperatures and drought conditions. Therefore, the recycling and reuse of water resources is essential. There are more than 16000 wastewater treatment plants in the US, with 80 percent of the U.S. population receiving their potable water from the wastewater treatment plants and approximately 75 percent of the U.S. population having their sanitary sewerage

treated by them [9]. In New York City, with a population of 8.336 million, there are 14 municipal wastewater treatment plants, which treat a total of 1.3 billion gallons of wastewater daily [10]. The wastewater treatment plants follow the wastewater treatment processes outlined above, with some minor variances between plants. For example, New York City, due to its large population, does not filter wastewater to reduce operational costs [11].

While wastewater treatment infrastructure is readily available in the United States, China does not have this luxury. As of 2021, 98.1% of municipalities and 28% of rural areas in China have access to wastewater treatment facilities [12]. The low percentage for rural areas is concerning considering that China's rural areas are severely underdeveloped relative to its cities. As such, it is crucial for China to invest in and implement more wastewater treatment facilities in its rural regions to ensure the health and safety of all. China has improved its wastewater treatment infrastructure rapidly in recent years, but more action is necessary.

## 4 Conclusion

The wastewater treatment process is a vital multi-stage system designed to remove contaminants from water used in residential, industrial, and municipal settings. By employing mechanical, biological, and chemical methods, treatment plants effectively eliminate pollutants such as organic matter, pathogens, heavy metals, and excess nutrients, ensuring that the treated water, or effluent, is safe for discharge or reuse. Developed countries such as the United States have implemented effective wastewater treatment systems that span nearly the entire country, while developing countries, such as China, still lack wastewater treatment systems in their rural areas. Reusable water is a key to a more sustainable future, and its further development and implementation will help make the world a better place.

## References

1. Sedimentation tank standards for construction sites. King County. (2024) <https://kingcounty.gov/en/dept/dnrp/>
2. How Sedimentation Water Treatment Works and How to Make it Efficient. Clearwater Industries. (2024) <https://clearwaterind.com>
3. Tiwari, R. K. Sedimentation Tanks: Design and Working. (2024) <https://www.slideshare.net/slideshow>
4. Common Pitfalls When Choosing A Chemical Coagulation Water Treatment System To Treat Your Water. Water Online. (2019) <https://www.wateronline.com>
5. Frequently Asked Questions About Activated Charcoal. Wisewell, (2024) <https://www.wisewell.com/blogs/news/carbon-water-filters>
6. The Truth Behind Reverse Osmosis Water Systems: Filtering Out Fact vs. Fiction. Hawaiian Coolwater, (2023). <https://hawaiiancoolwater.com>
7. J. M. Kunz, H. Lawinger, S. Miko, et al. Surveillance of waterborne disease outbreaks associated with drinking water-united states. *Surveillance Summaries*, **73(1)**, 1-23 (2024) <https://doi.org/10.15585/mmwr.ss7301a1>
8. Wastewater Technology Fact Sheet: Ozone Disinfection. United States Environmental Protection Agency. (2024) <https://www3.epa.gov/npdes/pubs/ozon.pdf>
9. Water and Wastewater Systems. Cybersecurity and Infrastructure Security Agency. (2024) <https://www.cisa.gov/topics/>
10. China - Environmental Technology. International Trade Administration. (2024) <https://www.trade.gov>

11. How to Choose the Best Water Filtration System for New York Drinking Water. High Water Standard, (2024) <https://www.highwaterstandard.com/blog/drinking-tap-water-in-new-york>
12. Wastewater Treatment System. NYC Environmental Protection. (2024) <https://www.nyc.gov/site/dep/water/wastewater-treatment-system>.