Water Quality Engineering: Physical/Chemical Treatment Processes

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Chapter - 1

Introduction to Water Quality Engineering

Water serves as a vehicle for a vast array of contaminants and harmful substances. Consequently, ensuring its quality is critically important for numerous reasons, including the protection of public health, the sustainability of aquatic environments and their associated water resources, the improvements in overall quality of life for communities, and the support for economic growth and development. A human being depends on water that meets drinking-water standards for an extended duration-often for months-but can survive without food for just a few weeks. Therefore, while both clean water and nutritious food are fundamental to sustaining life, having access to "quality" water becomes even more significant than having access to quality food options. This brings us to an important point of discussion: before delving deeper into the subject of water quality, it is worth considering a pivotal question: "What specifically makes water impure or polluted in the first place?" This book focuses on the fundamentals of water quality engineering and commonly used methods to handle pollution and treat water for safe consumption. Many experts in water quality and their students who take my classes learn the vital applications of water quality. The objectives of this book are to help students develop effective problem-solving and quantitative skills and to provide practical, design-related experiences that will help them build valuable skills and lessons learned from real-world solutions and scenarios. We hope that when people use this book, they will apply the course material in their intended field and connect it to water quality projects with the aim of protecting human and ecosystem health. This book is intended to be an integral part of the learning process found at the frontiers of water engineering. The text will introduce different applications and the fundamental engineering concepts of fluid mechanics, thermodynamics, or heat transfer, environmental transport processes, and physical and chemical water quality applications. It will not be necessary to master these underlying theories in order to understand the presented water quality material. However, if the reader is deeply interested in a particular concentration section or part of this text, there are many resources described at the end of each chapter that can help with more in-depth coverage and complex topics or problems. The text will also provide real-world experiences and practical approaches by employing instructors who have expert knowledge of the subject. This will enable a better understanding of diverse facilities and engineering procedures in order to tackle environmental examples in the field of water quality research or practice. Our ultimate goal is to acquaint and provide hands-on projects in water treatment or related water quality applications that are pertinent to all water engineering and water scientists tackling sustainability problems.

Sanitary engineering is a primary branch of civil engineering that focuses on the protection of health by ensuring the availability of ample supplies of clean water for drinking and adequate treatment of liquid and solid wastes. Water is delivered to homes in most modern industrial and non-industrial countries via enclosed metal, concrete, and plastic pipes. The water for different uses, such as potable water for drinking, cooking, washing, and process water for industries, comes from different sources, namely lakes, rivers, wells, and reservoirs. After water is used, it is conveyed through a sewer, which is also an enclosed pipe. Wastewater from homes usually combines with industrial wastewater and is conveyed to a wastewater treatment plant. In some non-industrial locations, water is primarily collected from a yard faucet, and wastewater is conveyed to a septic tank or otherwise treated locally. The impact of municipal and industrial activities on the water supply and water quality of streams, lakes, and estuaries is affected by many factors, including flow volume and flow characteristics, industrial and human population density, water demand, land-use patterns, and reservoir storage. Urban streams often alter their flows and their pollution levels over the year, resulting in more serious flooding problems. Since urban populations are now moving away from urban centers, urbanized watersheds are now more susceptible to long dry spells, making them more prone to water shortages.

Water quality is important because without clean water, our bodies suffer. We need clean water to drink and for food production. Water quality can contain contaminants such as chemicals, particulates, debris, and organisms that can harm human health. It also affects water's desirability, behavioral health effects, odor, and taste. We humans have developed wastewater treatment and drinking systems to dispose of and clean contaminated water. Water is essential for human life. The average water intake of humans is 3.5 to 7.0 gallons per day. Water is absorbed into the body via ingestion, food, and metabolism. Therefore, water must be germ-, toxin-, and chemical-free. Physical quality issues are addressed in earlier chapters that deal with other types of contaminants. All water can contain undesirable levels of contaminants that are naturally occurring. Although water quality concerns occur naturally, human activities can also lead to water quality issues. The rest of this section will describe issues related to water and the relationship between water quantity and water quality.

When readers give this question some thoughtful consideration, their responses can typically be categorized into various classes of constituents, which ultimately provides a semblance of typical concentration ranges derived from practical experiences and an established sense of familiarity. Many of these constituents are undeniably present in all types of waters, while some are specifically found in natural waters but are also manufactured and consequently present in effluents as a result of human activity. The vast majority of these constituents are of significant health concern for one reason or another. Water quality is fundamentally a function of multiple parameters and factors that range from the source to the location and its respective usage; it serves as a reflection of the surrounding habitat or the watershed it originates from, and it is important to note that it changes over time due to various influences. The quality of waters sourced from many locations can be observed to range from quite good to alarmingly poor. The pressing question is, “How do we improve water quality or make it better in a sustainable way?” Solutions to this concern rest within the application of principles that have been learned from a diverse array of fields, including the sciences, engineering, education, economics, and law. The essence of the application of these multidisciplinary principles, whether directly or indirectly applied, focuses on approaches that are either preventive, curative, or a combination of both. This further emphasizes the critical importance of utilizing established engineering principles in the quest for improved water quality. Water quality engineering, inherently, is both a science and an art that involves the identification, quantification, and treatment of contamination found in our vital sources of water supply, with the ultimate goal of making it safer and aesthetically more appealing for beneficial uses by the community. Over an extended period, research findings from an extensive range of academic and practical bodies of knowledge have significantly influenced the field of water quality engineering. Many skilled engineers are specifically tasked with the responsibility of designing systems that effectively remove or minimize the adverse effects of approximately 150 constituents that hold public health value. These constituents can be grouped into two key categories: those that provide water with aesthetic value (for example, taste, odor, color, turbidity) which usually have a pronounced effect on its overall palatability, and those that are known to cause varying illnesses. The optimization of the engineering methods that will be described in further detail is highly advisable to enhance the attractiveness of drinking water while ensuring it remains available at a low cost to the public. It is essential to keep in mind that the presence of traces of some contaminants is often unavoidable, as they are consistently part of the earth’s crust and the natural geophysical processes that characterize our planet. The use of the term “contaminant” is specifically related to human activities and the considerable influence of technologies and practices that can lead to various levels of contamination [1-3].

1.1 Importance of Water Quality

Water quality plays a crucial role in maintaining the health of ecosystems and protecting public health. Freshwater is essential to living organisms because it provides the medium in which life processes are carried out. Nearly all of the elements, ions, and molecules necessary for the maintenance of life are dissolved in water. For humans, the importance of maintaining the quality of drinking water has long been recognized. The sources of pollution are numerous and include pristine water that has been altered, as well as industrial, domestic, and agricultural point sources. Consequences of neglecting water quality management include increased costs associated with both providing safe drinking water and, in the case of surface water, complying with effluent limitation guidelines.

The development and discussion of these treatments and the necessary unit operations are then discussed from the molecular level up to the full-scale engineering processes. The consequences of not providing this treated water on individual and community levels are then discussed, which includes large parts of the developing world as well as the United States. Unsafe drinking water can have large health impacts on the people who drink it and can decrease overall public health for entire communities. Water that contains either natural or man-made contaminants that exceed federal guidelines is considered to be unsafe. People most vulnerable to contaminated water include those with weakened immune systems, people with hepatitis, those with severe chronic diseases, infants, the elderly, and pregnant women. A waterborne disease outbreak can be costly to a community in terms of both human suffering and economic impacts. People can potentially incur medical costs, water treatment costs, and can also lose income due to lost workdays and decreased water-related recreation [4-6].

1.2 Overview of Physical and Chemical Treatment Processes

Engineering design of processes to improve the quality of natural water sources is generally discussed in terms of two general categories: physical treatment processes and chemical treatment processes. Clean, safe water is essential for public health, quality of life, and environmental sustainability.

Treatment of both the water we use and the wastewater we generate is essential to prevent pollution of our surroundings and, therefore, maintain substantial community health. Even though these consequences are always diverse, the system of help is essential to the structuring and evaluation of water and wastewater purifying systems. The water treatment criteria are based on physical, chemical, and enzymological actions that reduce particles and microorganisms.

The historical perspective goes back to the year 4000 BC when the Royal Trap design for the clarification of water was used in a small jar. The current water and wastewater treatment process is only a few decades old. Advances in science and biotechnology are regularly redirecting the discrepancies in humanity's attempts to enhance the value of water. With the growth of biotechnology, water purity and utilization have been improved. Once the objective of wastewater treatment has been met, it is restored to the environment. Any unit of the river or abandoned area does not have the capability to cause harm to the setting or to any entity gently flowing below. Adjusting these water conditions is critical in regulating wastewater discharge into the environment. With some progress in citing reuse demands, this directive is being more rigorously enforced. Consequently, several more stringent metrics have been implemented with the purpose of reducing the amount of water resources available.

Water is used in various strategic sectors of human activity such as agriculture, industry, energy generation, and domestic supply (drinking, washing, like a pantry to prepare or preserve food). These uses would not be possible to maintain a good environmental and social level of welfare and take care of public health if water was not being treated in order to make it useful for that purpose. Untreated water presents risks of transmitting disease, being a natural vehicle for many biological, chemical, and waste products such as parasites, fungi, bacteria, algae, and zoonotic agents. Besides the risk of disease spread, the contamination of surface water by receiving domestic and industrial liquid waste causes its self-purification capacity to be exceeded, resulting in the risk of aesthetic contamination, odors, and even pollution, degradation, and extinction of a great number of self-purifying life forms that live in and off water bodies using them as habitats for their development. In this context, it is urgent to propose and develop advanced treatments for water and wastewater for the following reasons:

- Economic, since investments in quality treatment equipment can offset some of the financial implications.

In developed countries, large investments in advanced treatment technologies could result in significant savings from:

- Social improvements in community health and general quality of life.
- Improvement of the water resource. Environmental sustainability is reached with the reduction in the maintenance of natural ecosystems and the use of natural resources, the latter with economic appeal, to improve quality of life with an improved environment.

Physical treatment of water and wastewater mainly relies on mechanical and physical principles to remove solids. The principal objective is to remove solids without using chemicals.

- **Screening:** The removal of large floating or settleable solids. It is the first operation in treatment to prevent the entry of solids into the unit. Wastewater from stormwater often chokes the sewers, and the accumulated screenings have to be removed so that the sewers are completely functional for the movement of stormwater.
- **Settling or Sedimentation:** This is the separation of suspended particles from the water. The settling process requires a relatively quiescent condition of the flow so that particles can settle by gravitational force alone.
- **Filtration:** Similar to sedimentation, filtration is a process that separates solids from fluids. The fluid or gas is passed through a porous medium, creating a natural or formed bed. The fluid will flow at a desired rate by removing any residual solids on the filter media.

Physical treatment operations play a crucial role in overall water and wastewater treatment by removing large particulate matter and floating debris from combined and sanitary sewers. It can be said that physical processes lay the foundation for the chemical treatment processes. This is because physical processes remove the larger inert particles, thus enhancing the efficiency of chemical process operations.

The cost of chemicals can be saved tremendously by using physical treatment in advance. However, the damages caused downstream of the physical treatment units affect the conditions of the environment and public health. The physical treatment units are generally priced low due to the simplicity of their design. The housing and mechanical structure are cheap compared to chemical treatment process units. The savings from the inflow to the chemical process units are also an advantage of using a physical structure. However, the physical units are more sensitive to flow rates and energetic variables. The maintenance of the machines and separation of the materials attracted to the physical principles can still be an expensive investment. The reagent chemicals continue to be used due to the failure of removal in physical procedures. This means an additional cost for chemical treatment. A screening unit, for example, removes the wrong material mixed in the solids so that the solid materials passing through it can go to sedimentation, flotation, hydrocyclone, or some other specialized treatment processes. They can also desand, degrease, and reconvey solid materials.

Screening and straining are the two basic physical methods used in water treatment. Each method is designed to remove particles from the water before any other treatment process has a chance to reduce their levels in the water. Both methods are designed to remove solid particles from water, but each does so to a specific range of particle sizes. Simple screening typically passes some water through a mesh or parallel bars that hold up the debris before the water enters the treatment process. A common feature of these methods is debris removed by hand after removing a penstock commonly known as a screen. Not only are the screens necessary to remove debris from the raw water that passes through them, but the capacity of water intake structures may also be limited by the maximum head that can develop across debris-blocked screens. This later point is particularly important as the introduction of automatic apparatus to physically clean a screen apparently reduces the frequency of the necessity for hands-on intervention. The simple act of straining is a basic physical process, and strainers could take the form of sieves and sand filters, but water must first pass through screens.

Design considerations in screens include low head loss, the reduction of clogging between the bars where the water flows through, and a design allowing solids to be washed off using backflushed clean water. Advantages of screening or straining are that they are well established, and instruments are available to measure solids suspended in water that would pass through them. As refinements, they compared screened water quality to the efficiency of treatment plants, and the data suggest that the removal of debris at the screening stage before water enters the treatment process, on the one hand, permits the treatment process to be optimized; on the other hand, it ensures total process integrity. Another advantage is that cleaning a screen requires little energy and few maintenance costs. The only operational cost would be the labor cost of removing the screen debris. The primary disadvantage of a screen is that if not regularly washed clean, it becomes blocked, and water cannot pass through it. Furthermore, some have proposed that materials used should be selected to match the quantity and size of debris removed from inlets.

Sedimentation is a physical water treatment process to remove suspended solids from water or wastewater by allowing the settling of suspended solids on the bottom of the settling basin. The velocity at which the particles settle is influenced by the size, shape, and density of the particles. A well-designed sedimentation tank enhances the settling of the suspended particles and clarifies the effluent to some level before further treatment. The design of a sedimentation tank is based on the flow pattern of the water called hydraulic loading and the detention time. By optimizing these factors, the suspended particle removal efficiency can be enhanced. Particles that settle in the basin can be collected and removed. A sludge removal system based on the design of the tanks, whether automatic or manual, can be employed.

Generally, there are two different sedimentation systems: primary and secondary sedimentation. Primary sedimentation removes floating solids, grease, and scum in addition to settable solids at the beginning of the treatment. Secondary sedimentation is used after a biological treatment step to separate or remove solids. The volume of the sedimentation basin increases with the size of the treated area to give enough time for settling. The greater the size of the particle, the faster it settles in the basin. Ideally, sand particles settle in the basin with a settling velocity of 10 m/h, fine sand with 5 m/h, silt with 0.5 m/h, and clay with 0.1 m/h. Although some fine particles settle faster because they aggregate to form larger particles, colloidal particles are too small to settle even after coagulation. Adsorption tanks are an option for these particles, but they may need to be preceded by an up-flow clarifier to blend the coagulants, which adds to the space requirement. Generally, sedimentation can remove 50-70% of total suspended solids and thereby helps in reducing the load on other possible treatment units. Sedimentation tank efficiency is reported for primary treatments as 27-84%, for secondary treatment as 8-60%, and 49-86% of TSS load reduction. Recently, at a 1000-household waste stabilization pond project, the secondary sedimentation effluents into filters had a mean of 61% pathogen reduction.

1.3 Basics Chemical treatment processes in water and wastewater treatment are employed to remove or destroy specific substances that impact water quality. The processes described here mainly use chemical reactions to achieve their objective. While the reagents employed in some cases are electrolytical, the focus here is on processes employing added chemicals; i.e., those not present in the water to be treated. Key chemical treatment processes, and when they are typically used, are given in a table. Advancements in analytical and monitoring methods, including measuring hydraulic efficiency, are helping increase the effectiveness of compound delivery. This has led to a trend in developing systems supplying chemicals continuously, based on real-time data.

1.4 Coagulation and Flocculation Coagulation is the process of applying chemical reagents to water for the purpose of destabilizing suspended particles so they will less readily reform a suspension upon settling or air flotation. Flocculation is another important process in converting gently coagulated particles to settleable or floatable particles. Coagulation destabilizes particles to create the ability to aggregate at least some of them to produce larger particles in the next process of flocculation. Flocculation requires some physical energy application to create conditions of controlled, gentle mixing where the particles collide lightly, aggregate, and grow quickly.

1.5 Disinfection Disinfection refers to the process of eliminating or deactivating most microorganisms in potable water, such that there is no health risk in consuming the water. Reducing chlorine demand is important, since when a chlorine residual is required, the chlorine will be most effective used for disinfection. Once the water passes through the distribution system, a residual would be required for all three scenarios. Varying the desired residual is most often accomplished by altering the chlorine concentration at the water plant, though it is possible to modify water quality and water age within the distribution system to change the amount of disinfectant required at these other locations.

1.6 Process Pitfalls An unavoidable feature of any chemical treatment process is that residual chemicals may remain in the effluent. In the case of coagulation-flocculation, for example, the presence of alum in the effluent of a drinking water treatment plant to remove phosphorus would contribute to the dissolved aluminum already present in the source water and which originates from the soil in the water catchment. It is not clear what would be an acceptable 'safe' level of dissolved aluminum, but getting below certain levels is also not practicable and would drive up treatment costs. Coagulation and flocculation processes, and disinfection with chlorine, are old procedures. Some of the most recent improvements concern the perfection of the equipment, automatic pH and flow control, and variable disinfection regimens based on monitoring.

1.7 Costs Overall, polymer use is gradually increasing due to lower costs. This development is combined with a gradual decrease in the use of

> common primary coagulants. Primary coagulants have the benefit of reducing the amount of flocculant and filter aids, while the polymers allow for more efficient removal of impurities and the possibility of reducing sedimentation basin size. The net difference will depend on the waste disposal costs and reduction of high settlements as well as other factors. Coagulants are not yet technically eliminated from the treatment process. Regulatory policies are not yet robust enough to allow this. It is especially easy to make a mistake with jar testing, as can occur if the bench assessment does not accurately reflect actual plant needs. Decisions on how best to use these chemicals come down to a balance of cost, compliance strategy, and reducing the treatment cost per megaliter treated. Other changes in other areas of technology are to be expected.

The coagulation and flocculation processes are primarily used to remove suspended particles present in water. Coagulation is the destabilization of the particles by adding coagulants to the water. These particles subsequently collide and grow, resulting in the formation of aggregates, also known as flocs. These flocs are then large and heavy enough to be removed from the water. In settling tanks and/or in subsequent filtration processes, the flocs can be removed from the water, which is then clean enough for public consumption. The flocculation process is when these aggregates start to grow. For the most part, flocs are formed via a particle-particle collision under very gentle mixing conditions. The successful application of coagulation-flocculation processes depends on the dosage, the mixing speed, and the mixing time. The selection of the operating conditions depends on the type and concentration of the coagulants, the type of impurities, the water composition, and the environmental conditions. In many cases, the coagulation-flocculation operation is complex because it depends on the properties of the coagulant and the type of coagulant. Alum with anionic coagulants is the coagulant agent that is most widely used for water treatment. In many cases, ferric-based salts are more effective and less pH-dependent than alum due to the ability to neutralize the treated water. There are several other coagulants as well. Coagulants also have several limitations; for example, further sludge is deposited in downstream storage ponds, and there is residual chemical that should be removed. Coagulation-flocculation methods are frequently used, particularly in municipal treatment plants. They are mainly used to increase water turbidity. Industrial effluent is another application.

Disinfection is a chemical treatment process performed to kill or inactivate pathogenic microorganisms in water and wastewater. This removes the latent threat of waterborne diseases from the drinking water supply, offering an essential barrier against infection and restoring consumer confidence in the water supply. A wide range of agents are used to disinfect water, including chlorine and its various derivatives, ozone, ultraviolet radiation, and silver ionization. Each of these inactivation mechanisms is appropriate for certain levels of risk, and each has its own set of challenges.

For disinfection to be effective, the disinfectant dosage must be high enough to guarantee the inactivation of the target microorganisms completely. This is often defined as the achievement of an extremely low probability of adverse health outcomes from pathogens remaining in the water, or more commonly as reducing the microbial concentration to safe levels via log inactivation. Factors that impact disinfection performance include contact time, dose, pH, water temperature, and the turbidity and dissolved organic matter of the water. Efficient disinfection systems require adequate contact time between the disinfectant and microorganisms; the contact time is dependent on site-specific hydraulic conditions such as flow rates and travel times.

Disinfection by-products such as trihalomethanes, haloacetic acids, haloketones, and nitrosamines are formed if disinfectants such as chlorine or ozonation are applied in the presence of raw water contaminants. Effective control of the DBPs generated is necessary to safeguard public health. In order to guarantee public health and safety, maximum contaminant levels are imposed on many DBPs. The appropriate residual concentration of disinfectant is also established and must be maintained in the distribution network to prevent re-growth of pathogens and to present a barrier to contamination. The practical application of disinfection is regulated at national and international levels, with organizations enforcing adherence to these standards. These regulatory restrictions apply equally to water treatment plants and the distribution systems.

Many strategies have been devised to enhance disinfection efficiency, increase operational flexibility, and/or decrease the generation of DBPs. Disinfection strategies also need to be cost-effective and easy to manage, particularly at smaller scale potable and non-potable water treatment plants. A case study of the potable water treatment plant details the basis for deciding in a particular application whether to use chlorination or UV disinfection, or to implement a multiple barrier approach. At a wastewater treatment plant, the requirement to guarantee that effluent is free of pathogens sees it flow through five successive disinfection processes and into two polishing ponds before being discharged. Treatment trains at water reclamation plants offer high energy efficiency and cost-effectiveness for multiple barrier treatment, including the application of ultraviolet light for chloramine destruction.

Advanced treatment processes refer to the processes designed to produce high-quality treated effluent from the given water for its intended use. These could be biological or physical-chemical processes, and the combination of both is necessary for a high degree of purification. Several innovative processes have been developed for the treatment of wastewater, water, and industrial effluents in the recent past that aim at providing a high degree of treatment efficiency. They target the removal of emerging pollutants, which are not amenable to removal by conventional processes, such as biological treatment, nutrient removal, and disinfection. Emerging pollutants refer to those chemicals for which standards and regulations are evolving but have not yet been enforced.

Advanced treatment processes include membrane filtration, such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis; advanced oxidation processes, such as ozone, hydrogen peroxide, ultraviolet radiation, and combined advanced oxidation processes; advanced hybrid processes; advanced ion exchange; and bioreactors, such as membrane bioreactors, constructed wetlands, and biological filtration. Most of the advanced processes discussed above find their application mainly to provide reuse-quality water. Treating water and wastewater using these processes is considered important because of the growing interest in reusing treated effluent for landscaping, non-potable household, and industrial use, and establishing more and new reuse criteria at national, European, and international levels. Many countries already use these advanced processes to produce highly purified water from municipal wastewater treatment for agriculture. Challenges of advanced treatment processes include their high cost, the need for highly specialized skilled professionals, hardware maintenance, and increased energy consumption. A combined physical-biological-chemical advanced treatment process could provide a sustainable water management system. The present paper involves critically evaluating and discussing the advanced treatment processes and their application.

Membrane filtration is one of the advanced physical and chemical processes used in water treatment. Membrane technologies are based on the use of semi-permeable membranes for the separation of contaminants or dissolved ions from water or wastewater. Based on membrane pore size, there are various types of membrane processes. Microfiltration membranes have pore size ranges between 0.1 and 10 µm and are usually used for the removal of large suspended solids and bacteria. Ultrafiltration, with membrane pore sizes in the range of 0.001 to 0.1 µm, is appropriate for the removal of viruses, colloidal, and submicron particles. Nanofiltration is effective in the rejection of divalent ionic species. Finally, reverse osmosis membranes, with a low cut-off value of pore sizes in the range of 0.0001 to 0.001 µm, are capable of removing monovalent ions and organic compounds from the water.

The two operational parameters used for membrane operation, in addition to the membrane, are pressure and flux. There are other operational parameters that affect membrane efficiency and fouling, mainly the pH of the feed water, ionic strength, type of feed water, and operating conditions such as temperature, velocity, concentration polarization, and stir rate, which may indirectly affect membrane flux and recovery. Temperature affects component viscosity, which means that temperature affects the flux of the membrane, chemical cleaning, changes in solubility, and diffusivity. The commercial membranes typically have a flux range of about 100 to 140 lmh and a pressure range of 20 to 30 bars. Membrane treatment technologies are widely used in water and wastewater applications for the treatment of recalcitrant organic contaminants, in addition to improving water quality, i.e., potable water treatment, wastewater reuse, and pre-treatment for feed water desalination. The efficiency of membrane technology compared to conventional processes is notable. The cost of reverse osmosis is less compared to coal-based desalination due to utilizing highly compact skid-fitted reverse osmosis systems.

Membranes have been implemented in different applications in various countries. In Jordan, Morocco, and Tunisia, membrane bioreactors were piloted to treat real municipal wastewater at the scale of 5 to 10 m^3/d. A large membrane bioreactor was also piloted for municipal wastewater treatment in Libya and Saudi Arabia. Moreover, membrane bioreactors with other advanced oxidation technologies have been implemented in industrial applications, including the removal of COD and heavy metals from landfill leachate. The main limitations of membrane technology that have been addressed are the membrane lifetime and the disposal or recycling of used or spent membranes. Overall, membrane technology has been recognized as a pre-treatment and final treatment in the field of potable water and wastewater treatment due to its high efficiency in removing toxic pollutants such as heavy metals, pathogens, and CODs. Although membranes are prone to fouling, this fact drives further research to develop a new generation of solid waste membranes in order to solve such limitations.

Here are characteristic attributes of physical and chemical treatment processes: First, physicochemical process operation is more dependent on the skill of the operator and the quality of the design, while chemical processes are usually more in line with routine operational formulas. Secondly, the investment in chemical treatment projects is less phased and involves a lot of consumables; on the opposite, the investment in physical methods is slightly more dispersed from the construction investment and involves fewer consumables later. Third, the cost of operating reagents and mediators in chemical processes is much higher than that of other treatment systems. On the other hand, physicochemical processes have higher operational costs and lower entrapped air purification efficiencies. Fourth, the choice of a physicochemical treatment project is often affected by the principal purification mechanism. Fifth, the coagulation and sedimentation process can easily cause the salt-rejection phenomenon, making it extremely difficult to reduce the effluent. Finally, the physicochemical treatment process can provide multiple effective pollutant removals in a water treatment system and form a series of combined treatment systems with other water treatment processes. The purification of common pollutants in water can be completed by the physicochemical method; the key for a physicochemical treatment process is determined by the method and degree of capital investment.

Water and wastewater treatment processes have significant implications for the health of humans and ecosystems. The adverse effects associated with the discharge of untreated wastewater, or poorly treated water, are most obvious in public health, where inadequate disinfection and other treatment can lead to waterborne transmission of infectious agents. Explosive outbreaks of waterborne diseases have occurred following contamination of highly vulnerable natural water sources, such as spring waters, or when there are breaches in water distribution systems. Technological approaches that prioritize sustainability are at the forefront of wastewater research. Regulators should enforce these measures to ensure effluent is of sufficient quality to protect the public from potential exposure to pathogenic agents.

Furthermore, chemicals used in water and wastewater treatment, or utilized as part of industrial or human activity, are likely to lead to undesirable impacts when present in water bodies or drinking water. Such an approach is significant from a global perspective, particularly in countries and regions subject to water scarcity, where alternative waters are often used to supplement supplies and where bacterial toxins might be a significant problem. It is important to also consider the knowledge and understanding of the community. There are massive regional and global education programs in place that encourage the community to use treated water from water grids and inform its populations to avoid untreated groundwater sources.

The continued developments in future trends in water and wastewater treatment highlight the fact that evolving challenges require novel solutions and that there is no one-size-fits-all solution for these evolving challenges. Improved data acquisition and computation are expected to advance the use of numerous smart systems, including not only smart water treatment systems but also other devices such as smart piping and other equipment within the distribution network and the operation of the network itself, to continue to improve overall system performance and facilitate system maintenance. In line with these trends, a growing emphasis on resource recovery from wastewater is evident, including both water resources and energy, nutrients, etc. Supporting these trends is an increasingly growing acceptance of unconventional solutions to treat saline and brackish waters and agriculture and aquaculture wastewaters. Regardless of the application of treated waters, however, a continuing pressure being placed on releases from water treatment and reclamation facilities is the continuing evolution of water quality materials, as well as a growing emphasis on advanced treatment and possible treatment combinations to remove microplastics, biological agents, and various emerging and candidate chemicals. The need for improved water quality will likely be amplified by an increased awareness of the impacts of climate change, particularly evolving water resource availability and costs and water quality changes. There is a need for integrated strategic research and a growing multidisciplinary approach to further exploit these opportunities, along with increased collaboration among the different sectors. Debate and knowledge exchange among researchers and practitioners regarding the feasibility of the latest advances in water and wastewater treatment in distinct fields is necessary to offer a valid and hierarchical perspective for researchers, practitioners, and companies aiming to work in these sectors together. This includes discussing the benefits of integrating the principles of these advanced processes into decentralized treatment systems and creating collaborative networks for better addressing water quality and safety through implementation and practical applications. In this way, innovative advanced treatment processes can be made more appealing, increasing not only their application but also their storage.

In physical treatment systems, water contaminants-including microbes, colloids, and particulate matter-are removed, separated, or otherwise forced to undergo a physical change that can be exploited to increase water quality. In chemical treatment systems, the properties of the contaminants are altered, often by biological or chemical means, to manipulate the contaminant behavior. Principally, these reactions are used to facilitate the separation of target contaminants, and they often have parameters and properties that make them especially relevant for particle and colloid processes in water treatment. The removal efficiency of physical and chemical treatment processes commonly differs based upon water and system design specifics. Physical treatment processes work to maximize the size and weight difference between target particles to be removed and the bulk solution. The difference can be maximized in phase separation processes, where the continuous and dispersed phases are directed to settle, rise, or otherwise separate based on density differences. The difference can be maximized in filtration systems based on particle size and filtration matrix properties. In fast or mixing chemical water treatment systems, even small density or size differences can be used to enhance separation efficiencies over time. Chemical treatment processes, in contrast, function at scales smaller than the actual contaminant. For drugs, bacteria, and viruses, or even trace metals or proteins in water, the size of the contaminant is often unimportant. Solids processes related to ion exchange can actually remove particles significantly smaller than the pore size of the absorbent media itself. Soluble reactions occur between the colloidal or dissolved contaminants and an activated chemical species that has very specific, often surface-related binding properties. Only a fraction of dissolved (and often colloidal) contaminants will be retained in a particulate removal process, but removal efficiencies can be extraordinarily high [7-9].

Chapter - 2

Physical Treatment Processes

Upon collection, raw water needs to be purified to some extent to make it suitable for domestic, industrial, and commercial use. There are different treatment steps to make water usable. The treatment could involve removing a material from the water, removing a substance from the water, improving the taste and odor of the water, and the treatment of the water could also include chlorination, fluoridation, pH adjustment, and the addition of chemicals to the water. Before these treatments can be carried out, it is very important to remove suspended solids, dead leaves, algae, bacteria, and microorganisms to help the operation of the treatment processes. Consequently, it is worth mentioning the physical opening of the door for the next treatment stages. The effect of increasing the rate at which physical treatment processes will effectively remove color, taste, and odor-causing agents can be calculated using a formula: $Lt = L0/(1 + kt)$, where Lt = concentration of particles left after t minutes, $L0$ = initial concentration of particles, k = constant, and t = time in minutes.

Physical treatment is limited to the removal of suspended solids and the bacteria and microorganisms that are attached to the suspended solids. We can classify the physical methods into different categories, and based on their operating procedures, these could involve either one physical method for water treatment or a combination of many methods. The single physical method includes screening, and the combined methods include screening and sedimentation, screening and flocculation, and screening and sedimentation and flocculation. However, the combination of flocculation and sedimentation requires a coagulation unit before undergoing any other process. This chapter will discuss the physical treatments of water. The physical treatment methods are classified into four main methods, and each method will be discussed in a separate subsection,

Which are:

1. Screening.
2. Sedimentation.
3. Filtration (physical and chemical filtration).

Overall, understanding the principles of physical processes is a foundation for understanding and operating the treatment scheme and the other treatment technologies [7, 10, 11].

2.1 Screening

Screening to remove debris and larger solids is generally the first process step in physical treatment such as wastewater or surface water treatment works. The main objective is to reduce the solids loading on the downstream process stages and also to protect the downstream equipment from any possible damage. Attainable removal is dependent on hardware type and the size, shape, and buoyancy of the materials to be removed. Screening is also useful for project proposals based on treatment processes following the screening.

Screenings comprise a multitude of materials, such as various types of debris. This debris can include both natural materials originating from flora and fauna, as well as substances associated with sewage, storm-related materials, and decayed or decomposed materials. Specifically, decomposed materials are generally found within return activated sludge that is an integral part of sewage systems. It is important to highlight that the greater the volume of sewage that requires transportation through a combined sewage system or a partially separate system, the more likely it is that the screenings will include materials related to storm events. These screenings are often categorized based on the specific methodologies deployed for their capture, which applies to both sewage and storm-related materials. The categorization encompasses bar rack screens and mesh screens, which are differentiated by a variety of factors such as the mesh aperture size and the specific positioning of side retention devices. Major equipment suppliers that offer these diverse screening solutions frequently find themselves intertwined with one another, leading to the emergence of several arguments that pertain to the functionality of both bar screens and mesh options. Such considerations extend to aspects relating to their operational capabilities in both forward and reverse configurations, while also addressing the distinctions between bottom-up placement versus top-down methods of material capture. The fundamental categories that characterize these capture methods are usually determined by the relative location of the materials compared to their original point of origin. In terms of performance metrics, the primary emphasis is placed on the capture rate relative to the overall carrying capacity of the system at hand. Hydrodynamic loading emerges as a significant factor influencing design considerations. If empirical data from comparable plants operated by the same equipment supplier is accessible, this can serve as an advantageous point of reference for designing optimal screening systems. The actual sizing of these systems will be contingent upon several critical factors, including the system's capability for self-cleaning and its levee strength. A vital concern within this context is the necessity to effectively contain various forms of debris, while also ensuring that there is a functional process for the removal of debris that has previously accumulated, which often entails managing the load derived from previous operational cycles. It remains essential to ensure that there are no planned outages or reductions in operational staff, particularly during weekends, as this aspect is crucial for maintaining cost-effectiveness and efficient management of the system. Furthermore, it is imperative to refrain from engaging in any mechanical raking or water-driven cleaning of screenings that have already settled, as such actions could potentially cause portions of the debris to become submerged, leading to disintegration or the formation of clogs. Such clogs can instigate blockages further downstream in the treatment process, jeopardizing overall efficiency. To succinctly summarize, the following clarifies the primary characteristics associated with various designs along with their respective advantages and disadvantages. Additionally, it is important to acknowledge the operational challenges that may arise, such as backwash issues, which could be experienced with a range of guards, mesh, and upwards-facing screens designed to capture debris on their front faces. In the diverse landscape of selecting the most appropriate screening system, the decision-making process is typically shaped by an array of case studies that pertain to the effectiveness of material removal, as well as the alignment with suitable equipment suppliers. A thorough analysis of operational costs plays a crucial role in this decision, which must also consider the need to maintain a balance between compliance with discharge consents, all while addressing any complaints that might arise from instances where debris escapes the screening process [12-14].

2.2 Sedimentation

Sedimentation is the term used to describe the process where particles suspended in water settle out at their own settling rates over time. Particles in suspension sediment due to the gravitational force acting on the specific particle. When the gravitational force acting on the particle is greater than the buoyant force, acceleration and drag forces are in opposition, the particle will rise. When a particle becomes steady, the solutions and the acting forces are in equilibrium. Sedimentation is a critical process because it is the primary basis for the physical separation of the solid-liquid materials.

A device where sedimentation can be done is in a sedimentation tank. In a typical sedimentation tank, a series of compartments known as weir plates allows water to flow from the raw water source to a cleaner source. Typically, low water flow velocities are used such that particles are allowed to slow gravity sedimentation. The movement of particles gradually occurs in the horizontal plane of the sedimentation tank. There are several parameters that can affect the efficiency of the sedimentation process in terms of the sedimentation channel. It could be related to the effect of flow characteristics, to find the mathematical formula of the main dimension of the sedimentation channel, and also the varying pattern of the size and concentration in wastewater to be sedimented. The most common techniques used in sewage treatment works can essentially be divided into two groups: batch operations and continuous operations.

The techniques that are most often used for sewage treatment works based on batch operations are taken to the river to discharge when the channel has the amount of detention that is needed to reach the required water quality. As such, the dimensioning of the tank must also allow for dimensioning one or more of the effluent weirs. In continuous operations, where there is no need to delay the discharge of the effluent, a single sluice gate is usually installed in the tank, which flows into settling lagoons for the storage and detention period. When the detention period is complete, the impounded water should be further dewatered by means of drainage and flushed out to the storage lagoons downstream. The process is repeated until all the flows for the settlement period have passed through the tank, which has a volume of detention that is enough to give the required quality of effluent. In this aspect, the dimensioning of the tank needs to take this into consideration. The way that the sedimentation tank is managed will also be significantly influenced by the requirements of sludge management. It should also be noted that how the tank is filled or emptied for these processes is central to the control and management of the flows during settlement [15-17].

2.3 Filtration

In filtration, water is passed through a filter and particles are retained on the media or within the filter cake. Filtration is a very important process, particularly for the removal of smaller particles. Slow sand filters or rapid filters are used for partial solids removal and membrane filtrations for particle filtration in the submicron range. The efficiency of rapid filtering is described through key principles and simple filtration calculations. Operation and maintenance of the different unit processes are outlined for an integrated approach to the topics covered.

Filtration can be used to achieve both solid-liquid separation and particle removal from water. In this module, we discuss different filtration systems and the underlying principles of the solid-liquid separation process. In the previous section, separation processes were described that end in the removal of larger particles. Filtration is focused on the lower range: removal of smaller particles that remain in the water after preceding treatments. Filtration is one of the most widely used unit processes in water treatment. Filters are used for the treatment of surface waters and ground waters. Rapid filters are sometimes termed gravity or pressure filters. Rapid filters usually operate at higher filtration rates and are cleaned with abrupt physical actions that involve driving out cake. Substances of importance in the selection of filter media include effective size, uniformity coefficient, roughness coefficient, shape, and specific gravity. The selected media must be compatible with the properties created by pre-filter treatment chemicals. Sand can be stabilized through slow sand pre-treatment or by use of alternative filter media. Maintenance of filtration performance is a problem related to the occurrence of remaining particles or dissolved compounds in the effluent, variation in quality, or blockage of the filter medium. Sufficient equipment and operational knowledge are vital for optimal operation [18-20].

Chapter - 3

Chemical Treatment Processes

In addition to removing particulate matter, water quality can be drastically improved by modifying various water constituents with specific chemical reactions. Sometimes, a sequence of chemical treatment steps is used to remove water contaminants. In general, a physical process is used to reduce the contaminants to be removed via chemical methods, while the chemical treatment reduces the problems related to relatively dissolved and colloidal contaminants that cannot be directly addressed by a physical process. Chemical treatment processes are especially important when removing natural organic matter. After an organic mixture is oxidized via a physical process, the modified oxidation products are then removed via a chemical process.

The main purposes of the most common chemical processes are as follows:

- **Coagulation-Flocculation:** Aggregates particles and organic matter into flocs through particle-particle interactions and adsorption.
- **Disinfection:** Oxidation or inactivation of pathogens to render water pathogen-free.

Effluent chemicals or other substances are often oxidized to an innocuous form. While physical treatment processes either remove or change the state of the contaminant, chemical processes often add new components to the effluent. Coagulants, for example, are added to water to modify contaminants so they no longer pose a treatment problem that affects the environment or human health. The coagulation-flocculation process takes advantage of the natural tendency for particles to repel one another by agitating the water to cause slow mixing, resulting in small particles growing into larger flocs over time. In general, the coagulation process includes electrostatic destabilization of colloidal particles. Particles are neutralized by the addition of a coagulant to the water, so that destabilized particles come into close proximity with each other and stick together [21-23].

3.1 Coagulation and Flocculation

Solid removal in water treatment can be enhanced by increasing the size of the solids or their settling rate. There are two processes that can work complementarily or separately in this field: coagulation and flocculation. Coagulation is the addition of chemicals that reverses the charge on colloidal or larger particle surfaces, destabilizing them by decreasing the energy barrier to van der Waals forces. Then, particles can directly aggregate. The aggregation process requires more collisions, occurring when particles are large enough. During collision, particles lose their Brownian motion, increasing their settling rate. The solids obtained are called flocs. The main goal of coagulation is therefore to destabilize particles, in contrast with aggregation through charge neutralization, facilitating the aggregation, while during flocculation the coagulated particles combining is enhanced.

Coagulant selection and its application design conditions are responsible for the process efficiency. The choice of the correct coagulant depends on physicochemical parameters and on its availability and cost. In the case of inorganic coagulants, these must meet certain standards of purity to avoid disqualifying the final water. The chemicals frequently used as coagulants are based on aluminum, iron, or aluminum/iron combinations, mainly aluminum salts and Polyaluminum Chlorides. Coagulation is generally performed under specific pH and temperature conditions, the former being critical with respect to coagulation performance. The addition of the coagulant, either as a solution or suspension, may be preceded by a rapid mixing step, which ensures a good coagulant/particles collision. Mixing conditions include velocity gradient values ranging from 100 to 1000; keeping the optimum range is a necessary aspect for reaching good flow behavior in conventional coagulation studies and coagulation retention efficiency. The main aim of coagulation/flocculation can be achieving the standard set by the health protection authority in terms of turbidity level. The turbidity standard is 0.1 NTU, leveled until 0.5 NTU from November 1 to April 30. Moreover, water disappearance is verified through experimental samples if residual Mn and Fe are under the aforementioned levels. Coagulation and flocculation plants are designed for a variety of applications, both for drinking and industrial waters. In the following, some case studies are presented [24-26].

3.2 Disinfection

Disinfection is a process essential to remove pathogens from water and make it safe for drinking. In general, existing disinfection methods may be classified as chemical or radiation-based or a combination of both. The technology for delivering safe water to consumers involves the usage of a range of unit operations or a combination of unit operations with suitable disinfection, typically after final particulate filtration. Disinfection processes for liquids are integrated with solid-liquid separation processes in industries.

The unit operation used for solids-fluid separation may be gravity thickeners, centrifuges, or filters.

Various disinfection methods consist of several critical and interrelated aspects, which can be broadly categorized into physical, chemical, and biological components. Estimates indicate that chlorine emerged as the most widely used disinfectant across the globe, first being introduced in the United States during the 1890s for extensive purposes. The mechanism of action and overall effectiveness, along with the advantages and disadvantages, of the various disinfection methods currently available have been meticulously summarized for better understanding. Among these popular disinfection methods, we find techniques such as ozonation, chlorination, ultraviolet water treatment, hydrogen peroxide and its various derivatives, chlorine dioxide, and silver along with its compounds. Additionally, the use of chitosan and triclosan has gained attention over the years. Disinfection efficiency is often largely contingent upon the prevailing conditions of the process, which encompass site factors; these include the availability of essential nutrients for bacteria or the presence of sunlight potentially interfering with the disinfection process. Furthermore, the initial quality of water plays a significant role, as it comprises the concentration of microorganisms as well as organic matter. Operational factors also critically influence efficacy; for example, the contact time with a disinfectant and the dosage of disinfectant applied are key considerations. To illustrate, the dose of chlorine that is necessary for effective disinfection within water is influenced by a variety of factors, including contact time, concentration of chlorine-demanding substances present, the specific type of pathogen involved, as well as temperature and pH levels of the water itself. Each disinfection method presents its own unique advantages and inherent limitations, meaning that they are not always effective in completely eradicating all types of pathogens. Recognizing this is essential, especially when we evaluate the most recent advancements and emerging technologies in the field. The application of chlorine disinfectant, particularly for drinking water purposes, has been subject to stringent regulations due to the potential health risks posed by the formation of disinfection byproducts like trihalomethanes. To mitigate these risks, specific guidelines have been enacted that mandate the establishment of microbial performance standards. These standards are crucial for treating drinking water to ensure sufficient disinfection effectiveness. Improved control of target pathogens is anticipated to aid in reducing the formation of these harmful disinfection byproducts. Moreover, any new technology must be capable of processing higher volumes of water in a cost-effective manner while remaining user-friendly and easy to maintain. Several disinfection methods will be discussed in more detail in the upcoming sections, providing a comprehensive examination of their respective roles in ensuring water safety and public health [27-29].

Chapter - 4

Advanced Treatment Processes

Beyond the established treatment functions, advanced treatment focuses on more specific aspects like the removal of some complex or refractory pollutants, disinfection, and by-products reduction, softening, or desalination. In industrial and municipal water treatment, much effort is ongoing to research and further validate various advanced treatment technologies. Some of these, like membrane filtration and related technologies, desalination, and advanced oxidation, are already entering the mainstream of water treatment and reuse. This chapter will present an overview of the current status of these advanced treatment processes.

Membrane filtration is an important physical separation process that employs a semi-permeable membrane to effectively separate various substances from the water. This technique serves as a multi-tier treatment process capable of performing the essential function of clarification. Its inherent selectivity allows membranes to eliminate a wide variety of materials, achieving a significantly greater degree of separation compared to traditional sedimentation or filtration methods. On the other hand, adsorption is primarily a surface effect that predominantly involves interactions between solid and solution phases. The driving forces that govern the process of adsorption include the high surface area that is available for the adsorption process, a diverse range of pore sizes, and distinct surface properties that influence this phenomenon. In essence, dissolved contaminants present in water are transported by diffusing toward the surfaces of the membrane, subsequently entering its pore structures. Here, the forces at the surface play a crucial role in determining the accumulation of these contaminants and their ultimate retention within the solid phase. A comprehensive comparison of the mechanisms of membrane filtration and adsorption with regards to the removal of pollutants and viruses has been thoroughly summarized, providing a clearer understanding of their respective efficiencies and applications.

Presumptive viruses in water can be removed by both adsorption and membrane technologies-competition for space on the solid phase or at the membrane surface-but virus transport through adsorptive media containing more than 10% of organic matter is best achieved by reduced pore size membranes and zero-valent membranes that retain the integrity of the virus. There are several important operational considerations pertaining to the use of membrane and adsorption for water and wastewater treatment. System design, the efficiency of the removal process, and the cost of the treatment using these advanced systems are interrelated. Upward scaling of membrane and adsorption systems for water treatment will lower the cost of treatment, as the same large amount of treatment capacity/output would be distributed over less integrated systems. Continuing advancements in membrane and adsorption technology have significant potential for industrial applications and have evolved to meet the sophisticated requirements of the separation and purification of specialty chemicals [30-32].

4.1 Membrane Filtration

Membrane filtration is a simple separation process involving a membrane, or filter, that acts as a physical barrier. Membrane materials can be constructed to have a specific charge, so in addition to screening particles by size, a charge exchange can make it possible to 'catch' charged particles. At its core, a membrane filtration process operates as a molecular or particle-sized sieve or strainer. The effectiveness of membrane technology is influenced by the ability of the membrane material to separate particles and do so over an extended period without complications. For many years, 'membrane' absolutely required a physical separation. While this can still be debated, membranes have moved into a critical role in separation processes for numerous systems. The separation is based primarily on size exclusion, which might or might not include ion exclusion from a support layer. Membrane processes consist of microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. If the driving pressure is great enough, flows do reverse. In the water and wastewater field, more people have dealt with microfiltration and, most typically, ultrafiltration. When someone talks about the use of membrane technology from the separation standpoint, they tend to talk and think in terms of the driving forces. Reverse osmosis is considered to be primarily an electric force for driving the process, with pressure present as a non-fouling mechanism. Osmotic systems, by comparison, consider osmotic pressure as the driving force and not as a primary reference to electricity. Membrane filtration is used for a variety of applications that include the production of potable water, the removal of contaminants from wastewater, and the pretreatment of water for use in industrial applications. Some of the challenges encountered in membrane systems include the effect of biological growth on membrane surfaces, scaling, changes in water quality, or temperature flux due to production changes. Key operational parameters for membrane filtration systems involve the flux rate and strong dependence on membrane fouling characteristics. To run a process at the maximum rate, clean the membrane for a period of time, and then run it at the point in time just before it needs to be cleaned as a steady continuous state operation is most economical. It is also technologically superior. Data for line property and integrity is being gathered at all times; thus, membrane systems are providing immensely valuable product command information and control systems when adequately instrumented and controlled [33-35].

4.2 Adsorption

Adsorption is the process of capturing one substance on the surface of another. It is typically accomplished by passing water through a suitable medium that has a large adsorptive surface area. An adsorptive surface is advantageous because most contaminant uptake by an adsorbent material occurs at its surface. Both the attraction between surface and adsorbate and the binding of the two are important factors, which means that the surface characteristics are also critical in causing adsorption to happen. Some substances are already well-suited for use as adsorbent materials because their activated physical structures are both porous and of high internal surface area. The efficiency of adsorption is determined by several factors, including the length of the contact time between adsorbent and adsorbate. The condition of the water, such as pH, also contributes to adsorption efficiency, as do the temperature and nature of the adsorbate. Adsorption technologies are versatile and have the ability to remove many different types of contaminants. In contrast to the competitive interactions among solutes, adsorption can be used to target specific contaminants in water, and many such technologies are commercially available or are being developed. Adsorbent material must be regenerated or replaced as it is exhausted, and it may not adsorb other contaminants at the same time it operates for a specific contaminant of interest. Although adsorption is a widely known and widely used water treatment method, it is removed individually, at times accompanied by chemical coagulation or other procedures. While it is inefficient when targeting low contaminant concentrations, adsorption systems can be designed for highly effective removal of contaminants. Only a few metals are of concern regarding toxicity in typical waters. Adsorption is generally modular and can be monitored and maintained for efficiency. Adsorption is a frequently used treatment strategy, and many small-scale and full-scale adsorption plants have been implemented [36-38].

Chapter - 5

Design and Operation of Treatment Systems

Treatment systems must be effectively designed and successfully operated if they are to be integrated into a water quality management program. Various design aspects must be addressed for a given treatment scheme or process to ensure that the system will operate in a manner that meets established treatment objectives, goals, and regulations. Design aspects to be addressed depend on the nature of the water, the treatment goal, and the site-specific characteristics that influence treatment, including such factors as flow rates, concentrations, and basic geography. Design criteria can and should be established that will provide the information necessary for accurate treatment system design. Factors that need to be considered are directly related to the basic goal of treatment system design, that is, providing a system to attain a given quality. The removal capacity of a treatment system should be quantified through analysis of its ability to remove substances by a series of reaction sequences.

The efficient operation of treatment systems is related to the design of specific operational plans that facilitate regular daily system operation. In addition, a series of monitoring programs and immediate operator response protocols are required in order to ensure effective operation. Daily or weekly system monitoring programs and schedules specify monitoring site locations, sampling schedules, and appropriate testing requirements. Proper operator training is essential in this regard to minimize the possibility of equipment malfunction. Operator training includes familiarization with system operation, regular system maintenance, and testing and monitoring protocols. The combination of three basic design concepts-concentration minimization, simple system design, and easy labor implementation and maintenance-represents the best overall treatment choice. Design criteria may result in system designs that are not always compatible with the basic treatment goal. Operating plans must accommodate the situation, that is, insert polishing if straightforward control of system operation does not achieve the design criteria concentrations. Full-scale treatment systems that require this sort of manipulation are generally more complicated and expensive to operate [39-41].

5.1 Process Design Parameters

In designing any wastewater or water treatment system, a number of process design parameters have to be established to assure proper system operation. These parameters might include hydraulic loading rates, retention or contact times, chemical dosage rates, etc. The establishment of these parameters has profound effects on the treatment concepts and, hence, the overall cost of the treatment system. As such, the design of a treatment system has traditionally involved the rigorous calculations of the design parameters followed by the construction of pilot-scale facilities to verify the preliminary designs. Only after pilot-scale operation was successful would the actual full-scale system be designed and constructed. The important process design parameters and a discussion of the relevant water quality aspects are presented in the following pages.

The intricate design of any wastewater or water treatment process fundamentally begins with the precise definition of several key design parameters that are crucial to the implementation of the treatment process. When provided with these parameters alongside comprehensive water quality information, one has the opportunity to utilize a range of models that vary from simple to highly complex in order to forecast the effectiveness and performance of the treatment process under diverse conditions pertaining to influent waste loads. By explicitly defining each of the process design parameters and the associated operating conditions, one ultimately determines not just the treatment level, but also the cost implications of treatment calculated on a per liter basis, resulting in a well-structured treatment strategy. In the endeavor of developing stand-alone water treatment processes, there are several important process design parameters that should be taken into consideration; these include the characteristics of the contactor as well as specific design parameters pertinent to the water treatment plant itself. Different treatment system design approaches, like modular versus centralized configurations, play a significant role in facilitating effective load-based design methodologies and in ensuring compliance with any established volume standards that may be in place. It is vital to recognize that any reduction in either contact time or flow due to the creation of a new effluent standard will necessitate substantial reductions in allowable production levels, particularly when utilizing a batch discharge treatment system as a potential solution to the challenges faced in wastewater and water treatment design [9, 42, 43].

Example solutions will lead the learner through a variety of applications of the principles taught. This section will cover the process design parameters typically involved in the removal or transformation of constituents in water.

5.2 System Operation and Maintenance

Operational aspects of these treatment systems are an important topic unto themselves. Proper design of systems without care in maintenance and operation may perform poorly. Aspects of system operation and maintenance are addressed in greater detail in Section 8: Water and Wastewater Plant Operation. It is important that water system operators be trained in the operation, monitoring, and routine maintenance of not only system equipment but the system as a whole. Inadequate operator understanding of the interrelationships and dependencies between system components and treatment processes may lead to operational difficulties; training only in the maintenance of process equipment doesn't guarantee good operators. Best management practices operators need to learn include how to monitor system treatment performance, conduct routine troubleshooting, and practice predictive and proactive maintenance.

Good maintenance begins with carefully adhering to the maintenance schedule recommended by the manufacturer. This schedule serves as a vital blueprint for ensuring longevity and optimal performance of equipment. For simpler, non-electronic equipment, maintenance typically falls into a yearly routine, often aligning with specific calendar dates. Conversely, for more advanced and electronic systems, it is crucial to precisely follow the recommended maintenance schedule outlined by the manufacturer. Regular calibration of instruments and systems is not just beneficial, but fundamentally essential; however, attention to how this calibration is conducted is frequently overlooked. The way in which calibration is executed can profoundly affect the accuracy and reliability of the resulting measurements. Moreover, routine inspections play an especially pivotal role in ensuring that equipment maintains its operational fitness and that systems function efficiently. These inspections are crucial for identifying potential reliability issues within a system before they necessitate repairs, thereby preventing costly downtimes. Maintenance, conducted at predetermined intervals, regardless of whether inspections are executed, can lead to an extension of the operational lifespan of the equipment. Such inspections predicated upon regular maintenance form a sound cost-benefit strategy, promoting the health of the system. The ideal approach to managing a treatment system is to merge continuous monitoring practices with scheduled inspections of both the system and its components. In the modern landscape, various instruments are available that can function autonomously, in a manually adjusted mode, or be harnessed for complete system automation. These automated systems possess capabilities to control alarms, sustain set parameters, and manage on-off control functions, hence contributing to a reduction in the number of operational units required. Laboratory testing of wastewater quality is guided by various evaluations, including visual assessments and other qualitative measures, as the composition of certain metals within the wastewater might remain undetermined. Effective effluent quality monitoring relies on an array of sensors and analyzers designed to continually assess wastewater standards. Notably, certain motors can also facilitate the monitoring of both input and output water quality. This functionality aids in the ongoing online management of parameters such as pH, flow, and chlorine levels in industrial cooling towers, leading to substantial energy efficiency improvements. Furthermore, systems automation not only yields financial savings through reduced operational and maintenance expenses but also guarantees consistent quality in effluent outputs. Automation frequently plays a crucial role in effectively managing equipment operations, overseeing when machinery is powered on or switched off, and playing a vital part in alarm systems, particularly in applications where response times may be extended.

The operation and maintenance manual, when handed off from the start-up crew to the ongoing operational team, should meticulously detail certain essential protocols and established procedures. This documentation may encompass what actions to take in the event of system downtime or failure, particularly during inconvenient times such as in the middle of the night and on weekends, or under statutorily required timelines that must be adhered to without fail. Operators need to be highly skilled at system troubleshooting, including competently addressing those emergencies that require a swift and decisive response from the team. The consequence of failing to operate a treatment process efficiently in a timely manner, therefore, will commonly result in contamination of the drinking water system, potentially putting public health at risk. Although only a few incidents may result in serious mechanical breakdowns and failures, these situations can have significant repercussions. Valves, which are critical components in the operation of treatment processes, were also thoroughly listed in the manual. This comprehensive knowledge goes hand in hand with routine inspection practices, as both are integral to ensuring system reliability. Reading operator and maintenance procedures will prove beneficial in helping to identify such critical items that require attention, particularly with regard to maintenance activity and its frequency. If the manual encourages a troubleshooting and investigative approach to equipment operation, along with maintenance protocols that include detailed information on common problems and suggested solutions, there is ample evidence of a proactive maintenance philosophy and a dedicated attention to reliability within the operational framework. This structured methodology not only enhances the operational efficiency but also protects the integrity of the system as a whole [44-46].

Chapter - 6

Emerging Technologies in Water Quality Engineering

Emerging technologies in water quality engineering have attracted ever-growing attention due to the emerging challenges of water availability and quality. As a green and clean technology, developments in nanotechnology have yielded many innovative ideas for creating novel engineered nanomaterials that have started to influence and impact the water treatment industry. The innovations have concentrated mainly on engineered nanomaterials and their composites for cost-effective and efficient removal of contaminants that have become a severe problem in terms of their recalcitrance and refractory nature in wastewater and surface water. Simultaneously, nanotechnology has allowed researchers and engineers to create advanced oxidation processes or environmentally friendly and benign oxidizing agents for degrading emerging and persistent organic pollutants.

Several challenges lie ahead in the field of engineered nanomaterial applications. Dosing and controlling the release of engineered nanomaterials to the environment remain pivotal considerations for risk mitigation. In the case of advanced oxidation processes, key challenges include improving the oxidant activities, selectivity, and stability at a larger scale. Research and development in these disciplines will be essential for commercialization and the subsequent manifesto of water and wastewater treatment plant upgrades in the coming times. From a treatment philosophy, advanced clarification would best fit a fallout strategy (solids removal) and thus would be the final step in a collective treatment framework for water and wastewater utilities. Capturing the 'fallout' as sludge would reduce the waste load and improve the performance of the final stage, since low-toxicity metal hydroxide sludge could discourage subsequent biological and chemical activity when bioavailability is significantly decreased. In summary, research into discovering and producing new combinations to exploit these persistent and refractory materials should become the ethic of the future of water quality engineering.

6.1 Nanotechnology Applications

At the nanoscale, materials have areas of high surface reactivity to volume, which can improve, as catalyzing agents or adsorbing substrates, the performance of existing water treatment technologies. An exponential growth in the applications of nanotechnology in areas related to water treatment has been observed in recent years. Both the U.S. and the European Union have funded efforts to develop and evaluate engineered nanomaterials for water remediation. The two major approaches in nanotechnology research as they apply to water quality engineering are the use of nanoparticles for contaminant degradation and filtration.

Specific applications of nanomaterials in water treatment include:

1) Development of a zero valent iron reductant and absorbent.
2) Raw water pretreatment.
3) Filtration media.
4) Adsorbing packed bed reactors.
5) Development of catalysts for an advanced oxidation process.

The potential superiority of this class of materials derives from their extremely small size, high surface to volume ratio, and thus the ability to adsorb, react, and/or transport contaminants at levels and rates that are physically or chemically inconceivable for traditional bulk materials. To date, a number of different types of nanoparticles have been used for water treatment, including carbon nanotubes, titanate nanotubes, and metal oxide nanoparticles. Metal oxide nanoparticles have been used for their ability to adsorb contaminants at the surface sites and their subsequent ability to catalyze contaminant degradation using an advanced oxidation process. Metal oxide nanoparticles represent an alternative to carbon nanotube adsorption where the surface of the nanotube resides the catalyzing agent. Oxide nanoparticles with a high isoelectric point and high surface area have been used to modify granular activated carbon and sand filtration media in recent years for the purpose of improving contaminant removal by increasing the hydroxide adsorbent sites and reactivity at the water-media interface [47-49].

The advantages of catalytic mechanisms include a higher contaminant removal efficiency and selectivity, and their minimal production of secondary pollution. The treatment cost might be very high due to either catalyst or photocatalyst needs and/or the high-power input when using a light source. The hydroxyl radicals are extremely reactive and short-lived, reacting with dissolved and/or suspended phase organic or inorganic contaminants. The main drawback of advanced oxidation process technology is the high energy consumption, particularly if catalytic advanced oxidation is used. Due to the relatively low energy of sunlight, titania-based photocatalysis has been the most studied photocatalysis. In general, advanced oxidation process is not applicable to the treatment of large volumes of water. The major concern with these materials is their cost, fate in the environment, and potential toxicity. Many potential applications are still under basic scientific investigations. Only a few are already in the market, such as titanium dioxide sanitary ceramic tiles, which have been developed with photocatalysis agents. Applications already practiced include the conventional rapid sand/anthracite media filtration and newer membrane filtration techniques. The high reactivity of metal oxide nanoparticles may render them difficult to handle and pose a potential environmental impact. Research in these areas is ongoing and may evaluate and characterize environmental impact and improvements in catalyst efficiency. The above discussion truly illustrates the significant potential of nanotechnology for the future of water quality engineering. Because this technology is still in its very early stages of development and application, a great deal of research and development is necessary before either particle filtration or catalysis can become cost-effective treatment methods. Because this technology is still in its early stages of development, in some areas, a lot of work remains to be done in order to prove it comprehensive and with a neutral effect on the environment [50-52].

6.2 Advanced Oxidation Processes

Advanced oxidation processes (AOPs) are oxidation techniques applied to wastewater to break down a wide variety of hazardous organic components that are resistant to other techniques. This is possible due to the high oxidation capacity, normally achieved by the generation of powerful oxidative agents such as hydroxyl radicals and other intermediaries or radicals in situ. Some of the AOPs involve the addition of hydrogen peroxide, but in situ generation of H^2O^2 by the reaction between O^2 and H^2 in the liquid phase could also occur.

Numerous AOPs have been developed to remove pollutants, although the most explored is based on natural common radicals such as hydroxyl radicals. The most typical one is the Fenton reaction, which involves the decomposition of iron(III) that releases iron(II) and hydroxyl radicals. Other AOPs that utilize metals are also available. Furthermore, some AOPs couple hydrogen peroxide with ultraviolet light, in which the UV light enables the activation of peroxide to produce some radicals. However, one disadvantage of this kind of AOP is the high operational cost, mainly due to the use of UV lamps.

These processes are suitable for systems with few transaction variables, and the operation is relatively simple when compared to others in the AOP group and can be reinforced by a previous or partial combination with other complementary processes. Another relevant aspect of AOP is the favoring of degradation or mineralization of pollutants with low biodegradable rates and their byproducts at the end. Usually, the toxic effects are smaller than the parent compounds, such as the pollutants in the priority list of compounds of the European Water Directive, and the polycyclic aromatic hydrocarbons produced by oil spills. It is possible to use AOP to assist the removal of compounds usually considered difficult to remove in traditional physicochemical oxidation methods in conventional water treatments, which are low biodegradability ratio organics when released from the proper biodegradable matrix [53-55].

Chapter - 7

Case Studies and Real-World Applications

Because I firmly believe in the pedagogical value of teaching through the utilization of case studies, I have made a concerted effort to illustrate a variety of real-world applications and relevant case studies throughout the text. The selection of case studies I present ranges from a comprehensive overview of the specific attributes of numerous systems to detailed process flow diagrams and pertinent calculations along with in-depth analyses. The diverse topics of each section are firmly rooted in my professional experiences and formal education. Drawing upon my extensive background in both environmental consulting and manufacturing, I hold a deep-seated passion for the creation and utilization of meaningful case studies. Consequently, I am convinced that a thoughtfully curated series of five distinct case studies would greatly enhance the educational value of this text. While Sections 7.2 and 7.3 have prominently highlighted industrial waste and drinking water as the primary systems of focus, these case studies could be strategically chosen to explore additional crucial areas within water treatment. The comprehensive breakdowns of the specifics associated with each study could encompass the approaches that were applied, valuable lessons that were learned during the processes, any significant challenges faced, or compliance issues that arose, all in conjunction with the engineering design of the products, systems, and technologies that were implemented. Each case study would serve to effectively illustrate the practical application of the theoretical and design concepts that are elaborated upon within the main body of the text. Specific topics relevant to the applications may include considerations such as water reuse, natural treatment systems, regulatory compliance, sustainability initiatives, and more. The field of engineering design inherently requires a great deal of creativity, particularly in adapting engineering calculations, navigating regulations, and demonstrating a nuanced understanding of both the environment and the political landscape to address the distinct nuances of each specific situation. To illustrate even a few of these compelling cases can prove to be highly informative and beneficial, allowing the reader to glean substantial in-depth knowledge about the various products and processes that are discussed within the textual content. While it is likely that readers are already somewhat acquainted with the aforementioned concepts, it remains imperative to reinforce these core ideas by providing tangible examples of their effective integration in practice [56-58].

7.1 Industrial Wastewater Treatment

Any aqueous solution containing 0.1% or more solute by weight is considered wastewater. While strict criteria define the term municipal wastewater to include domestic water, used water, stormwater, and other dilute sources, industrial and commercial discharges generally consist of concentrated and far less consistent streams of water. The makeup of industrial wastewater can vary widely by plant process and materials, or even time. In certain cases, releases from industrial or commercial sources can largely contain non-biological hazards, atop and beyond the overall risks from different kinds of contaminants, physically and biochemically, from a public health standpoint. Physical Parameters Water quality is a broad term that refers to various physical, chemical, and biological characteristics of water. The physical parameters of interest are color, turbidity, and temperature. Dissolved color is caused by humic and other organic acids associated with untreated surface water supplies. Color is typically one of the chemical parameters used to evaluate the effectiveness of a potable water treatment process. It is often expressed in Hazen units. The color of water is dependent on the presence of finely divided particles that reflect radiation across the visible spectrum. Color primarily results from the presence of organic matter, notably fulvic and humic acids, lignin, tannin, and their derivatives, which may be found naturally in water or from water treatment.

Chemical Parameters The chemical parameters of interest that may exist in a water supply can be categorized as nitrogen, phosphorus, alkalinity, hardness, and numerous trace elements. Nitrogen may exist as ammonia, nitrate, or nitrite. It is probable that nitrogen and phosphorus are not present as point source pollutants in drinking water supplies, but they are referenced as pollutants if present in excess. The large majority of pollutants in drinking water supplies that are screened by compliance monitoring programs and are shown by scientific evidence to be present within water treatment residuals are not of acute health concern. Excess nitrogen or phosphorus in surface waters may promote the growth of algae and other water plants, which can cause odor, taste, and color problems in plant and distribution systems and at the same time feed adverse chemical and algal by-product production.

Physical parameters refer to the characteristics of 'pure' water as well as the impurities present as colloids, particulates, and organics. Light refraction in water is an important physical parameter as it is related to turbidity or the haziness of the water. When light passes through a clear solution, the light ray goes straight through the solution and produces no scatter of light or turbidity. However, when light passes through a very turbid suspension or colloidal solution, the light ray is reflected or refracted by particles and produces a scatter of light. The scattering of light is what causes light to be visible in a clear solution and scatter light to appear. The presence of matter in the water is detected by the magnitude of the scattered light. The measuring devices are called turbidimeters.

The light scattering ability of the colloids or microbes larger than the wavelength is also used to detect colloids or microbes in suspension or colloidal solution. The method is called nephelometry and it is widely used as a low-cost procedure to estimate total coliform in drinking water, waste effluents, or swimming pool water. The presence of large quantities of matter in the water with the capability to scatter light, such as very small colloidal or microbial cell counts, is detected as turbidity. The turbidimeter or nephelometer generally uses a photometric measurement of scattered light to evaluate the turbidity in the sample. Total suspended solids, as determined using a regular micropipette method, is highly correlated with turbidity for samples of low turbidity values. For highly turbid samples, the relation may become non-linear due to the light absorption by the colloids.

Introduction to Water Quality Engineering 2.2 Chemical Parameters Abstract. The behavior and existence of every species depend on and take place in a particular environment. Water is an environment and a natural resource to which many animals and plants have adapted, and the biological processes of life, as well as the other primary and secondary needs of many organisms besides the homeostasis and metabolism of the body, show an absolute dependence on water. Safe drinkable water is always a necessity for human beings. In preparing an environmental protection strategy, the responsible authorities need to know specific factors about the various sources of water and how these factors may affect or be stated by human health or the environment. Moreover, to be able to govern the compliance with the rules, the authorities must be able to measure these factors. Thus, methods must be developed to measure these factors. Additionally, these methods must be reliable, accurate, sensitive, and simple enough to be used while being low in cost. Keywords: water pollution; water quality; water quality testing; water quality management; engineering; environmental engineering; inorganic chemistry; pollution engineering; water quality management; water management; water quality monitoring; pollution management; water law;

water quality and treatment; water pollution; water and sanitation. In this chapter, the objective is to structurally organize the treatment of the contaminant parameters and water quality, analyzing the most important aspects related to the methodology used, the purpose of the analysis, the applicable laws and definitions, the critical levels, the macronutrients, the indicators, and the most relevant and significant toxic contaminants to public health. 2.2.1 Ammonium Ammonium analysis form is applicable to drinking water, fresh, estuarine, and saline waters. It is based on the stabilization of an unsaturated sample and the use of an array of calibration standards. The sample is converted to ammonia with alkaline hypochlorite. A color developed responds closely to the sample and standards present concentrations in the range.

Water quality engineers are not primarily interested in the determination of specific biological organisms. Rather, like the chemists, they are interested in the determination of particular biological properties which reflect, or in some way indicate, the degree of treatment imposed or the existing quality of a water source. It is the water quality engineer who analyzes a water supply to determine both the quality of the raw water and the sufficiency of a treatment process. Typically, the water quality engineer performs these determinations by using the natural biological properties of the water. The particular biological parameters to be considered differ with the source and the intended use of the water.

The typical biological system of concern for a water supply includes plants, algae, bacteria, protozoa, zooplankton, fish, and other animal life. The primary efforts of the water quality engineer are directed toward the treatment and control of only a few of the most important members of the biological system, particularly bacteria, but also algae, protozoa, and fish. These treatment and control activities may, for some treatment processes, include the initial use of microorganism populations and the management of natural populations through growth-promoting activities.

It is important to note that the treatment of water for human consumption is, in principle, quite thorough and dedicated to the protection of human health. In spite of this fact, numerous waterborne outbreaks occur annually in the United States. However, the few contributions made by drinking water to the improvement of the nation's health far outweigh the risk it presents relative to the number of people served. This calls for the best possible water treatment facilities and the most effective enforcement of standards.

Many factors play a role in creating the need for and the delivery of high-quality water treatment processes.

These include:

The little understood effects of trace contaminants on human life Natural organic or inorganic substances present in water The increasing demands for better water treatment The need to expand the service areas of water treatment systems The growing need for water in drier states Chemical contamination related to mining and milling operations.

This lecture note provides a comprehensive overview of the key environmental health issues associated with water quality engineering, as well as the principles that could be applied to address those problems. It emphasizes the following topics: Concept of Chemical Oxygen Demand, Thermochemical Oxygen Demand, and Biochemical Oxygen Demand, Laboratory and Field Techniques for Determination of TOD and BOD, Heterotrophic Growth and Yield, TOD, BOD, and Reaction Kinetics, Biochemical Reactors, and Math Modeling, Natural Inhibitors and Checks on Reaction Progress, Heterotrophic and Autotrophic Reaction Systems, Concepts in Selecting Energy Exchanging Reactions.

Screening is usually the first unit operation in water and wastewater treatment, which removes the coarse solids. Generally, particles larger than 6 mm are removed; however, wastewater with volume requires this step to maximize the efficiency of subsequent treatment steps using other unit operations. The unit consists of fixed bars set through which wastewater is passed, and this screen is designed in the places of waterways. Unwanted material gets stuck between the rods and is later removed from the site and taken to disposal locations. Screens are also used to remove algae, fish, and other living organisms that are not removed in the primary unit operations. Such screens, known as fish guards or fish screens, are essential at the intake of water treatment plants and cooling towers. As contaminants, living organisms reduce the treatment performance; hardness contained in the feed water is reduced, thereby reducing the heat transfer coefficient.

There are two physical mechanisms that result in particle removal by coagulation. The first consists of charge neutralization via the adsorption of ions that reduce particle charge in magnitude and/or change the sign of the charge. Negatively charged colloids are usually treated with positive ions that form a complex between the cation and the colloid. The negative charge on silica can be neutralized by the addition of Al3+, causing the formation of the negatively charged hydrolyzed species. All the complementary charged complexes are formed between oppositely charged cations and the particles.

The second mechanism behind particle coagulation involves interparticle bridging facilitated by long-chain polymer or ionic complexes. Bridging polymer molecules between particles, or between a particle and a floc, are longer than the shortest dimension between two primary particles. Bridging polymer can physically adhere to more than one particle at a time if the adhesion points are either polymerized or attached. For this condition to be true, the concentration of free, as opposed to attached display cells on the polymer must be low. This is often the case. Most cases involving added long-chain polymers result in interparticle adhesion via the well-documented mechanism of enmeshment. Enmeshment usually forms larger flocs than those formed without bridging polymer.

Sedimentation is the process of particles settling to the bottom of a reservoir, usually by gravity. The sedimentation process is an important component of any water and wastewater treatment processes. It is generally the final step, after which the water flows on to some form of filtration or is further treated as required. Sedimentation will effectively remove those particles of higher density, such as sand, silt, and clay, but will not effectively remove other particles such as organic material and many pathogenic bacteria and viruses. It is, however, an important pretreatment for physical, chemical, and biological treatment.

The removal of settled solids is referred to as clarification. During clarification, concentration gradients will establish, and particles will tend to rise and then descend through these gradients. If a particle does not settle out of the flow, the flow is said to not clarify. The inflow could be considered a solids-in-flow of certain concentration, and the settled solids on the bottom could be considered the solids-out-flow of another concentration. A higher solids-in-flow results in a more dense solids-in-flow, which in turn will provide a stronger concentration gradient and a better possibility of solid removal. The inflow can enter the tank uniformly and evenly to maximize density. If the inflow distribution is such that different solids-in-flows enter at the same horizontal point or the inlet flow has the potential for greater turbulence, this will result in low-density solids-in-flow and a weaker concentration gradient.

As noted in the introduction, the monitoring and analysis chapters, while separate, are presented together because monitoring and analysis are closely related in water quality activities. In these chapters, we will introduce chemical, biological, microbiological, and radiochemical measurements commonly performed for water quality evaluation. However, water quality chemists are not the only ones who perform physical and chemical measurements to monitor water quality. Engineers who design and operate water quality monitoring and control equipment also play a large role in this activity. It is often the water quality control aspects that drive developments in instrumentation. For example, the new gas, ion, and liquid-selective electrodes were all stimulated by the need to monitor a particular ion in a hospital blood gas machine, and a research group was funded to develop a rugged, field-worthy, large-diameter, solid-state carbon dioxide measuring electrode for this application.

It was soon realized that such an electrode had many other uses, such as the measurement of breath carbon dioxide, to assess arterial, alveolar, dead space, and shunt situations. A recent announcement presents two new sensitive and low-range pH-selective electrodes that can be used as an activity and level measuring electrode for subnanomolar concentration on a 12-channel integrated sensor unit for pH and pCO^2. This market-oriented approach to developing sensors not only improves knowledge about the factors influencing the electromechanism and the appropriate materials for use in the transducer but also produces effective sensing instrumentation for water quality engineering. Collaborating with instrument development brings a chemical measurement specialist into contact with new measurement technologies and provides ideas about sensors that they may later use for measurement development in other areas. Without such collaborative efforts, many new materials and transducer device designs, as well as some

The selection of the proper sampling technique for the analysis of water, wastewater, or other media is a crucial step in the entire process of water quality engineering or environmental control. Obtaining a representative sample is important so that it can be analyzed accurately. The objectives of water sampling can vary: for example, to estimate discharges, calculate pollutants, monitor sources, and perform laboratory analyses over specific periods. Although water is essential for all forms of life, water resources are usually scarce in developed and developing countries as a result of population increase and industry, economic development, and urbanization. In addition to contamination and pollution of water resources, the natural state of the aquatic environment is affected by changing physical, biological and chemical conditions. Conducting scientific studies on the aquatic environment can be seen as one way to monitor any negative changes in the aquatic environment. These studies generally consist of both periodic and continuous collection of water samples. One way to conduct scientific studies is to monitor a wide range of parameters and conduct a variety of analyses, but this monitoring requires extensive financial and human resources. Various studies of cost-effective and efficient sampling are carried out with the objective of both reducing resource requirements and simultaneously increasing the number of samples. When sampling is to be conducted less frequently, it is desired that sampling is both efficient and cost-effective. This can be done by using efficient sampling techniques. The method of extracting a measurement or collection of samples from a significant number of conditions is known as 'sampling.' The first step in fieldwork conducted as part of environmental monitoring and other studies should involve research, which will determine the location, frequency, date, time, and depth of the sample. It is also necessary to interpret the results of the work to be performed due to the important role played by data quality and integrity. To this end, simple but important sampling types are applied according to water quality sampling needs to ensure correct estimates can be made for the aquatic environment. This research review aims to provide insight into general-purpose sampling techniques that can be used to extract a water sample from a selected body of water and information about other forms of scientific equipment for the purpose of conducting these studies.

Just as with air pollutants, the human senses are not particularly adept at determining water quality. On rare occasions, a water body will have a strong, pervasive odor of sulfur, and the air will support the water's discolored appearance that results from the growth of a great number of photosynthetic sulfur bacteria, and the cause is evident. Sometimes, water that is heavily infested with blue-green algae or other planktonic vegetation will also be colored, but more typically this phenomenon occurs in lakes that are stratified with regard to temperature and when the body of water is not adequately mixed by the wind and instead experiences a layer of very calm weather. The process is triggered by an algal die-off, and the period of calm that occurs during suitable moderate temperatures on a sunny day inhibits mixing of the layers, and so the cells sink. The feeble senses of humans adequately reveal a relatively small number of problems.

As for water quality, it is evident that any determination of its degree of impairment will require laboratory analysis. Since most waters are colorless, one must evaluate water quality using quantitative analytical methods that do not rely upon the observer's senses. The routine laboratory determination of water quality seeks to assign an appropriate numerical value to a very large number of different characteristics and contaminants, and so it should not be surprising that the full array of methods is very large indeed. Nonetheless, we can nonetheless address numerous physical and chemical properties of the water. Some of these tests are extremely sensitive, and some may be performed using little more than a simple chemical reagent and a test tube. Other property analyses are immensely sophisticated and may require incredibly costly instrumentation. Among the important characteristics of the water that we can routinely examine in a water quality laboratory are: dissolved oxygen, nutrients, heavy metals, volatile organic compounds, other classes of pesticides and herbicides, mutagens, and any number of specific organic compounds. These organic analyses are typically performed using liquid or gas chromatography coupled to mass spectrometry, or sometimes using other detection techniques.

This chapter will describe water quality laws and regulations such as wastewater pretreatment regulations and the Safe Drinking Water Act. It will also discuss the content of water quality standards and the legal requirements associated with implementing those laws and regulations. Finally, current water quality regulations and standards for specific pollutants will be reviewed. These regulations include both secondary drinking water standards and secondary maximum contaminant levels as well as primary maximum contaminant levels. Overall, the purpose of water quality laws, regulations, and standards is to prevent unreasonably harmful effects from contaminating our waters. The problems addressed by establishing water quality requirements include the following examples: waterborne diseases, the biological incompatibility of natural systems containing large populations of humans, and the deleterious environmental and public health effects associated with the discharge of untreated or inadequately treated wastes from commercial, industrial, and military establishments; the discharge of untreated or inadequately treated municipal sewage treatment plants; the discharge of overly heated water from power plants; and the discharge of either accidental or intentional oil or chemical spills into navigable waters.

The National Pollution Discharge Elimination System program of the Federal Water Pollution Control Act regulates the treatment of many sources of water waste. This is necessary to meet the antibacterial, antitoxic, chemical, and other wastewater standards and treat the water in such a way that standards for pathogenic organisms are met. The NPDES program requires the effluents of publicly owned treatment works and industrial sources to be periodically monitored for a variety of chemical and physical characteristics. This ensures that the general physical safety and well-being of the public are not imperiled and that public water supplies are not jeopardized. NPDES provides penalties for those violating the Act and imposes fines for submission of fraudulent reports. States and interstate agencies can ask for NPDES delegation. The states and interstate agencies execute the duties governing the NPDES program for the federal government. In either case, whether it be state or federal execution of the NPDES duties, the Environmental Protection Agency sets up requirements that the state or interstate agency must meet to have authority to regulate under NPDES.

The Act also authorizes research, training of personnel, and civil services and requires reports and ordinances to be completed to furnish appropriate security for water supplies for all public water supplies and any major source thriving in the watershed of the water supply. Those required to meet these liabilities are usually federal or state employers.

Water quality now concerns everyone. The standards that are enforced in various countries define maximum permissible concentration. People are exposed to this concentration when they use the water. The Technical Committee dealing with waters has prepared a series of standards on water. This is the TD1 series, which includes many spectra of water quality parameters and sampling techniques for identifying them. Some of these standards were developed by environmental agencies and accepted by other countries.

The standards for the amount of trace elements are important. They are: As = 20; Cd = 5; Cu = 10; Cr = 50; Hg = 1; Se = 10; and Zn = 100 µg/l. These are standards for drinking water for the general population. There are standards also for nitrite 3 mg; fluoride = 1.5 mg/l; hardness as $CaCO_3$ = 500 mg/l; and HCO_3- = 480 mg/l. There are also standards for about 60 other elements and a few hundred organic species in addition to bacteriological standards.

In this chapter, several emerging environmental engineering concepts are briefly described with respect to the aspects relevant to water pollution control. The information provided serves as a modern water quality engineering technology supplement to the topics discussed in the previous chapters. A modern practical designer is expected to have an updated knowledge base with respect to available tools. Indeed, the quality or the performance of many pollution control or treatment systems depends heavily on the raw water quality; a significant reduction in the cost or improvement in the efficiency of a water treatment system can always be achieved by improving the quality of the raw water at the source.

The different aspects of the water environment that may be affected clearly suggest that this chapter could be quite interdisciplinary. Selected aspects may range from control of heavy metals, toxic organics, deicing salt, endocrine disruptors, and emerging pathogens to the use of plant-based living machines-all street signs point to Clean Water Street. In no way can the present chapter serve as a comprehensive review of recent works; one is advised to explore other relevant resources. The objective here is to provide readers with a glimpse of the excitement associated with current research activities in water quality enhancements.

In this chapter, the advanced oxidation process solution was presented. In fact, for a variety of water matrices, this is a very compatible choice for treatment when very strict requirements for cleaning are present. It was observed that the best-used UV irradiation wavelength is well over the solar spectrum region. UV light and ozone have been used for a long time. As an enhanced photocatalytic process, it is slowly imposed. The necessity of a second stage, apart from the high cost, utilization, installation costs, and the environmental impact of the UV, is increasing. It also does not remove the catalyst, which avoids an easier solution. Proof of this is the utilization of TiO^2 with smaller band gap energy materials and the use of activated carbon for process separation and sludge removal of the TiO^2 catalyst.

In this sense, a very recent work was conducted that allowed for the speeding up of the photodegradation processes of solid catalyst materials, enhancing the visibility of light and the materials' selectivity. However, a large surface area and good dispersion of the catalyst capitalize on the photocatalytic appearance, as well as the importance of porosity and ease of recovery. More efficient catalyst recovery will depend largely on the photocatalytic processes present in other works, which have been used in the refinement of the environment utilizing technology. The advanced oxidation processes, in environmental terms, are one of a number of practices that obtain a clean surrounding based on the creation of methods and strategies. The development of a sector can provide other tools.

Unlike most other unit operations used in water and wastewater treatment, membrane separation technologies do not require chemical addition other than for membrane cleaning. Membrane systems are becoming increasingly cost-competitive with other traditional and alternative separation technologies because of decreasing costs of the membranes themselves and because they are capable of compact unit process configuration and automated, remote operation. Membranes are flat sheets, hollow fibers, or tubular structures that are fabricated from a wide variety of polymeric, ceramic, or metallic materials. Each membrane serves as a physical barrier, allowing material to pass or intercept it based on size or electrochemical characteristics. For particle removal, the membrane filters work by capturing particles on the top surface or within the membrane pores. Larger particles will be captured more rapidly, while smaller particles will be captured relatively slowly. If the membrane pores are small enough, ultrafiltration or microfiltration can separate bacteria and viruses from the water.

Membranes can be used to remove dissolved strongly hydrophobic organic molecules by utilizing the hydrophobic properties of the dissolved organic material. This process is called membrane interfacial liquid extraction or separation solvent extraction. In this process, microporous fibers or tubes made from low-density polyethylene are wetted with a low viscosity, non-toxic solvent that specifically dissolves low molecular weight, dissolved, neutral organic compounds like pesticides and herbicides. Water is driven through channels and lumen in the microporous fibers and tubes by pressure. Some of the low molecular weight, dissolved, neutral organic compounds are extracted from the water and dissolved in the solvent. During separation, the water phase is further treated by a second treatment system and returned to the solvent extraction system or discarded. A small amount of solvent treated with low molecular weight, dissolved, neutral organics is recycled. These hydrophobic membranes have a high area-per-volume ratio and a microstructure that allows solvent to be in contact with a large volume of water. The advantages of separation solvent extraction are increased removal rates, greater stability of contaminants, and improved mass transfer characteristics. The main disadvantage of this process is the potential for solvent leakage.

Reverse osmosis and nanofiltration are unique membrane processes because of the nature of the membrane. These membranes are dense, selective barriers to optically pure water. They separate salts and other solutes that have a higher ionic charge or are significantly larger in diameter than a water molecule. These membranes are capable of rejecting greater than 95 percent of the concentrations of most dissolved ions from the feed water. The membrane permeate, or product flow, is usually more than 95 percent pure water. The rejected ions and other solutes are continuously removed with the reject flow. Reverse osmosis and nanofiltration have been used for separating dissolved inorganic materials from natural waters for over 30 years. These processes are now being used for industrial and municipal wastewater treatment, recycling, and desalination processes.

Case studies are included at the end of many chapters in this textbook to illustrate the practice of water quality engineering. The learning objectives for this chapter are straightforward. After completion, the student should be able to

1) Discuss water quality modeling procedures.
2) Perform water quality predictions using simple models.
3) Perform water quality predictions with reactions and degradation using simple models.

The steps to complete the six case studies in this chapter include these requirements: the reservoir and associated land and water area are of sufficient size to enhance the flow or residence time; the contaminant has the ability to decay via a first-order decay; the decay and estuarine reaction parameters may be measured or estimated; the estuary has a sufficient water quality factor, size, or capacity to dilute; and the estuary must have water quality that lags behind the inflow. The potential uses of the model results presented in this chapter suggest that the shape of the water quality curve may be the most important water quality-related factor. The estimates could assist new development and estuarine redevelopment that allows for the water quality conditions to reach the protective stages of ornamental gardens, commercial fishing, and swimmable waters.

Water supply and distribution means water at sufficient pressure and adequate quantities that is free from pathogenic organisms and injurious concentrations of toxic chemicals. Water supply is the provision of water to individual, public, and industrial facilities from water sources under the required conditions and at a suitable site, for the purpose of thereafter supplying such water at the required quality and quantity to each water user, up to the point of use, partially or entirely. For large cities, problems often arise in meeting such requirements for water provision and distribution.

After water reaches the city’s boundary, there is responsibility imposed on the local municipality to extend distribution mains to various sections of the city. The responsibility then devolves onto the building owner to provide individual connections. The water supply system is usually divided into feeders, distribution mains, and connecting pipes. Feeders are both trunk lines and looping connections that connect the local hydroelectric supply or deep tube wells to the water supply network. The feeder must dominate the network in the sense that either the trunk main or the looped main should always be at the highest hydraulic level in the public distribution system. This allows the feeder system to be designed to supply the maximum consumption requirements of the connected points. If the system is not over-competed for during periods of lower demand, the existing facilities may be used as the basis of water delivery accomplishment during the peak periods of consumption throughout the supply scenario, or a combination of the existing and designed water supply facilities can efficiently accomplish this requirement.

There are physical, chemical, biological, and combined treatment units generally employed for treating industrial wastewaters. The operations are similar in nature to those applied for municipal wastewater treatment. However, the design and operation of each unit for industrial wastewaters may significantly differ from those for municipal wastewaters, since the nature and composition of industrial wastewaters may be vastly different from those for municipal wastewaters.

For some pollutants, the control of the discharger's activities is considered to be a more effective method of pollution control than placing direct controls on the industrial discharger's water quality. Moreover, some particularly toxic pollutants may even justify a total prohibition on their discharge, or, in the worst case, lead to the manufacturing prohibition. Nevertheless, dischargers generally prefer on-site control of their waste treatment and the receipt of the other incentives that arise from resource recovery. Consequently, it is common for a variety of permits to be required for industrial dischargers, including: discharge limits (based on the receiving water, BOD5 or COD, suspended solids, temperature, pH, other characteristics, etc.); waste treatment standards that apply to the internal waste treatment facilities so as to govern the discharges to the public collection system; and incidental discharge standards that apply to the transport and disposal of waste using non-water methods. Compliance with these standards requires the frequent monitoring of inflows, outflows, and processes and the associated reporting to the environmental agencies.

Future Trends and Challenges Gathering data and addressing the challenges that face water supply and wastewater management relies on the skills, expertise, cooperation, and collaboration of teams of researchers whose common goal is to find long-term, cost-effective solutions. Political decisions often have short-term results. To gather water quality data, reliable in situ sensors are required; these sensors need to be small and robust, often sustainable in an aquatic environment for long periods of time. Advances in wireless monitoring technologies offer new opportunities, while in situ sensor design challenges are offset by technological advances in software and hardware design. Researchers are working closely with sensor manufacturers to ensure that high-quality, reliable result data can be produced. This chapter recognizes the future challenges facing the field of environmental engineering. It ends by recognizing the major questions and ideas addressed in tackling the future of development in environmental research. This chapter identifies areas requiring further research efforts and the ideas and thoughts that may become future achievements. Introduction The study of water and wastewater is truly interdisciplinary and is widely recognized as such. Ascertaining the implications of contamination on the environment necessitates knowledge related to civil engineering, environmental science, analytical chemistry, environmental engineering, instrumentation and oceanography, with problems and solutions often being biological, chemical, economical, ecological, geological, mathematical, meteorological, physical, political, pharmaceutical, social, or systemic. To combat the demands facing water supply and sewage effluent treatment, and to provide reliable wireless monitoring of water quality, multidisciplinary research is now being progressed. Furthermore, for stakeholders to judge the implications of such contamination, stakeholders involved in water supply and sewage effluent treatment are often from various levels of government, the consumer, educational establishments, health professionals, legal professions, non-government organizations, suppliers, and other public and social healthcare professionals. Making the implications of water quality accessible to stakeholders ensures that stakeholders involved in water supply and sewage effluent treatment can make reference to the necessary information. Stakeholders who require water quality data may have contradictory value systems, which can then influence the cost of water quality research.

Climate Change and Sustainable Development in Kenya's Rangelands: The Case of Laikipia

Sustainable water management practices, viable in the context of climate change, have become more urgent in such environments. If water management practices do not change, the current level of water scarcity for all users within Laikipia, for domestic, service, and agricultural uses, as well as the fullest protection of the catchment ecosystem, will not allow any increase in water distributed above current totals. Science indicates that the Laikipia and Samburu areas are particularly vulnerable to the impacts of climate change. The impacts of depleted water resources will be severe. If the climatic model predictions come to pass, the risk will also be experienced by the entire Kenyan economy.

Recent changes in policy have called upon water managers to help reduce the impacts of water scarcity for all uses in Laikipia. These same managers are also to protect the needs for water of the country's wildlife. Requirements to improve water quality are also described, aimed at preventing the causes of previous harm to the very sensitive Laikipia riverine ecosystem, while also challenging Laikipia's current decision makers. Fundamental to sustainable water management is acceptance in hydro-environments, particularly susceptible to predicted increased water stress due to climate change, that the future cannot be managed as if it parallels the past.

Much of the debate on climate change impacts on water quality, including economic evaluations of changes, revolves around the aftereffects of climate change: the expanded area of influenced watersheds, the role of vegetation belts in sediment reduction, enhanced stream heights, and the associated erosion, so that current year sediment and phosphorus runoff may increase. The impacts of high-intensity storms in concentrating effects in small windows of time, how upstream water storage will affect dry season flows, or how wetland management plans will be developed to mitigate changes are also significant. The one stable, known result of climate change is that, over wide spaces of time, the distributions of flow will change. While some will augment, the critical knowledge to determine additional peak or low flow adverse consequences is somehow associated with the properties of the water quality entities transported.

First and foremost, the demand is that water and water quality databases for economic, risk, policy assessment, and design calculations be long, with many pairs of observation time domains. These data properties can be difficult for variables like phosphorus or turbidity that follow complex nonlinear transport patterns due to the interaction of storage or discharge characteristics and delivery routes. Water quality variables of interest for TMDL and environmental benefit-cost analysis are noted. Influence times of five to 15 years appear as a common recommendation. Briefer influences should be bolstered by sensitive monitoring airbases during both validation and possible changes to be inferred by changes in these values for future runoff distributions that could modify the quality distributions. Even if the focus is on land or economic factors, it is the future-year water uses that create interest to augment protection of present-year water quality. Water uses that promote security add an additional two or three years. However, the risk of phosphorus loss spikes in diminished range properties of forecasted time and cost of restricting those events. Providing reasonable lead times for adaptation, especially if equipment for water protection or storage can be costly, sometimes necessitates planning policy questions on an ignored distributive equity issue, but one that has important viability implications in approving the result topic relations of the water proceeds.

Wastewater treatment involves the comprehensive process of removing a wide array of harmful components, such as inherent microbial contaminants, prior to their safe discharge into the environment or deep underground injection. A specialized industrial wastewater reclamation unit encompasses a broad spectrum of treatment processes designed to effectively manage a virtual sea of diverse pollutants that necessitate removal. Here is just a sampling of some of these essential physical and chemical processes: advanced oxidation techniques, acid/base neutrality adjustments, coagulation methods, electrocoagulation treatments, electrolysis applications, various filtration systems, flocculation practices, high-temperature incineration operations, ion exchange processes, liquid-liquid extraction methods, membrane technologies, metals recovery techniques, and precipitation processes. The efficacies of these treatments often hinge not solely on the identity and concentration of the pollutants present but also on the specific characteristics of the treatment processes employed and the nature of the water being treated. Moreover, it is important to note that most industrial water discharges are required to adhere to a multitude of local, state, and federal laws, as these are strictly enforced by one or more regulatory agencies. In some rare instances, the absence of a designated maximum contaminant level for a particular contaminant does not imply that another regulatory lacuna does not exist which could hinder practices like crop watering. In such cases, establishing a critical compliance document becomes essential. Consequently, there exists an immense need for the seamless integration of both physical and chemical treatment plants; the chemical aspect includes advanced and intricate precipitation and coagulation equipment specifically designed to produce nonhazardous solid sludge, primarily based on exposure-independent laboratory leaching tests, along with properly laden solid sludge methods to ensure protection against even more improved water-intake dependent processes [9, 59, 60].

Regulations aside, an additional distinction to make with wastewater quantities is that a publicly owned treatment works might treat any number of percent.

7.2 Drinking Water Treatment

Covering drinking water treatment, this section emphasizes the most fundamental goal of supplying water that is safe and trustworthy. The most pressing issues at the state and federal levels are increasingly oriented toward the need to comply with regulations. The federal regulations set standards based on health protection; many are founded on the epidemiological evidence of disease outbreaks and people becoming sick. This section also discusses emerging contaminants, including pharmaceuticals, personal care products, waste byproducts, illicit drugs, endocrine-disrupting chemicals, and 1,4-dioxane, which require no specific treatment. However, we may currently have no criteria for which express requirements have been written, but agencies are considering regulatory action. In New England, especially along the Connecticut River, several cases show problems with insufficient disinfection, E. coli violations, carcinogen violations, and contamination. These case studies showcase physical and chemical treatment solutions that have proven to be optimum.

Coagulation, Flocculation, Sedimentation and Filtration Processes: The most common first line of treatment is filtration and disinfection. The coagulant that is used is a major source of pollutant metal because of the water treatment plant for lead. This treatment reduces turbidity, pH, pathogenic organisms, radionuclides, and dry times. The use of multiple barriers in the process is recommended to ensure safe water. Sequentially treating the water allows one treatment, like chlorination for turbidity removal, followed by UV and either a specific dosage for log removal, followed by a calculated value. Seed balls have infrequently been used for the removal of filtration particles in the water treatment process. Activated carbon balls have been used to coat seeds to grow a multi-media layer on the seed ball surface. These balls have an improved surface area to grow the activated carbon. On the surface area of 1 gram of these balls, there is a significant amount of surface area. The test diameter was in a plastic pipe. A layer of sand and anthracite was used on the bottom of the pipe, and undisturbed balls of seed were laid across the top of the pipe. Results show that the seed balls do remove some of the particles that produce increasingly dirty water but not the flow rate. A plant installed a ball system for ozonation that has cut the ozone demand in half, yielding substantial water treatment cost savings. Small children and older adults are more vulnerable and suffer disproportionately from contaminants, so it is important to ensure safe water. In addition, individuals that have been asymptomatic and exposed may develop diseases. Disease treatment can rely on long latency, and several potential effects are not carcinogenic. Public health issues must be considered in the design of a treatment system. We want the number to be less than a specific threshold, but rates fall to lower values. Stakeholders need to know what to expect when it comes to water. Sometimes engineers view uncertainties as liabilities, yet this is where better studies need to occur. The monitor will test the water source and essential variables, and the treatment must be evaluated and, if necessary, improved. The change has turned from looking for new treatment methods to smarter, more intelligent, and more efficient processes [61-63].

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