CHAPTER 1
THE PURPOSE AND
FUNDAMENTALS OF WASTEWATER
TREATMENT

Learning Objectives
This chapter provides information concerning the reasons behind wastewater treatment, the characteristics of wastewater, and the role of an operator in this treatment process. At the end of this chapter, the student should be able to:

- Explain the hydrologic cycles,
- List the principal causes and consequences of water pollution,
- Identify major categories of wastewater sources,
- Describe the composition and characteristics of domestic and industrial wastewater,
- Describe the elements of a sampling and analysis program,
- Describe the fundamental elements of a conventional wastewater treatment system, and
- Define the principle duties and responsibilities of the wastewater treatment plant operator

Purpose
All life depends on water - clean water. Figure 1.1 shows what happens in the hydrologic cycle. When water is exposed to the atmosphere, the sun causes it to evaporate and become water vapor. Evaporation is the conversion of moisture into vapor. Moisture is also released to the air by plants in a process called transpiration. On a hot day, a large tree may give off, or transpire, as much as a four liters (one gallon) of water per minute. The moisture in the air rises and forms clouds. When the clouds cool, the water vapor condenses into tiny droplets of water. When these droplets become heavy enough, rain precipitates and falls to the ground. The water that falls to the earth flows to oceans, lakes, and rivers. This water also soaks into the ground to recharge groundwater sources. Sometimes, the water that has soaked into the ground flows through the crevices and eventually forms a spring. When the water is exposed to the warm air, it begins to evaporate. Thus, the water cycle starts over.
Moving rivers and streams provide one of nature's ways of purifying water. The churning of the water over the rocks increases the dissolved oxygen concentration in the water, which helps sustain aquatic life. Aquatic life in the stream then feed on the waste, reducing its volume and purifying the water. However, humans often dispose so much waste into rivers and streams that these receiving waters, as they are called, cannot naturally purify themselves. When the natural treatment capacity of a body of water is exceeded, the water becomes polluted. Stated another way, the streams assimilation capacity, or the ability of its aquatic life to consume waste, is being overtaxed. More waste is being put into the receiving water than can be removed by assimilation.

Plant and animal life in water need oxygen to survive. When a body of water becomes polluted, algal blooms and surges in the quantities of other microorganisms occurs. They quickly use all of the oxygen available in the water. Oxygen levels can quickly become too low to support other plants and animals. When this happens, the stream’s water quality continues to degrade. This pollution can kill fish and other aquatic animals and can pose a danger to communities that use the water. To combat pollution, communities in many countries have constructed wastewater treatment plants (Figure 1.2). These plants were built to reduce the amount of pollutants released to the natural waterways. They help us control pollution and disease and preserve a clean source of water for domestic uses, swimming, and other recreational purposes. In order to ensure that wastewater treatment plants do not overload their receiving waters, many countries use a permit system to monitor wastewater discharges. In the United States, these permits are issued by state regulatory agencies and are called National Pollutant Discharge Elimination System (NPDES) permits. These permits are used as a tool to assist in protecting public health and preserving or restoring the quality of the water bodies receiving wastewater discharges.
Sources of Wastewater

The terms "raw sewage" or "raw wastewater" are commonly used to describe the water and solids that flow through a collection system into a wastewater treatment plant. Wastewater that is collected in the community can come from several different sources. These sources are generally referred to as

- Domestic
- Commercial
- Industrial
- Stormwater, and
- Groundwater

Domestic wastewater is wastewater that comes from households. It consists of waste streams such as those from toilets, laundering, cooking, bathing, and dishwashing.

Commercial wastewater comes from small businesses and institutions such as laundromats, restaurants, schools, and hospitals.

Industrial wastewater is generated from manufacturing plants. This wastewater must be carefully monitored because it can contain toxic wastes, nutrient-deficient waste, high organic loadings, extreme pH variations, and other such substances and characteristics that could negatively affect the performance of the treatment plant. Excessive quantities of harmful substances in wastewater such as metals, poisons, or other similar materials are referred to as toxic wastes. Nutrient-deficient wastewater is commonly generated by canning factories.

Wastewater that is nutrient-deficient is harmful to microorganisms because the wastewater does not contain sufficient quantities of nutrients such as nitrogen and phosphorus, which are essential to sustain life. Industrial wastes can pose other treatment issues as well. For example, a slug dose of high-strength (high BOD) wastewater can pass through a treatment plant without being
sufficiently treated and result in plant effluent violations. Wastewater from a dairy, for example, is commonly high in organic strength (BOD).

Stormwater consists of water and solids that are collected during a rainstorm. Some communities collect stormwater and send it untreated to a nearby natural water body (Figure 1.4). Other communities collect this stormwater and combine it with the raw wastewater. Combining the stormwater and wastewater causes surges in plant flow during rain events that can result in hydraulic overloading (excessive flow) at a wastewater treatment plant.

Groundwater may enter the collection system through faulty sewer joints or cracked pipes. The process of groundwater entering the collection system is referred to as infiltration. Infiltration is usually minimal in new, well-constructed sewers.

Operators should be aware of the types of sewers that are present in the system they work with. The three major types of sewers are

- Sanitary sewers
- Storm sewers, and
- Combined sewers.

Sanitary sewers contain domestic and industrial wastewater, which is conveyed to the treatment plant. Storm sewers contain only stormwater, which usually goes directly to a water body such as a river or stream. Combined sewers contain both wastewater and stormwater, which is conveyed to the treatment plant. Figure 1.3 shows a basic collection system layout for a section of a metropolitan area.

![Figure 1.3 Overview of Basic Collection System](image)

**Characteristics of Wastewater**

Wastewater that enters a treatment plant normally contains about 99.98% water and 0.02% solids. Raw wastewater normally appears cloudy and gray in color and smells musty. If the wastewater is black in color and smells bad as it enters a treatment plant, this probably indicates that the wastewater has become septic. Septic wastewater results when there is no dissolved oxygen in the wastewater and anaerobic (or oxygen-lacking) conditions prevail. Typically, wastewater turns septic because of long detention times in the collection system, pumping station wet wells, and force mains. Warmer temperatures can also lead to septic conditions.

Let us now review the composition of wastewater. Wastewater consists of water containing solids that are either dissolved or carried in suspension. The solids are usually less than 0.2% of the wastewater composition by weight. This small amount of solids is what treatment plants are designed to remove. The solids in wastewater are classified in a number of ways. For example, they can be divided into two general groups:

- Organic solids, and
- Inorganic solids.

Organic solids are the waste products of plants and animals. These solids will decay or decompose. Inorganic solids, on the other hand, usually will not decay or decompose. Inorganic solids include materials such as sand, gravel, silt, and salts. Organic and inorganic solids can be further classified as suspended solids and dissolved solids (Figure 1.4).
Suspended solids are those organic or inorganic solids that you can see floating in the water. These solids can be removed from the wastewater by physical and mechanical means, such as by allowing them to settle out or by filtering them. Suspended solids include the larger floating particles like fecal solids, paper, wood, pieces of food, garbage, and other similar materials. Most of the suspended solids in wastewater are organic. An Imhoff Cone (Figure 1.5) is a cone-shaped container that has measurements marked on the side. These cones, which hold a 1-liter sample, are used for measuring settleable solids in the wastewater.
Another type of solids that enters a wastewater treatment plant is dissolved solids. Dissolved solids are actually in solution in the liquid. For example, when you mix sugar into hot water, the sugar dissolves into the water. The sugar is now a dissolved solid. In normal domestic wastewater, about half of the dissolved solids are organic and the rest are inorganic. Dissolved inorganic solids are typically not removed in the wastewater treatment process.

We have talked about suspended and dissolved solids, as well as organic and inorganic solids. The combination of both types of solids added together is referred to as total solids. Another type of solid that operators should be familiar with is colloidal solids. Colloidal solids are extremely fine suspended particles that will not settle in a typical wastewater treatment process unless they are converted to larger settleable solids. They are sometimes filtered out of the process.

The next important wastewater characteristic operators should understand is biochemical oxygen demand, or BOD. Biochemical oxygen demand is an indirect measure of the amount of organic material in the wastewater. The BOD is determined by measuring the amount of oxygen consumed by microorganisms in a wastewater sample during a 5-day period at a controlled temperature of 20°C. The BOD parameter is important for determining the organic loading into the treatment plant, the biological processes, and the receiving stream. Two other important variations of the BOD test are carbonaceous biochemical oxygen demand, or CBOD, and soluble biochemical oxygen demand, or SBOD. The CBOD is important when a sample is affected by nitrification. The CBOD test measures only the carbonaceous BOD portion of the sample and not the BOD caused by nitrifiers. More information on this test is given in Volume 2 - Chapter, Activated Sludge. The SBOD measures the BOD in the soluble portion of the sample. This test is important for fixed film reactor systems such as trickling filters and rotating biological contactors. The SBOD test is also important at some activated sludge facilities that receive industrial waste high in SBOD. Both solids and BOD are two of the most important pollutants that conventional wastewater treatment focuses on removing. Figure 1.6 shows the essential components of a BOD analysis.

Figure 1.6  BOD Analysis Components – Bottles, Dilution Water, Samples, DO Probe and Meter

Another important chemical parameter to monitor in wastewater is the pH. pH is the measurement of the hydrogen ion concentration in a solution. For the purposes of wastewater the range that is typically monitored spans from 1 to 14, with 7 being neutral. The lower the pH reading, the more acidic the solution is. Likewise the higher the reading the more basic or alkaline the solution is. pH is extremely important for biological wastewater treatment because the microorganisms primarily involved in the treatment process thrive only within a narrow pH range close to neutral (roughly 6.5 to 8). Therefore it is important to both monitor the pH and maintain this optimal range. Raw wastewater typically has a pH near 7. Major deviations found while monitoring the influent typically indicate a nondomestic or industrial discharge. Also, anaerobic conditions lower the pH. This low pH combined with the observation of a black or dark colored influent and the presence of sulfide odors are strong indicators of septic conditions. Figure 1.7 demonstrates the pH analysis for two identical samples. It is often necessary to analyze samples in duplicate to avoid analysis process errors.

Figure 1.7  Duplicate pH Analysis of Treated Secondary Effluent

Note: 4 photos in series showing analysis and rinsing of probe. Each photo will have footnote describing action

We will now examine the two primary nutrients found in wastewater, nitrogen and phosphorus. In wastewater, nitrogen occurs in four basic forms:

• Organic nitrogen,
• Ammonia nitrogen,
• Nitrite nitrogen, and
• Nitrate nitrogen.

Total nitrogen is the sum of the organic nitrogen, ammonia, nitrite and nitrate nitrogen. Domestic wastewater typically contains 20-50 mg/L of total nitrogen and 12-40 mg/L of ammonia nitrogen. Microorganisms require nitrogen to thrive. If there is a shortage of nitrogen in the wastewater, nutrient-deficiency problems could develop in the secondary treatment process.

Phosphorus, like nitrogen, is an essential element for biological growth. In wastewater, phosphorus is found in three forms:

• Orthophosphorus,
• Polyphosphorus, and
• Organic phosphate.

Orthophosphorus is the form most readily available to the microorganisms and is used as a control parameter in biological phosphorus-removal processes. Treatment plant operators often measure the total phosphorus of the plant influent and effluent. Total phosphorus is a combination of all three forms of phosphorus. Domestic wastewater has a total phosphorus concentration in the range of 5-15 mg/L. It is important to note that treatment facilities control the discharge of both nitrogen and phosphorus because they serve as nutrients for algae growth in receiving waters. The excess growth of algae in receiving waters leads to oxygen depletion and, eventually, serious pollution.

Sampling

Since it is impossible to test all of the wastewater that enters or leaves a treatment plant, operators must collect representative samples. If samples are not properly collected, accurate plant process control measures cannot be made. Also, accurate testing is necessary to report plant performance to regulatory agencies.

There are two types of sample-collection procedures commonly used in wastewater treatment plants:

• Grab samples, and
• Composite samples.

A grab sample is a single sample that is collected manually. Grab samples are used if the operator must know the characteristics of the process stream soon after sample collection. Grab samples are used for unstable parameters such as dissolved oxygen, pH, and temperature. They represent a “snapshot” of the characteristics of the waste stream at the moment the sample was taken.

The second type of sampling procedure commonly used is the composite sample. A composite sample is collected either manually or automatically to provide information on the average characteristics of a sample over a longer period of time. Composite samples are collected as either

• Timed composites, or
• Flow-proportional composites.

Timed composite samples are collected at regular intervals and at fixed volumes. For example, an operator may collect a 300-mL sample every 2 hours for a 24-hour period. A flow-proportional composite sample is collected by varying either the sample frequency or volume to collect a more representative sample. Flow-proportional samples are usually required whenever wastewater characteristics can differ with changes in flow. Flow-proportional samples are usually taken using automatic samplers. These samplers can be programmed easily to meet a variety of conditions. In larger plants, data for some parameters are continuously collected and analyzed.
by on-line analyzers. These analyzers are used to measure such parameters as pH, dissolved oxygen, temperature, and total residual chlorine.

The primary goal of sampling is to obtain a representative sample of the process liquid. Sample location and sample collection technique are important factors in obtaining a representative sample. The sample point selected must be a well-mixed location. Influent samples should be collected upstream of any recycle, or sidestream flows. When collecting the sample, the sides of the channel or tank walls should not be scraped, and no large chunks of solids should be collected. Sample containers should be clearly marked, and proper preservation techniques should be followed. Most samples can be preserved by refrigeration at 4 °C. However, other samples require that chemicals be added for preservation purposes. After a sample is properly collected, it should be delivered to the laboratory for analytical or microbiological examination. Some tests, such as temperature or dissolved oxygen, must be performed immediately after the sample has been collected. Figure 1.8 is a table of sampling requirements for many common wastewater parameters. Refer to Standard Methods for the sampling requirements of all wastewater parameters.

Figure 1.8 Sampling Requirements for Common Wastewater Parameters
Note: Create new table with major NPDES parameters and 4 process control parameters from Standard Methods

Conventional Wastewater Treatment

These training manuals (Volumes 1 and 2) cover all major aspects of wastewater treatment including natural treatment systems such as lagoons and wetlands. Each aspect will be covered in greater detail in the chapters to follow. Figure 1.9 shows a schematic of a conventional activated sludge treatment plant. Let us briefly look at each of these different treatment components.

Figure 1.9 Conventional Activated Sludge Wastewater Treatment Process

- Preliminary treatment – In preliminary treatment large debris and a varied assortment of undesirable solids (such as grit, sand, etc.) are removed from the influent using screens and grit removal systems. Common examples of screens are manually cleaned and
mechanically cleaned bar screens. Grit removal systems come in such forms as grit
classifiers and cyclone/vortex grit removal systems.

- Primary treatment – Primary treatment consists of the use of primary clarifiers, although
their use depends on the type of treatment used. In well-designed primary clarifiers,
BOD removal can be as high as 30-40% and solids removal can range from 50-60%.
The solids removed from this process are often sent to the solids handling portion of the
plant.

- Secondary treatment – Secondary treatment will vary depending on the type of treatment
system used. The most common system used is the activated sludge process that
utilizes aerated biological reactors for treatment. Other systems used are fixed-film
systems such as Rotating Biological Contactors (RBC) and trickling filters. Typically
these systems are always followed by secondary clarification where the remaining bulk
solids are removed and sent to solids handling.

- Filtration – Though not routinely used for wastewater treatment, it may be required if
your permit requires that effluent solids levels be kept very low. Filtration will also help
with your disinfection process.

- Disinfection – Disinfection is used to destroy pathogenic organisms in the effluent before
it is discharged to the receiving stream. The most common disinfecting agent used is
chlorine. The other commonly used systems are ultraviolet radiation (UV) and
ozonation.

- Solids Handling – Solids removed from the treatment process are often processed for
use as fertilizer or made acceptable for landfills. The three common processes used in
solids handling are thickening, stabilization, and dewatering.

- Lagoons and Wetlands – These are known as natural treatment systems because they
use a process similar to the process described at the beginning of the chapter. Lagoons
store wastewater for a specific period of time and allow bacteria to eliminate the waste.
These lagoons are often either naturally or mechanically aerated. Wetlands or overland
flow utilize the vegetation, soil, and microorganisms of a cultivated section of land to
eliminate the wastes in raw wastewater. While these are called natural systems, they
must be carefully maintained, monitored, and operated.

Role of the Operator

Wastewater treatment plants require an essential element to ensure that the effluent
meets permit requirements. That important element is the treatment plant operator. Treatment
plants can be found in many parts of the world. The size of the community determines how big
the plant will be. Large plants with complex processes may have operators that remain in one
process area, such as sludge processing, whereas smaller plants require that the operator
understand all aspects of the plant and be able to operate the entire range of processes. The
need for understanding all operations and maintenance aspects of a treatment facility are now
also becoming a necessity for operators at large facilities as well.

The operator is responsible for keeping the treatment plant running efficiently. This
literally means that he or she turns valves, throws switches, collects samples, lubricates
equipment, reads gauges, records data, performs tests, and so on. Technology has improved for
both treatment and monitoring wastewater processes. Operators must regularly update their
skills and become familiar with new techniques as they are implemented at their facility. At many
plants, the operator may also maintain equipment and care for the facilities by repairing and
cleaning equipment, painting, and tending to the facility grounds. The operator also makes
operational decisions, keeps records, observes conditions around the plant, performs calculations
to make sure the plant is running properly, and plans the necessary repairs. Operators have the
responsibility of helping to explain to a utility’s governing board, civil groups, and the general
public what the plant is doing and why it is important to budget sufficient money and resources to
keep the plant running at its best. A plant operator may works for a town or city, sanitation
district, or other public agency. Operators may also be employed by a large industry that
operates its own treatment plant or by private companies that also manage treatment plants. By whatever measure - pay, prestige, job satisfaction, community service, or opportunities for advancement - an operator's returns are limited only by what he or she puts into the job.

The wastewater treatment field, like so many others, is changing rapidly. New and more plants are being constructed, both treatment and monitoring technology are steadily advancing, and the need for highly skilled operators is increasing and is expected to continue into the future. To ensure that only qualified operators are in charge of these important facilities, training materials like this are being developed to help guide you in this field. Operators in the wastewater treatment profession can take pride in the job they do to protect the environment and public health. These chapters will cover the different treatment processes in a wastewater treatment facility.

Chapter Quiz

1. In wastewater, nitrogen can be found in the form of:
   a. Ammonia
   b. Organic nitrogen
   c. Nitrite
   d. All of the above

2. Green plant life (algae) in a stream will add dissolved oxygen to the stream only during cloudy days or the night.
   a. True
   b. False

3. In order to discharge treated wastewater to a receiving water in the United States, the operator of the facility must first obtain a(n):
   a. Discharge permit from the state regulatory agency
   b. Written waiver from adjacent landowners
   c. Written waiver from downstream users
   d. Bond for potential liability in excess of $1,000,000

4. Wastewater that is generated from normal household functions is termed:
   a. Sanitary
   b. Institutional
   c. Commercial
   d. Domestic

5. The major ingredient of domestic wastewater is:
   a. Water
   b. Dissolved solids
   c. Grease
   d. Suspended solids
Chapter Quiz Answers

Question 1

Answer is “d”
Reference: Page 1-6
Immediate Feedback: Total nitrogen is the sum of the organic nitrogen, ammonia, nitrite and nitrate nitrogen. Domestic wastewater typically contains 20-50 mg/L of total nitrogen and 12-40 mg/L of ammonia nitrogen.

Question 2

Answer is “b”
Reference: Page 1-7
Immediate Feedback: Nitrogen and phosphorus serve as nutrients for algae growth in receiving waters. The excess growth of algae in receiving waters leads to oxygen depletion and, eventually, serious pollution.

Question 3

Answer is “a”
Reference: Page 1-2
Immediate Feedback: Many countries use a permit system to monitor wastewater discharges. In the United States, these permits are issued by state regulatory agencies and are called National Pollutant Discharge Elimination System (NPDES) permits.

Question 4

Answer is “d”
Reference: Page 1-3
Immediate Feedback: Domestic wastewater consists of waste streams such as those from toilets, laundering, cooking, bathing, and dishwashing.

Question 5

Answer is: “a”
Reference: Page 1-4
Immediate Feedback: Wastewater that enters a treatment plant normally contains about 99.98% water and 0.02% solids.