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WASTEWATER TREATMENT

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WASTEWATER TREATMENT

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FOREWORD

This book represents a contribution to the efforts to present technical challenges and the significance of wastewater treatment as a part in the wide area of water management. It consists of many aspects, from the influence to water resulting from technology processes, demographic expansion and the strive to the modern way of living, but also explaining the processes regulated by the law of nature and classic and modern techniques and technologies in wastewater treatment.

This book gives a comprehensive outline on the syllabus of the corresponding course at the Faculty of Mechanical Engineering in Skopje. Its content is accessible to the students, but it can also be very useful to a wider audience of young researchers, enthusiasts and technical experts when dealing in practice with this particular matter.

Having in mind water domain is interdisciplinary and complex, every remark and suggestion for its improvement will be carefully considered and integrated in the next edition.

The Authors

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INTRODUCTION

1. INTRODUCTION

1.1. What is wastewater?

Wastewater is the flow of used water from a community. It can originate from households or industry and include contents such as human and animal wastes, industrial wastewaters, storm runoff and groundwater infiltration. Water management requires the effective operation and control of a wastewater treatment plant (WWTP). The operators of such plants should possess knowledge of the composition of the influent, effluent, and internal process streams.

Depending on the size of the WWTP and the composition of the influent, wastewater characterization may require complex tests in a well-equipped or accredited laboratory.

1.2. Sources

Wastewater can be categorized as originating from domestic, commercial, or industrial sources. Wastewater is conveyed to a treatment facility in a collection system that is either separate or integrated with the stormwater collection system. However, it should be noted that the addition of stormwater can alter wastewater characteristics and affect plant treatment processes.

1.3. Flow variations

It makes difference whether the wastewater influent comes from separate or combined collection systems, because stormwater flows in combined systems can adversely affect plant hydraulics. Even plants served by separate sanitary sewer systems will receive some extraneous water from inflow of surface runoff and infiltration of groundwater, which can cause seasonal flow variations. These effects are influenced by the age, condition, and type of collection system. Combined systems cause major changes in wastewater flow from the runoff of stormwater or snowmelt. In addition to the hydraulic effects on the plant, changes may occur due to the organic matter and dissolved contaminants contained in runoff flushed from streets and other impervious surfaces. The effects of hydraulic and pollutant loadings from combined sewers are especially pronounced during the first hours of a storm following a dry period.

Wastewater flows typically vary over days, weeks, seasons, and years. Daily (diurnal) flow variation depends largely on the size and shape of the collection system. In general, a smaller collection system will result in a greater diurnal variation. Other influences on flow variation include the number and type of pumping stations, types of industries served and population characteristics. Daily flows for treatment plants typically peak between 8:00 and 10:00 a.m., between 12:00 and 2:00 p.m. and between 4:00 and 7:00 p.m. Minimum flows typically occur late in the evening and early in the morning and the peaks and minimums tend to smooth out as the length of the collection system increases. Depending on the system size, the typical daily peak flow exceeds the daily average flow by 50 to 200%.

Although characterization of wastewater by source provides some general information about plant influent, such information is insufficient to determine process control or permit compliance. Most of the necessary data depends on testing the influent, effluent and plant process streams to determine their physical, biological and chemical characteristics. Bio monitoring of the plant effluent can determine its toxicity.

1.4. Chemical composition of wastewater

Chemical analysis of wastewater and internal process streams provides a wide variety of information concerning the characteristics of wastewater and conditions of the treatment processes.

The legal regulation permit may require several chemical analyses. Chemical constituents can be separated into numerous categories, depending on the purpose of classification.

Chlorine. Free chlorine is not typically found in raw wastewater because of its extreme reactivity. However, it can be present in less reactive forms, such as chloramines. As chlorine is commonly used for disinfection, measuring the chlorine residual and understanding the meaning of the results can provide an effective means of controlling the disinfection process. Approaches for measuring chlorine residual include several manual techniques and online instrumentation. The online instruments can be incorporated to a mechanism for controlling the chlorination process automatically through the constant measurement of total chlorine residual. Although automatic instrumentation may need frequent calibration, it provides a continuous feed rate and eliminates the need for frequent manual adjustments.

Nitrogen. In wastewater, nitrogen occurs in four basic forms: organic nitrogen, ammonia (both ionized and free ammonia), nitrite, and nitrate. The forms of nitrogen present in wastewater indicate the level of organic stabilization. Raw wastewater has higher concentrations of organic nitrogen and ammonia and contains little or no nitrite and nitrate. As the organic nitrogen is metabolized, it changes first to ammonia and then, if conditions are suitable, to nitrite and nitrate. Additionally, the biological mass assimilates nitrogen for cell growth and thus removes some of the nitrogen.

Changes in the distribution of nitrogen can provide excellent information on processing conditions in treatment units. An increase in the ammonia concentration across primary clarifiers often signals developing septic conditions from excessive sludge accumulation. An increase in nitrite and nitrate across the secondary units indicates nitrification. Conversely, a decrease in nitrate indicates denitrification, which may be desirable if it occurs in the activated sludge process before the secondary clarifiers. It will most likely be undesirable if it occurs in the secondary clarifiers because the released nitrogen gas tends to cause solids to float to the surface. Floating solids in the secondary clarifiers can also be the result of “bulking” sludge. If there is a question regarding the cause of the floating solids, testing for nitrates provides a relatively quick check to distinguish between denitrification and bulking sludge.

Typical ranges of nitrogen concentrations in raw domestic wastewater are from 20 to 85 mg/L for total nitrogen (the sum of organic nitrogen, ammonia, nitrate, and nitrite nitrogen); 8 to 35 mg/L organic nitrogen; and 12 to 50 mg/L ammonia-nitrogen. Much lower nitrite- and nitrate-nitrogen concentrations are present. If the plant treats industrial flows with high BOD and low nitrogen levels, the wastewater may become nitrogen-limited. If so, complete stabilization of the BOD would require nitrogen addition from another source.

An analysis of nitrogen in wastewater involves several procedures and techniques. The organic nitrogen level is determined by performing a Kjeldahl nitrogen analysis, which measures both the organic nitrogen and ammonia and then subtracts the ammonia value, which is measured separately. Nitrite-nitrogen is measured directly.

The nitrate concentration is determined by a procedure that measures total nitrate and nitrite and then subtracts the nitrite. Ammonia-nitrogen may also be measured directly using an electrode. The nitrogen analysis throughout the nitrifying treatment system indicates whether or not the process is being performed correctly. If ammonia is not being metabolized into nitrate and/or nitrite, the system is not processing wastewater effectively. In this case, other tests should be done to determine the problem.

Phosphorus. Phosphorus, like nitrogen, assumes different forms in wastewater and serves as an essential element for biological growth and reproduction. Phosphorus can be present as orthophosphate, polyphosphate and organic phosphate which are often measured all together as a measurement of total phosphate. Orthophosphate, the form most available to biota, sometimes requires control. Some polyphosphate compounds, called hydrolysable compounds, convert to orthophosphate under acidic conditions.

Normal domestic total phosphorus levels range from 2 to 20 mg/L, including 1 to 5 mg/L of organic phosphorus and 1 to 15 mg/L of inorganic phosphorus. An oversupply of phosphorus in surface waters leads to excessive algae blooms and eutrophication. As a result of these adverse effects to effluent streams, many plants have effluent limits for phosphorus.

Hydrogen sulfide. Frequently associated with adverse health effects and the corrosion of sewer pipes and plant equipment, hydrogen sulfide requires control. It causes the “rotten-egg” odor of septic wastewater and is best controlled at its source, before being discharged to the collection system or treatment plant. Measurement of the sulfide concentration can indicate the severity of potential corrosion and the effectiveness of sulfide control programs. It can be differentiated as total versus soluble sulfide and requires concurrent measurement of pH to accurately quantify.

Hydrogen sulfide can be neutralized in lift stations with the addition of commercially available products. Peroxide, permanganate and ferrous or ferric chloride can also be used.

Fats, Oils, and Grease Fats, oils, and greases (FOG) in plant effluent can result in floating material in the receiving water. FOG can enter the plant as discrete floatable particles, as emulsified material or as a solution and can be classified as polar or nonpolar. Polar FOG, typically biodegradable, originates from animals while nonpolar FOG, much less readily biodegradable, typically comes from petroleum products. FOG measurements upstream and downstream from the treatment units provide data on removal efficiencies. If excessive levels of FOG enter a secondary system, the low-density FOG constituents merge with the biomass. This merge can cause poor settling ability of the biological solids with the result of excessive solids loss to the effluent.

A true representative sample of FOG is almost impossible to obtain because of the surface concentration of FOG and its adherence to the surfaces of the sampling device and storage container. Consequently, grab samples are used and the entire sampling container is rinsed with solvent to capture the attached oil and grease.

Elimination of FOG at the source using grease traps or other recovery technology is the best method for controlling what enters the collection system and treatment plant.

1.5. Physical characteristics

The physical characteristics of wastewater include settling materials, temperature, color, odor and turbidity. Of these characteristics, color, odor and turbidity can quickly be checked by sight and smell before actual testing is carried out.

Settling materials. Settling materials include the materials which sink and are separated in the sand traps up to the dimension of 0.1 mm. This also includes floating materials that are separated up to the dimension of around 0.001 mm after longer stay in the primary sedimentation basin.

Their determination is done with a 1L sample from the wastewater in Imhoff tank. After 2 hours, eventually shortened to 0.5 hours, the deposited volume is determined.

Influent: around 1 to 20 ml/l

Effluent: around 0.3 to 0.6 ml/l

Temperature. The temperature of wastewater indicates the amount of thermal energy it contains. Wastewater is typically warmer than unheated tap water because wastewater contains heated water from dwellings and other sources. As buried pipes convey wastewater long distances to the plant, the influent temperature typically approaches the temperature of the ground. Accordingly, summer wastewater temperatures exceed winter temperatures. The annual mean wastewater temperature typically ranges between 10 and 20 °C, and in the winter period the temperature of the water is kept around 10 °C. Because the water between and in the components of the WWTP is in constant movement (except in the sedimentation basins), often there is no danger of freezing even in winter.

In general, the rate of biological activity depends on temperature. As temperature increases, microorganisms accelerate consumption of organics and use of oxygen in the wastewater. The reaction rates approximately double with every 10 °C (18°F) increase in temperature until higher temperatures begin to inhibit biological activity. A significant increase in temperature over a short period typically indicates the presence of an industrial discharge. A significant drop in temperature often indicates intrusion of stormwater.

Wastewater treatment plant operators in areas subject to wide temperature swings between summer and winter must be aware of the effects that temperature changes will have on the activity of the microorganisms. The warmer the temperature of the water is, the higher the activity it will contain.

Color. The color of wastewater depends on the amounts and types of dissolved, suspended and colloidal matter present. Normal raw wastewater is gray. Wastewater becoming septic will be darker, indicating the need for further aeration. Other colors typically indicate the presence of industrial discharges.

For example, green, blue or orange discharges may emanate from plating operations; red, blue, or yellow discharges are often dyes; and white, opaque discharges often come from dairy wastes or latex paints. Knowledge of the types of industries contributing to the collection system and the colors of their discharges is of great value to the operator.

The normal color of the wastewater in the inlet to the WWTP is light gray. If the color tends more to brown gray, that is often a sign that the materials contained in the wastewater are decaying. In the outlet after good treatment in the WWTP, the water is clear, eventually with yellowish color.

Odor. Though odor is a highly subjective parameter, it can offer valuable information about wastewater constituents. Fresh wastewater typically produces a musty odor. Other wastewater odors, such as petroleum, solvents or other abnormal scents, can indicate an industrial spill.

Because some of the compounds present in wastewater may be toxic, caution must be used when smelling wastewater, especially when it comes to bottled samples. Detection of unusual odors in a plant, particularly in confined areas, requires the exercise of caution and strict adherence to safety procedures.

Anaerobic decomposition of wastewater produces hydrogen sulfide, which has a distinctive, rotten-egg odor. When hydrogen sulfide is present, measures to increase the oxygen content of the liquid stream must be taken. In addition to indicating process problems, the presence of hydrogen sulfide raises concerns for other reasons. It is poisonous at relatively low levels, corrosive to concrete and potentially explosive. It is also important to note that hydrogen sulfide is particularly dangerous because it essentially paralyzes one’s sense of smell when present at high concentrations. In this situation, one would initially note the rotten-egg odor, but it would seem to quickly go away. If one interprets the disappearance of the rotten-egg odor as no hydrogen sulfide being present, it could quickly lead to one or more fatalities. Methane gas, which is even more explosive, may accompany hydrogen sulfide. The conditions that produce methane and hydrogen sulfide demand oxygen, often resulting in an oxygen-deficient atmosphere. Therefore, the presence of hydrogen sulfide and methane demand extreme caution and rigorous application of established safety procedures. This includes using appropriate gas detection equipment before entering a confined space and turning on ventilation equipment, if available.

Turbidity. Turbidity is a measure of the quantity of suspended floating matters. Turbidity, measured with a device called a turbidimeter, indicates the quantity of suspended and colloidal material in the flow stream, particularly at low solids concentrations. Turbidity is measured in nephelometric turbidity units, which have to do with the type instrument used, in this case, a nephelometer. Turbidity does not directly correlate with suspended solids concentrations, because color can interfere with the turbidity measurement. However, it is easy to determine a relationship between turbidity and suspended solids for any given system. To determine the relationship, multiple grab samples must be taken and analyzed for suspended solids over a suitable range of turbidity values. The simple determination of turbidity is done by defining the depth visibility or by using a plate made for that purpose. Such a plate is lowered in the water until it becomes fully submerged, or one vertical large cylinder in which a clearly written paper is placed and the cylinder is filled with water until the text is no longer visible. The depth visibility of the water of one good functioning WWTP should be at least 50 cm.

1.6. Chemical characteristics

The chemical characteristics of wastewater include pH, alkalinity, chemical oxygen demand (COD), conductivity and oxidation–reduction potential (ORP).

pH. The term *pH* is traditionally used to represent the concentration of hydrogen ions in a solution, where pH is determined by the following:

$\mathrm{pH} = - \log [H^+]$,

Where $[H^+]$ is the actual hydrogen ion concentration of a solution.

For example, neutral water has a pH of 7, which means that the hydrogen ion concentration is 10_7 mol/L. The pH scale ranges from 1 to 14, with 7 being a neutral reading. Readings below 7 indicate acidic conditions and those above 7 indicate basic conditions. The pH level is extremely important in biological wastewater treatment because microorganisms remain active only within a narrow range, generally between pH 6.5 and 8. Outside this range, pH can inhibit or completely stop biological activity. Nitrification reactions are especially pH-sensitive. Biological activity declines to near zero at pH levels below 6.0 in unacclimated systems.

Raw wastewater typically has a pH of around 7. Although significant departures may indicate industrial or other non-domestic discharges, other conditions can cause pH to deviate from the norm. Anaerobic conditions lower the pH of a wastewater. Low pH values, coupled with other observations, such as sulfide odors and black color, provide evidence of septic conditions in the collection system or within the treatment process. Only nitrification reactions in the secondary aeration basins may reduce the pH enough to inhibit biological activity in some low-alkalinity systems. Conversely, denitrification reactions by themselves will increase pH. Covered high-purity oxidation systems can also lower pH as a result of the buildup of carbonic acid.

Alkalinity. Alkalinity is a measure of the ability of the wastewater to neutralize acid. Alkalinity is reported as milligrams per liter of calcium carbonate. However, other compounds also contribute to alkalinity. The characteristics of the raw water supply influence alkalinity, which can be high in areas which have hard water (typically associated with groundwater sources) or extremely low in areas which have soft water.

High-alkalinity wastewater allows a WWTP to better survive an acidic industrial discharge. Some process conditions, such as nitrification in the secondary units, will consume alkalinity and may lower pH. Thus, a reduction in alkalinity across the secondary process units denotes nitrification in the secondary process. Conversely, denitrification will generate alkalinity and may increase pH. Therefore, a treatment system that supports both denitrification and nitrification can regain some of the lost alkalinity; that is, denitrification will return approximately 40% of the alkalinity lost to nitrification.

Chemical Oxygen Demand. COD is defined as the amount of a specified oxidant that reacts with the sample under controlled conditions in which the quantity of oxidant consumed is expressed in terms of its oxygen equivalence. In short, it provides a measure of how much oxygen a sample will consume (oxygen demand) and it does so in three or four hours. The COD test, therefore, provides a means to quickly estimate the five-day BOD (BOD5) of a sample.

The correlation between BOD and COD varies from plant to plant. However, COD results are typically higher than BOD results because all the organics are oxidized. Use of the COD test for process control requires that the BOD tests first be run in parallel with the COD tests to determine this correlation.

This allows BOD-to-COD ratios to be developed for each plant, varying across the plant from influent to effluent. The BOD-to-COD ratio is typically 0.5:1 for raw wastewater and may drop to as low as 0.1:1 for a well-stabilized secondary effluent.

Conductivity. Conductivity measures the ability of an aqueous solution to carry an electrical current. The conductivity of domestic wastewater generally ranges from 50 to 1,500 ìS/cm, although some industrial wastewaters have conductivities higher than 10,000 ìS/cm. The conductivity of wastewater indicates the quantity of dissolved inorganic material present in the water. Wastewater has a normal range of conductivity associated with the dissolved solids concentrations in the water supply. A significant increase in the conductivity of the wastewater indicates an abnormal discharge, probably from an industrial source.

Conductivity measurements can be used to determine flow time between pump stations or between other points in the collection system. This procedure involves injecting a solution of conductive material, such as salt, to the flow and noting the elapsed time until conductivity increases at the downstream point.

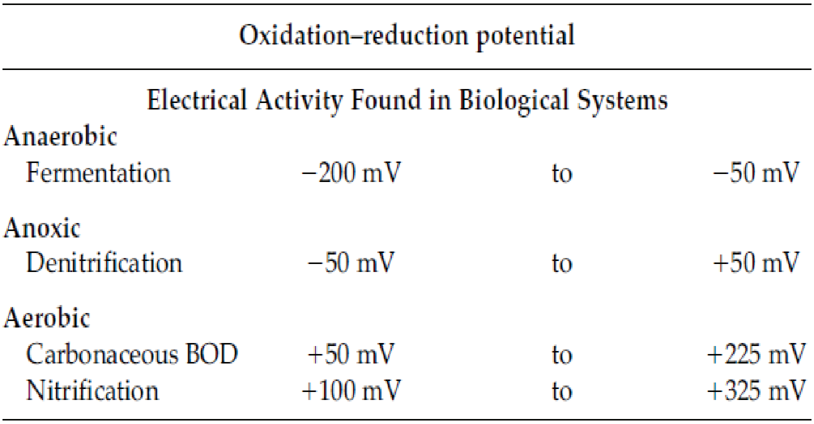
Obtaining reliable data with conductivity-monitoring equipment requires care of electrodes to prevent fouling and adequate sample circulation. Conductivities greater than 10,000 to 50,000 ìS/cm or less than 10 ìS/cm can be difficult to measure.

Dissolved Oxygen. Dissolved oxygen is simply the molecular oxygen present in water or wastewater. The maximum amount of oxygen in water or wastewater is temperature-dependent, with colder water being capable of containing more dissolved oxygen than warmer water. However, colder water may actually contain less dissolved oxygen than warmer water, depending on conditions in the water. The dissolved oxygen in a particular section of a wastewater treatment system is one of the determinants of what type organisms will live and thrive. As dissolved oxygen concentrations decrease, aerobic organisms slow down. Low dissolved oxygen concentrations favor filamentous organisms that may cause sludge bulking, while excess dissolved oxygen concentrations may result in pinpoint flocks that will not clump and settle. Therefore, dissolved oxygen concentration is an essential control factor in wastewater treatment and it must be maintained in a range that favors the desired organisms.

Oxidation–Reduction Potential. Certain substances release or take up electrons when dissolved in solution. The intensity or ease of electron loss (oxidation) or electron gain (reduction) is the Oxidation-Reduction Potential (ORP). An example of this is shown in Table 1.1.

It is commonly referred to as the *redox potential* and it measures the potential of the treatment system in millivolts. It can identify current operational conditions, a weak link in the treatment train and if operational conditions have improved a system. It provides an immediate response to critical controls. Redox potential is measured using a data logging meter and an ORP submersible probe. It can be used to monitor incoming raw wastewater, primary effluent, suspended growth systems, fixed-film systems and aerobic digesters.

Table 1.1 Example of the ORP



Oxidation–reduction potential

Electrical Activity Found in Biological Systems

Anaerobic			
Fermentation	−200 mV	to	−50 mV
Anoxic			
Denitrification	−50 mV	to	+50 mV
Aerobic			
Carbonaceous BOD	+50 mV	to	+225 mV
Nitrification	+100 mV	to	+325 mV

Raw wastewater influent has a typical ORP of _200 mV. A strong influent measures approximately 400 mV and weak influents (such as those containing infiltration and inflow) measure 50 mV.

Ideally, ORP values of a system's primary effluent should be the same as that of its raw influent. A decrease may indicate a need to increase the removal of primary sludge or indicate side stream interference, as from a supernatant recycle.

1.7. Biological characteristics

Bacteriological testing determines the presence of pathogenic (disease-causing) organisms or indicator bacteria for such organisms in the raw wastewater, process streams and treated effluent. Because testing for all possible pathogens is impossible, accepted procedures involve testing for what are called *indicator bacteria*. Their presence signals the likely presence of pathogens.

Tests to determine biological activity include BOD, pathogen and microscopic examination.

Biochemical Oxygen Demand*.* The BOD test measures the amount of oxygen needed to biologically oxidize material in wastewater. Because the rate of biological activity depends on temperature and complete stabilization may require as long as 20 days, the BOD5 test has been standardized to conditions of 20°C for five days. This test provides a relative measure of the amount of food material available to the biological system, degree of stabilization of the wastewater and prospective effect of the effluent on the receiving water.

For practical reasons it is agreed as measurement parameter for degradable organic load of wastewater to be taken the quantity of used oxygen in duration of 5 days from the beginning of the measurement. Additionally, the temperature of the measurement is defined to be 20 °C because the effect of the bacteria is dependent on the temperature.

The measurement of BOD5 is a significant parameter and provides an important basis for determining plant loading and design considerations. As designed, the BOD5 test typically measures the amount of oxygen required to oxidize the organic matter in a sample. The amount of oxygen required to oxidize only the carbonaceous organic matter (not nitrogen) is referred to as *carbonaceous BOD* (CBOD). If the sample is allowed to react further, a second phase of biological oxidation, known as *nitrification*, begins to occur. During this phase, a different group of bacteria convert ammonia to nitrite and nitrate, consuming oxygen during the process. The time required for transition from carbonaceous to nitrogenous reactions varies, depending on the sample. If nitrifying organisms are initially present at background levels, an appreciable nitrogenous oxygen demand may sometimes be exerted before five days have elapsed.

Secondary treatment plants are typically designed to remove CBOD, but not nitrogenous BOD. Nonetheless, nitrogenous reactions frequently occur in some well stabilized secondary effluents during the five-day test period. The BOD5 of domestic wastewater in the United States typically ranges from 100 to 250 mg/L, but is likely to be higher. Because nitrogenous oxidation can sometimes result in substantially higher BOD5 test results than those from oxidation of organic substances, the US Environmental Protection Agency (US EPA) has approved the use of a modified BOD test in which a nitrification inhibitor is used to suppress the nitrification reaction. Use of the CBOD test for permit reporting must be approved by the regulatory agency of each state.

Pathogens*.* Pathogens are disease-causing organisms that are present in large numbers in raw wastewater, process streams and treated effluent. The presence of pathogens can be determined by testing for indicator organisms, including total and fecal coliform, *Escherichia coli*, enterococci and, in some cases, fecal streptococcus.

Viruses. Viruses excreted with feces, urine, blood or any other body fluids or secretions from humans and any species of animals may pollute water. Especially numerous and of particular importance to health, are the viruses that infect the gastrointestinal tract of humans and are excreted with the feces of infected individuals. Because viruses multiply only within susceptible living cells, their numbers cannot increase in wastewater. Wastewater treatment, dilution, natural inactivation and water treatment further reduce viral numbers in municipal wastewater. Because viruses occur less frequently than bacteria and are much more difficult to measure, routine examination of water and wastewater for viruses is not performed. If testing is required, it should be done by competent and specially trained water virologists.

Microscopic Examination. Microscopic examination of wastewater and process streams can provide valuable information on the biological characteristics of the system and serve as a powerful tool for process control, particularly for activated sludge. Examination of sludge under a microscope can reveal sludge conditions and warn of impending process problems. Microscopic examination can show flock appearance, clarity of supernatant liquid, types and distribution of protozoa and the presence or absence of filamentous bacteria.

1.8. Solids

Treatment plant operators use mechanical devices and microbiology (the population of naturally occurring microorganisms) to remove or condition solids to ensure that the system effluent meets regulatory requirements. They use screening, skimming, pumping and filtering devices to remove the large solids (or macro solids) and any floating solids. They primarily use microbiology to condition the remaining smaller or micro solids, such that they will settle to the bottom of undisturbed water or be converted to gas or water. The treatment is not perfect, consequently operators must compare the amount of solids in the water entering the treatment system with the amount in the water leaving the treatment system to measure the treatment's effectiveness and assess whether the system is in compliance with applicable regulations. They can also measure changes in the different solids types at various stages in the treatment process to assess treatment effectiveness throughout the process so that they can make necessary changes.

It is, therefore, important to understand the different types of solids and be able to determine the quantities of each type. This knowledge of solids, coupled with collecting the appropriate data, provides the information operators need to effectively operate and control wastewater treatment systems.

Total Solids. Total solids are all the solids in wastewater. They can be grouped based on what they do in water: those that settle (i.e., sink); those that do not settle (i.e., non-settleable solids that float or stay dispersed throughout the water); or those that dissolve.

Total Solids = Settleable Solids + Non-settleable Solids + Dissolved Solids;

All solids that are not dissolved are considered to be suspended solids, so:

Suspended Solids =Settleable Solids + Non-settleable Solids;

And,

Total Solids = Suspended Solids + Dissolved Solids

To determine the total solids concentration, first determine the mass of total solids per unit volume as follows:

1. Measure the mass of an oven-dried container,
2. Fill it with a known volume of wastewater,
3. Put the filled container in an oven,
4. Leave it in the oven until the water evaporates, and

5. Remeasure the mass of the dry container with the remaining solids residue,
6. Subtract the original mass of the empty dry container from the mass of the dry container with the remaining solids residue to find the mass of the total solids, and
7. Divide the mass of total solids by the volume of wastewater used at the start to find the total solids concentration in terms of mass per unit volume (e.g., mg/L).

It is important to measure the total solids entering the treatment system because they can serve as an indicator as to whether something unusual is occurring in the collection system (i.e., sanitary sewers feeding into the treatment system). For example, if an influent total solids database has been established and there is a significant change relative to historical data, this may be an indication of illegal discharges or some sort of failure in the collection system. This change from historical data may provide early indications of a problem and allow for timely corrective action to prevent an upset of the treatment system.

Total solids can also be grouped based on whether they will pass through a filter of a particular pore size. The dissolved solids pass through the filter with the water and the solids caught by the filter are called *suspended solids*. They can be thought of as "suspended" by the filter because they cannot pass through it with the water. Suspended solids are typically those that are visible in water and give it a dirty, unpleasing appearance. They consist of solids that settle on the bottom, float throughout or float on top of the water.

The solids that float throughout the water as opposed to sinking to the bottom or floating to the top are generally relatively small particles, referred to as *colloidal solids*. They stay dispersed throughout the water because of their small size, a specific gravity approximately equal to that of the wastewater and/or an electric charge that tends to repel them from each other and keeps them from settling.

Suspended solids are particularly important in wastewater treatment because they are one of the criteria used by regulatory agencies to assess regulatory compliance. Unless they color the water or are present in very high concentrations, dissolved solids are typically not visible in water. Sugar or salt dissolved in water are examples of dissolved solids. In general, dissolved solids and their effect on wastewater treatment are assessed via other tests and will not be discussed further in this section.

To determine the suspended solids concentration, determine the mass of suspended solids per unit volume as follows:

1. Measure the mass of an oven-dried filter,
2. Filter a measured volume of wastewater through the filter,
3. Put the filter with the trapped solids in an oven,
4. Leave it in the oven until the water evaporates, and
5. Remeasure the mass of the dry filter with the remaining solids residue.

Subtracting the original mass of the dry filter leaves the mass of the suspended solids. Dividing the mass of suspended solids by the volume of wastewater used at the start then gives the suspended solids concentration in terms of mass per unit volume (e.g., mg/L).

Solids can also be grouped based on whether they burn off (or volatize) at a certain temperature. Those solids that burn off are called *volatile solids* because they volatize when subjected to heat, and those that remain are *fixed solids* because they remain fixed in spite of the heat treatment.

In general, it is important to know the volatile solids value, because volatile solids provide a good approximation of how much organic matter is present in wastewater. It is primarily organic matter that can be converted and/or conditioned by the microorganisms. Accordingly, before and after treatment, volatile solids determinations may provide an indication of the treatment's effectiveness.

One of the primary means of removing solids from wastewater is to simply let them settle to the bottom of tanks called *clarifiers* and let the clarified water overflow weirs at the top. The effectiveness of settling depends on how well the operators control the treatment system to grow the best mix of microorganisms that will produce or condition solids that will settle and how well they manage the solids inventory (i.e., the total amount of suspended solids in the treatment system). If the microorganism-conditioned solids are too heavy, they sink too fast and leave many of the very small particles dispersed throughout the water, which then go out with the treated water. If the microorganism-conditioned solids are too light, they settle too slowly or not at all and go out with the treated water.

TYPES OF POLLUTED Wastewater

2. TYPES OF POLLUTED Wastewater

Any natural water which becomes unusable or dangerous for humans or the environment is considered to be polluted water. This change in quality can occur both naturally or artificially.

Water contaminated as a result of human activities can be divided into municipal, industrial, agricultural and other.

2.1. Municipal wastewater

The amount of sewage water depends on many factors. These include the used water in households in settlements, the communal organization of the settlement related to the drainage of storm water, flood waters through sewage systems and purification systems, disposal of urban municipal waste in appropriate landfills and appropriate handling. Municipal wastewater from households is primarily burdened with organic substances that are completely biodegradable, usually of plant or animal origin. However, in recent decades, due to changes in the lifestyle of people, the quality of waste communal water is changing, especially because of the use of synthetic means for washing, cleaning and other sanitary needs.

According to some estimates, the amount of organic and inorganic substances in sewage water is around 1,300 g / m3 of water, containing 48% insoluble and 52% soluble substances. Of the insoluble substances, 67% is organic matter and 43% inorganic, while soluble substances are 50% organic and 50% inorganic solids.

In the winter months the use salt, sand and other materials on roads may add to the pollution of urban water utilities. This is especially high in the spring months when these substances are washed from the streets directly or indirectly and carried through the sewage network, eventually arriving in rivers or water reservoirs. Urban water utilities, particularly fecal and water originating from the landfill of organic waste and biologically contaminated with pathogenic viruses, bacteria, parasites and other microorganisms. Biological contaminants originally coming from animal and human excrement are found in wastewaters and through various routes of transmission, infectious diseases are transmitted to individuals. These diseases caused by pathogens transmitted by water are designated as digestive diseases. Viruses are commonly transmitted in water, such as the enteroviruses that cause polio. This disease is manifested by paralysis of the lower limbs, and as the most severe form of the disease is a paralysis of the nerve. From the pathogenic bacteria that commonly cause diseases like digestive *Enterobacteriaceae*, the most common are: *Streptococcus faecalis*, which is the cause of infections in the urogenital tract and toxicoinfections that are difficult to treat; and *Escherichia coli*, causing summer diarrhea that are most dangerous to infants and children. In urban wastewater utilities there are various bacteria, parasitic worms, tapeworms and other contaminants, which can also cause various diseases. Surface waters, especially running waters, are heavily burdened with municipal wastewater.

Domestic wastewater comes primarily from residential, nonindustrial business and institutional sources.

Wastewater with a predominantly domestic origin tends to be fairly uniform in composition.

Composition varies somewhat among communities because of differing social, economic, geographic and climatic conditions.

Municipal wastewater from Industrial and Commercial activities. Most municipal sewers convey wastewater from industrial and commercial sources and from domestic sanitary sources. Industrial wastewater typically contains substances derived from raw materials, intermediate products, byproducts and end products of the industry manufacturing or production processes. Industrial wastewater changes with changing production mixes and schedules.

This wastewater is more variable than domestic wastewater. Food-processing wastes, which typically contain high concentrations of soluble organic constituents, often cause extreme variations in plant loading because of the seasonal production associated with crop harvests. Food-processing wastes may also be nutrient-deficient (i.e. low in nitrogen), which can have an adverse effect on the activated sludge process at the WWTP.

Commercial sources, such as retail businesses, contribute primarily domestic wastewater; other commercial sources, such as warehouses and distribution centers, may contribute variable wastewater from washing and other operations.

Infiltration and inflow can affect hydraulic loadings.

Infiltration enters sewers through leaky joints, cracks or holes in pipes. Groundwater is a common source of infiltration, particularly when the ground is saturated. Inflow results when storm or runoff water enters the system through leaky manhole covers or cracked casings.

2.2. Industrial wastewater

Industry is one of the largest sources of water pollution, given that more than 50% of wastewater of industries is often discharged into surface waters through direct or indirect ways without prior treatment. Depending on industry origins, the wastewaters can be grouped as originating from the industries of mining, chemical, petrochemical, ferrous and non-ferrous metallurgy, food, textile, manufacturing industry paper, rubber, leather and so on. Industrial wastewater used in the process of cooling may cause thermal pollution of waters.

If there are large amounts water from cooling, they can make changes to the temperature regime of running waters, sometimes increasing the temperature to over 10 0C. Thermal pollution can have direct and indirect harmful effects on wildlife water. Increased water temperatures can impair the activity of enzymes in living organisms and may reduce the content of oxygen. This leads to a reduction in the populations of certain groups of lower organisms in the trophic chain which serve as a source of food for other organisms of higher order, which in turn can affect the populations of the fish fauna as representatives of vertebrates.

2.3. Wastewater from Agriculture

Agriculture as a major economic sector is an important source of surface soil and groundwater pollution. Pollution in this industry primarily derives from the pits for silage, landfills for collecting solid and liquid manure, the big farms of cattle, dairy, water areas around which are built farms for poultry, storage and use of various fertilizers and pesticides, etc. Wastewater resulting from organic farms produces pollution, but often can cause contamination with heavy metals that are part of some chemicals.

NATURAL BIOLOGICAL PROCESSES

3. NATURAL BIOLOGICAL PROCESSES

3.1. Introduction

Stabilization lagoons and land treatment processes are natural systems commonly used to treat municipal wastewater of small communities with populations of less than 20,000. Stabilization lagoons typically provide secondary treatment, while land treatment systems often provide higher levels of treatment.

3.2. Lagoons

Lagoons are typically basins constructed entirely of earth. By using cut and fill to remove the original topsoil, lagoons are built above ground by enclosing an area with earthen dikes. Traditionally, lagoons have been lined with compacted, natural materials such as clay. With current groundwater concerns, newly constructed lagoons are often lined with synthetic barriers or composites of natural and synthetic barriers. Groundwater monitoring, although traditionally not extensive, is receiving more emphasis today. The microorganisms existing within the lagoon make the wastewater treatment lagoon work and lagoons are generally classified according to the biological processes that occur within the basin. These classifications of lagoons are aerobic, anaerobic and aerobic-anaerobic. They are further classified according to how oxygen is imparted to the system. Unaerated lagoons are systems that do not require mechanical assistance for oxygen addition. Conversely, aerated lagoons require mechanical facilities for the addition of oxygen.

The oxygen distribution within the lagoon determines the type of lagoon it is. Aerobic lagoons have oxygen distributed throughout the water, anaerobic lagoons have no oxygen and facultative lagoons have both an aerobic layer and an anaerobic layer. The degree of waste stabilization achieved is governed primarily by the particular biological community established within the lagoon and affecting the oxygen demand.

Lagoons can be constructed in a series of ponds. Sedimentation of solids and anaerobic decomposition of settled organic material occurs in the first cell, or *primary cell*. Secondary treatment, whereby organic matter is oxidized aerobically into stable products, reducing the biochemical oxygen demand (BOD) and suspended solids (SS), is accomplished in the primary and secondary cells. A third step is often included to polish the treated wastewater. The cells of this third step, referred to as *tertiary* or *polishing* lagoons, are lightly loaded to remove additional BOD and suspended matter. Figure 3.1 presents the typical flow schematic of a lagoon.

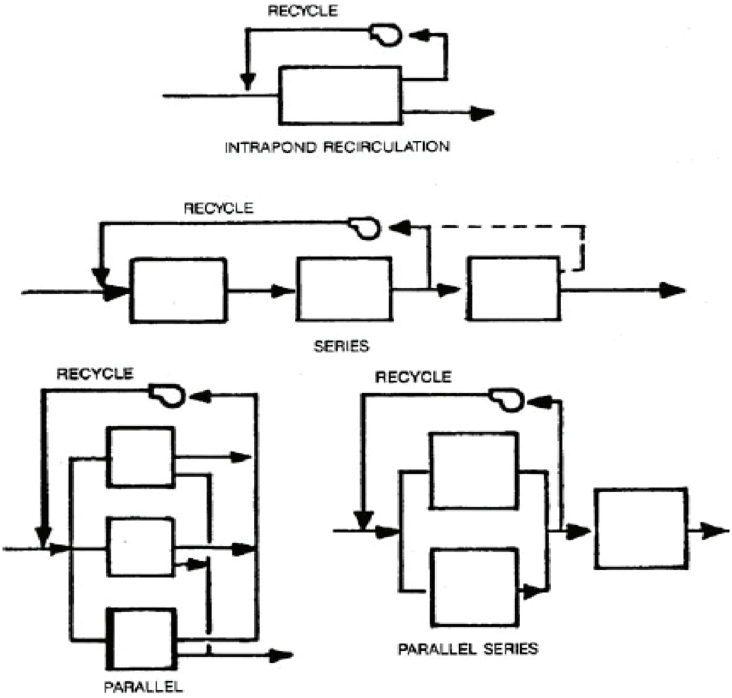


Figure 3.1 Common lagoon configurations and recirculation systems (US EPA, 1983)

Unaerated Stabilization Lagoons. An unaerated lagoon can be aerobic, anaerobic or facultative. Organic contaminants in the wastewater are assimilated by aerobic and facultative bacteria. Oxygen required for aerobic bacterial respiration is provided by the natural transfer of oxygen at the air-water interface and by photosynthetic algae. During photosynthesis, algae use energy from sunlight and byproducts excreted by bacteria to produce sugars and oxygen.

The amount of natural oxygen transfer at the water surface depends on the amount of wind-induced turbulence. Oxygen transfer is also affected by the solubility of oxygen, which is a function of the water temperature. Oxygen solubility is greater at lower temperatures than at higher temperatures. Unaerated stabilization lagoons are shallow ponds with 0.9 to 1.5 m of liquid depth.

Aerobic Lagoons. In aerobic lagoons, contaminants are biologically degraded in the presence of dissolved oxygen (DO). The physical dimensions, temperature, amount of sunlight and amount of natural or artificial turbulence are used to maintain a desired DO concentration. Aerobic lagoons are typically 0.9 to 2.4 m deep. It should be noted that, in practice, it is not possible to maintain a completely aerobic lagoon as the bottom sediments will contain some facultative bacteria. An example of an aerobic lagoon is a polishing lagoon.

Anaerobic Lagoons. In an anaerobic lagoon, where no DO is present, bacterial degradation of waste produces reduced products such as methane (CH_4) and hydrogen sulfide (H_2S). The conversion of organic acids to methane and carbon dioxide by methane bacteria is affected by dissolved oxygen, pH and temperature; therefore, the efficiency of the anaerobic lagoon process is sensitive to these parameters.

An anaerobic lagoon is quite often used as a roughing process before an aerobic or facultative lagoon. With this serial design, intermediate products from the anaerobic process can be oxidized in the aerobic process. The water depth in an anaerobic lagoon is typically greater than 3 m (10 ft).

Economy, groundwater level and heat retention considerations dictate the lagoon depth.

Facultative Lagoons. Most lagoons are facultative and are designed to provide zones in which dissolved oxygen is absent (for anaerobic decomposition of waste) and zones in which DO is present (for aerobic degradation of anaerobic byproducts and other waste constituents). As wastewater enters a lagoon, the heavy solids settle out near the inlet bottom where anaerobic bacteria stabilize the organic matter.

Stabilization of settled solids occurs anaerobically in two steps [2]:

1. Acid bacteria break down the complex organics by feeding on the soluble matter, thereby converting it to organic acids.

The methane bacteria feed on the organic acids, thereby converting them to carbon dioxide, ammonia, hydrogen sulfide and methane gas.

The aerobic bacteria in the upper layers of the basin feed on the liquid and gaseous byproducts from the anaerobic decomposition of organic matter. Aerobic bacteria use the soluble organics in the raw waste and the soluble organics from anaerobic decomposition to produce some inert material, dissolved sulfate, nitrate, phosphate and carbonate compounds as a source of energy for anaerobic bacteria. Algal photosynthesis, atmospheric reaeration and/or mechanical aeration provide oxygen sources for the aerobic bacteria. Facultative lagoons are typically 0.9 to 1.8 m in depth.

Aerated Lagoons. Unlike the shallower unaerated stabilization lagoons, aerated lagoons do not depend on algal photosynthesis to furnish oxygen for bacterial respiration. Dissolved oxygen is provided by mechanical or diffused air aeration equipment. Lagoons designed for mechanical aeration are typically 3 to 4.5 m deep. There are several types of aerated lagoons including completely mixed aerated lagoons, partially mixed facultative lagoons and a combination of the two. These lagoons vary by the amount of DO in the lagoon profile and in the DO concentration variation during the day.

3.3. Land treatment systems

Land treatment of wastewater is the controlled application of wastewater to the land surface in order to achieve a designed degree of treatment through physical, chemical and biological processes within the plant-soil water matrix. The basic soil properties that influence the success of land treatment of waste include soil texture, soil structure, permeability, infiltration and available water capacity.

Wastes are removed physically through filtration by the soil and their concentrations are altered by dilution, either upon entering the groundwater or in the soil that contains natural rainfall or snowmelt. Filtration is limited by the clogging of soil pores with suspended solids, which can be avoided by pretreatment and rest periods between applications.

Adsorption and precipitation are the main processes involved in the retention of wastes in the soil. The effectiveness of soil in the removal of waste depends on the type of waste being treated, the contact between dissolved substances and the soil phases. Biological processes decompose organic matter and the rate of decomposition depends on many factors including the composition and form of the waste being applied and the temperature of the soil-water environment.

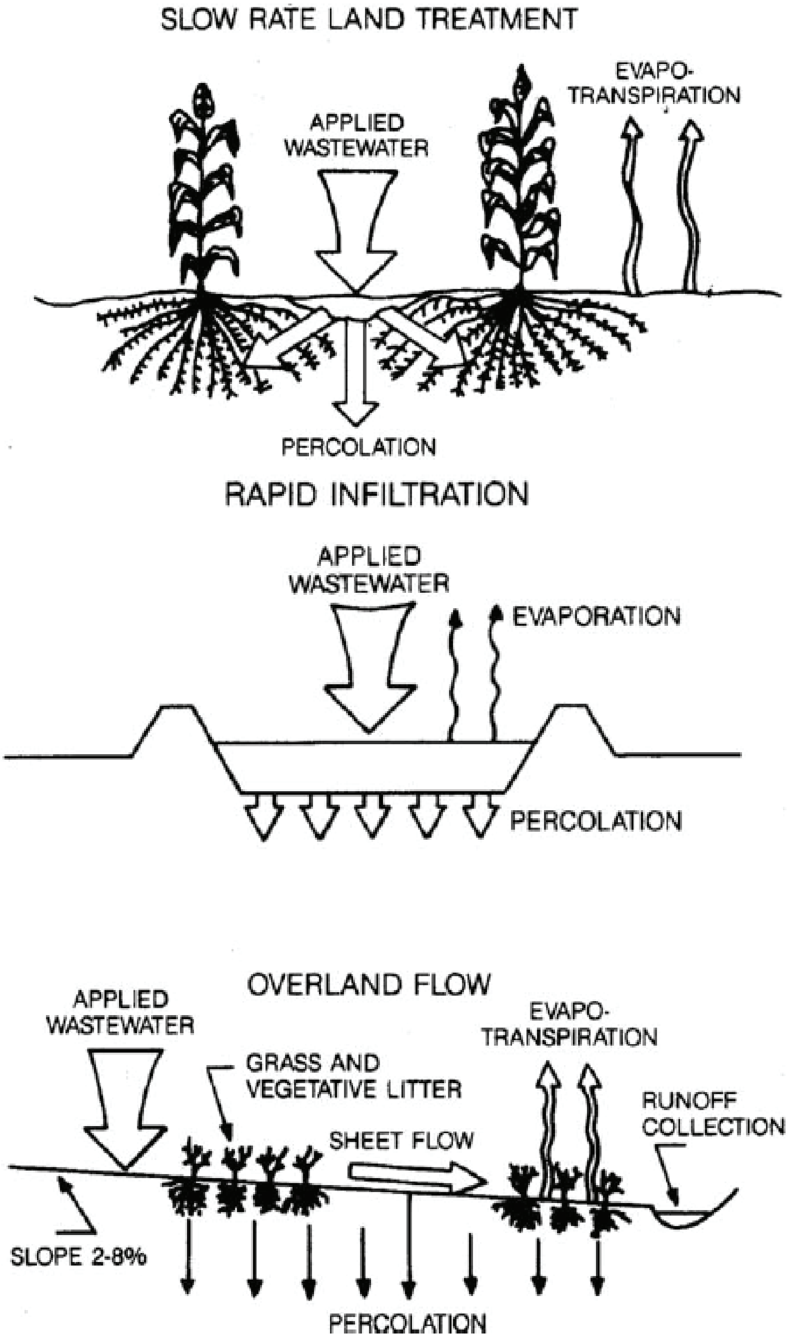
The ability of soil to treat wastes is limited by the loading of nitrogen, phosphorus, water, the addition of potentially toxic substances and the sodium adsorption ratio of the soil. In most situations, nitrogen is the major factor limiting the application of waste to the soil.

Normally, soil permeability and nitrogen removal limitations govern design of hydraulic loading rates to land application systems. Hydraulic loading rates are used to determine land area and storage requirements. Land treatment processes employ wastewater application and drying cycles to stimulate nitrification-denitrification processes.

Preliminary treatment processes are usually selected before determining the hydraulic loading because pretreatment can affect the quality of the wastewater applied to the land. Basically, the three reasons for the preliminary treatment of wastewater are:

- Protection of public health;
- Prevention of nuisance conditions; and
- Prevention of operating problems in the distribution system.

The three major land treatment processes are slow rate, rapid infiltration and overland flow (see figure 3.2). Wetlands treatment is an extension of overland flow with the application of varying types of vegetation.



SLOW RATE LAND TREATMENT

RAPID INFILTRATION

OVERLAND FLOW

Figure 3.2 Schematics of the three major forms of land treatment (US EPA, 1981).

PRELIMINARY TREATMENT

4. PRELIMINARY TREATMENT

Preliminary treatment of wastewater includes screening, grit removal, odor control (where appropriate), and flow measurement (Figure 4.1). The removal of debris in the screening area and the removal of sand, rocks, gravel, and other inorganics in the grit removal system protect downstream treatment processes. Should the screening or grit removal equipment fail, other downstream treatment processes may also fail. Various screening and grit-removal systems exist to properly prepare influent wastewater for advanced treatment later in the plant.

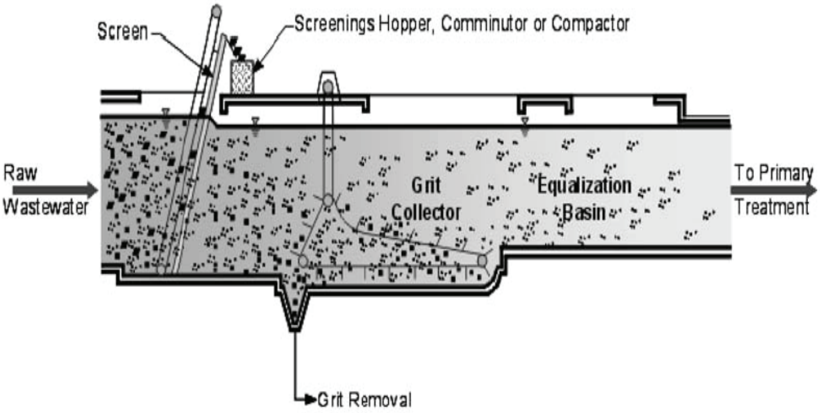


Figure 4.1 Preliminary treatment schematic.

4.1. Screening process

The screening process removes large solids and trash that could otherwise interfere with the operation of a wastewater treatment plant (WWTP). As the plant's first treatment unit, coarse screens (figure 4.2) protect plant equipment against damage such as clogging of pipes, pumps, and grit aeration diffusers. Fine screens (figure 4.3) are being used more frequently in wastewater treatment plants for added removal of debris. The debris captured on the bar screen depends on the bar spacing and the size, configuration, and amount of debris. If the bar spacing is too small, organics that should be treated by subsequent processes will be captured and removed; if too large, much debris will not be captured and will cause downstream difficulties.

Figure 4.2 Coarse screens [3]

Figure 4.3 Fine screens [3]

Screenings debris accumulated on the screens is removed at appropriate intervals by the use of either manual or automatic control methods. The cleaning rate depends on many variables, including the type of collection system (separate or combined), demographics, diurnal-flow patterns, condition of collection system, and seasonal factors (such as leaves during the fall).

Debris removed from the coarse bar racks typically consists of wood, tree limbs, rocks, and other large items. Debris removed from the bar screens typically includes rags, small plastic objects, leaves, paper, and other small objects. Screenings may be loaded onto conveyors for transport elsewhere in the plant or deposited directly into containers. Ultimately, the screenings are transported for final disposal at a landfill or incinerator. Increasingly, screening presses and vacuum containers are being used at wastewater treatment plants to remove the liquid from the screenings before transport to remove excess water, volume, and weight.

Trash racks, also called bar racks, are constructed of heavy, parallel rectangular or round steel bars with 50–150 mm spacing set in a channel. Bars are sloped at an angle ranging from 30 to 45 degrees from the vertical. Bar racks may be cleaned manually or mechanically with robust steel rakes (figure 4.4). Some multichannel installations use a single rake mounted on a traveling bridge that moves from channel to channel. Trash racks are mainly used in wastewater plants that see high amounts of large debris.

Figure 4.4 Robust steel rakes [4]

Bar screens resemble bar racks except that they have smaller clear spacing between the bars, typically 18.75–50 mm. Bar screens are designed as stationary structures built into concrete channels. Some units are designed with cables or cog wheels attached to the submerged end of the screen and a pivot arrangement at the upper end to permit lifting of the submerged end for easy inspection and maintenance. Bar screens are usually installed in a nearly vertical position, with a mechanical, sturdy steel raking device that cleans the screen. The bar screen is typically positioned at 15 to 30 degrees from the vertical for ease of operation of the raking mechanism.

The typical overall widths for a screen channel vary from 0.6 to 4.2 m. The straining efficiency (screenings removal) of a screen and the hydraulic flow through the screen depend on the clear spacing between the bars. The smaller the spacing, the more debris is captured and the more head loss is developed across the screen.

Sizing the screen opening usually depends on downstream operations and the maximum particle size they can effectively and economically remove. Screens with smaller spacing require wider channels for a given flow to enable flow to pass through the screens.

Most plants include two screening channels, especially when one or both channels are equipped with mechanically cleaned bar screens. Thus, if one unit malfunctions, the other unit and channel may remain in service during repairs. Stop gates for the channels allow diversion of flow to clean, maintain, and repair the screening equipment. Influent flows should be equally distributed among all of the channels with screens to ensure uniform loading among the screens. Uneven loading will require more frequent cleaning of some screens than others.

A common type of mechanically cleaned bar screen is the front-cleaning unit with the rake mechanism on the upstream side of the bar screen (Figure 4.5). The typical front-cleaning unit includes a toothed hopper (rake) that swings out from the bar screen as it travels down to the bottom of the channel. After reaching the bottom of the channel, cables, chains, or cog wheels draw the toothed hopper toward the bar screen.

The teeth of the hopper (rake) then slide between the bars and, during the upward movement, drag the screenings out of the wastewater. A variation of this type of screen is the rear cleaning unit with the rake mechanism on the downstream side of the bar screen and the rake teeth protruding through the bars to the upstream side.

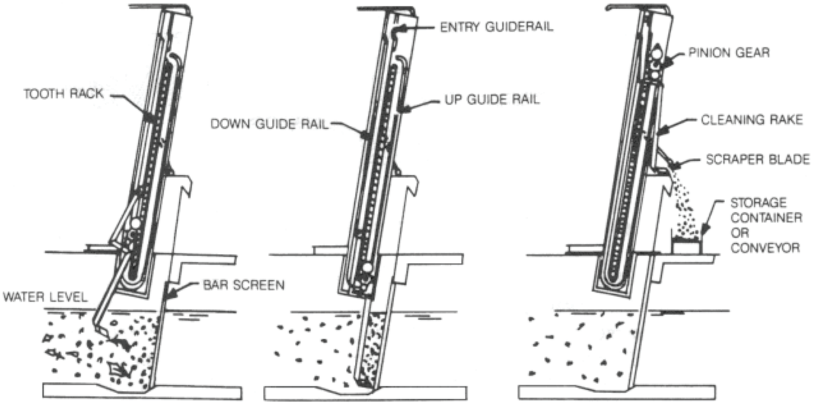


Figure 4.5 Front-cleaning bar screen

Another type of mechanically cleaned bar screen is the continuous self-cleaning screen. This screen consists of a continuous belt of plastic or stainless steel elements that are pulled through the wastewater to provide screening along the entire length of the screen. Continuous screens may have openings as small as 1 mm. Solids are captured on the face of the screen and, as the belt rotates, teeth protrude on the upward movement to collect the screenings.

When the amount of atmospheric wastewater is getting higher, the frequency of cleaning the screens or if it is possible, placing extra screens just for that period of time.

Process Control. Typically, electric motors drive the raking mechanisms of the mechanically cleaned bar screens. Manual controls with an on–off switch activate drive motors. Clock-operated timing switches, level-sensing devices, or programmable logic controllers (PLCs) may control the motors automatically. Of the four control methods, the clock-operated timing switches are the most frequently used; however, more facilities are installing PLCs. Once experience indicates the number of raking operations needed during the average day at a particular installation, the clock-operated timers are set to operate the raking mechanism the required number of times each day. Timers work well but cannot adjust to accommodate sudden large accumulations of debris that can occur during high flow periods. Therefore, level-sensing devices such as bubbler or ultrasonic level systems are usually installed in parallel with the timers and are designed to override the timer control.

More and more new and retrofitted treatment facilities are installing fine screens, such as static or drum screens. Fine screens typically consist of wedge-wire, perforated plate, or closely spaced bars with openings of 2–6 mm. These screens are freestanding units typically installed downstream from coarse screens. Wastewater is applied to the top of the screen and the solids are captured on the face of the screen (Figure 4.6). Wastewater passes through the screen and flows to the next process. The solids fall into a trough or conveyor where they are collected and sent to final disposal.

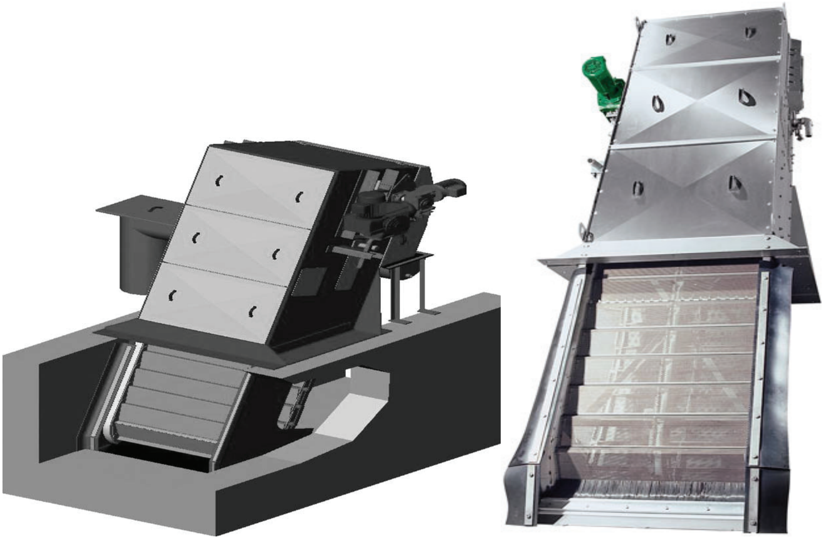


Figure 4.6 Environmental fine screen (JWC Environmental).

Rotary drum fine screens consist of a rotating horizontal drum that may be internally or externally fed (Figure 4.7).

In either case, the solids are captured on the wedge-wire and the wastewater passes through the small openings. The drum slowly rotates to remove the solids and pass the screen through a spray wash system for cleaning purposes.

Figure 4.7 Rotary drum fine screen (JWC Environmental).

Screenings Presses. Screenings presses not only allow for debris to be accepted by landfills by removing excess water, but also reduce the volume of debris for more efficient disposal. Screenings presses (Figure 4.8) consist of a ram, a hopper section, and a wedge section. Presses operate at a range of 4500 to 6000 kPa.

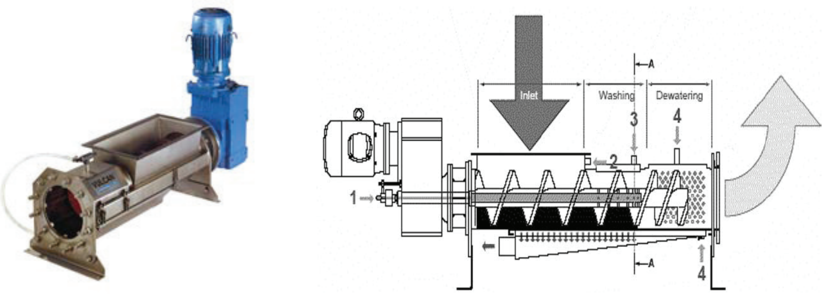


Figure 4.8 Screenings presses (Vulcan Industries, Inc.)

4.2. Grit removal

Wastewater grit material generally consists of fine, discrete, non-biodegradable particles that have a settling velocity greater than that of organic solids. Such materials include sand, cinders, rocks, coffee grounds, cigarette filter tips, and other relatively non-putrescible organic and inorganic substances. Grit removal, an essential element of preliminary treatment, protects equipment by reducing clogging in pipes and protecting moving mechanical equipment and pumps from abrasion and accompanying wear. This process helps by preventing accumulation of materials in downstream processes such as aeration tanks, digesters, or other solids-handling processes that result in loss of usable volume.

Grit chambers are used to settle grit from the wastewater. The settled grit is then consolidated and separated from the wastewater using bucket elevators, screw conveyors, pumps, and cyclones. Grit is finally rinsed by classifiers to remove unwanted organics. Grit removal begins with the grit settling in square, rectangular, or circular chambers or by centrifugal force. There are three types of grit settling chambers: hand-cleaned, mechanically cleaned, and aerated vortex, which are the most typical degritting units.

Hand-cleaned grit chambers are used in the smallest plants with flows generally less than 3.8 ML/d (1 mgd). This type of grit chamber consists of at least two elongated gravity channels with control devices at their outlets to regulate the wastewater velocity at approximately 0.3 m/s. Maintaining 0.3 m/s can sometimes be difficult with this type of grit tank. If the flow velocity is more than 0.3 m/s the grit inorganics could be flushed out of the tank. Inversely, if the flow velocity is less than 0.3 m/s, then organics settle in the tank. Some have hopper-shaped bottoms for grit storage. Floor drains are provided to empty the tanks for manual grit removal by shoveling.

Mechanically cleaned grit chambers are gravity-type units that are rectangular, circular, or square tanks. Most of the rectangular grit tanks have velocity control devices and a mechanical cleaning mechanism, such as a chain-and-flight system. Grit is scraped to a sump hopper and removed by bucket elevators, screw conveyors, grit pumps, or airlift pumps. Square or circular tanks contain deflector baffles at the inlets and a weir at the effluent end to equally distribute the flow. These units include a circular collector mechanism that scrapes the grit to a central collection hopper (sump) where it is removed by grit bucket elevators, reciprocating rakes, grit pumps, airlift pumps, or a screw conveyor system.

Aerated grit chambers provide a period of wastewater detention to trap grit through air-induced rotation of the wastewater at approximately 0.3 m/s. Compressed air, typically from the plant's process air supply, enters the grit chamber through diffusers at a controlled rate to induce the proper velocity of the spiral roll for the settling of grit. Typically, 4.6 to 12.4 lit/s_m of tank length is required for proper aerated grit operation.

Adequate ventilation is essential if the chamber is enclosed; otherwise, the corrosive atmosphere will inevitably affect all exposed elements including electric wiring and controls. Aeration risers and headers should be inspected at least annually for corrosion or rupture.

Vortex grit chambers are gravity-type grit chambers that swirl the raw wastewater in the chamber. Inorganics are removed in the tank hopper section and the organics remain in suspension where they are carried out by the tank effluent. Some vortex tank designs rely on natural hydraulics to achieve the proper rotational rate, while other designs use natural hydraulics and a slow, rotating-paddle-type mixer to achieve the proper separation. The grit that settles in these tanks can be removed by an airlift pump or a non-clogging, recessed-impeller-type grit pump. Grit removed from these tanks can be transferred to a grit dewatering channel, cyclone, grit classifier, or other grit handling equipment to remove additional water.

Cyclones. Cyclones (Figure 4.9) use centrifugal force in a cone-shaped unit to separate grit and organics from the wastewater. A pump discharges a slurry of grit and organics into the cyclone at a controlled rate. The slurry enters the cyclone tangentially near its upper perimeter. This feed velocity creates a vortex that produces a grit slurry at the lower, narrower opening and a larger volume of slurry containing mostly volatile material at the upper port. The grit stream falls into a grit washer, and the degritted flow leaves the cyclone through the opening near the top of the unit and is returned to the treatment process. In some systems, a mechanical mixer induces the centrifugal effect.

The cyclone degritting process includes a pump as an integral part of the process because the cyclone has no moving parts and depends on a steady supply of liquid. The volume of pumped slurry and the resultant pressure at the cyclone are critical requirements specified by the cyclone manufacturer. Temperature, solids concentration, and other characteristics of the slurry may require changes in the sizes of the upper and lower orifices after installation and some initial operating experience. In some designs, these orifices are manually adjustable.

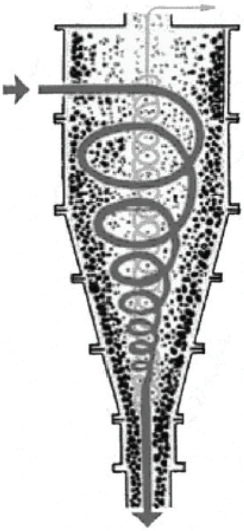


Figure 4.9 Cyclone (Weir Specialty Pumps)

Classifiers. Grit classifiers (Figure 4.10) effectively remove organics from the grit. Screw and rake grit classifiers have proved to be reliable and usually produce a product low in organics. To ensure a low volatile content, however, ample dilution water is required. Pumps normally provide sufficient dilution water, but bucket elevators may not, especially during periods of peak grit capture. Consequently, they may require supplementary liquid. Grit washing occurs at the low end of the classifier in a well that has an adjustable weir to govern the depth of liquid above the settled grit. Most washers are equipped with spray nozzles to remove stray putrescible. For optimum washing, some cyclones use an adjustable lower orifice to change the volume of liquid discharged with the grit.

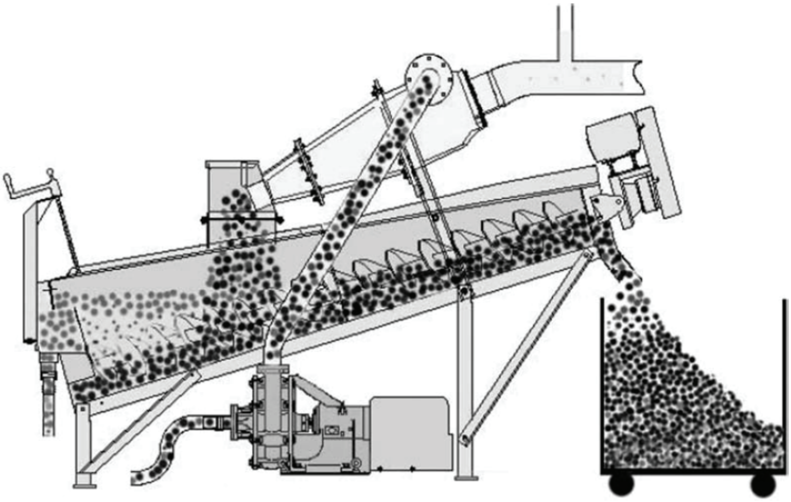


Figure 4.10 Grit classifier (Weir Specialty Pumps)

Few more processes need to be implemented in the preliminary treatment of wastewater, such as **reducing flow fluctuations** and **regulation of the odor**.

Reducing flow fluctuations (diurnal and storm) in the collection system benefits the operation and performance of the treatment plant. Temporary storage of flows in existing sewers, or the use of separate flow-equalization facilities or retention basins, merits consideration because limiting flow fluctuation is beneficial to the equipment operations. Plant flows through parallel units, such as screens and grit chambers, need to balance to aid optimum performance of each unit.

Odors often emanate from the headwork of a plant because of the long duration of wastewater transit through the collection system. This may produce hydrogen sulfide and other anaerobic byproducts of decomposition that cause dangerous confined-space situations and complaints. Whenever possible, septic influent flows should be eliminated in the collection system using appropriate techniques). Otherwise, odor control with prechlorination, iron salts, potassium permanganate, hydrogen peroxide, or pre-aeration may be necessary.

PRIMARY TREATMENT

5. PRIMARY TREATMENT

Primary treatment separates the readily settleable and floatable solids from wastewater by providing a tank where the velocity of the wastewater is reduced to a fraction of a centimeter per second. Benefits of primary settling include the equalization of side-stream flows and removal of the biochemical oxygen demand (BOD) associated with settleable solids. To improve settling performance, pre-aeration or chemical addition sometimes precedes the movement of wastewater to sedimentation basins. Some treatment facilities install special chemical-feed equipment strictly for the addition of chemicals to the wastewater flow to enhance flock formation or settling.

Other treatment plants use chemicals for odor control or phosphorus removal and receive the additional benefit of increased settling in the primary sedimentation tanks in the process. However, most primary sedimentation tank facilities do not use any chemicals to enhance settling.

5.1. Description of process

Suspended particles may be classified as granular or flocculent. Granular particles such as sand or silt settle at a constant velocity with no change to their size, shape, or weight. Ideally, most granular particles will be removed upstream in grit chambers. Flocculent particles such as organic matter, flocs formed by coagulants, or biological growths tend to flocculate during settling, experiencing changes in size, shape, and relative density. The clusters usually settle more rapidly than individual particles. Settleable solids, including portions of the granular and flocculent material, settle under quiescent (calm) conditions within a timeframe. Non-settleable solids are finely divided or colloidal materials, are too fine to settle within usual settling times.

Chemicals are used to remove the finely divided and colloidal materials that is not possible with sedimentation alone. The chemicals react with constituents of the wastewater or in combination with other added chemicals to form a heavy, flocculent precipitate. The settling precipitate then traps the suspended and colloidal particles and adsorbs them on the floc surface.

Removal of floatables, including grease and scum, helps protect downstream plant unit processes, reduces discharged pollutants and improves the aesthetics of the plant effluent. Under quiescent conditions, part of the grease and scum settles with the sludge, whereas the remainder floats to the surface for removal by a suitable skimming device.

5.1.1. Variables affecting settleable solids removal

The efficiency of a settling basin depends largely on hydraulic loading parameters, namely surface overflow rate and hydraulic retention time, tank configuration, wastewater and particle characteristics, temperature, and industrial wastewater contributions. Each of these variables are discussed below and the operational considerations affecting settling efficiency are presented in the subsequent section on process control.

Hydraulic Loading Parameters and Tank Configuration. Settling tank performance depends on tank surface area (length and width or diameter), tank volume (area and depth), and the positioning of the inlet and outlet structures (Figure 5.1). For any influent flow, tank area governs the surface overflow rate and tank volume determines the hydraulic retention time. Although the rate of removal of granular particles settling at uniform velocities depends almost entirely on the tank surface area, the rate of removal of flocculent particles settling at variable velocities depends on the tank volume, including depth and surface area. The surface overflow rate (SOR) is expressed as:

$$SOR\left(\frac{m^3}{m^2\cdot d}\right)=\frac{Q\,(\frac{m^3}{d})}{A\,(m^2)} \tag{5.1}$$

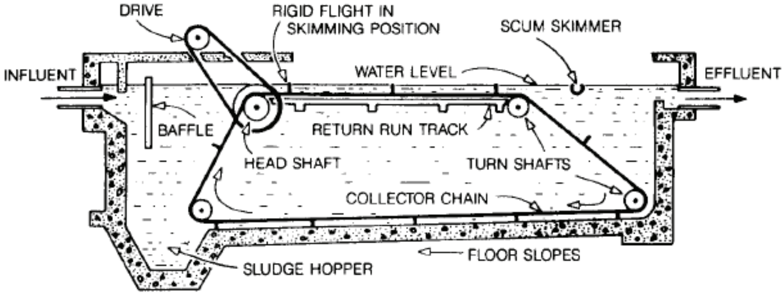


Figure 5.1 Section of a single rectangular tank for primary sedimentation [5]

The hydraulic retention time is the time required for a unit volume of wastewater to pass entirely through the tank at a given flow rate . The formula for detention is:

$$HRT\ (h)=\frac{V\left(\frac{m^3\times 24\ h}{d}\right)}{Q\ (m^3/d)} \tag{5.2}$$

The hydraulic retention period should be sufficient enough to allow nearly the complete removal of settleable solids. An extended hydraulic retention period would not necessarily improve removal as it might actually impair the efficiency of removal by allowing the wastewater to become septic.

Because the dimensions of settling tanks are fixed, the overflow rate and detention time will vary with flow, resulting in variation of removal efficiency. Consequently, this may affect the number of units required for sedimentation if the flow changes significantly.

Sedimentation is affected by the freshness of the wastewater, particle characteristics, temperature, and the amount and type of industrial wastes. A discussion of each of these variables follows.

Freshness. Solids in septic wastewater settle less readily than those in fresh wastewater because the biological degradation of septic wastewater reduces the sizes of particles and the gel generated by the biological reaction tends to float the particles. The collection system also affects the freshness of the wastewater. The time elapsed while wastewater flows through the sewer system depends on the physical characteristics of the system, such as sewer slope and length, number of pumping stations, and the operating method of the collection system. In regard to the latter, many raw wastewater pumping stations store flows in the sewer, thus extending flow time through the entire sewer system and significantly diminishing the freshness of the wastewater. Large contributions of oxygen-consuming industrial wastewater may also affect the freshness of wastewater.

Particle Characteristics*.* Characteristics of particles affect the process of sedimentation. For example, a dense particle settles more quickly than a light one, a particle with a large surface area to weight ratio settles slowly, and a particle with an irregular shape settles slowly because of its high frictional drag. The size, shape, and density of a particle will depend on the sewer network and the types of upstream unit processes. The age or freshness of the wastewater in relation to the wastewater collection system also influences particle characteristics. Some preliminary treatment processes, such as pumping, fragment the particles and reduce their ability to settle.

Temperature. Wastewater temperature influences the rate of settling in many ways. Warm weather increases the rate of biological activity, thus diminishing the freshness of the wastewater in the collection system and promoting gasification in the settling basins . This results in slow settling. On the other hand, the lower viscosity of warm water compared with that of cold water allows particles to settle faster. At a water temperature of 27°C (80°F), the settling rate exceeds that of 10°C (50°F) by nearly 50%.

Primary tank efficiency decreases during winter months because of high wastewater viscosity at cold temperatures. Another reason for poorer winter performance is the increased density of cold wastewater. As water density increases, settling rates decrease.

Industrial Contribution. The amount and type of industrial wastewater could influence sedimentation. Industries may contribute large, short-term hydraulic or organic loads that may "shock" the treatment plant unit processes. Shock loads of organic matter, in either suspended or soluble form, may cause septic conditions and other associated settling problems. High industrial peak flows can also increase surface overflow rates and decrease hydraulic retention times, thus impairing settling performance.

5.1.2. Variables affecting removal of floatables

Efficiency of grease and scum removal depends on tank configuration, wastewater characteristics, and the type and condition of the removal mechanism.

Primary tank baffles (barriers) at the outlet must be continuous and deep enough to prevent grease and scum from traveling underneath the baffles. Grease removal efficiencies vary slightly depending on the equipment and the system used.

Two wastewater characteristics that influence grease and scum removal efficiency are temperature and pH. At summer wastewater temperatures or at a pH less than 7 (acidic), grease and scum may tend to stay in suspension, sometimes joining the settled sludge instead of floating to the surface.

Depending on the type of tank scum, removal mechanisms may consist of a scum beach and box, scum troughs, paddle wheel removal mechanism, a telescopic valve, or other such mechanisms.

5.2. Description of equipment

5.2.1. Sedimentation tanks

Sedimentation tanks can be rectangular, circular, or square. In the rectangular type, wastewater flows from one end of the tank to the other and scrapers move the settled sludge to the inlet end. In the circular and square types, the wastewater typically enters at the center and flows towards the outside edge (Figure 5.2) and the settled solids are scraped or otherwise transported to the center. In some circular tank designs called peripheral feed clarifiers, wastewater enters at the outer edge and flows inward. Imhoff tanks perform the dual function of sedimentation and anaerobic digestion; however, these tanks are of an old technology and are no longer allowed in some countries.

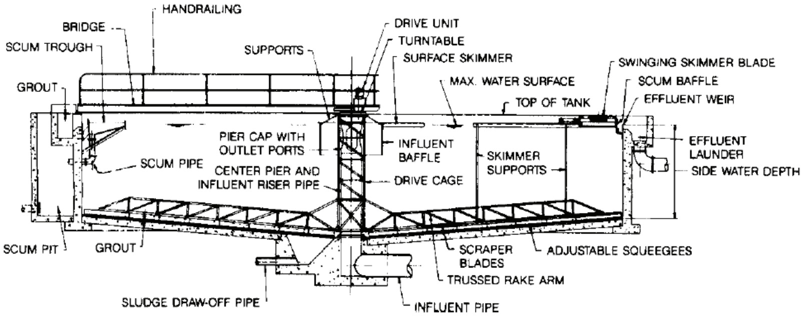


Figure 5.2 Section of a circular sedimentation tank [5]

The collection process entails moving settled solids to a point in the settling tank where they are drawn off. Primary sedimentation tanks use mechanical collection, except for those in very small plants which rely on manual removal. One of the following types of equipment may be used:

- Flight and chain (rectangular basins),
- Traveling bridge with screens (rectangular basins), or
- Rotating scrapers (circular and square basins).

Typically pumping, but sometimes gravity flow, removes sludge from the settling tanks. Positive-displacement-type pumps such as piston, progressive cavity, or diaphragm pumps are typically used. A number of plants also use torque-flow, centrifugal-type pumps, or hose (peristaltic) pumps.

Rectangular Tanks. A rectangular tank can be either a single unit or one of several adjacent units, which typically have a length that is several times its width. Either wood or nonmetallic flights are mounted on parallel strands of steel or nonmetallic conveyor chain (Figure 5.3). A single bottom scraper mounted on a bridge moving on rails fastened to the tank walls (Figure 5.4) moves settled sludge to a hopper at one end of the tank, typically the inlet end.

Chains and flights, guided by submerged sprockets, shafts, and bearings, are driven by a motor through a speed reducer. The flights are typically arranged to push floating surface material towards the effluent end of the tank and push settled solids back to the influent end of the tank on as they return. Nonmetallic chains, flights, and sprockets are currently used more often in new installations and in retrofits of existing tanks. The nonmetallic equipment is lighter, making it easier to maintain and requiring less power to operate. Also, nonmetallic equipment is less susceptible to corrosion. However, some plants prefer metallic-type chains for their collector mechanisms because they are less likely to decay in sunlight and are less affected by temperature or other outside influence In some tanks, flat water sprays angled toward the liquid surface move the scum and grease towards the skimming device.

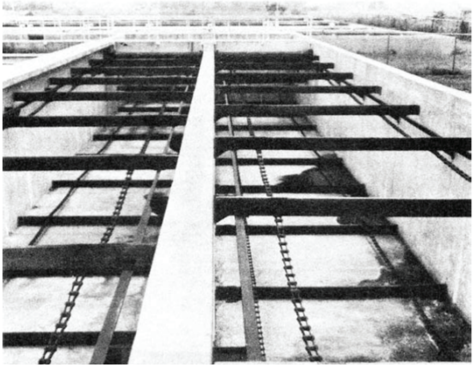


Figure 5.3 Rectangular primary sedimentation tank with wood or nonmetallic flights mounted on parallel chains [5]

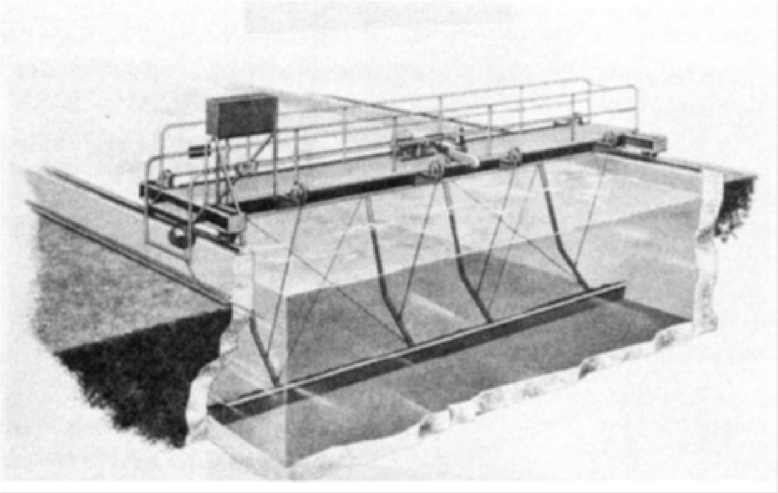


Figure 5.4. Rectangular primary sedimentation tank with traveling bridge sludge collector [5]

A traveling bridge, towed by a cable or powered by a traction drive, skims grease and scum with a surface scraper and moves sludge to the pit with its lower scraper blade. As the bridge travels with the flow, the scraper is raised while the grease skimmer is down. When the bridge is moving opposite to the flow, the scraper is down to move the sludge to the hopper while the skimmer blade is raised. The material is then pumped or conveyed to another process, such as a digester, concentrator, or holding basin.

Circular Tanks. In the most common type of circular tank, a center feed well introduces the flow in a manner that dissipates inlet velocities and distributes the flow evenly around the tank (Figure 5.2). The wastewater moves from the feed well to the weir and overflow trough along the perimeter of the tank. Settled solids are raked to a hopper near the center of the tank by arms attached to a drive unit at the center of the tank (Figures 5.5 and 5.6) or by a traction unit operating on the tank wall. A surface blade attached to the collector (Figure 5.7) moves floating material to a scum hopper.

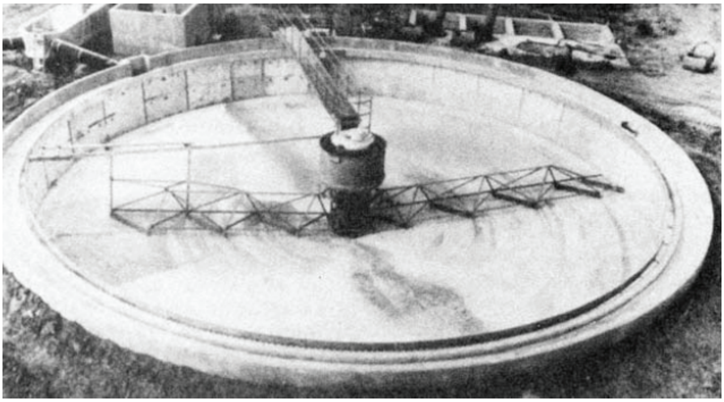


Figure 5.5 Circular sedimentation tank with sludge-scraping mechanism [5]

Figure 5.6 Scraper arms move the settled solids to the center of the tank [16]

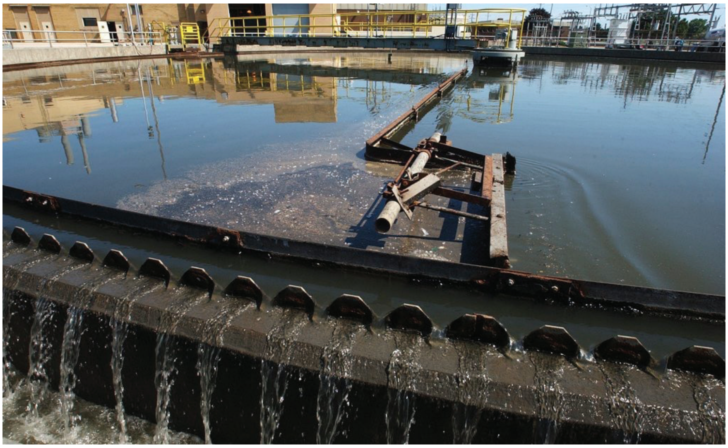


Figure 5.7 Circular sedimentation tank showing grease skimmer and effluent weirs

Square Tanks. These tanks remove settleable solids and floatables in a manner similar to that of circular tanks, with the added help of corner sweeps attached to the scum and sludge collector arms to remove floatables and settleables from the corners. Sometimes these corner sweeps can result in mechanical and operational problems. Some designs use sloped concrete fillets in place of corner sweeps.

Appurtenances include clean-outs in grease lines, sludge lines, pumps, flushing systems and line-cleaning devices. The flushing of lines, pumps, and sumps uses high-pressure water or air. Sludge lines may also be cleaned with steam or hot water. Line cleaning equipment includes hydraulically propelled tools made of metal or plastic which have special fittings to insert and catch the cleaning device.

5.3. Expected performance

The efficiency of BOD and suspended solids removal in a primary sedimentation tank depends on many previously described variables, however it is typically dominated by the surface overflow rate. Figure 5.8 shows BOD and suspended solids removal efficiencies related to the hydraulic loading factor (SOR); that is, the ratio of actual SOR to design SOR. With a loading factor of 1.0, the figure shows suspended solids removals ranging from 50 to 65% and BOD removals of 25 to 35%. Use of chemicals can increase suspended solids removals to the 75 to 85% levels, with a proportionate increases in BOD removals as well.

Performance for grease and scum removal cannot be accurately measured. However, a lack of scum or floatables in the primary effluent or secondary influent channels generally indicates good performance.

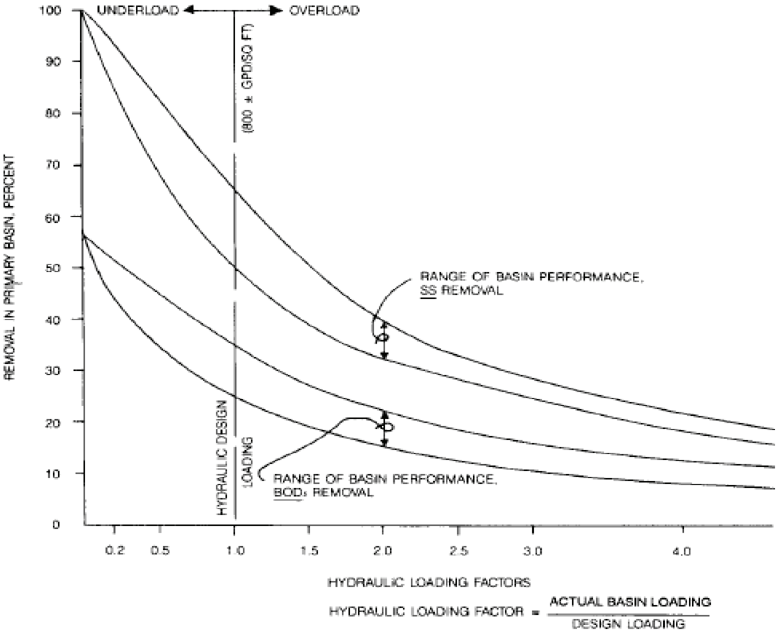


Figure 5.8 Estimated removals of suspended solids and five-day BOD (BOD5) in primary basins at various hydraulic loadings (without chemicals) [5]

5.4. Sludge handling

Two variables of sludge, its thickness (or solids concentration) and quantity, affect the operation of its handling. The quantity depends on thickness and the suspended solids loading, as well as the removal efficiency of the primary tanks.

The **thickness** of the sludge removed from primary sedimentation tanks depends on the type of solids-handling facilities downstream. If the sludge is pumped to thickeners, a "thin" concentration 0.5 to 1.0% may be permissible. If the sludge is pumped to digesters or a dewatering process, a thicker concentration is necessary.

Thin primary sludge may needlessly burden downstream solids-handling processes. With reasonable control of solids removal, the operator may obtain a sludge thickness of 4 to 6%. The process control goal is to find a level that provides a thick sludge without adversely affecting tank removal efficiency, overloading collector equipment, or allowing decomposition in the bottom of the clarifier.

The operator may estimate the volume of sludge to be removed from the primary tank by measuring the influent and effluent suspended solids, percentage of dry solids in the pumped sludge and wastewater flow. The method of calculating the wet sludge volume to be removed is given below.

$$\text{Dry solids removed (kg/d)} = \frac{\text{mg/L removed} \times \text{Flow (m}^3\text{/d)} \times 1000}{10^6} \tag{5.3}$$

$$\text{Wet sludge removed (kg/d)} = \text{Dry solids removed} \times \frac{100}{\text{Dry solids, \%}} \tag{5.4}$$

From these equations, the operator may derive the approximate duration of pumping for a known pump capacity. Lack of daily analytical information may prevent daily use of the above equations; however the estimated values can be used to provide an appraisal of wet sludge volumes valuable to the operator as a general guideline. Chemical additions would generate more material for removal than indicated by these equations.

Collection. The collectors may run continuously or intermittently depending on the type of plant, equipment and characteristics of the wastewater. If the plant is designed to pump a thin sludge to thickeners or to a degritting unit, the collectors must run continuously. If the primary tanks are square or circular, running the collectors continuously is necessary because sludge movement to the hoppers requires more time than that for rectangular tanks. Continuous operation also avoids the possibility of overloading the mechanism with accumulated solids. Regardless of tank type or plant design, continuous collector operation allows easy operation of an automatic withdrawal system. Because of its many advantages, continuous sludge collector operation is preferred for most plants. Intermittent operation of the collectors may be necessary if the primary tanks are used to thicken the waste sludge from the secondary process or if primary sludge is pumped directly to digestion or dewatering units.

Sludge Pumping. Positive-displacement pumps such as piston, progressive cavity, or diaphragm pumps are typically used to remove sludge from the primary sedimentation tanks. Many plants use centrifugal torque flow pumps or hose pumps to remove primary sludge. Pumping may be either continuous or intermittent. This can be done with several pumps and each pump may withdraw sludge from a single hopper simultaneously. However, a single pump should withdraw from only one hopper at a time because variations among the suction lines to different hoppers may cause unequal sludge withdrawals from the individual tanks.

Pumping for short durations at frequent intervals is a good practice, while pumping for long periods at infrequent intervals should be avoided because excessive sludge to an anaerobic digester can upset the process. Ideally, pumping should be close to continuous operation to evenly feed downstream processes.

5.5. Floatable solids skimming

Grease, fats, oils, plastics, and other floatables must be consistently removed. Skimmings and floatables that are removed from primary tanks are pumped to various disposal facilities in wastewater treatment plants. Some plants transfer their skimmings to concentrators or dissolved air flotation thickeners. The concentrated skimmings are then transferred to an incinerator or trucked off site for disposal. Other plants transfer skimmings to dewatering facilities such as belt presses, whereas others pump their skimmings to anaerobic digesters. This practice of pumping is gradually being phased out because of problems within the digesters due to excessive scum buildup. The removal frequency depends on the amount of floatables in the incoming wastewater, flow variations throughout the day and wastewater temperature. Circular tanks, because of their design, are skimmed continuously while most rectangular tanks remove skimmings periodically. Rectangular tanks need skimming at least once a day and more frequently whenever grease or floatables appear in the primary effluent, secondary influent channels or the final clarifiers. Rectangular tanks typically use scum troughs that are manually operated or they can be automatically operated by a timer or PLC. Control of odors may also require more frequent skimming. The skimming process must capture enough wastewater to allow scum conveyance through screw conveyors, and pipelines.

5.6. Hydraulic considerations

Surface overflow rates and hydraulic retention times for proper settling generally vary within the following ranges: average SOR without waste activated sludge should be between 32 to 49 $m^3/m^2 \cdot d$, and the peak SOR should not exceed 122 $m^3/m^2 \cdot d$. If waste activated sludge is co-settled in the primary tank, the average SOR should be between 24 to 32 $m^3/m^2 \cdot d$, and peak SORs should be in the range of 49 to 61 $m^3/m^2 \cdot d$. The detention time is 1 to 2 hours.

The two hydraulic control variables for the primary influent are the flowrate and the number of tanks in service. Because most plants must accept flow as it enters the plant, flow control is limited. Nonetheless, variations in flow sometimes can be reduced by changing the pumping rates at the pumping stations in the collection system or at the plant headworks. This practice takes advantage of the temporary storage capacity available in the sewer system. Also, storm-related variations in flow can be reduced by an aggressive infiltration–inflow correction program and through the proper maintenance of diversion chambers in combined sewer systems. Some plants have equalization basins to smooth diurnal flow variations.

SECONDARY (BIOLOGICAL) TREATMENT

6. SECONDARY (BIOLOGICAL) TREATMENT

Biological nutrient removal consists of mainly two types of processes, activated-sludge process and the use of a biological filter.

6.1. Activated-sludge process

The activated-sludge process is still the most widely used biological treatment process for reducing the concentration of organic pollutants in wastewater. Well-established design standards based on empirical data have evolved over the years. Our understanding of the process has advanced from a system originally designed simply for biochemical oxygen demand (BOD) reduction to one that now is designed to remove nutrients such as nitrogen and phosphorus. Despite these advances, poor process performance can still present problems for many treatment plants.

The activated-sludge process is a predominantly aerobic suspended-growth process, that maintains a high microorganism population (biomass) by means of recycling solids from the secondary clarifier. The biomass converts biodegradable organic matter and certain inorganic compounds into new cell biomass and products of metabolism. Biomass is separated from the treated wastewater in the clarifier for recycling or solids handling processes. Preliminary treatment processes precede the activated-sludge system and primary treatment is typically used in all but some of the smaller treatment facilities.

The following terms are used for describing the condition of the environment:

1. Aerobic: in presence of oxygen
2. Anoxic: no presence of oxygen, but presence of nitrites/ nitrates
3. Anaerobic: no presence of oxygen or of nitrites/nitrates

Figure 6.1 presents a general schematic of a conventional flow-through activated-sludge process. In the conventional flow sheet influent wastewater and recycled biomass are first combined, mixed, and aerated in a biological reactor. The contents of the biological reactor is referred to as mixed liquor and consists of microorganisms, biodegradable, non biodegradable (suspended, colloidal) and soluble organic and inorganic matter.

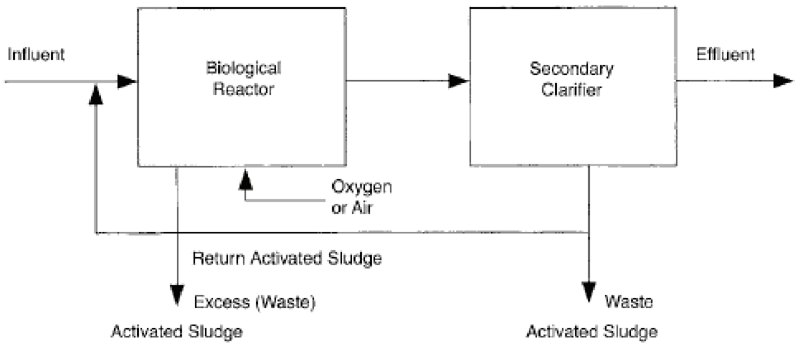


Figure 6.1 Schematic diagram of a typical activated-sludge process

Microorganisms consist primarily of organic matter (70 to 80%). The system is referred to as an *open culture* system in which the organisms are in a dynamic state of change depending on external environmental conditions.

Wastewater components are biodegraded, sorbet, or remain untreated (recalcitrant or non-degradable wastes) in the biological reactor. After sufficient time for appropriate biochemical reactions, the mixed liquor is transferred to a settling reactor (clarifier) to allow gravity separation of the sludge from the treated wastewater. Settled solids are then returned (return activated sludge [RAS]) to the biological reactor to maintain a concentrated biomass for wastewater treatment. Because microorganisms are continuously synthesized in the process, some of the sludge must be wasted from the system. Wasting is accomplished by diverting a portion of the RAS or biological reactor solids (waste activated sludge [WAS]) to solids-handling processes. Sludge wasting strategies are used to increase, decrease, or maintain a selected biomass concentration in the system. This is a principal mechanism used for process control.

Basic activated-sludge systems consist of a number of interrelated components:

- A single biological reactor or multiple reactors designed for completely mixed flow, plug flow, or intermediate patterns of flow designed to achieve carbonaceous organic matter removal. If required, these may also provide ammonia oxidation and remove nitrogen and phosphorus depending on target effluent requirements. The primary biological reactors may be preceded by an aerated, anoxic, or anaerobic selector reactor designed to control bulking, denitrify, or select polyphosphate uptake microorganisms to promote enhanced phosphorus removal.
- A source of oxygen and equipment to disperse atmospheric, pressurized, or oxygen-enriched air into the biological reactors at a rate sufficient to maintain positive mixed liquor dissolved oxygen (DO) concentration.
- The means to appropriately mix the biological reactor contents to ensure suspension of the sludge without shearing the floc.
- A clarifier to separate and possibly thicken the sludge from the treated wastewater.
- A method to collect settled MLSS within the clarifier and returns it to the biological reactors.
- The means of wasting sludge from the system.

Activated-sludge system designs are based on the hydraulic retention time (HRT) in the biological reactor, the amount of time biomass is retained within the system (mean cell residence time [MCRT]), the organic loading and the organic load (food) to biomass (microorganism) ratio.

The qualitative biochemical reaction that occurs in the process may be expressed as

Food + Nutrients + Organisms + Electron acceptor →New organism + products;

More specifically, for a chemoheterotrophic aerobic reaction commonly activated in sludge systems, the general (unbalanced) expression might be:

Organic matter + Oxygen (O_2) + Nutrients + Microbes →New microbes + CO_2 + Water (H_2O) (6.1)

For a chemoautotrophic aerobic reaction occurring in nitrifying systems, the overall expression of the two-step process might be:

Ammonium (NH_4^+) + O_2 + CO_2 + Bicarbonate (HCO_3^-) + Microbes →New microbes + H_2O + Nitrate (NO_3^-) (6.2)

Finally, a chemoheterotrophic anoxic reaction that might take place in a clarifier or dedicated anoxic zone of the biological reactor in the presence of nitrate might be expressed as

NO_3^- + Organic matter + Carbonic acid (H_2CO_3) + Microbes →New microbes + Nitrogen (N_2) + H_2O + HCO_3^- (6.3)

The activated-sludge process may be designed and operated to remove carbonaceous biochemical oxygen demand (CBOD), to oxidize ammonia to nitrates, to remove nitrogen compounds or to remove phosphorus. The design of the system must provide for adequate biological reactor size, oxygenation capacity, and separation facilities to achieve the effluent target requirements.

The CBOD represents all carbon-based organic matter in the wastewater that is biodegradable, measured as BOD. It is important to note that the five-day BOD (BOD5) represents only a fraction of the biodegradable carbonaceous organic components in the wastewater (typically 60 to 65%). The BOD consists of both soluble (dissolved) and particulate fractions. The soluble fraction is often consumed rapidly once in contact with the MLSS. The particulate fraction may be consumed rapidly into the biomass and degrade at a rate depending on its composition. The biological reactor size depends on the rate of BOD uptake and the rate of its degradation. High biomass concentrations are desirable and can result in smaller reactor sizes. However, there is an upper limit to biomass concentration that can be achieved in a given plant based on the oxygen-transfer capacity of the system and the size of the clarifiers. Systems are occasionally designed with oxygen-enriched air processes and oversized clarifiers to reduce biological reactor size, but cost considerations often dictate an optimum size of all components of the system.

Oxygen transfer is an important element of the system. Oxygen must be supplied at a rate equal to demand. Oxygen demand is determined from BOD and nitrogen measurements (if nitrification is anticipated) but recall that BOD5 values are inappropriate measures of the total carbonaceous demand. Long-term BOD measurements or estimates of total oxygen demand must be provided for accurate estimates. It should also be noted that nitrogenous oxygen demand (nitrification reactions) is often measured as a portion of BOD in analytical determinations. Addition of nitrification inhibitors may be used to separate carbonaceous and nitrogenous demand measurements, if required. Variability in oxygen demand occurs both with time and distance in the biological reactor (often referred to as temporal and spatial variation). Sufficient oxygenation capacity must be available to meet much of this variation if a high-quality effluent is required and to avoid selection of undesirable microbial populations.

For typical municipal wastewater, a well-designed and operated activated sludge system should achieve a CBOD effluent quality of 5 to 15 mg/L. Effluent suspended solids (SS) should also typically be less than 15 mg/L. Note that effluent SS may include a significant fraction of CBOD. To achieve consistent BOD and total suspended solids (TSS) concentrations less than 5 mg/L, some type of tertiary treatment would be required.

6.1.1. Biological phosphorus removal

In the conventional activated sludge process for municipal wastewater, the biomass will include phosphorus for growth and metabolism in a way that will result in approximately 2% of the biological sludge mass on a dry weight basis to be phosphorus. Phosphorus cannot be transformed into a volatile gas, therefore its removal is achieved through sludge wasting. Thus, wasting in a conventional plant may result in phosphorus removal rate of 10 to 30%. The activated-sludge process may be managed to select for microorganisms for the population that will store excessive quantities of phosphorus in the range of 3 to 6%. Wasting of this phosphorus-enriched sludge can result in effluent phosphorus concentrations less than 1 mg P/L.

The selection process involves an anaerobic step that results in the release of stored phosphate followed by an aerobic step in which the organisms consume large amounts of phosphorus. In the anaerobic phase, soluble CBOD is consumed by the organisms and stored as organic polymers to serve as future source of energy. The energy required for this storage step is provided by excess phosphorus stored as polyphosphates in the aerobic stage. As energy is released in the anaerobic phase, the phosphates are released into the solution. Once entering the aerobic zone, energy is produced by the oxidation of the stored organic carbon products and polyphosphate storage is initiated by the organism. There are many organisms capable of storing excess amounts of phosphorus in their cells. These polyphosphate storing organisms are found in wastewater and can be easily selected with proper system design and operation.

Biological phosphorus removal (BPR) processes for activated sludge systems will be described in the following section. With proper design and operation, a BPR system should produce effluent phosphorus concentrations less than 2 mg/L and often less than 1 mg/L.

6.2. Reactor configuration

Reactor configuration deals primarily with the hydraulic characteristics of the secondary treatment process. Continuous-flow systems are often categorized as ideal plug-flow or completely mixed systems, although most operate under a non-ideal flow regime somewhere between the two. Batch systems behave like ideal plug-flow systems with respect to biological process performance. In these systems, the reaction time for the batch is interchangeable with the space–time for the plug-flow reactor.

6.2.1. Ideal Complete Mix

Ideal complete mixed flow implies that the composition of the mixed liquor is the same throughout the reactor volume. The influent wastewater immediately and completely mixes with the reactor contents so that the concentration of a given component is the same as the effluent concentration. As a result, the mixed liquor oxygen uptake rate, DO, soluble BOD, VSS, TSS, nitrogen species, phosphorus concentrations, pH, temperature and other characteristics are identical throughout the reactor. Because the concentrations of BOD are at the target effluent concentrations for the process, the system has the capability of attenuating wide swings in effluent concentration. Completely mixed flow is difficult to achieve, although the use of square or round reactors with intense mixing can approximate the condition. As it will be discussed later, it can also be approximated by providing multiple feed points along the reactor periphery. Aeration is provided uniformly throughout the reactor by mechanical aeration equipment or diffused aeration.

There are several disadvantages to completely mixed reactors. They are often plagued by filamentous bulking problems. This can be overcome, in part, by using selectors which provide short term conditioning of the RAS and influent wastewater ahead of the biological reactor. Theoretically, the process also requires longer reactor retention times (20-30 days) to achieve comparable effluent quality. These systems are often used for low-rate applications or for treating industrial or industrial–municipal wastewater where large variations in load are anticipated.

6.2.2. Ideal Plug-Flow

In an ideal plug-flow system, the fluid particle entering the system will move uniformly along the reactor length without dispersing in the fluid (Figure 6.2). The particle will remain in the reactor for a time equal to the theoretical detention time (Volume [*V*]/Volumetric flow [*Q*], *V*/*Q*). As a result, the concentration of BOD and the oxygen uptake will decrease along the reactor length. The TSS and VSS will increase along the reactor length as biomass is produced. This type of flow is approximated by long, narrow reactors with length-to-width ratios greater than 10. Plug-flow may also be simulated by basins-in-series or by folding rectangular reactors. Like the complete-mix configuration, it is not practical to produce a true plug-flow system.

By definition, this configuration results in a high organic load and oxygen uptake rates at the inlet of the reactor, therefore oxygen-transfer devices must be capable of high mass transfer at the inlet. Distribution of oxygen along the reactor may be tapered to follow oxygen demand. Theoretically, the plug-flow reactor delivers the highest removal rate per unit volume. It is also less susceptible to filamentous bulking provided that sufficient DO is present at the inlet.

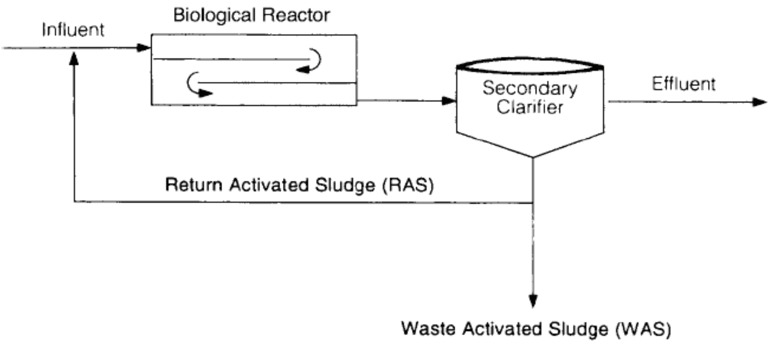


Figure 6.2 Plug flow activated-sludge process with folded biological reactor

6.2.3. Reactors-in-Series

The reactors-in-series configuration can be described as two or more completely mixed reactors operating in a series configuration approximated with baffles or by folding reactors in a sinusoidal fashion. This configuration, with three or more reactors-in-series, attempts to simulate a plug-flow condition that has a kinetic advantage over mixed-flow systems as mentioned above. This configuration also seems to mitigate filamentous bulking.

6.2.4. Sequencing Batch Reactors

A sequencing batch reactor (SBR) is a fill-and-draw activated-sludge system in which the steps of aeration and clarification take place in the same reactor. Settling occurs when the air and mixers are turned off and a decanter provides for the treated effluent to withdraw. Discrete cycles are used during prescribed, programmable time intervals and MLSS remains in the reactor throughout all cycles. In conventional systems, there are five steps: fill, react, settle, decant, and idle (Figure 6.3). As a result of the batch nature of the process, flow equalization and multiple reactors must be used to accommodate continuous-flow operation. Mixing and aeration are carried out by equipment similar to that found in conventional continuous-flow plants and specially designed decanters are provided for effluent withdrawal. An intermittent-cycle extended-aeration system allows influent to be fed continuously to the reactor for all cycles, but effluent is withdrawn intermittently.

The SBR is typically designed for small-flow applications, 4000 m3/d (1 mg d) or less, often as extended-aeration systems. Some larger installations have been built, however, ranging in size from 150 000 to 700 000 m3/d.

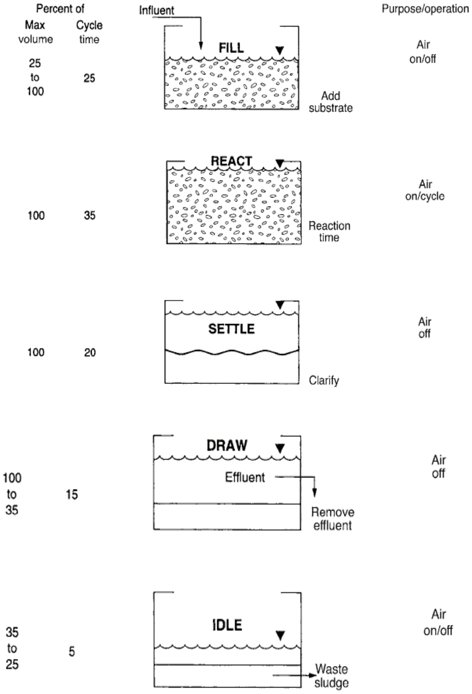


Figure 6.3 Typical sequencing batch reactor operation for one cycle

6.2.5. Oxidation Ditch

In the typical oxidation ditch, mixed liquor is pumped around an oval or circular pathway by brushes, rotors, or other mechanical aeration devices and pumping equipment located at one or more points along the flow circuit (Figure 6.4). The mixed liquor is moved at a velocity of 0.24 to 0.37 m/s through the channel resulting in a circuit time of less than 15 minutes. Most oxidation ditches are designed as low-rate processes with long HRTs of approximately 24 hours. The cycle time is therefore short and the hydraulic system may be considered to be completely mixed. Ditches may be designed with a single channel or multiple interconnected concentric channels. They are widely used for small to medium sized communities.

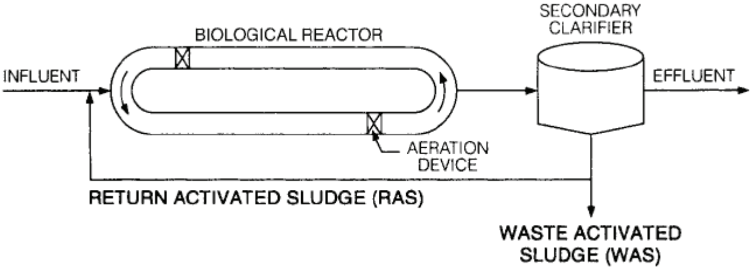


Figure 6.4 Oxidation ditch

6.3. Biological filters

Trickling filters, biotowers and rotating biological contactors (RBCs) are known as *fixed-film treatment processes*. Of these three processes, the trickling filter process predates biotowers, RBCs, and combined fixed-film and suspended growth (FF/SG) processes.

In fact, trickling filters predate most of the treatment methods discussed in the other chapters of this book and they are still a viable process. New types of filter media are now used. Filters using rock media systems are known as *trickling filters* and plastic media systems are known as *biotowers*. Trickling filters are being incorporated into wastewater facilities using new methods and many rock filters are being refurbished for continued use. This chapter will describe the operations and maintenance requirements of trickling filters that are used in existing and new systems.

Although their performance is generally positive, stand-alone RBC equipment operation is typically plagued by problems. Combined processes of trickling filters, biotowers, or RBCs coupled with suspended-growth (activated sludge) processes now number several hundred in the United States. Combined TF/SG processes are designed to take advantage of strengths and minimize weaknesses of each process. In many cases, the practice of combining the processes is used to reduce construction costs by avoiding the need for additional tankage. In some industrial or high-strength-waste applications, the FF/SG processes have helped eliminate shock loads to the activated sludge process. While the coupling of biological processes has solved many problems, it also produces concerns and challenges regarding criteria for control.

Fixed-film biological processes remove dissolved organics and finely divided organic solids from wastewater. Removal occurs primarily by converting soluble and colloidal material into a biological film that develops on the filter media. Raw domestic and industrial wastewater typically contains settleable solids, floatable materials, and other debris. Failure to remove these solids before the wastewater enters the fixed-film reactors can interfere with their oxygen-transfer capabilities, plug the filter media, result in high solids yield or create other problems. Therefore, both fixed-film and combined-growth processes are typically preceded by screenings and grit removal processes.

6.3.1. Trickling filters and biotowers

Trickling filters attempt to duplicate the natural purification process that occurs when polluted wastewater enters a receiving stream and trickles over a rock bed or rocky river bottom. In the natural purification process, bacteria in the rock bed remove the soluble organic pollutants and purify the water. Since the late 1880s, trickling filters have been considered a principal method of wastewater purification. The principle of using a rock bed for purification was applied in filter design, with the rock beds typically ranging from 0.9 to 2.4 m deep. After a decline in use in the late 1960s and early 1970s, trickling filters regained popularity in the late 1970s and early 1980s, primarily because of new media types. The new high-rate media has become preferred over rock media because it offers more surface area for biological growth and improved treatment efficiency. High-rate media can minimize many of the rock media problems including plugging, uncontrolled sloughing, odors, and filter flies. Consequently, almost all trickling filters constructed since the late 1980s use high-rate media and are known as *biotowers*.

There are four basic categories of filter design based on the organic loading of the trickling filter or biotower. In the first three categories, low, intermediate, and high-rate filters, the filter removes all or nearly all of the BOD applied (Table 6.1). In the fourth category, that of roughing filters, the filter is typically combined with another biological treatment step such as activated sludge, RBC, or another filter type where a substantial amount of BOD removal occurs.

Table 6.1 Applied BOD removal rate by filters

	Trickling filter categories			
Operating characteristics	Low	Intermediate	High	Roughing
Organic loading, lb BOD/d/1000 cu ft/day	<25	25–40	40–100	100–300
Filter media[a]	Rock or high rate	Rock or high rate	Rock or high rate	High rate
Nitrification[b]	Yes	Partial	Unlikely	No
Combined process required[c]				
—For secondary treatment	No	Unlikely	Likely	Yes
—For tertiary treatment	Yes	Yes	Yes	Yes
Type typically used[d]	TF/SC ABF	TF/SC ABF	TF/SC TF/RBC 2-stage filters	TF/AS BF/AS RF/AS 2-stage filters

The categories of trickling filters and biotowers are typically based on BOD5 loading to the filter divided by the volume of filter media, calculated as follows:

$$\text{Organic (BOD}_5\text{) load} = \frac{\text{BOD}_5 \text{ applied, lb/d}}{\text{Volume of media, 1000 cu ft}}$$

Where

BOD_5 applied = kg primary effluent BOD_5/d;
= (primary effluent BOD_5, mg/L)(flow, ML/d) and

$$\text{Volume of media} = \frac{\text{horizontal (plan) area, m}^2 \times \text{media depth, m}}{100} \tag{6.4}$$

The structure, distribution and support system used with the media are collectively named either a *trickling filter* or a *biotower*. The term *trickling filter* typically applies to relatively shallow filters [1.2 to 3.0 m deep] that use rock media. Processes using plastic or redwood media with depths greater than 3 m are referred to as *biological towers* or *biotowers*.

A similar term, *biofilter*, sometimes refers to filter towers in which biological solids from an activated sludge system are recycled over the media.

The following six basic components are common to all trickling filter and biotower systems:

- Distribution systems,
- Filter media,
- Drainage systems,
- Containment structures,
- Filter pump stations or dosing siphons, and
- Secondary clarifiers.

Description of equipment. These basic components are illustrated in Figure 6.5. The two basic types of distribution systems are fixed-nozzle and rotary distributors. Fixed-nozzle distributors were frequently used during the early to mid-1900s, but their use on new trickling filters is limited. Fixed-nozzle distributors consist of a piping system, often supported slightly above the top of the trickling filter media, that feeds wastewater and recycled wastewater from a pumping station or siphon box through spray nozzles. A number of advances in fixed-nozzle design include springs, balls, and other mechanisms which evenly distribute wastewater at more controlled flows. Even with these improvements, obtaining an even distribution with a fixed nozzle distribution system is more difficult than with rotary distribution systems. Fixed distributor systems have also declined in use because it is difficult access to the nozzles for cleaning, raising safety concerns.

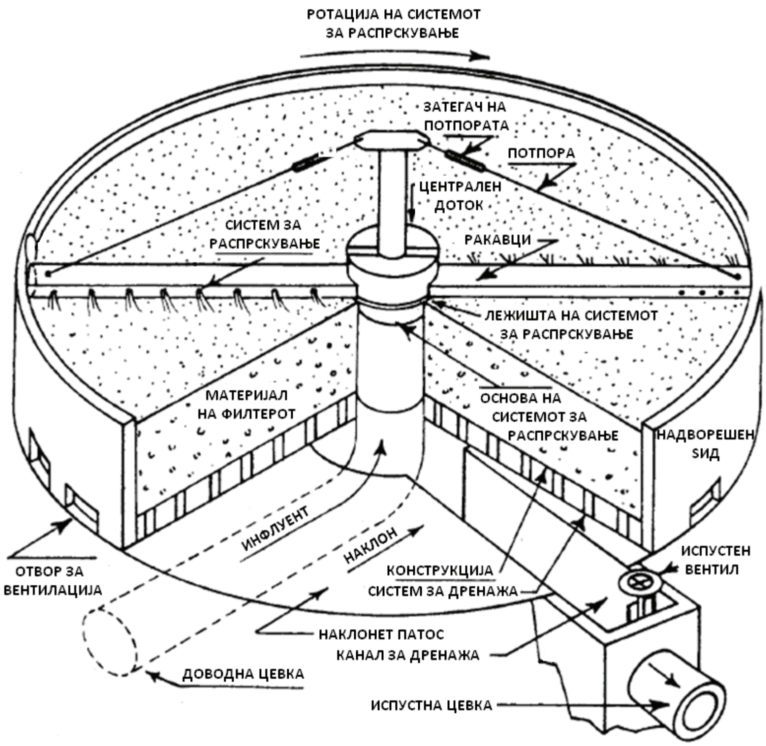


Figure 6.5 Trickling filter parts

Rotary distributors consist of a center well, which is typically metal, mounted on a distributor base or pier. The distributor typically has two or more arms that carry the pumped or siphoned wastewater to variously sized orifices for distribution over the media surface. The thrust of the water spray drives the filter arms forward. Speed-retardant back-spray orifices are often used to adjust the distributor’s rotational speed, while simultaneously maintaining the desired flow rate to the filter. Recently, some rotary distributors have been equipped with motorized drive units to precisely control the distribution speed of wastewater flow. Distributors may be set up to be mechanically driven at all times or just when stalled. These operating provisions are aimed at selecting a distributor speed to increase biomass sloughing. Decreasing distributor speed may prevent plugging, decrease performance and odors, especially in heavily loaded filters.

Adding motorized drives can also increase the performance of an existing tricking filter or biotower.

The distributor support bearings are either at the top of the mast or the bottom of the turntable. Both types of bearings are widely used. Another newer method of more precisely controlling the wastewater flow distribution to trickling filters is a system of pneumatically controlled gates that open and close the orifices on both sides of the distributor arms. As flow to the trickling filter may vary, the speed is maintained by automatically adjusting the gates over the orifices.

Of the many **types of media materials** used to support biological growth, the most common types are shown in Figure 6.6. Media are typically classified as either high-rate with a high surface area and void ratio or standard rock media.

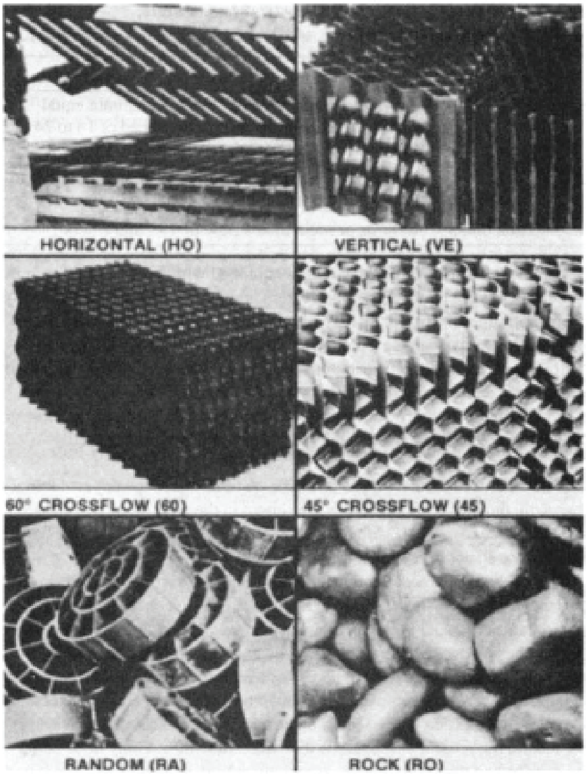


Figure 6.6 Types of media materials [2]

Filter media types made of plastic sheets include vertical, 60-degree crossflow and 45-degree crossflow. Random media may include open-webbed plastic shapes. For carbonaceous BOD removal, their surface area typically ranges from 89 to 105 m^2/m^3 of media and their void percentage is between 92 and 97% (open-space percentage of unit volume). Filter media for nitrification (post-BOD removal) are available with surface areas in excess of 131 m^2/m^3. Based on numerous studies to compare trickling filter media, the present consensus is that cross-flow media may offer better flow distribution than other media, especially at low organic loads. Compared with 60-degree cross-flow media, vertical media provide nearly equal distribution and may better avoid plugging, especially at higher organic loadings.

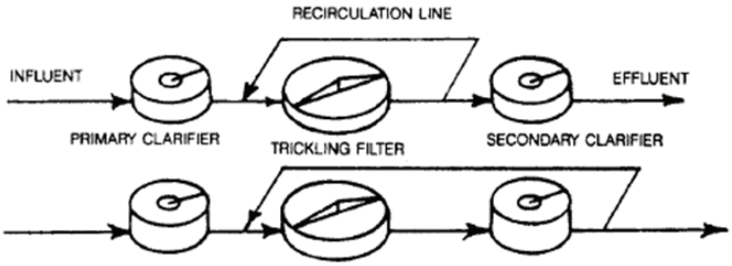
Rock media may consist of either graded material from natural river beds or crushed stone. Most rock media provide approximately 149 m2/m3 of surface area and less than 40% void space.

A significant difference between rock media and plastic media is that most loose stone aggregates have a dry weight (density) of approximately 1282 kg/m3 compared to a density of 32 to 48 kg/m3 for plastic media. Additional provisions required for plastic media include UV protective additives on the exposed layers of plastic media filters, thicker plastic walls for media packs installed in the lower sections of the filter where loads increase and under certain conditions, a means for shielding the top layer from the effects of the distributor's hydraulic force.

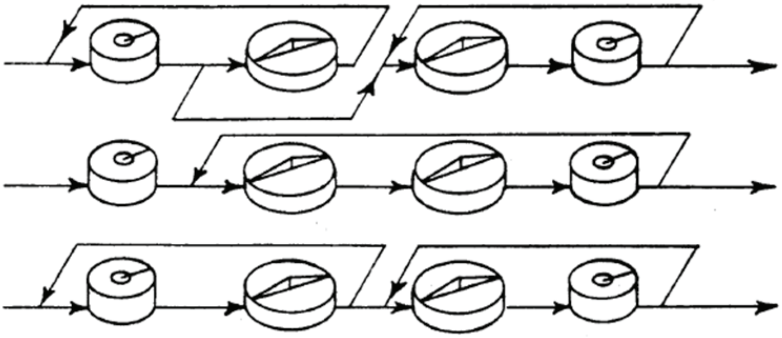
As a principal process control measure, operators can control the rates at which wastewater and filter effluent are distributed to the filter media. Recirculation can serve several purposes, as follows:

- Reduces the strength of the wastewater being applied to the filter;
- Dilutes any present toxic wastes,;
- Reseeds the filter's microbial population;
- Provides uniform flow distribution; and
- Prevents filters from drying out.

The most common recirculation patterns used for trickling filters and biotowers are shown in Figure 6.7. If odors emanate from the primary clarifier or headworks, recycling filter effluent to either location may help control them. When the recirculated water passes through either the primary or secondary clarifier, operators need to prevent excessive hydraulic loading of the clarifier.



TYPICAL SINGLE-STAGE RECIRCULATION PATTERNS



TYPICAL TWO-STAGE RECIRCULATION PATTERNS

Figure 6.7 Recirculation patterns for trickling filters

The manner in which secondary clarifiers are operated can significantly affect trickling filter performance. Although clarifier operation with fixed film reactors is not as critical as that with suspended-growth systems, operators must still pay close attention to final settling. Sludge must be removed quickly from the final settling tank before gasification occurs or denitrification causes solids to rise. Use of the secondary clarifier as a principal means of thickening (rather than simply for the settling of solids) may not produce the best effluent quality, especially during summer months when denitrification is likely to occur. The sludge blanket depth in the secondary clarifier should be limited to 0.3 to 0.6 m. Continuous pumping or intermittent pumping with automatic timer control are used to accomplish solids wasting.

6.3.2. Rotational biological contactors

A rotating biological contactor's filter media consist of plastic discs mounted on a long, horizontal and rotating shaft (Figure 6.8). A biological slime similar to that found in trickling filters or biotowers grows on the media. However, rather than being stationary, the filter media rotates into the settled wastewater and then emerges into the atmosphere, where the microorganisms receive oxygen that helps them consume organic materials in the wastewater.

Rotating biological contactors have been extensively used in hundreds of locations in the world to treat municipal and industrial wastewater. It is estimated that more than 600 RBC plants are now used for industrial and municipal wastewater treatment. Most of the plants are designed and used for BOD5 removal and a few for both BOD5 and nitrogen removal. When RBCs were initially introduced for wastewater treatment during the late 1970s and early 1980s, mechanical problems and organic overloading occurred frequently.

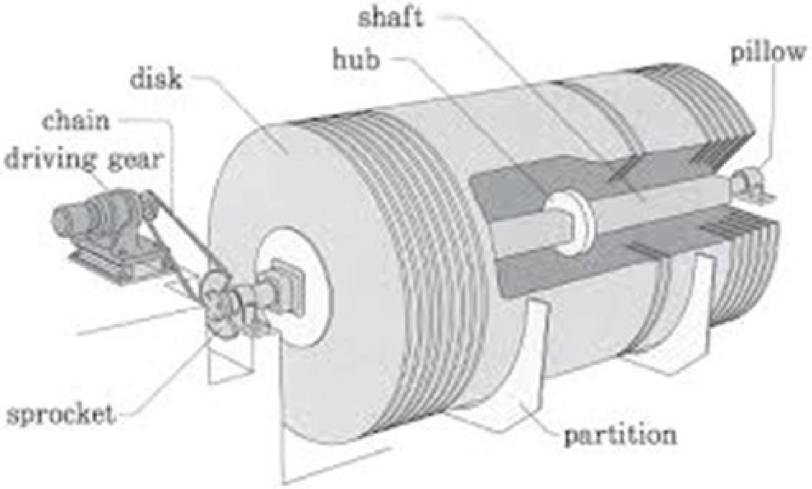


Figure 6.8 Rotating biological contractor

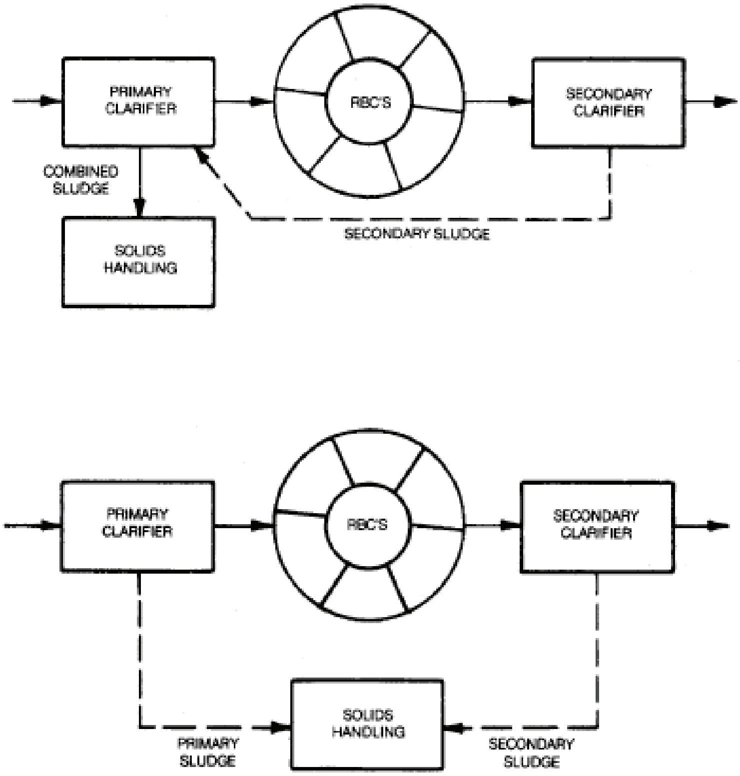


Figure 6.9 Rotating biological contactor process flow schematic

The flow pattern for RBC treatment of wastewater resembles that for most other biological systems, because good preliminary and primary treatment are essential to remove solids that would otherwise interfere with RBC performance (Figure 6.9).

A secondary clarifier must be provided to remove sloughed solids from the treated wastewater. Solids that settle in the secondary clarifier can either be recycled to the primary clarifier for co-settling or pumped directly to a solids-handling system (Figure 6.9). The term *shaft* typically is used to describe both the metal support and the filter media discs. The discs are made of high-density circular plastic sheets, typically 3.6 m in diameter (although larger sizes are available from some manufacturers). The sheets, bonded and assembled onto the horizontal shafts, are typically 7.6 m long. Each shaft typically provides approximately 9300 m^2 of surface area for microorganism attachment. Lower density media are typically used for carbonaceous BOD5 removal and higher density media are typically used for ammonia nitrification.

Rotating biological contactor systems consist of plastic media, typically a series of vertical discs mounted on a horizontal shaft that slowly rotates, turning the media in and out of a tank of wastewater. Rotating biological contactor shafts are rotated by either a mechanical or a compressed air drive so the media are immersed in the wastewater up to 40% of their diameter. The wastewater being treated flows through the contactor by simple displacement and gravity. Bacteria and other microorganisms that are naturally present in the wastewater adhere and grow on the surface of the rotating media. The biological film sloughs off whenever the biomass growth becomes too thick and heavy for the media to support. The sloughed biofilm and other suspended solids are carried away in the wastewater and removed in the secondary clarifier.

The biological slime in the first stages is typically 0.15 to 0.33 cm thick. A healthy biomass on the first stage tends to be light brown, while it tends to have a gold or reddish sheen in the later processes. Lightly loaded units may be nearly devoid of visible biomass. A white or gray biomass indicates domination by filamentous bacteria, which is an unhealthy sign.

Rotating biological contactor systems typically include the following equipment items:

- Tankage,
- Baffles,
- Filter media,
- Covers,
- Drive assembly, and
- Inlet and outlet piping.

Figure 6.10 illustrates various equipment components that are typically used in the RBC process. The names for individual equipment components may differ slightly, depending on the manufacturer.

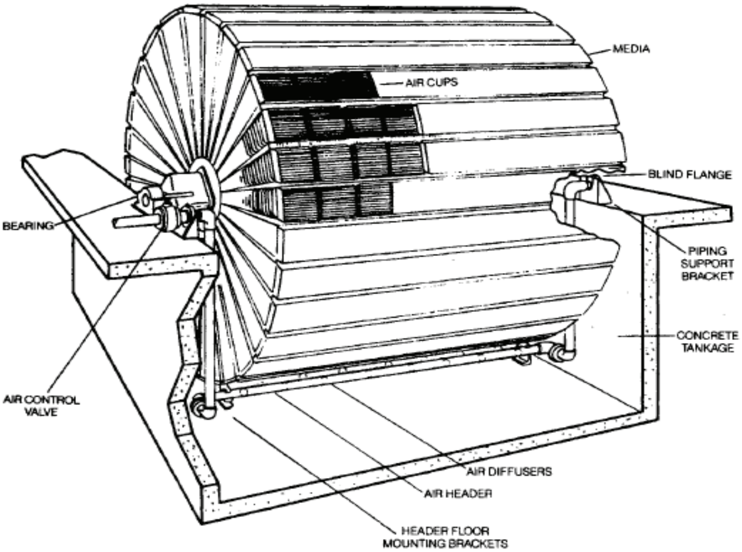


Figure 6.10 Air-driven rotating biological contactor

The equipment manufacturer's recommendations should govern the selection of rotational speed for RBC discs. Typical rotational speeds range from 1.0 to 1.6 rpm. While less energy is required to rotate RBCs at slower speeds, slower speeds will also reduce the oxygen-transfer capability. Some facilities have observed increased efficiency by rotating countercurrent to influent flow (when perpendicular to the shaft), while others have found no change regardless of the direction of rotation.

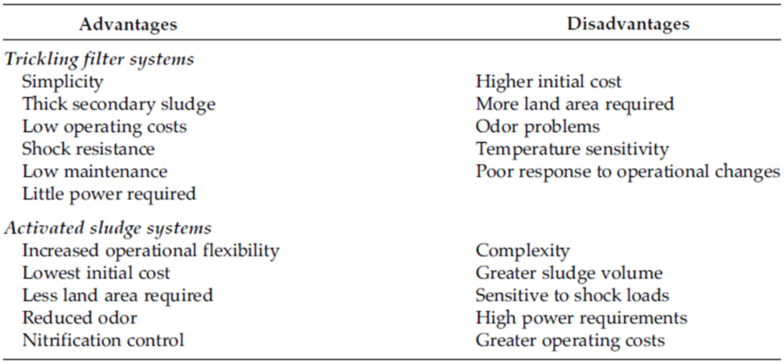
Clarifier operation with the RBC process resembles that already described for trickling filters. Use of the secondary clarifier as a principal means of thickening should be avoided to minimize denitrification or solids carryover with the treated effluent. Sloughing of the discs may result from toxic loads, temperature changes, or normal hydraulic shear action. Daily monitoring of the clarifier sludge blanket and accounting for the amount of solids pumped (in kilograms per day) will help operators identify potential solids buildup or other problems.

Rotating biological contactors are also used to nitrify secondary effluent. Secondary treatment systems used ahead of separate-stage RBC nitrification include a variety of activated sludge and attached-growth systems. Separate-stage RBC nitrification is typically used as an add-on step to existing secondary biological systems that are required to meet ammonia-nitrogen (NH3-N) effluent limits.

6.4. Combined processes

Treatment is typically thought of as occurring in sequential major steps: preliminary, primary, secondary, and tertiary. However, the major secondary treatment step sometimes combine use of fixed-film reactors such as trickling filters and RBCs in a series or in conjunction with other forms of biological treatment such as activated sludge. These combined processes are often referred to by a number of terms, such as *step systems*, *two-stage*, *series*, *dual*, *coupled*, or *combined processes*. This section covers the operation and maintenance of what, for lack of a better term, will be called *combined processes* that couple together fixed-film and suspended growth processes.

Table 6.2 Advantages and disadvantages of trickling filter and activated sludge processes



Advantages	Disadvantages
Trickling filter systems	
Simplicity	Higher initial cost
Thick secondary sludge	More land area required
Low operating costs	Odor problems
Shock resistance	Temperature sensitivity
Low maintenance	Poor response to operational changes
Little power required	
Activated sludge systems	
Increased operational flexibility	Complexity
Lowest initial cost	Greater sludge volume
Less land area required	Sensitive to shock loads
Reduced odor	High power requirements
Nitrification control	Greater operating costs

In the late 1970s, filter media improvements included the development of high-rate media, as described earlier in this chapter. The first applications of high-rate media were in roughing filters used primarily by industry to accommodate high loadings. The new media allowed trickling filters to be organically loaded 10 to 15 times higher than rock media loadings without odor or plugging problems. It soon became evident that biological treatment could often be accomplished through a combination of highly loaded trickling filters followed by activated sludge. Advantages and disadvantages of the parent trickling filter and activated sludge processes are given in Table 6.2. Combining the processes has effectively coupled the simplicity, shock resistance, and low maintenance of the trickling filter with the improved effluent quality or increased nitrification of the second-stage activated sludge or contact basin. Figure 6.2 compares the reliability of combined, activated sludge, and trickling filter processes in achieving good effluent quality.

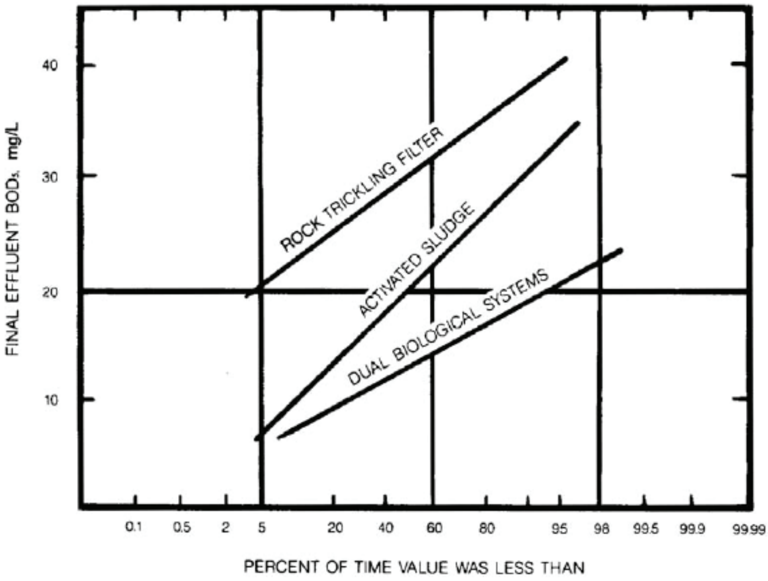


Figure 6.11 Comparison of the effluent quality provided by rock trickling filters, activated sludge and dual treatment systems [2]

Numerous combinations of processes are possible depending on the trickling filter and activated sludge processes used, the loading of individual units and the point at which sludge or other recycled streams are reintroduced to the main flow stream.

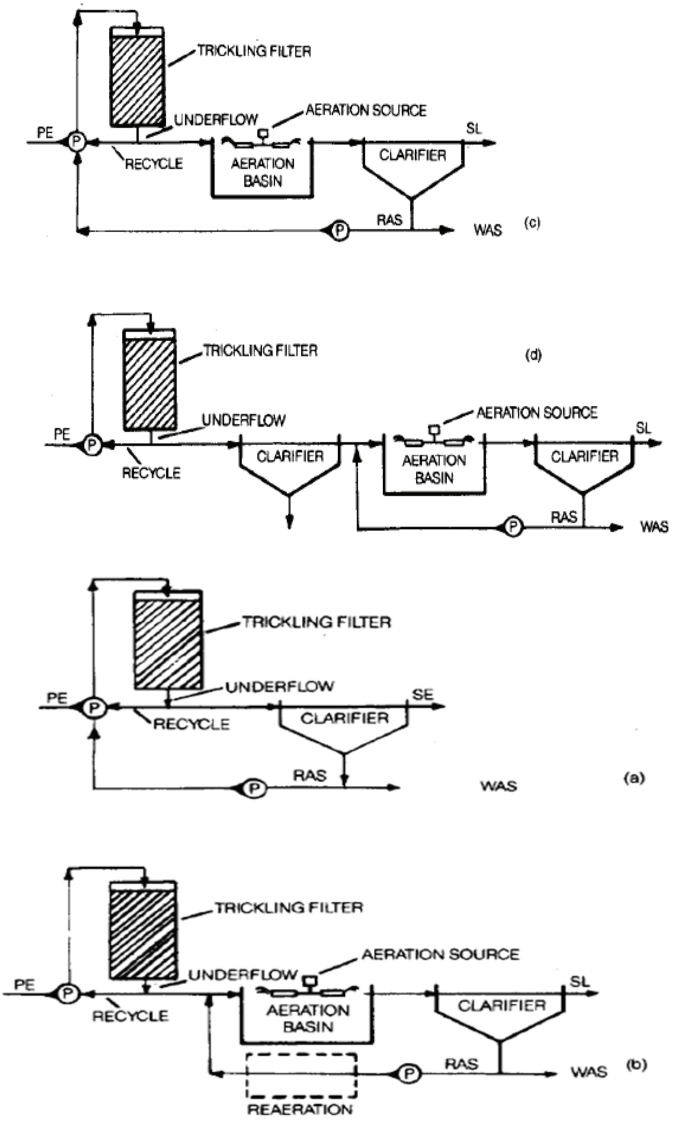


Figure 6.12 Combined system process schematics: (a) activated biofilter (ABF, (b) trickling filter–solids contact (TF/SC) and roughing filter–activated sludge (RF/AS), (c) biofilter–activated sludge (BF/AS), and (d) trickling filter–activated sludge (TF/AS) [2]

6.5. Biological nutrient removal

6.5.1. Overview

Treatment plants typically remove nutrients such as nitrogen and phosphorus from wastewater because of environmental, public health, and economic concerns. In the environment, the presence or lack of nutrients can affect algae growth in surface water. Researchers have found that 0.005 mg/L (5 _g/L) of soluble orthophosphate will limit algae growth [2] while other studies have shown that more than 0.05 mg/L of inorganic forms of nitrogen such as ammonia-nitrogen or nitrate-nitrogen may enhance algae growth.

Molecular or free (un-ionized) ammonia can be toxic to certain species of fish. More than 0.2 mg/L of un-ionized ammonia may cause acute toxicity. Because of this, it is often controlled via factors such as water pH, temperature, and ammonium ion concentration.

There are also public health concerns related to drinking water that contains nitrogen. Regulators typically prefer for drinking water sources to contain less than 10 mg/L of nitrate-nitrogen. Nutrient removal may also reduce a treatment plant’s overall operating costs. When aerobic biological treatment processes must nitrify wastewater, denitrifying the effluent (converting nitrate-nitrogen to atmospheric nitrogen) can recover lost oxygen and alkalinity, thereby saving aeration energy. Denitrification also can reduce or eliminate the need for chemicals to maintain an optimum pH for biological treatment.

If phosphorus removal is required, biological phosphorus removal (BPR) may reduce chemical needs and eliminate associated sludge. Finally, biological nutrient removal (BNR) may produce a sludge with better settling properties than the sludge produced via conventional treatment.

Several nutrient removal methods are available. One effective method is source control to limit the use of phosphorous in consumer products such as soap and detergents. Some agencies have eliminated more than 50% of the phosphorus in raw wastewater via good source control.

Natural systems such as wetlands, overland flow, or facultative lagoons may also be used to control nutrients as explained in Chapter 3. Nutrients also can be controlled via chemical and biological processes.

Wastewater characteristics also affect both the ability to remove nutrients and the rate of removal. For example, if the influent's non-biodegradable solids change, operators may need to lengthen the solids retention time (SRT) or mean cell residence time (MCRT) to maintain nitrification.

Both BNR and BPR depend on sufficient amounts of readily biodegradable organic substrate [chemical oxygen demand (COD) or BOD]. Wastewater treatment professionals have determined that 8.6 mg of COD is needed to remove 1 mg of nitrate-nitrogen from wastewater, but only 0.7 to 1.9 mg of a more readily biodegradable substrate (e.g., methanol) is needed. Experiments have indicated that 50 mg of COD is consumed per 1 mg of phosphorus removed from municipal wastewater.

Because of the need for sufficient biodegradable organic substrates, numerous treatment plants in cold climates (where BOD constituents break down slowly) enhance or condition wastewater by fermenting sludge or managing recycle streams to ferment byproducts, a process known as *primary sludge fermentation*. Primary sludge fermentation is typically done on-site and may eliminate the need for methanol or other commercial, flammable substances. It probably will be unnecessary during warm weather, when natural fermentation in the collection system produces enough volatile fatty acid (VFA) for nutrient removal processes.

6.5.2. Biological nitrogen removal processes

During secondary treatment, nitrogen's ultimate fate depends on the carbon compounds (measured as BOD and COD), the type of sludge (measured as TSS and VSS), and the oxidation methods involved.

Mean cell residence time (also called *sludge age* or SRT) is the most commonly used parameter when operating a conventional activated sludge system. It measures the average length of time in days that microorganisms (sludge) are held in the system, and is calculated as follows:

$$\text{MCRT} = \frac{\text{Mass of MLSS in the aeration basin}}{\begin{array}{c}\text{Mass of total suspended solids (TSS) wasted}\\ \text{from the system per day}\end{array}}$$

When nitrogen [total Kjeldahl nitrogen (TKN)] enters the wastewater treatment plant, it is composed of organic nitrogen and ammonia-nitrogen. Domestic wastewater typically contains 40 mg/L of TKN, which consists of 25 mg/L of ammonia-nitrogen and 15 mg/L of organic nitrogen. Biological treatment of ammonia-nitrogen involves either incorporating it to the biological cells (MLVSS) or oxidizing it to nitrate (Figure 6.15). If incorporated into biological cells, then the ammonia and organic nitrogen are discharged with the WAS. If oxidized to nitrate, then the oxidized ammonia (nitrate) may be converted to nitrogen gas via denitrification and emitted into the atmosphere. Wastewater characteristics can also affect nutrient behavior. For example, if about 20% of the organic nitrogen (15 mg/L) hydrolyzes to become ammonia, then the total ammonia-nitrogen available for cell synthesis is:

$$15\left(\frac{mg}{L}\right)\cdot 0{,}2 + 25\left(\frac{mg}{L}\right) = 3.0\left(\frac{mg}{L}\right) + 25\left(\frac{mg}{L}\right) = 28\;(mg/L) \qquad (6.5)$$

Typical effluent from the primary treatment process contains 160 mg/L of BOD. During secondary treatment, the equivalent of about

80 mg/L of biological VSS is produced. The resulting biological sludge is approximately 10% nitrogen and 2% phosphorus.

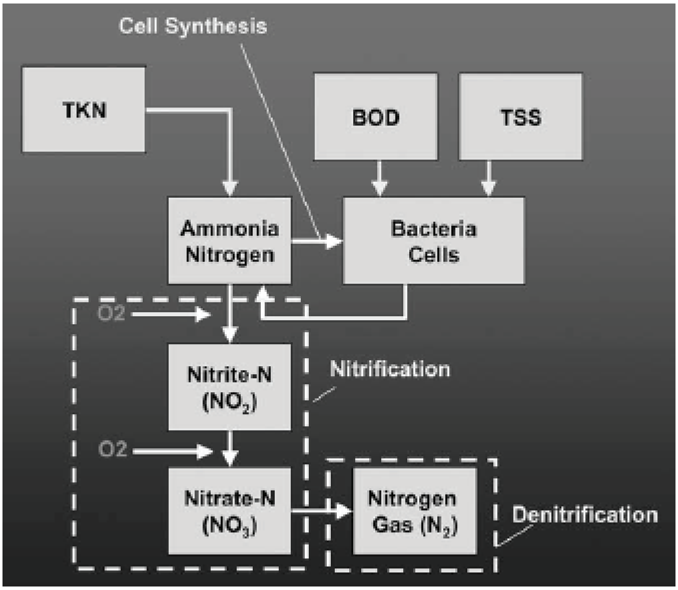


Figure 6.15 Nitrogen removal in wastewater treatment systems [2]

The difference between conventional activated sludge and BNR systems is that a conventional activated sludge system only removes nitrogen via sludge wasting. A biological nutrient removal facility can remove nitrogen via sludge wasting and a combined biological reaction to oxidize the remaining ammonia (nitrification) and reduce oxidized nitrogen (denitrification). If the treatment plant has an ammonia limit, it may only nitrify the wastewater. If the plant has both ammonia and oxidized nitrate limits, then it will need to both nitrify and denitrify the wastewater.

6.5.2.1. Nitrification

Nitrification is the biological conversion of ammonia-nitrogen to nitrate-nitrogen. Nitrification is done by *autotrophic microorganisms.* These organisms use inorganic materials as a source of nutrients and photosynthesis or chemosynthesis as a source of energy. They oxidize ammonia-nitrogen and reduce carbon dioxide to produce new biomass, typically requiring 6 to 9 days of MCRT to produce up to 0.2 mg of VSS per 1.0 mg of ammonia removed.

The first step in nitrification is oxidizing ammonia-nitrogen to nitrite-nitrogen via *Nitrosomonas* bacteria. Then *Nitrobacter* bacteria oxidize nitrite-nitrogen to nitrate-nitrogen.

The following equations illustrate the nitrification process:

$$2NH_4^+\text{-}N + 3O_2 \xrightarrow{\textit{Nitrosomonas}} 2NO_2^- + 2H_2O + 4H^+ \tag{6.6}$$

$$NH_4^+\text{-}N + 2O_2 \xrightarrow{\textit{Нитрификатори}} NO_3^-\text{-}N + 2H^+ + H_2O \tag{6.7}$$

$$2NO_2^- + O_2 \xrightarrow{\textit{Nitrobacter}} 2\ NO_3^-\text{-}N \tag{6.8}$$

Nitrification is typically a complete reaction, which means that the result is predominantly nitrate (little or no nitrite). However, treatment plants that nitrify seasonally may find that nitrite will accumulate until the slow-growing *Nitrobacter* becomes an established population. The nitrite buildup may lead to a *nitrite lock* with excessive chlorine demand by incompletely oxidized nitrite (5 mg of chlorine per 1 mg of nitrite-nitrogen).

Effective nitrification depends on sufficient oxygen and alkalinity which maintains a suitable wastewater pH. *Nitrosomonas* and *Nitrobacter* require 4.57 mg of oxygen and 7.14 mg of alkalinity (as calcium carbonate) for each 1.0 mg of nitrate-nitrogen formed. They yield about 0.06 to 0.20 mg of VSS for each 1.0 mg of nitrate-nitrogen formed.

Autotrophic bacteria typically grow two to three times more slowly than heterotrophic bacteria, which are the predominant organisms in a biological treatment system. Understanding the relationship between the bacteria's growth rate and MCRT (sludge age) can help treatment plant staff determine how temperature, dissolved oxygen and other factors affect biological treatment. The *biomass growth rate* (μ) is calculated as follows:

$$\mu = \frac{\text{amount of bacteria grown per day}}{\text{amount of bacteria present}} \tag{6.9}$$

The *maximum growth rate* (μ_{max}) for nitrifying bacteria at 20 °C is typically between 0.14 and 0.23 kg/d (0.3 and 0.5 lb/d). The minimum MCRT is the inverse of the maximum growth rate:

$$\mathrm{MCRT}_{\mathrm{MIN}} = \frac{1}{\mu_{\mathrm{MAX}}} \tag{6.10}$$

Nitrification depends on the ammonia-nitrogen concentration, dissolved oxygen concentration and wastewater temperature. Standard conditions used to describe the rate of removal are a temperature of 20 °C, 2 mg/L of dissolved oxygen and 10 mg/L of ammonia-nitrogen. If dissolved oxygen or ammonia concentrations drop, then nitrified growth will slow down. In nontoxic conditions, lowering the temperature below the standard will probably have the most significant effect on reducing the nitrifier growth rate.

Nitrification is also affected by pH. The optimum pH level is typically 7.5. As the pH level drops, so do the growth rate and activity of the nitrifiers. Nitrification may be inhibited when the pH is less than 6.5, but some information sources have indicated that nitrifiers are able acclimate in spite of low pH.

Some metal, organic, and inorganic compounds can inhibit the growth of autotrophic bacteria. If plant personnel suspect that toxins are inhibiting bacteria growth, they should conduct a bench-scale test to assess the nitrification rate. Such tests can be conducted onsite or samples may be sent to a contract laboratory for testing.

6.5.2.2. Denitrification

In denitrification, bacteria reduce nitrate to nitrogen gas. Because nitrogen gas is not very water-soluble, it is released into the atmosphere. The atmosphere naturally consists of more than 70% nitrogen, so the emissions do not harm the environment.

Denitrification is done by *heterotrophic microorganisms,* which are organisms that use organic materials as a source of nutrients and metabolic synthesis as a source of energy. Heterotrophic organisms spend less energy on synthesis than autotrophic organisms, therefore growing faster and yielding more cell mass. They typically require 2 to 4 days of MCRT to produce 0.5 mg of VSS per 1.0 mg of BOD removed. Numerous heterotrophic bacteria can denitrify wastewater. *Denitrifiers,* the bacteria that reduce nitrate, are facultative bacteria that are able to function in both oxic and anoxic environments. Denitrifiers prefer to use molecular oxygen, but if the environment contains less than 0.3 to 0.5 mg/L of dissolved oxygen, they will cleave

the oxygen from nitrate-nitrogen molecules to synthesize carbon compounds (e.g., BOD):

$$\begin{aligned}\mathrm{NO_3^-\text{-}N} + \text{carbon source} + \text{facultative bacteria} &= \mathrm{N_2} + \mathrm{CO_2} + \mathrm{H_2O} + \mathrm{OH^-} \\ &\quad + \text{new bacterial cells}\end{aligned} \tag{6.11}$$

The biochemical reactions associated with denitrification are key factors in operating wastewater treatment plants. For example, reducing nitrate-nitrogen eliminates some of the BOD demand, so the anoxic reactors help remove CBOD. If CBOD is the only treatment consideration, then MCRT calculations could include the biomass in the denitrification process.

Theoretically, 2.86 mg of oxygen is recovered for every 1.0 mg of nitrate-nitrogen reduced to nitrogen gas. This is more than 60% of the oxygen needed for nitrification, so this recovered oxygen could be used to greatly reduce the amount of aeration equipment needed in other areas of the treatment plant.

Denitrification also results in new bacterial cells. The cell yield depends on the carbon source. For example, if methanol is the carbon source, then the cell yield is about 0.5 mg VSS per 1.0 mg of nitrate-nitrogen removed. If BOD is the source, then the cell yield is about 1.5 mg VSS per 1.0 mg of nitrate-nitrogen removed. In addition, about 3.57 mg of alkalinity (as calcium carbonate) is produced for each 1.0 mg of nitrate-nitrogen removed, replacing about 50% of the alkalinity lost during nitrification through denitrification. Denitrifiers are less sensitive than nitrifiers, so if the treatment plant environment does not inhibit the nitrifiers, the denitrifiers should have no problem functioning at optimal growth rates. Nitrification and denitrification can occur in one treatment unit [this is called *simultaneous nitrification/denitrification* (SNDN)] or denitrification can occur separately in either post- or pre-anoxic reactors. In the 1970s, BNR and denitrification typically were done via post-anoxic reactors with methanol as the carbon source. A relatively small post-aeration reactor followed the denitrification process to oxidize any remaining organics.

In the 1980s, many wastewater treatment plants were upgraded with selectors for controlling filamentous organisms [Figure 6.19(b)]. Those that nitrified their wastewater found that the anoxic zone was denitrifying RAS as well as controlling filaments. Because methanol is expensive and a hazardous material, most plants took advantage of this revelation. They added an MLR system and used a pre-anoxic selector for denitrification. In this selector, either raw wastewater or primary effluent is used as the carbon source for denitrification.

Overall, the denitrification rate drops as wastewater passes through various anoxic cells because less readily biodegradable BOD is available in downstream anoxic zones than in upstream ones.

Temperature and pH also influence denitrification rates, but the most important parameter is molecular oxygen. Treatment plant staff should minimize the concentration of molecular oxygen in the wastewater. There is a practical limit to denitrification. Nitrate removal is a function of the nitrate produced in both the aerobic zone and in secondary effluent.

6.5.2.3. Common nitrogen removal processes

Ludzack–Ettinger Process. In the 1960s and 1970s, engineers made a number of modifications

to the conventional activated sludge process to improve nitrogen removal. Researchers Ludzack and Ettinger developed a version in which RAS and secondary influent are combined in an anoxic zone that is followed by an aerobic zone [Figure 6.16(a)]. The nitrate formed in the aerobic zone is returned to the anoxic zone via RAS for denitrification. Because the anoxic zone's only source of nitrate is the RAS, denitrification is limited by the amount of RAS flow. Because of this, the process is only suitable for denitrification if nitrate limits are liberal or high RAS flows can be maintained.

Modified Ludzack–Ettinger Process. The difference between the modified Ludzack–Ettinger (MLE) process and the original Ludzack–Ettinger (LE) process is that the MLE process recycles mixed liquor from the oxic zone to the anoxic zone [Figure 6.20(b)]. The mixed-liquor flow may equal 100 to 300% of the secondary influent flow, depending on how much denitrification is desired. Effluent nitrate concentrations typically range from 4 to 7 mg/L.

The mixed-liquor pumps may be relatively small because short distances and large transfer pipes typically result in pumping heads of less than 0.9 m. They also may resemble a fan rather than the conventional centrifugal pumps used at wastewater treatment facilities. This design [Figure 6.20(b)] is the cornerstone of many other BNR processes, including those used for BPR, so the MLE process will be referred to in many subsequent process descriptions. Although Figure 22.12 shows the anoxic (or anaerobic) selector as one reactor, it most likely consists of two or more cells, zones, or compartments operated in a series. If nitrified effluent is recycled for denitrification, the MLR is typically transferred to the second or third cell in the anoxic selector to minimize dissolved oxygen in the first compartment, thereby better controlling filamentous bacteria and providing optimal conditions for *Acinetobacter* organisms.

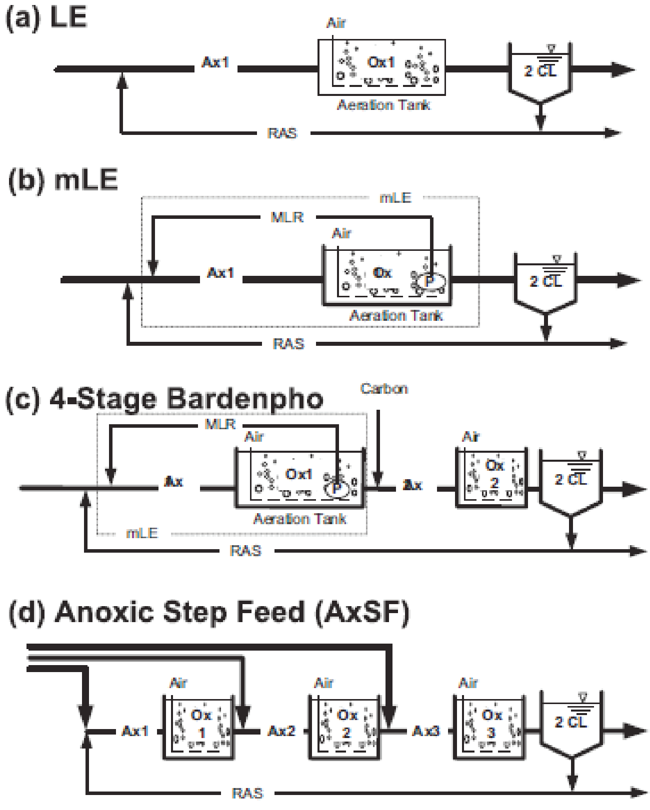


Figure 6.16. Suspended-growth pre-anoxic processes [2]

Four-Stage Bardenpho Process. The four-stage Bardenpho process is an MLE process with subsequent anoxic and oxic zones [Figure 6.16(c)]. Developed by James Barnard, the process was originally used for both denitrification and BPR. The name of the process is a compilation of the first three letters of the inventor's name and the words *denitrification* and *phosphorus*. Its original carbon source was acetic acid or methanol, but a later adaptation, called the enhanced MLE process, uses wastewater instead and is configured with denitrification (rather than phosphorus removal) as the primary goal. Both processes can achieve effluent nitrate concentrations of less than 3 mg/L.

Anoxic Step-Feed Process. Anoxic zones can be established in a conventional step-feed process to increase mixed-liquor concentrations in early stages. This results in a four-stage BNR step-feed process with a 30 to 40% longer MCRT than that of a conventional plug-flow arrangement [Figure 6.16(d)]. If the anoxic and oxic reactors are the same size, a four-stage system should have an influent flow split of about 15:35:30:20% with a consistent F:M ratio in each step. Each stage should have its own influent controls. The flow into the last step is critical because the nitrate produced there will not be reduced further. So, the anoxic step-feed process is best used when the effluent nitrate limit is more than 8 mg/L.

Sequencing Batch Reactors. A conventional SBR, which is designed to remove CBOD, will consist of four phases: fill, react, settle, and decant (Figure 6.17). To denitrify wastewater, the fill phase is adjusted to mixed fill, in which the influent is stirred but not aerated. At facilities with effluent nitrate limits less than 5 mg/L, a second anoxic phase may be added after the react cycle and a carbon source (e.g., methanol) may be added to enhance denitrification before the settling and decant phases.

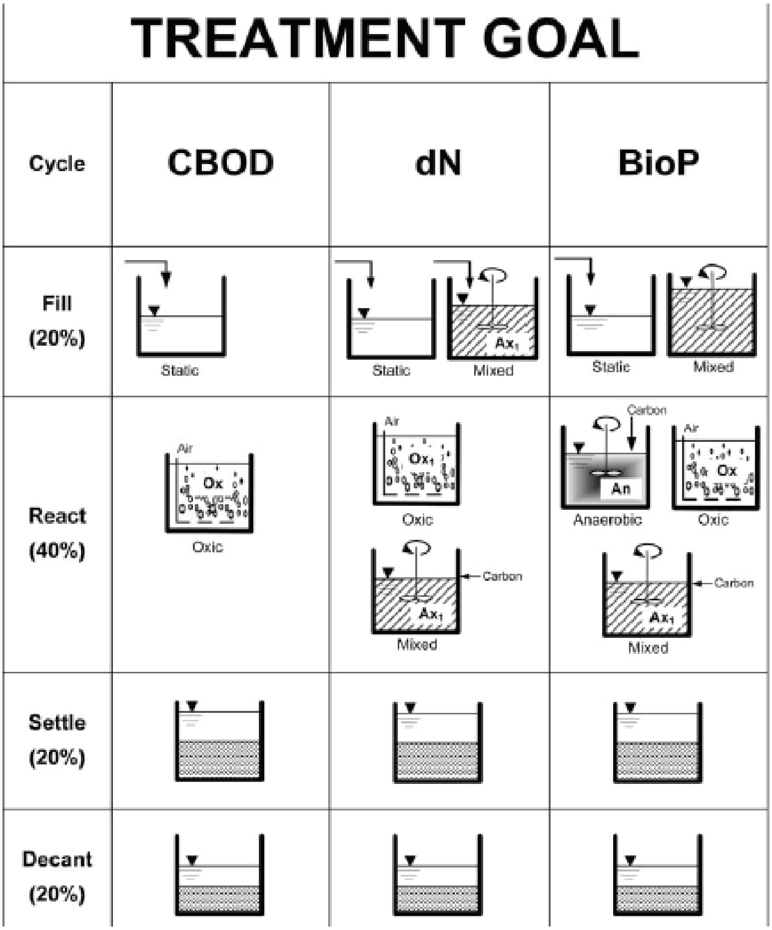


Figure 6.17. Sequencing batch reactor processes [2]

Oxidation Ditches. Oxidation ditches are typically sized based on long aerobic MCRTs of 20 to 25 days, so excess volume is available for denitrification (Figure 6.18). This is typically achieved by turning off one or more aeration rotors to create an anoxic zone [Figure 6.18(a) and (b)]. Because the SDNRs are low, the zone must be large enough to provide the necessary anoxic time.

Another approach is to cycle the aeration by turning the aerators off at least twice a day [Figure 6.18(c)]. Submerged mixers maintain recirculation in the ditch during the anoxic phases. A variation of cyclic aeration, called the Nitrox™ process, involves the use of ORP for control.

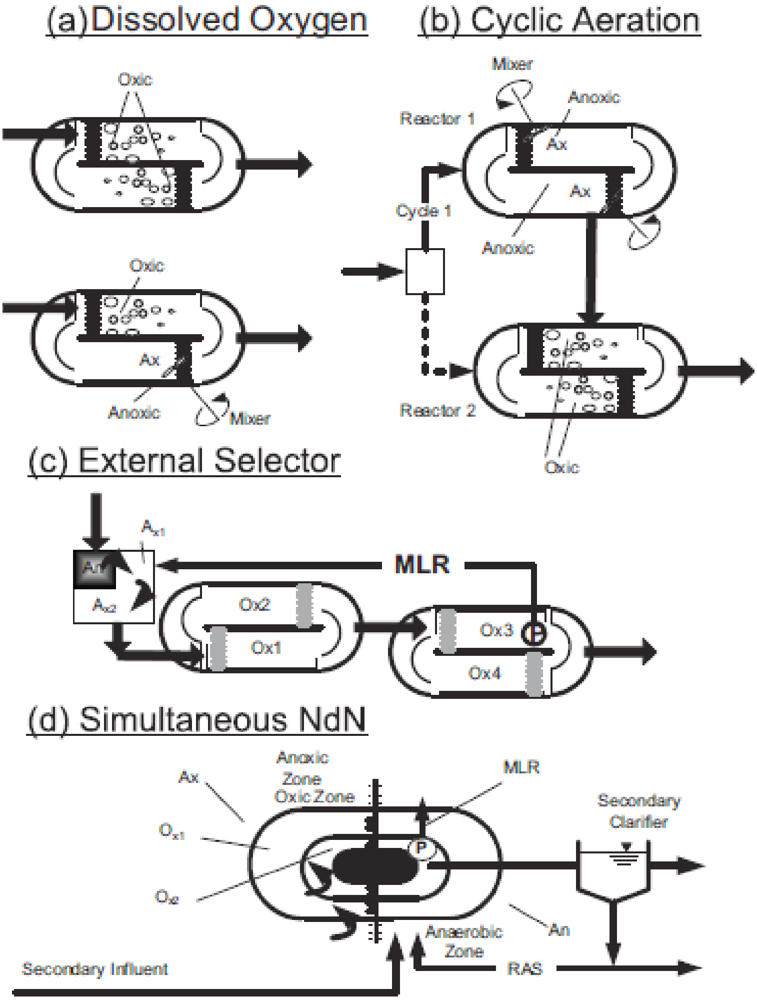


Figure 6.18. Oxidation ditch processes [2]

A third approach is phased ditch operation [Figure 6.18(d)]. In this process, two oxidation ditches are operated in a series with secondary influent pumped alternately into them. When the influent enters the ditch, its aeration equipment is turned off and the reactor becomes anoxic. Submerged mixers maintain recirculation. After a period of time (typically 1 to 2 hours), the influent is sent to the second ditch. At the time of the switch, the aerators are turned on in the first ditch, making it oxic, and the aerators in the second ditch are turned off. This cycle continues, allowing periods of aeration and anoxic fill to occur. A variation of phased ditch operation, called the Bio-denitro™ process, uses four phases to enhance oxidation and denitrification (Stensel and Coleman, 2000).

6.5.3. Biological phosphorus removal

A conventional activated sludge system removes phosphorus from wastewater naturally when its microorganisms take up soluble phosphorus to generate new biomass. Each milligram of VSS (dry weight) produced in such systems contains about 2% phosphorus. If 0.5 mg of VSS is produced per 1 mg of BOD removed, then about 1.0 mg of phosphorus is converted to cell mass per 100 mg of BOD removed. So, traditional sludge wasting reduces phosphorus by about 1 to 2 mg/L.

Acinetobacter (BioP) microorganisms consist of up to 35% phosphorus. Mixed liquor with a high percentage of *Acinetobacter* organisms may contain about 6% phosphorus. Systems designed to identify and remove such organisms are called *enhanced biological phosphorus removal* (EBPR) systems. They can reduce phosphorus concentrations by 3 to 6 mg/L. Chemicals can also be used to precipitate phosphorus, but EBPR minimizes the need for them and reduces their side effects such as alkalinity loss and extra sludge production. Enhanced biological phosphorus removal systems also produce a better settling sludge.

The disadvantages of EBPR include a higher capital cost (for baffles and mixers to create selector zones), sensitivity to nitrate or oxygen toxicity, and more complex operations.

Biochemistry

Enhanced biological phosphorus removal works because Acinetobacter organisms, which are heterotrophic, have a metabolic quirk: they can absorb soluble BOD under anaerobic conditions and store it until they are in an aerobic environment, where it is then metabolized. This is because most heterotrophic bacteria cannot transfer soluble BOD under anaerobic conditions. So, in the right environment with the right type and amount of BOD, they prefer short-chain carbon compounds and Acinetobacter organisms will predominate.

Enhanced biological phosphorus removal is a two-step process in which an anaerobic environment is followed by an aerobic one (Figure 6.19). In the anaerobic selector, Acinetobacter organisms release phosphorus thereby obtaining the energy to uptake readily biodegradable organics. This ability enables Acinetobacter organisms to become dominant. It also tends to result in orthophosphorous concentrations as high as 40 mg/L. Phosphorus release typically occurs within 0.5 to 1 hour of HRT.

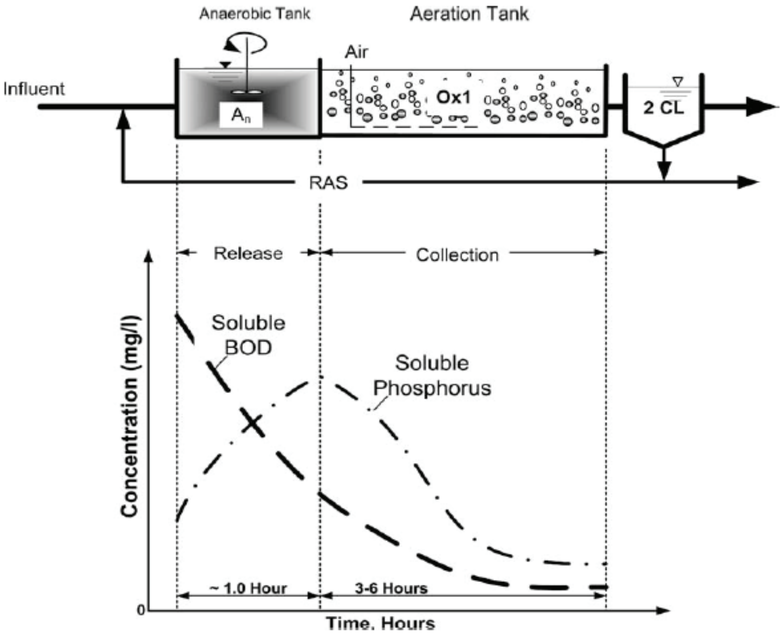


Figure 6.19. Biological phosphorus timeline [2]

When the mixed liquor enters the aerobic zone, Acinetobacter organisms grow new biomass and take up phosphorus, typically in greater amounts than the amount they released in the anaerobic zone. EBPR effluent may contain less than 1.0 mg/L of soluble phosphorus.

Soluble BOD also drops from between 70 and 80 mg/L to 1.0 mg/L (Figure 6.19).

Additionally, some wastewater facilities have reported that operating in the EBPR mode provides superior sludge settling.

Acinetobacter organisms grow slowly, however still faster than nitrifying bacteria. To avoid washout, the process' overall MCRT should be between 2 and 3 days. Longer MCRTs (up to 40 to 60 days) do not hurt Acinetobacter organisms, but the RAS' nitrate concentration could prevent the first zone from being truly anaerobic. Ideally, an EBPR facility should avoid nitrification, but if both nitrification and BPR are necessary, then plant staff should take steps to eliminate interference from combined oxygen.

Settled or waste sludge from EBPR processes must be managed carefully to avoid secondary release of phosphorus emitted from sludge held under anaerobic conditions. Such phosphorus can be inadvertently recycled to the process reactors.

Influences

Good BPR will depend on the right environment (low ORP) and right type and amount of organic matter. Most wastewater will contain enough readily biodegradable BOD to allow EBPR.

Acinetobacter organisms prefer short-chain carbon compounds, also called VFAs. If the treatment plant is in a warm climate or the collection system has an extended retention time to allow septic conditions to occur, then the wastewater will typically have enough VFAs.

In areas with colder climates or wastewater diluted by infiltration and inflow (I/I), staff may need to supplement the naturally occurring VFAs. Some treatment plants generate VFAs by holding a portion of the primary sludge (only 20 or 30%) for processing in a gravity-based thickener called a primary sludge fermenter. Others maintain a sludge blanket in the primary clarifier. In either approach, staff maintain a sludge blanket with a 1- to 3-day MCRT to generate enough VFAs so the overflow can supplement the treatment plant influent and allow EBPR to occur.

To optimize EBPR, either nitrate-nitrogen must be removed from the RAS or the RAS flow must be reduced (typically 20 to 30%) to minimize dissolved oxygen entrainment.

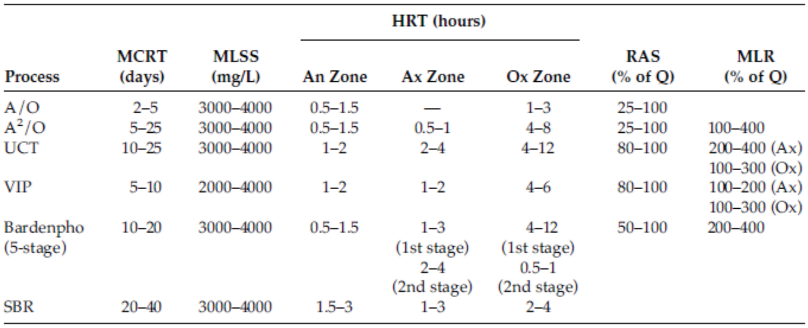
The ratio of BOD to total phosphorus is also important. A ratio of 25:1 or more is considered necessary to achieve a good level phosphorus removal, however the actual BOD-to-total phosphorus ratio needed depends on the process involved.

Suspended solids at an EBPR facility may have a phosphorus concentration of 6% or more, compared to 2% at a conventional biological treatment system. Likewise, a secondary effluent with 30 mg/L of TSS will contain 1.8 mg/L of particulate phosphorus at an EBPR facility, but only 0.6 mg/L at a conventional plant. So, effluent filtration may be necessary to meet low total phosphorus limits.

Common combined nitrogen and phosphorus removal Processes

Optimal operating parameters for BPR processes are plant-specific, but the parameters typically used for operation and design are listed in Table 6.3. Descriptions of common BPR processes follow, most of which remove both nitrogen and phosphorus.

Table 6.3 Typical parameters for phosphorus removal processes



Process	MCRT (days)	MLSS (mg/L)	HRT (hours) An Zone	HRT (hours) Ax Zone	HRT (hours) Ox Zone	RAS (% of Q)	MLR (% of Q)
A/O	2–5	3000–4000	0.5–1.5	—	1–3	25–100	
A^2/O	5–25	3000–4000	0.5–1.5	0.5–1	4–8	25–100	100–400
UCT	10–25	3000–4000	1–2	2–4	4–12	80–100	200–400 (Ax) 100–300 (Ox)
VIP	5–10	2000–4000	1–2	1–2	4–6	80–100	100–200 (Ax) 100–300 (Ox)
Bardenpho (5-stage)	10–20	3000–4000	0.5–1.5	1–3 (1st stage) 2–4 (2nd stage)	4–12 (1st stage) 0.5–1 (2nd stage)	50–100	200–400
SBR	20–40	3000–4000	1.5–3	1–3	2–4		

Anaerobic/Oxic Process. Developed in the 1970s and patented in the early 1980s, the A/O process has a similar flow scheme to that of the LE process [Figure 6.20(a)], except that it uses an anaerobic zone rather then an anoxic one. Another main difference between the LE process and the A/O process is that A/O does not nitrify. Typically, the HRT of its anaerobic zone is between 30 and 60 minutes to select Acinetobacter organisms and the MCRT of its oxic zone is between 2 to 4 days to discourage nitrification. The A/O process typically is not used at treatment plants that need both nitrogen and phosphorus removal because other processes are able to do both more effectively.

Anaerobic/Anoxic/Oxic Process. The proprietary anaerobic/anoxic/oxic (A2/O™) process is a modification of the A/O process in which an anoxic zone denitrifies the MLR. Essentially, it is an MLE process preceded by an anaerobic zone [Figure 6.20(a)]. Typically, its anaerobic zone is about the same size as that in the A/O process, while the anoxic zone has an HRT of 1 hour and the MLR is 100 to 400% of the secondary influent. The A2/O process allows Acinetobacter organisms to be competitive in the anaerobic zone, even while nitrification is occurring, by lowering the nitrate content in the RAS. It can achieve good denitrification via proper sizing of the anoxic zone.

Modified University of Capetown Process. The modified University of Capetown (UCT) process has anaerobic and anoxic zones preceding what is essentially an MLE process [Figure 6.20(b)]. It returns denitrified mixed-liquor recycle (MLRAx) from the first anoxic zone to the anaerobic zone to maintain nitrates at a lower concentration than most other EBPR processes are able to achieve. The UCT process is especially beneficial when treating weak wastewater, which may lack the proper nutrient ratios, because it allows Acinetobacter organisms to compete with other microorganisms diluted wastewater. Sometimes the UCT process is modified with selector zones to operate at higher hydraulic rates. In this case, the HRT may be 1 to 2 hours because the mixed liquor in the anaerobic zone will be less than in a comparable A/O process. The flow rate for the MLRAx is typically twice the secondary influent flow. A variation of the modified UCT process is the Virginia Initiative Plant (VIP) process, which has a similar flow schematic [Figure 6.20(b)] but its anoxic and toxic zones are staged to allow operation at a lower MCRT. In this process, the RAS is mixed with the MLROx before the anoxic zone to minimize dissolved oxygen recycle.

Five-Stage Bardenpho Process. When an anaerobic zone precedes the four-stage Bardenpho process, the resulting five-stage process can be used to encourage the growth of Acinetobacter organisms. The flow schematic of a five-stage (modified) Bardenpho process resembles the A2/O process followed by a second anoxic zone and a re-aeration (oxic) zone. This process is typically designed to operate with a total HRT of about 22 hours, although the HRTs vary for each zone: anaerobic (2 hours), anoxic (3 hours), aerobic (12 hours), secondary anoxic (2 hours) and reaeration (1 hour).

Johannesburg Process. Originally used in Johannesburg, South Africa, this process is essentially a simpler version of the modified UCT process. The Johannesburg (side-stream denitrification) process minimizes the amount of nitrate fed to the anaerobic zone by including an anoxic zone in the RAS flow pattern. It uses the bacteria’s endogenous respiration to denitrify the RAS, while a second (mainstream) anoxic zone denitrifies the MLR. Its anaerobic zone can operate at a higher MLSS concentration than the modified UCT process, thereby reducing the HRT necessary for BPR.

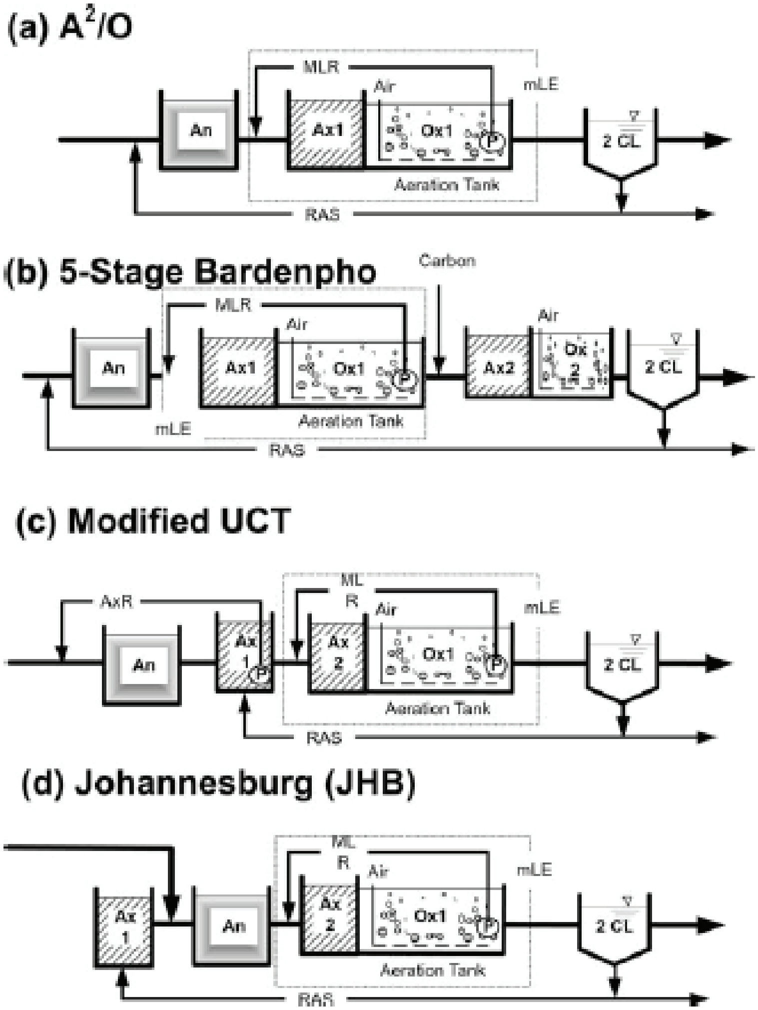


Figure 20. Suspended-growth processes for phosphorous removal [2]

PHYSICAL–CHEMICAL TREATMENT

7. PHYSICAL–CHEMICAL TREATMENT

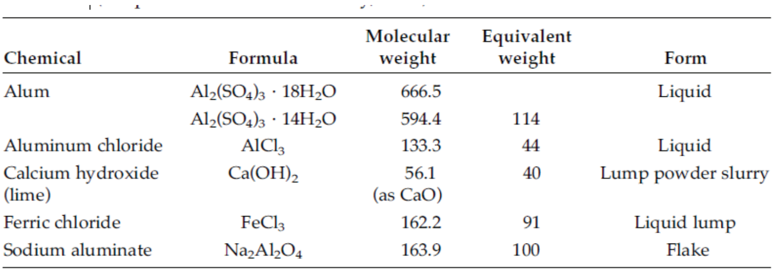
7.1. Introduction

There are three basic types of wastewater treatment processes: biological, chemical, and physical. Biological processes include trickling filters, rotating biological contactors, activated sludge and anaerobic digestion. Chemical processes include heavy metal precipitation, phosphorus precipitation, acid or alkali addition for pH control and disinfection with chlorine or hypochlorite. Physical processes include grit removal, primary and secondary clarification, sedimentation, filtration and centrifugation.

7.2. Fundamentals of the coagulation and flocculation processes

In the wastewater treatment industry, coagulation involves adding inorganic chemicals (Table 7.1), organic polymers, or a combination thereof to wastewater to promote solids or phosphorus removal. Suspended colloidal particles all carry the same surface charge (usually negative) and the resulting mutual repulsion is enough to prevent settling. Coagulants destabilize these charges, reducing the repulsion between particles and promoting settling. Coagulants also chemically react with soluble phosphorus to form an insoluble precipitate that can be removed via sedimentation or filtration.

Table 7.1 Inorganic chemicals commonly used for coagulation in wastewater treatment



Chemical	Formula	Molecular weight	Equivalent weight	Form
Alum	$Al_2(SO_4)_3 \cdot 18H_2O$	666.5		Liquid
	$Al_2(SO_4)_3 \cdot 14H_2O$	594.4	114	
Aluminum chloride	$AlCl_3$	133.3	44	Liquid
Calcium hydroxide (lime)	$Ca(OH)_2$	56.1 (as CaO)	40	Lump powder slurry
Ferric chloride	$FeCl_3$	162.2	91	Liquid lump
Sodium aluminate	$Na_2Al_2O_4$	163.9	100	Flake

Flocculation is similar, except that the chemicals “chain” the particles together into flocs (aggregates) that float or sink, making them easier to remove from the system. In the flocculation step, the chemically treated water is gently stirred to form large flocs of suspended solids or phosphorus precipitates, which are then removed via sedimentation and filtration. When the proper type and amount of coagulant or flocculent is added to wastewater, it can remove approximately 90% of the phosphorus and suspended solids normally present in a secondary effluent.

If treatment plant staff are considering using an organic polymer, they should work closely with their consultant and polymer supplier because many products are commercially available and their applications are often site-specific. Coagulant typically is added to a tertiary process. However, some WWTPs add coagulant to the activated sludge tank to be mixed by the aeration process and remove the resulting floc from the secondary clarifier. Others add coagulant to raw wastewater as it enters the plant and remove the resulting solids from the primary clarifier. When coagulants are added to primary clarifiers, however, care must be taken not to remove all the phosphorus, which is an essential nutrient for biological growth in secondary treatment. Also, chemical coagulation will increase the volume of sludge that must be handled.

7.3. Sedimentation

Depending on the treatment levels required, coagulated and flocculated effluent may enter a clarifier or settling basin, where gravity causes the solids to settle on the bottom. Chemical coagulation increases the volume of sludge that must be handled. This varies depending on the type of chemical used. For example, iron salts or alum will produce less sludge than lime will. As a general rule, the amount of sludge that can be attributed solely to alum addition can be calculated (in mg/L) as 0.26 times the alum dose. This is in addition to the TSS and other solids removed via the alum. For example, suppose a treatment plant receives 10 mgd (38 854 m3/d) of wastewater containing 220 mg/L of TSS. Suppose that TSS removal in the primary clarifiers is 60% without alum addition and 80% with 25 mg/L of alum addition. So, without alum, the primary clarifier generates the following amount of sludge:

= 0,6 * 38.854 m^3/d * 220 mg/lit * 0,973 mg/lit = 4.990 kg/d

With alum addition, the clarifier generates more sludge:

= (0,8 * 38.854 m^3/d * 220 mg/lit * 0,973 mg/lit) +
(0,26 * 38.854 m^3/d * 220 mg/lit * 0,973 mg/lit) = 6.904 kg/d

As a result, 542 kg/d of sludge is attributable to alum addition and the overall sludge production increased from 11,000 to 15,220 kg/d, or approximately 39%.

Similarly, the amount of sludge that can be attributed solely to ferric chloride addition can be calculated (in mg/L) as 0.66 times the ferric chloride dose. At the plant mentioned in the above example (again, assuming 60% TSS removal without ferric chloride and 80% removal with ferric chloride), a 40-mg/L ferric chloride dose would itself generate about 2,200 kg/d of sludge and increase overall sludge production to 16,900 kg/d, or approximately 54%.

This extra sludge can overload digestion and dewatering units unless design engineers take these additional quantities into account when sizing the units in the solids processing train. The chemicals also can affect the dewaterability of solids as chemical sludges can be difficult to dewater. In the case of alum, the added sulfate can also affect odor production through the breakdown of the sulfate ion and the formation of hydrogen sulfide.

7.4. Filtration

During filtration, effluent passes through a filtering medium, using either one or a combination of media, to remove suspended or colloidal matter. Filtration is typically a tertiary treatment step located downstream of secondary processes. Its primary goal is to remove suspended solids from a secondary, coagulation–flocculation, or tertiary sedimentation process effluent. For example, filtering coagulation, flocculation, and sedimentation effluent can typically reduce suspended solids concentrations from between 3 and 5 mg/L to virtually zero and phosphorus concentrations from between 0.5 and 1 mg/L to 0.1 mg/L or less. An efficient filtration system should also be able to be cleaned (backwashed) using less than about 5% of its influent flow.

Occasionally, filtration alone without upstream coagulation and flocculation is used to further reduce suspended solids concentrations in activated sludge effluents. This is, however, less effective for trickling filter and rotating biological contactor effluents because their solids are less naturally flocculent. Also, while filtration alone may technically meet recycled water standards, regulators will tend to err on the conservative side to meet the related health standards and typically mandate a treatment scheme using either:

- Coagulation, flocculation, and sedimentation before filtration; or
- Direct filtration, in which the sedimentation step is eliminated, alum is added in a rapid-mix environment, and a nonionic polymer is added to the filters.

Many types of media can be used for filtration. In addition to traditional granular media (such as sand and anthracite), natural or synthetic fiber or fabric, synthetic fuzzy balls and beads and other filtration media are available. Nevertheless, most WWTPs using filtration use granular media.

Depending on the cleaning (backwashing) method used, granular media systems can be further classified as semicontinuous (conventional) or continuous filters. Semicontinuous filters have to be taken offline periodically for backwashing, while continuous filters are able to filter and backwash simultaneously.

In semicontinuous down flow filtration systems, wastewater passes through a 0.3- to 0.9-m-deep granular bed composed of 0.35- to 1.5-mm particles. As the wastewater passes down through the filter, larger particles are captured near the surface of the filter by the coarser filter media and smaller particles penetrate until captured by the finer filter media deeper in the filter. Eventually, the filter becomes plugged with material removed from the wastewater and must be cleaned by reversing the flow of the wastewater (backwashing). The upward backwash rate is sufficient to suspend the media particles and wash the filtered solids from the bed. Air or surface scouring of the media during backwash ensures adequate cleaning and prevents mud balls from forming. The backwash wastewater is typically less than 5% of the total influent flow in a well-run filter and is recycled through the WWTP.

To avoid hydraulic surges through the plant, backwash is often diverted to a storage tank and then recycled by the plant at a controlled rate. Backwashing requires conventional filters to be taken offline and the cumulative production downtime can be significant. To circumvent this problem, continuous backwash granular media filters were developed. These proprietary filters backwash and filter simultaneously, and filter secondary effluents effectively.

Granular media filtration can be done via gravity flow in open concrete or steel structures, or under applied pressure in steel pressure vessels. Its operation and control may be readily automated.

7.5. Recarbonation – pH adjustment

If lime is added to an effluent as a coagulant, the effluent's pH will rise to between 10 and 11 and the carbonate (hardness) in the water will precipitate as calcium carbonate, as illustrated by the following reaction:

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O$$

Calcium carbonate can tenaciously encrust and bind downstream filter media, softened water must be stabilized before filtration by adding carbon dioxide or acids to it. Carbon dioxide is typically used, hence the term "recarbonation", and the resulting chemical reaction is as follows:

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$$

One reason carbon dioxide is preferred is that its storage and handling requirements are less restrictive than those of strong acids. Another reason is that acids tend to increase the total dissolved solids (TDS) in the final effluent.

7.6. Description of processes and process equipment

7.6.1. Coagulants

Depending on the treatment objective, coagulants either destabilize similarly charged particles so they will settle more readily or react chemically with compounds to precipitate them. These functions are not mutually exclusive. For example, a coagulant added to enhance settling may also precipitate phosphorus and even reduce heavy metal concentrations and improve disinfection efficiency. A list of common coagulants and some of their properties is provided in Table 7.1.

The amount of coagulant needed depends on allowed time and wastewater characteristics. For example, the aluminum and iron salt concentrations needed for good phosphorus removal are typically proportional to the phosphorus concentration and, to a lesser extent, the water's alkalinity. Magnesium hydroxide, a gelatinous precipitate frequently formed when lime is added to hard water containing the magnesium ion, helps remove colloidal material efficiently, but may adversely affect dewatering.

While all coagulants typically increase sludge production, aluminum and iron salts add significant quantities of dissolved solids (sulfates, chlorides, etc., as measured by the TDS parameter) to the final effluent and are not currently amenable to recovery and reuse. Also, alum and ferric chloride lower the effluent's pH and help to consume part of the alkalinity. In water with low natural (background) alkalinity, utility staff may want to consider alternatives (e.g., sodium aluminate or aluminum chloride). Alum also enhances heavy metal removals and high concentrations of heavy metal in the precipitated sludge could affect biosolid management options.

Metal salts (e.g., alum and ferric chloride) are commonly used coagulants in wastewater treatment; however, the coagulant should be chosen based on anticipated performance, cost, and material handling issues. The capital costs for coagulant addition facilities are similar, but the operations and maintenance costs depend on the wastewater characteristics and desired effluent pollutant levels. Unless there are specific concerns about the handling and disposal of solids, alum will often be selected over ferric chloride because it is less expensive, less corrosive, safer and easier to handle.

Coagulant-addition equipment typically includes storage facilities (e.g., plastic tanks), feed equipment (e.g., feed pumps) and a containment area (sized to hold the contents of the largest storage tank in the instance that it were to fail when full). Wastewater utilities should keep adequate quantities of the chemical on hand and be aware of its special properties. For example, a 49% alum solution will begin to crystallize at approximately 0°C and freeze at approximately 7.7°C. Likewise, a 35 to 40% solution of ferric chloride has a freezing point of -50°C, but may start to crystallize at approximately 0°C.

So, the storage and feed equipment may require heat tracing. Utilities should keep onsite at least as much coagulant as (a) the amount for one month at average daily use, (b) 3 to 4 days of peak daily use, or (c) 150% of a typical delivery volume [typically 28 to 30 m3 because most tank trucks hold between 17 and 19 m3].

Most coagulant feed systems use positive-displacement pumps (e.g., diaphragm metering and progressing cavity pumps), although other variants (e.g., gear pumps and peristaltic hose pumps) can be used. Large plants may require centrifugal pumps or large progressing cavity pumps. If dry chemicals are used, dry feeders (screw, rotary, gravimetric, etc.), dissolver tanks, mixing tanks or solution storage tanks may be required.

The coagulant system’s controls tend to be relatively simple: either manual, flow-paced, pH-based or adjustable based on historical and anticipated diurnal loadings.

In addition to metal salts, polymers or polyelectrolytes may be added to promote coagulation and flocculation.

7.6.2. Coagulant mixing

Coagulants may be added to the flow stream in several ways, depending on the application point and mixing device used (Figures 7.1 through 7.4).

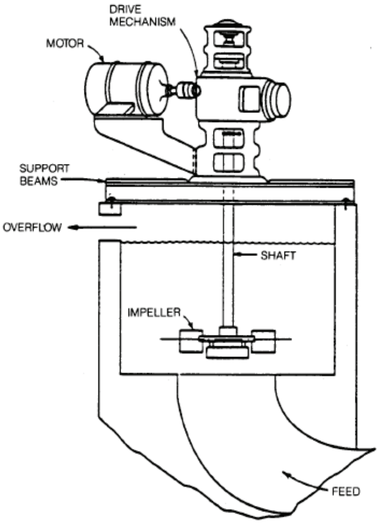


Figure 7.1 In-basin mechanical rapid-mixing device

For example, coagulants may be added to basins via mechanical mixers; injected into pipelines via in-line diffusers, static mixers, or modulating valves; or into open channels either directly or through an open-channel diffuser. Open channels typically have turbulent flow downstream of a Partial flume, a similar flow measurement device, or a hydraulic control point (e.g., a weir). If an open channel lacks turbulent flow, it can be simulated by adding in-channel mixing vanes, an air sparger or an inchannel rapid-mixing device below the chemical-feed diffuser.

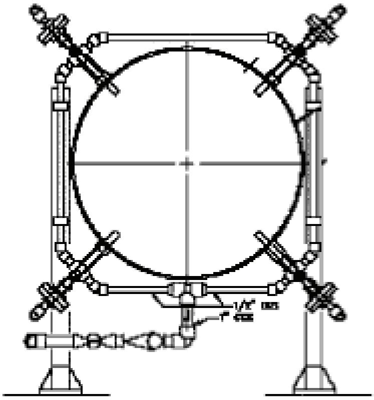
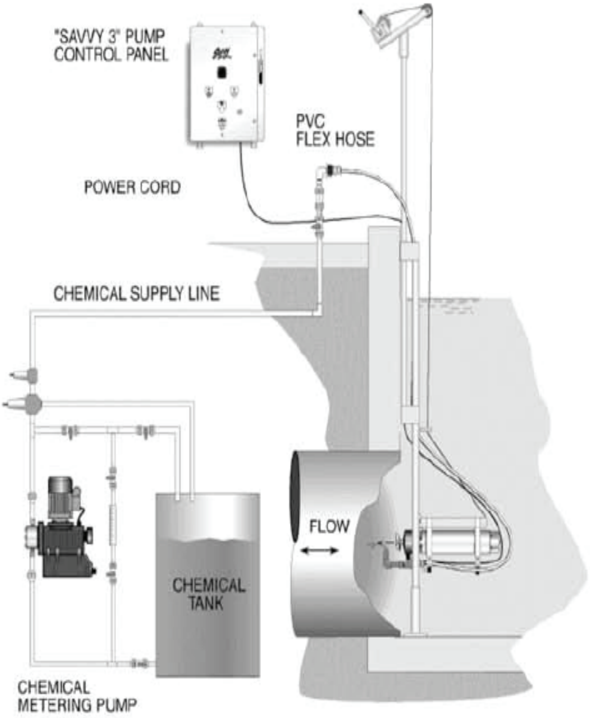


Figure 7.2 In-line diffusers[2]

Sufficient mixing energy, mixing control and detention time are critical to ensure that the coagulant is used efficiently and functions effectively. Mixing energy typically should range from 4.26 to 17.02 kW/m^3/s of flow. Mixing controls should be able to vary the mixing energy so coagulant can be used more efficiently. Basins equipped with variable-speed flash mixers are popular because they can control the mixing energy. On the other hand, using open channels for coagulant addition can be ineffective because turbulent mixing cannot be controlled. This can be compensated for through overfeeding the coagulant, but this solution may be unnecessarily expensive. If the plant hydraulic profile requires that coagulant be added in an open channel (commonly encountered in plant retrofits), jet mixing devices (Figure 7.3) could be used to create the required turbulence, depending on hydraulic characteristics.



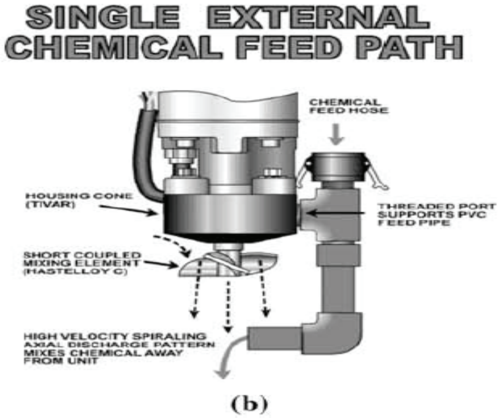


Figure 7.3 (a) In-channel rapid-mixing device (schematic) and (b) close-up of in-line rapid-mixing device (discharge end) [2]

Because coagulant chemical reactions are rapid, detention times are less critical than mixing energy and mixing control. However, time should be factored in the process. For example, rapid-mix basins typically have a detention time of 15 to 60 seconds to allow coagulants to disperse.

Poor mixing performance is typically the result of low mixing energy input, hydraulic short-circuiting or other factors. Traditional tools (e.g., dye or tracer studies) or new analytical techniques [e.g., computational fluid dynamics (CFD), digital particle image velocimetry (DPIV), laser Doppler anemometry (LDA) and laser induced fluorescence (LIF)] may be used to study and resolve these issues. Of these, the most common technique is CFD or its specific subspecialty: computational fluid mixing (CFM).

7.6.3. Flocculation

Flocculation increases the collisions of coagulated solids and promotes chemical bridging between particles so they agglomerate to form settleable or filterable flocs. Whether done in separate basins before sedimentation or within the sedimentation tank (e.g., flocculating or high-rate clarifiers), flocculation involves prolonged and gentle agitation of coagulated particles to form larger, denser particles. Mixing intensities are low: velocity gradients of less than 60 s^{-1} are typical. The flocs should never be subjected to mixing more intense than that used for *initial* flocculation or else the floc will break up.

During flocculation, the coagulated effluent is stirred slowly via air or mechanically driven paddles causing the solid particles to agglomerate, become heavy, and settle on the tank floor. Flocculation basins are often baffled or may be two or three basins in series; their total detention times typically range from 10 to 45 minutes. As the effluent moves through the process, the stirring gradually becomes more gentle.

Flocculation can be thought of as a simple reaction:

$$\text{Dispersed solid} + \text{Preformed flocs} \leftrightarrow \text{Flocs}$$

As in most chemical reactions, both forward and reverse reactions occur. In this case, the forward reaction is aggregation and the reverse reaction is floc breakup. Equilibrium is reached when the aggregation rate equals the breakup rate.

Several flocculation basins in series will perform better than one large basin with the same total volume because they provide better mixing and can use different mixing energies.

The following types of mechanical mixers are used for flocculation (Figure 7.4):

- Paddle- or reel-type devices;
- Reciprocating units (walking-beam flocculator, in which the paddles move in a vertical, up-and-down pattern);
- Slow-speed, flat-blade turbines; and
- Slow-speed, axial-flow propellers or turbines.

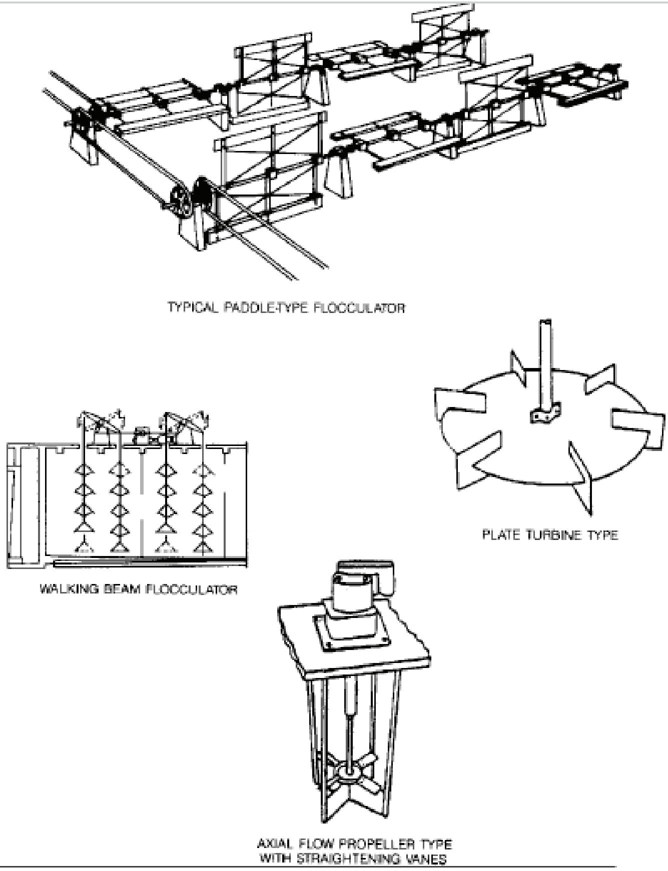


Figure 7.4. Typical flocculation mixers

7.6.4. Sedimentation

Sedimentation separates solids from liquids via gravity. The settling basins (or clarifiers or sedimentation tanks) typically contain mechanically driven scrapers that continuously move the settled sludge to a hopper, from which it is pumped or removed via hydrostatic pressure. The tanks may be either rectangular or circular horizontal-flow tanks and the degree of treatment obtained depends largely on the upstream processes (i.e., the type and quantity of chemicals used, mixing times, and the degree of care in process monitoring and control).

In the reactor zone of a solids-contact unit, influent combines with reactants and preformed solids from the presettling–thickening zone to flow up through a draft tube where a specially designed turbine initiates flocculation (Figure 7.5). As the mixture resettles, its density increases. The internal recirculation rate is up to ten times that of the influent flow, producing optimum floc density. The flocculated effluent enters the presettling–thickening zone over a submerged weir. The solids then sink to the bottom of the vessel, where a slow-moving rake helps make them thicker and denser. This maintains the solids' homogeneity, while simultaneously releasing more entrained water. Thickened sludge is periodically blown down from the bottom of the thickener and typically pumped to a final dewatering mechanism. In the clarification zone, supernatant flows upward through settling tubes and is polished. The settling tubes allow rise rates of up to 0.068 $m^3/m^2 \cdot s$ for most metal salt coagulation processes, often higher for lime addition processes. The clarified water is uniformly collected in effluent launders above the tubes.

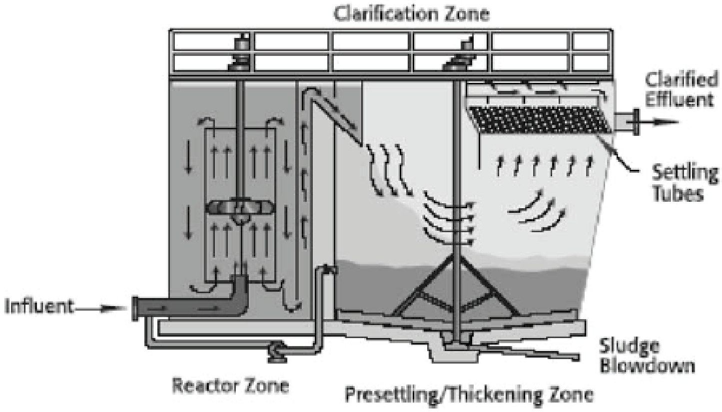


Figure 7.5. High-rate solids contact clarifier [2]

The ballasted media system (Figure 7.6) uses a technique that consists of fixing the flocs (suspended solids) onto micro sand with the aid of a coagulant and a polymer. It is reputed to reduce mixing time fivefold compared to classical flocculation and to increase the rise rate tenfold compared with conventional tube settling. Lamellar settlers, in turn, provide a large clarification surface area in a small tank volume.

After being rapidly mixed, the water enters a maturation zone where it is gently mixed for an additional 4 minutes. This allows the microsand ballasted flocs to grow larger, so they can trap random flocs and settle faster in the sedimentation tank. The polymer works like a glue to affix the flocs to the microsand. The water then enters the settling tank, where the microsand ballasted flocs settle immediately. Finally, the water flows up through settling tubes to collection troughs at the surface and exits the process.

The microsand ballasted sludge is pumped from the bottom of the settling tank to a hydrocyclone, where the microsand is cleaned from the sludge via centrifugal force. The sludge is continuously removed for treatment and the microsand is re-injected into the system to be continuously recycled.

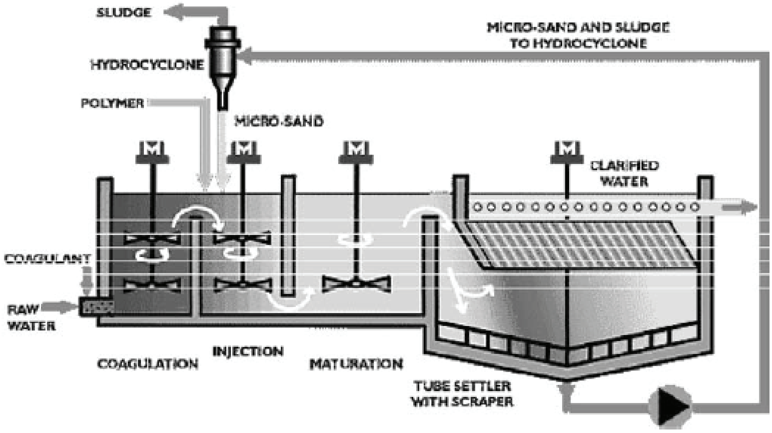


Figure 7.6 Ballasted media, high-rate clarification system [2]

7.6.5. Recarbonation – pH adjustment

During lime coagulation, the water's pH is often raised to between 10 and 11. At these pH values, the water is unstable and calcium carbonate will readily precipitate. This tenacious precipitate tends to encrust any downstream filters or carbon particles. To avoid this difficulty, the water is stabilized by lowering the pH to less than 8.8. In large WWTPs, pH reduction typically involves injecting carbon dioxide (CO2) gas into the water, a process known as recarbonation. The carbon dioxide may be obtained from the stack gases of onsite incinerators, purchased as liquid carbon dioxide or formed via fuel burning. An option for plants using a high-purity oxygen (HPO) activated sludge process would be to use the carbon dioxide-rich off-gas from the HPO process supplemented with an outside source of carbon dioxide. Some plants use sulfuric acid injection, which adds sulfates to the water.

Recarbonation may be done in one or two stages. In the single-stage process, enough carbon dioxide is injected to lower the pH to the desired value in one step. It also dissolves the calcium in lime, so the plant effluent will have a calcium concentration. In the two-stage recarbonation process, enough carbon dioxide is added in the first stage to lower the pH to between 9.5 and 10. The resulting calcium carbonate precipitate is allowed to settle, thereby removing calcium from the water and making it available for lime recovery.

7.6.6. Filtration

Filtering wastewater is difficult. The wastewater's solids content varies and could be high if upstream processes are improperly operated. Variable wastewater flow also causes operating difficulties. For example, rapid sand-filter media are used widely in water treatment but not in wastewater treatment because of poor performance when filtering flows with high suspended solids concentrations.

The gravity and pressure filter structures (Figures 7.7 and 7.8) often used for water treatment are readily adaptable to wastewater filtration. Wastewater is more difficult to filter than well or surface water because the solids are sticky from biological activity and more highly concentrated. In typical shallow-bed sand or diatomite water treatment filters, wastewater tends to quickly reduce the filter surface.

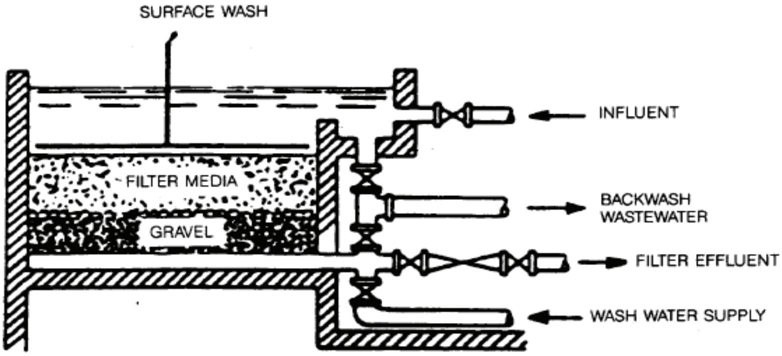


Figure 7.7. Cross-section of a typical gravity filter [2]

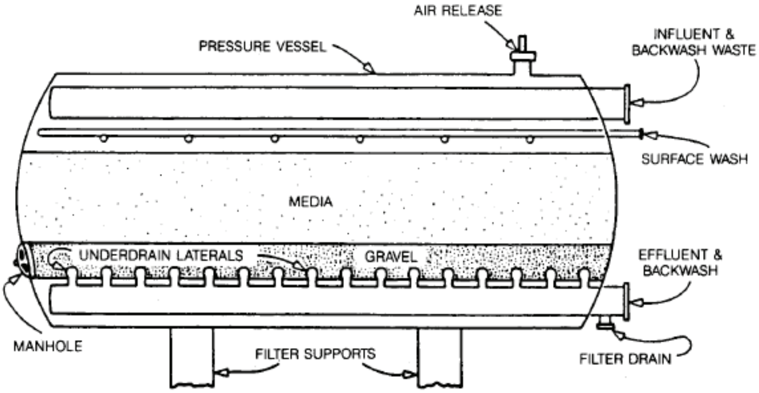


Figure 7.8. Typical pressure filter [2]

Dual-media and multimedia filters allow more of the filter depth to be used to capture solids, making wastewater filtration practical. A multimedia filter is a coarse-to-fine filter with its pore space gradually shrinking as the water moves toward the output point (Figure 7.9). As the pore space decreases, the number of media grains typically increases. However, the grain size is not uniform because the filtration media have three specific gravities. This structure enables removed solids to be stored throughout the depth of the bed rather than only at the surface, greatly extending the length of filter runs between backwashes.

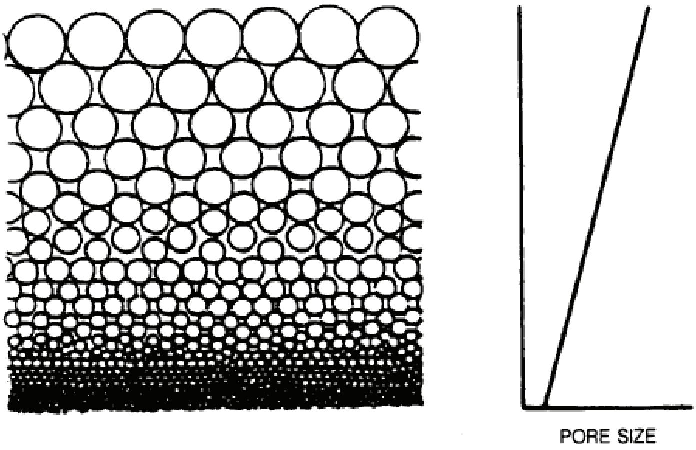


Figure 7.9 Schematic cross-section of an ideal filter, uniformly graded from coarse to fine from top to bottom

In a continuous backwash-upflow filter (Figure 7.10), influent flows from the feed line (A) through the feed assembly (B) and enters the inlet distributor (C) in the lower section of the unit. It then flows upward through the sand bed (D). Simultaneously, the sand bed and the accumulated solids are drawn downward into the airlift pipe (F) at the center of the filter. A small volume of compressed air is introduced at the bottom of the airlift. The air rises, drawing the sand into the airlift and scouring the sand of trapped particles.

When it reaches the top of the airlift (G), the dirty slurry spills over into the central reject compartment (H). The sand is returned to the sand bed through the washer/separator (I). As the sand falls through the washer, which consists of several concentric stages, a small amount of filtered water passes upward, washing away the dirt while allowing the heavier, coarser sand to fall through to the bed. By setting the reject weir (K) lower than the filtrate weir (J), a steady stream of washwater is assured. The continuous reject exits near the top of the filter (L) while the filtered water exits through the filtrate line (E). During this process, the sand bed is cleaned while producing both filtrate and reject. Because the process is continuous, it does not need to be taken out of service for backwashing.

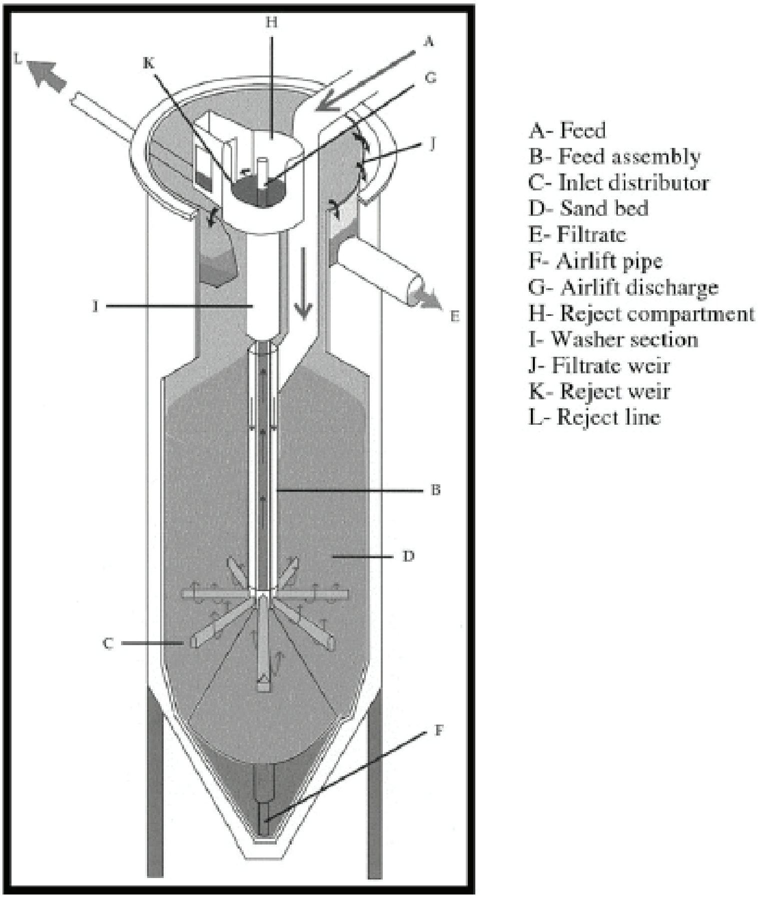


Figure 7.10. Schematic of a continuous backwash, upflow filter [2]

NATIONAL AND EU LEGISLATION

8. NATIONAL AND EU LEGISLATION

National legislation and European directives relating to water domain shall be given in brief.

8.1. National legislation

Within this chapter there will be a brief overview of national legislation, including laws and regulations that regulate water domain. Significant document concerning the waters is the Decree on classification of waters.

Water Law

» Water Act (amendment)

“Official Gazette” no. 52/16; no. 163/13; 23/13; no. 44/12; No.51 / 11; No.83 / 10; no. 161/09; no. 6/09; no. 87/08

Water Monitoring

Rulebook on the content and manner of preparation of the information mapped outlines of monitoring water

“Official Gazette” no. 148/09

Urban Wastewater

» Rulebook on the criteria for determining the areas sensitive to discharges of urban wastewater

“Official Gazette” no. 130/11

» Rules on the conditions, manner and emission limit values for discharges of wastewater, the method of their calculation, taking into account the specific requirements for protection of protected areas (*)

“Official Gazette” no. 81/11

- Rulebook on the conditions, manner and maximum allowable values and concentrations of the parameters of purified wastewater for re-use

“Official Gazette” no. 73/11

- Rulebook on the requirements for collection, drainage and treatment, the manner and conditions for designing, construction and operation of systems and plants for purification of wastewater, as well as technical standards, parameters emission standards and quality norms of pre-treatment, disposal and treatment of wastewater, taking into account the load and method for treatment of urban wastewater discharged into sensitive areas of discharge of urban wastewater

“Official Gazette” no. 73/11

- Rules on the manner and procedure for the use of sludge, the maximum values of concentrations of heavy metals in soil used mud, values for concentrations of heavy metals in the sludge in accordance with its purpose and the maximum annual quantities of heavy metals that can be introduced into the soil

“Official Gazette” no. 73/11

Wastewater discharge

Rules for hazardous and harmful substances and their emission standards that can be discharged into the sewer or drainage system, in surface or groundwater bodies as well as in coastal areas and wetlands

“Official Gazette” no. 108/11

Rules on the conditions, manner and emission limit values for discharges of wastewater in purification, the method of their calculation, taking into account the specific requirements for protection of protected areas (*)

“Official Gazette” no. 81/11

The monitoring of wastewater discharge

- Rules on the methodology, reference measurement methods, method parameters monitoring of wastewater, including sludge from the purification of urban wastewater (*)

“Official Gazette” no. 108/11

Decree on the classification of surface water

The Decree on the classification of surface water determines the classification of surface water. The objectives of the classification of surface water:

- avoiding deterioration of water and impacts that cause deterioration of aquatic ecosystems and chemical status of surface water or surface water body;
- achieving a good status of water bodies and aquatic ecosystems, and the ecosystems that depend on water; and
- achievement of good chemical status and good ecological potential of heavily modified water bodies and artificial water bodies.

The status of surface waters belong to the category of rivers or lakes and in accordance with Article 71 of the Law on Waters are determined according to their ecological and chemical status.

The classification of the ecological status of surface waters belonging to the category of rivers or lakes are determined in terms of biological, hydromorphological, chemical and physico-chemical elements and specific pollutants.

Ecological status of rivers, lakes and artificial and heavily modified surface water bodies is classified by taking into account four main groups of quality elements such as:

1. Biological elements:
   - the composition and abundance of aquatic flora;
   - the composition and abundance of benthic fauna
   - composition, abundance and age structure of fish fauna.

2. Hydromorphological elements that appear to support the biological elements:

a. Hydrological regime:
   - the amount of the dynamics of the flow of water;
   - connection to groundwater bodies; and
   - continuity of the river.

b. Morphological conditions:
   - variation of depth and width of the river;
   - structure of the substrate of the riverbed; and
   - structure of the coastal zone.

3. Chemical and physico-chemical elements that appear to support the biological elements:

a. General items:
   - thermal conditions;
   - oxygen conditions;
   - salinity;
   - situation and acidification; and
   - conditions with food substances.

b. Special items:
   - pollution by all priority substances identified to be discharged into the water body; and
   - pollution by other substances which have been identified to be discharged into the water body.

4. Specific pollutants:
   - specific pollutants emitted in significant amounts in the water body.

The classification of the ecological status of rivers and lakes based on the general physico-chemical elements are made in accordance with the Standards for environmental quality.

The assessment of the ecological status of surface water body of rivers and lakes on the general physico-chemical elements is carried out by taking samples of water of representative measuring points in the manner prescribed by the regulations.

The mathematical equations for calculating the percentile values are also laid out within the regulations.

The classification of the ecological status of surface water body of rivers and lakes to specific pollutants in this Regulation shall be made on the basis of quality standards for specific environmental pollutants given in the ordinance. The assessment of the ecological status of surface water body of rivers and lakes in terms of specific pollutants of this Regulation is done by taking samples of water of representative measuring points as follows:

1. The assessment is carried out for surface water body of rivers and lakes using monitoring data collected for one calendar year;

2. The value of the 95th percentile of the monitoring data used to compare with the quality standards of the environment given in the regulation and the results of the assessment on pollutants are classified as:
   - excellent;
   - good; or
   - does not meet standards for environmental quality.

3. The poor condition is determined by the weakest result for one or more specific parameters ("according to the lowest parameter"). The mathematical equations for calculating the percentile values are given in the regulation.

The surface waters of rivers and lakes in terms of environmental condition are classified based on the results to assess the quality elements such as:

- High environmental conditions;
- good ecological status;

- moderate ecological status;
- insufficient ecological status; or
- poor environmental condition.

The classification of chemical status of surface water bodies is determined by the presence or absence of concentration of priority substances and other pollutants into the water in accordance with the Standards for environmental quality for priority substances and other pollutants.

Based on the presence or absence of priority substances and other pollutants, surface water bodies in terms of its chemical status are classified in the following manner:

- good chemical status is a condition when there is no surpassing the standards for environmental quality to any one of the priority substances and other pollutants and
- achieves good chemical status is a condition when the concentrations in water of one or more priority substances and other pollutants exceed either the annual average - quality standards for environment

8.2. EU Directives

Water is one of the most transparently regulated areas of EU environmental legislation. Regulations in force in EU member states:

- Water Framework Directive (2000/60 / EC);
- Directive for the treatment of urban wastewater (91/271 / EEC);
- Groundwater Directive (80/68 / EEC);
- Directive for sludge treatment (86/278 / EEC);
- Directive on hazardous substances (76/464 / EEC); and
- Nitrates Directive (91/676 / EEC).

Framework Directive no. 60 of 2000 sets a framework under which all of the above directives are part and establishes a policy for water management. These laws are implemented and changed through amendments.

8.2.1. Framework Directive 2000/60 / EC

This Directive expands the scope of water protection for surface and groundwater and aims to ensure good ecological status of all species in a certain period. This strategy is combined with peak values and quality standards in order to ensure good status. The use of the two instruments protects human health and sets maximum limits to preserve the natural ecosystem. Member states, initiated through local authorities and coordinated on a national level, should take all measures to achieve a good standard of water quality, to restore polluted areas and to progressively reduce pollution by all measures prescribed by law.

8.2.2. Directive on treatment of urban wastewater 91/271 / EEC

This Directive has two aspects: collection, treatment and discharge of urban wastewater from agglomerations and treatment and discharge of degraded biological wastewater from industrial sectors. The definition of urban wastewater specified in the Directive includes wastewater from households or mixed wastewater from households and industry in addition to storm water. This Directive aims to protect the environment from adverse effects that may arise from wastewater. Member States must ensure the collection and treatment of wastewater before discharge in accordance with standards and deadlines. With regard to the treatment of water, secondary (i.e., biological) treatment is a general rule, additional treatment (treatment of third degree)may also be needed.. For certain areas, primary treatment alone is sufficient.

The next element of this Directive is to provide that industrial sewage flows into the collector system are subject to prior regulation and legislation imposed by the competent authorities. Furthermore, it states that each Member State should set their requirements according to the existing industry regarding their effluents. This allows Member States to set standards that will be relevant to the local conditions in the country. Furthermore, it specifies that pre-treatment is required to ensure smooth operation of treatment plants and permit the use of same sludge in agriculture.

Directive Article 14 regulates the removal of sludge from the treatment plant and general rules, including registration or approval. Additionally, it prohibits the removal of sludge with its discharge into surface waters. Management of sludge should be considered from the Directive. 86/278 / EEC.

8.2.3. Groundwater Directive (80/68 / EEC)

The aim of this Directive is to prevent groundwater pollution by certain dangerous substances. Member States must follow the effects of effluents on groundwater.

The Directive prohibits the discharge of substances on the list of harmful substances and allows to obtain approval from the relevant authorities for the discharge of certain substances.

8.2.4. Standard of urban wastewater

EU directive on urban wastewater and its treatment aims to ensure the smooth operation of treatment plants and allow sludge treatment to carry on unobstructed. This implies that water must receive some degree of pre-treatment of industrial wastewater to ensure the operational capacity of the treatment plant.

The standard defines the values to contain the treated wastewater before leaving the treatment plant to be released into the water recipients. Parameter under consideration, the maximum allowable concentrations, as well as the method in which the measurement is in accordance with European standards for urban wastewater (adapted from 91/271 EEC).

8.2.5. Dangerous substances and limit values for outlets

Directive 91/271 / EEC remains an opportunity for Member States to set standards on industrial pollution consistent with the general Directive on hazardous substances. The directive specifies that each Member State must set standards depending on the type of industry in question. Certain limits for discharge of effluent into the water recipient are being set. This applies to industrial enterprises with their own wastewater treatment. Additionally, the application of limit values can be adjusted at the point of discharge of effluents into the sewerage system. This is the case when wastewater flows into the treatment plant.

WASTEWATER TREATMENT BY TYPE OF INDUSTRY

9. WASTEWATER TREATMENT BY TYPE OF INDUSTRY

9.1. General

Wastewater industry by nature is complex and varies so is able to cause severe damage. Therefore, it needs to be analyzed separately by industry with all the specifics and the appropriate process of treatment should then be applied.

Typical materials that are found in most industrial effluents are:

1. Insoluble materials that can physically be distinguished as:
   - solids in suspension (sand, oxides, sludge); and
   - lightweight fabrics and materials that swim (fat soluble and non-emulgated hydrocarbons).
2. Soluble solids that can physically be distinguished as:
   - substances that can absorb (colorants, detergents, radioactive elements, etc.); and
   - salts that may be separated by inverse osmosis or by changing the ions.
3. Substances which can be separated by neutralization:
   - organic and inorganic acids or bases whose salts can be dissolved to a certain limit concentration is not toxic.
4. Substances which can be distinguished only by oxidoreduction:
   - oxidants or reducing agents which oxidized form or reduced sufficiently soluble and non-toxic; and
   - sulphides cyanides, chromates and others.
5. Substances which can be separated by precipitation:
   - metals that can and must be non-toxic and can precipitate in the form of hydroxides; and
   - sulfides, fluorides, some inorganic and organic acids.

6. Substances which can be distinguished by flocculation and decantation or flotation:

- Overall, colloidal substances; and
- substances in emulsion (resins, soluble oils, emulgated hydrocarbons).

7. Substances which can be distinguished by degas or extraction liquid gas:

- gases tied or dissolved; and
- phenolic compounds, etc.

8. Substances which are distinguished by one of the procedures of biological treatment.

The relationship between BOD and COD in industrial wastewater differs significantly from the corresponding ratio in wastewater. It changes during various stages of treatment, so that COD can increase the BOD5 five times. The presence of highly toxic active substances can mask the existence of biodegradable materials and affect the accuracy of the BOD5.

9.2. Determining the characteristics of the effluent

To build a proper plant for wastewater the following data is needed:

- the daily consumption;
- maximum and minimum flow per hour;
- if the inlet is continuous or discontinuous;
- size and periodicity of pollution;
- local opportunities for treatment and recycling; and
- secondary pollution, even very small or incidental, as it is able to threaten the work of some devices for treatment (glue, resins, fibers, oil, sand, etc.).

At the stage of construction of new factories, this data is obtained based on the analysis of production and by comparison with the existing factories.

9.3. Preliminary treatment processes

It is often necessary to analyze the conditions before treatment in order to separate secondary pollution and eliminate the most significant physical pollution due to discharge of the process of treatment. The process of pre-treatment includes the trickling, removal of sand, oil removal, decantation and the like.

9.4. Processing of sludge

Concerning the choice of procedures and working conditions, it should consider the following:

- filterability and decantibility spinning in the sludge not only depends on the chemical composition of the sludge, but also the way it is set up; and
- heat the sludge.
- Certain problems can arise concerning the collecting of processed sludge including:
- stable sludge which is not toxic and can be located completely in the open space;
- sludge which has low solubility or toxicity which should be kept to prevent any danger of rinsing and blowing or to be collected in containers;
- sludge subjected to fermentation (volatile organic sludge, oil sludge) should pass through the complete process of processing which can include incineration.

9.5. Food industry

All types of wastewater from the food industry are characterized by organic and biodegradable pollutants, fast souring and rapid fermentation. All these waters are processed biologically.

9.5.1. Dairy

The composition of the waste of this industry depends on its origin. Since plants for pasteurization and fermentation of pure milk only receives water from washing, corresponding to diluted milk. There are times when the water is too acidic or base for the use of nitric acid or caustic washing pasteurizer and other appliances. Plants for the production of cheese and casein give serum containing lactose a lot but little protein plants while giving whey which is rich in lactose and protein but poor in fatty substances. BOD5 wastewater from milk moves 20.000 - 40.000 mg / l. In practice, these byproducts are usually used as feed and water for washing goes through the process of industrial treatment. An optimal solution is biological treatment techniques and active sludge with extended aeration, thus deposition should take place slowly. Extended aeration to limit the mass of sludge produced. If the concentration of milk or serum is greater than 1-2%, wastewater begins to quickly sour and to aerobically ferment, which can cause complete blockage of any biological activity. A possible solution is to water or fertilize the land with these wastewater flows, which should be limited to 20-40 m3 of water per day per hectare, depending on the porosity of the land.

9.5.2. Processing of fruit and vegetables

These industries operate seasonally and emit a relatively small amount of contaminated water from washing. The process of purifying these effluents uses filtration which would mention the waste of vegetables, fruits, leaves and husks. Thus the separated solids are either used as compost or incinerated. Taking into account the seasonal nature of these pollutants, it can be said that an aerated lagoon the method that best suits this type of industry.

9.5.3. Slaughtering and processing of meat

The amount of wastewater varies and depends on evacuated fecal matter, the size of the slaughterhouse and the type of animals processed. Before discharge of wastewater from slaughterhouses into drains, pre-treatment removes grease and sand as the water trickles through the bars and through fine sieves, reducing the degree of pollution by 10-15%. Nowadays the idea of chemical treatment of wastewater through flocculation and decantation has been completely rejected, since those proceedings organic pollution is reduced to 50%, which creates large amounts of sludge. It is colloidal sludge and prone to fermentation, and therefore has problems with drying and evacuation. Accordingly, the biological treatment with extended aeration is being used.

9.5.4. Breweries and fermentation industries

Wastewater from breweries comes from scouring the halls for boiling the beer containers cooling tanks for fermentation and storage, followed by the washing of bottles and barrels. These waters contain suspended solids, nitro compounds, residues of beer and yeast, malt particles and more. The concentration of pollutants in waters used to wash fermentation tanks and filters is about 3.000 mg / l BOD5 and waters used to wash tanks for the storage of beer is about 16.000 mg / l. Treatment of this wastewater uses active sludge with a low load on the table and is very effective because it prevents the development of filamentous bacteria that are able to block bacterial filters and slow the process of precipitation. Such a device is able to reduce BOD5 by over 95%. The resulting fresh sludge can then be processed by filtration under reduced pressure with conventional conditioning using iron salts, lime or spinning by adding organic flocculants.

9.5.5. Sugar and alcohol factories

Sources of pollution generated by sugar factories are numerous, however, the most important are listed below:

- wastewater produced in the laundering of rapeseed;
- water from the production process; and
- effluents from the regeneration of the devices for demineralization of sugar juice.

The water used for washing rapeseed usually is recycled because within the process there are put decanters - sedimentation tanks that make the reduction of suspended solids in the water. Decantation can get sludge to a concentration of 300 g / l. It is recommended that the water pass through a grid before entering the sludge plant. Lime is not injected to improve the decantation process. All wastewater from a sugar factory today often expose anaerobic digestion in large pools.

In wastewater from alcohol factories, the most acceptable solution for applying to treatment is directly controlled anaerobic digestion. In this way recycled water is decanted and the resulting anaerobic sludge is recycled in the digester. With this procedure, BOD5 can be reduced by 90%, so it will need further treatment in order for aerobic wastewater pollution be brought to acceptable limits.

9.6. Factories for oil and soaps

Depending on the type of plant, the differences in terms of pH in wastewater industry can be large. Thus, plant fatty acid washing water is very acidic (pH between 1 and 2), while the neutralization of fatty acids obtained very alkaline wastewater (pH almost 13). Because of it, it is best for all wastewater to be mixed. The previous physical-chemical treatment which removed fat and carried flocculation allows the reduction of organic pollutants by 50 - 70%. Then it can be applied to additional biological treatment with active sludge.

9.7. Chemical and pharmaceutical industry

There are many biological processes that can be applied to wastewater from chemical and pharmaceutical industries because it has been shown that bacteria that carry wastewater treatment are very adaptable. Therefore, wastewater resulting from the production of antibiotics can successfully be processed using active sludge.

9.8. Plants for the tanning of leather

These industries consume very large amounts of water that reaches up to 5 m3 to 100kg while leather is being processed. Wastewaters become heavily polluted and contain colloidal proteins, fats, tannins, waste leather fibers, colorants and toxic elements. These sulfides are, in particular chromium obtained. Anaerobic digestion of the sludge is out of the question because of the chromium toxic effect on the fermentation. After neutralization and decanting of these effluents, any of the biological treatments can be applied.

9.9. Manufacture of paper pulp

In wastewater treatment plants of paper, there should be prior treatment that includes neutralization and removal of sulphides from the effluent. To dilute wastewater originating from washing and bleaching, biological processes into aerated lagoons are applied.

9.10. Oil and petrochemical industry

Treatment of wastewater from these industries contain one or more stages:

- a phase of the physical removal of oils through gravity separation;

- a cleaning stage of the process of flocculation;
- a decantation or flocculation process with flotation depending on the degree of treatment required.

The main objective of this process is to completely remove free hydrocarbons, partially eliminate emulgated oil and to reduce COD.

9.11. Petrochemicals

Wastewaters form the petrochemical industry contain many complex organic compounds from plant synthesis. Some substances can be eliminated by extraction using selective solvents or stripping., while some wastewater is very concentrated and can be directly exposed to incineration or pyrolysis. COD in the concentrated liquid can be reduced by means of activated carbon. Biological treatment is the most appropriate procedure for treatment of large amounts of water containing complex pollution, provided they are not too concentrated.

9.12. Animal farms

What will be the wastewater discharged from farms depend on how the cleaning is done, whether dry or water way.. Impurities can be separated from the water by mechanical action. The remaining water is then mixed with lime or dolomite to obtain mineral fertilizer that can be packaged. The best way is to expose biological treatment with extended aeration and get good results despite the high content of ammonia in these effluents. A similar procedure can be applied to poultry farms.

9.13. Metallurgical industry and machinery

Metallurgical plants use closed circuits and their wastewater in most cases are liquids discharged from these circuits for deconcentration. These liquids are already neutralized and decanted, but may contain cyanide, especially if they are used to wash the gases from furnaces. Cyanide can be removed in a classical way with alkalinization and chlorine, maybe using a compound superoxide of sulfuric acid. Wastewater from industry machines undergo in decanters or through a filter layer consisting of absorbent material. Eventually, it gets blurred and inorganic sludge can be eliminated with incineration. Other wastes, such as towels, soaps and creams which always has in this kind of industry.

9.14. Effluents obtained from metal surface treatment

Target surface processing elements of metal and some synthetic fabrics either protects those elements from corrosion or change their appearance. Pollutants that are specific to this type of production include:

- organic substances that are mostly created in the removal of oil; and
- suspended solids and especially dissolved and ionized inorganic compounds.

Those leads from flushing can often be processed using the ion exchanger, with pure water recycled and the pollutants concentrated in a small amount of liquid used for regeneration Before the final choice of the treatment devices, it is necessary to be familiar with many parameters. For example, the method of production technology in the industrial plant, the amount of wastewater, the type of contaminants, environmental conditions in the recipient, etc.

SYSTEMS FOR TREATMENT OF INDUSTRIAL WASTEWATER

10. SYSTEMS FOR TREATMENT OF INDUSTRIAL WASTEWATER

10.1. Introduction

The process of treatment for municipal and industrial wastewater is different. Industrial wastewater contains different pollutants, has a different composition and can even contain toxic substances. The design, build and function of treatment plants also defers.

Industrial objects can release their treated wastewater directly in the recipient or indirectly into the public wastewater treatment plants. However, direct release needs extensive treatment before it can occur. The procedures and technologies that are described in the following sections can be applied for both ways of treated wastewater release.

Pre-treatment of wastewater includes reduction, removal or alternation of the pollutants in the industrial wastewater before releasing it in the public WWTP. This process may be of a necessity for some treatment plants so they can:

1. meet legal requirements for discharging the wastewater;
2. meet the standards for water quality;
3. meet municipal regulations for the collecting and sewage systems; and
4. influence the general perception of industrial facilities as the main water polluters.

For that matter the industrial objects have to invest in pre-treatment systems for wastewater.

10.2. Composition and quantity of industrial waste water

Based on its creation and composition, wastewater can be:

1. Industrial water for production purposes in technological process;
2. Hygienic-sanitary water from toilets in administrative and manufacturing buildings, swimming pools, chairs, showers, etc.; and
3. Atmospheric water such as rain or melted snow.

Industrial wastewater can be polluted and unpolluted (conditionally).

Polluted industrial wastewater can have different composition and properties.

Quantitative indicators that are needed as input parameters when designing a WWTP:

1. Amount of characteristic components of the corresponding production (oil, faeces, surface active agents, toxic substances, radioactive substances, etc.);
2. Amount of organic matter expressed as BOD and COD;
3. Active reaction of the water;
4. Degree of mineralization;
5. Intensity of colouring; and
6. Temperature of the water.

According to the degree of aggressiveness wastewater can be:

1. highly aggressive;
2. lowly aggressive; or
3. Nonaggressive wastewater.

The following parameters are crucial influence on the composition and quantity of wastewater:

1. Type and quality of water supplies reater use of recirculating water systems means less wastewater); and

2. The type of enterprise, enterprise size, production technology, type of plant, the water supply system, the capacity of the sources.

Determining the quantity of wastewater is essential for the design process.

For water released during production processes:

$$Q_{av/day} = \frac{mM}{1000} \; [m^3/d] \qquad (10.1)$$

$$Q_{max/h} = \frac{mM_1K_1}{\mathrm{T} \cdot 3600} \; [l/s] \qquad (10.2)$$

Where:
m - Norm for wastewater per unit of product or raw material in m3;
M - quantity of raw material per day;
M1 - the same for the shift with the highest production;
T - number of hours of the shift with the highest production
K4 - hour to ratio imbalance

Sanitary water needs according to the norms for wastewater per employee are:

1. For employees in work places with thermal exposure more than $84 \cdot 10^3$ [J/m^3h] (heated plants)45 l / employee in 1 shift
2. 60 l for 45 min after the shift

1. For all the other work places (non-heated plants)
   1. 25l / employee in 1 shift
   2. 40 l for 45 min after the shift.

The quantity of the sanitary wastewater is determined by the following formulas:

1. From the plants

$$Q_{av/day} = \frac{25N_1 + 45N_2}{1000} \; [m^3/d] \qquad (10.3)$$

$$Q_{max/h} = \frac{25N_3K_4' + 45N_4K_4''}{\mathrm{T} \cdot 1000}\ [m^3/h] \qquad (10.4)$$

$$Q_{max/h} = \frac{25N_3K_4' + 45N_4K_4''}{\mathrm{T} \cdot 3600}\ [l/s] \qquad (10.5)$$

1. From showers

$$Q_{av/day} = \frac{40N_5 + 60N_6}{1000}\ [m^3/d] \qquad (10.6)$$

$$Q_{max/h} = \frac{40N_7 + 60N_6}{45 \cdot 60}\ [l/s] \qquad (10.7)$$

- Number of employees in a day (2 – heated, 1 – cold plants),
- the same for the shift with the greatest production,
- hour ratio imbalance for heated and cold plants.

In lack of specific indicators:
- number of employees that use the shower per day,
- the same for 1 shift.

Unpolluted water

Some branches represent the largest percentage (90%) of the general water management. These include:
- Water cooling of machines and products; and
- Water from the compressor plant and heat exchangers.

These waters are practically not contaminated, as they are only heated during their use. Their composition and quantity is different and depends on the adopted production technology.

Rain water

The quantity and composition of rain water depends on: climate, geographical, topographical conditions and choice of location of the industrial complex.

To determine the dimensions of the sewage networks and treatment plant, the following is an input data which must be acquired:

- All day and night discharges: The quantities of wastewater that are released during the 24-hours
- The regime of its distribution by hours. What is the peak release quantity and how the quantities are distributed during the 24-hours.

Release of wastewater can be balanced or unbalanced per shift or day and night (depending on the type and technology). Some industries periodically discharge heavily contaminated and toxic water (once per shift, day and night or week).

Besides the change in quantity, we need to know the change of the composition and quality of the wastewater in an hour, day or week, as well as physical-chemical parameters and specific polluting components (toxic surfactants, radioactive, etc.). Figure 10.1 is a scheme for the balance of the water and wastewater disposal.

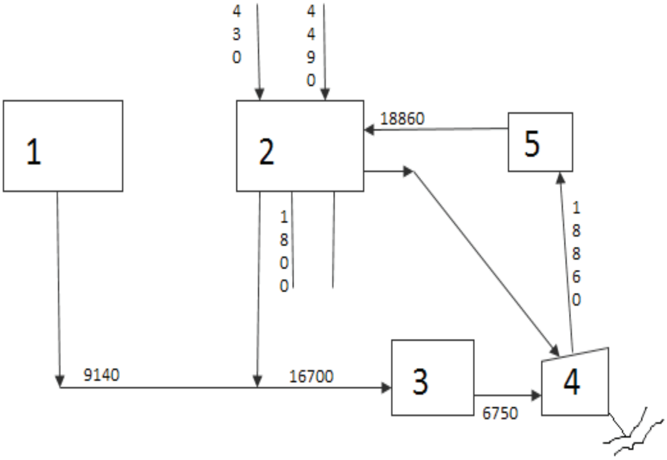


Figure 10.1 Example for balancing the need of water and wastewater disposal

1-Municipality, 2-Chemical plant, 3-Biological treatment plant, 4-Plant for additional treatment, 5-Cooling unit

10.3. Determining the necessary degree of treatment of industrial wastewater

To correctly determine the necessary level of treatment wastewater must receive prior to discharge, there has to be detailed data on the quantity and composition of wastewater, the type of recipient, the amount and degree of contamination of its water, hydrological data and more. Concentrations of polluted substances where water is used from the recipient should be smaller than the allowed value. The necessary degree of wastewater treatment is usually determined by the following key indicators:

1. concentration of suspended solids;
2. dissolved oxygen content of the recipient; and
3. BOD of mixed water (the recipient and wastewater),
4. pH - value of the water recipient,
5. the water temperature of the recipient,
6. toxic substances, smell, taste, colour...

Allowed concentrations of pollution in certain parameters in the inflow of sewage into rivers is determined by the equation:

$$q \cdot c_{tww} + a \cdot Q \cdot c_{prev} \leq (a \cdot Q + q) \cdot c_{alw} \qquad (10.8)$$

or

$$c_{tww} \leq \frac{a \cdot Q}{q}\left(c_{alw} - c_{prev}\right) + c_{alw} \quad [\mathrm{g/m^3}] \qquad (10.9)$$

Where:

C_{ww}- concentration of pollution for a given indicator in treated wastewater.

C_{prev} – the concentration of pollution in the same indicator in the water recipient (river) before the discharge of sewage (before the point of discharge), g / m3.

C_{alw} – allowed concentration of pollution for the same indication in the river water in the discharge of wastewater, depending on the category of the river g / m3.

a – the ratio of mixing is determined by the Rodsiler formula.

Q – average monthly discharge in the river in water at least 95% at the discharge point of wastewater m^3 / s,

q- average discharge of wastewater per hour, m^3 / s.

In the discharge of wastewater into stale recipients (ponds, lakes, seas), the allowed concentration of pollution is determined by the formula:

$$c_{tww} \leq n_T\left(c_{alw} - c_{prev}\right) + c_{prev} \quad [g/m^3]$$

Where n_T - ratio of total interference.

The necessary level of treatment is determined by the formula:

$$\eta = \frac{c_o - c_{tww}}{c_o} \cdot 100\%$$

In which c_o is the concentration of pollution in an indicator before wastewater purification, g/m^3.

10.4. Basic methods for treatment of industrial wastewater

There are two basic methods for treatment of industrial wastewater:

- regenerative,
- destructive.

Regenerative methods are applied to extract valuable substances. These methods include some physicochemical methods including ion exchanged and extraction.

Destructive methods break the pollutants and transform them into harmless water compounds through oxidation and reduction. The products formed as a result are separated as either gas or deposits, or remain in dissolved state. These methods include:

Biological treatment in aerobic and anaerobic conditions and methods of chemical treatment.

Treatment of wastewater depending on the level of pollution will be applied using the following methods:

1. mechanical,
2. chemical,
3. physical-chemical,
4. biological methods.

Mechanical treatment is the separation of undissolved impurities [through processes including] trickling, sedimentation, filtration and separation of dissolved impurities with cyclones and centrifuges.

Chemical treatment is applied when the separation of pollutants is possible only through a process of chemical reactions between pollutants and reagents added to wastewater. These methods include:

1. neutralization,
2. oxidation,
3. electrochemical oxidation.

Treatments based on physical and chemical methods are:

1. coagulation (flocculation),
2. absorption,
3. extraction,
4. evaporation,
5. flotation,
6. ion exchange,
7. crystallization,
8. dialysis,
9. inactivation,
10. deodorization, electrolysis
11. reverse osmosis.

Combination with other methods is possible and such methods include:

1. coagulation - absorption,
2. coagulation - flotation - absorption,
3. coagulation - ion exchange

Biological treatment methods include the following:

1. aerobic (pool with active sludge, biological filter, various procedures)
2. anaerobic (various techniques)...

10.5. Flow and Load Equalization

Equalization is the process by which operating parameters (e.g., flow, suspended solids, other pollutants and temperature) are made uniform within a given time frame (typically 24 hours) to reduce their downstream effects. While the timing of these spikes depends on the situation, a 30 to 60 minute interval is common. This could be made faster or slower, depending on the specific flow/load/temperature variation, sampling ability and on the measurement accuracy available.

When considering equalization in industrial pretreatment, the designer should include capital cost savings and operating stability as primary benefits. In situations where high flow peaks are common, equalization reduces the size of virtually all downstream systems in which flow rate is a design factor. This includes process pumps, piping and valves, biological and chemical reactor vessels, activated carbon vessels, sand filters and chemical feed systems. In situations where pollutant loadings spike, equalization will normalize these peaks with the same impacts on reducing the size and cost of downstream facilities.

The principal operating benefits of equalization are stable operations and consistent effluent quality. Hydraulic spikes can lead to:

- Carryover of solids in settling basins and DAF units;
- Unpredictable solids breakthrough in sand filters;

- Poor BOD and nitrogen removal and solids washouts from biological processes;
- Poor organics removal in granular activated carbon because of insufficient contact time; and
- Poor process control in chemical reactions because of the lack of chemical feed mixing and reaction times.

These are just a few examples of the effect of hydraulic spikes on industrial processes. In addition to operating effects, equalization will reduce the size and capital costs of downstream processes by reducing the peak flow rates that must be handled.

Equalization also reduces pollutant spikes. Pollutant load spikes (e.g., suspended solids; fats, oils and grease (FOG); ammonia; organic compounds; heavy metals; acids and alkalis; and temperature) can cause the following problems in industrial pretreatment operations:

- High effluent solids and FOG levels from settling basins and DAF units because of high influent solids loadings;
- Failure of biological systems because of low dissolved oxygen, toxic conditions, organic overload, and unacceptable pH and temperature levels; and
- Effluent violations because of upstream process failure.

Equalization is often required in industries with manufacturing or production variations that result in wastewater flow and load variations. Because these variations can cause serious difficulties in the performance of downstream treatment processes, they must be controlled and minimized. Typical difficulties caused by spikes in flow and pollutant loads of greater than 25% of the average daily value include:

- Hydraulic overload of downstream pumping and processing units;
- Solids carryover from sedimentation and flotation units;
- Difficulties in maintaining stable chemical feed systems and unit processes;

- Dissolved oxygen deficits in biological processes;
- High differential pressure across filtration units, requiring the premature backwash or the use of additional units; and
- Less contact time across activated carbon processes, reducing removal efficiency.

Industries that often require equalization include dairies, food processors, soft drink bottlers, chemical and petrochemical plants, pharmaceutical manufacturers, and industrial laundries. Large metal finishers with multiple streams at varying pH levels often use equalization to neutralize the streams before treatment. The need for flow equalization is determined primarily by the wastewater's potential effects on the industrial pretreatment facility or the POTW. This effect is determined by two key components:

- The variability of the operating parameters to be equalized (e.g., flow rate, pH, BOD, COD, ammonia, and toxicity); and
- The volume of the flow being discharged.

Defining the need for flow equalization requires sufficient background information on two factors, the relative cost of constructing and implementing effective flow equalization and the anticipated cost savings by reducing the size of downstream treatment processes.

There are three basic equalization processes:

- Alternating flow diversion;
- Intermittent or off-line equalization; and
- Completely mixed on-line equalization.

These processes can vary from unmixed to completely mixed, depending on the constituent to be equalized or controlled. For example, hydraulic equalization of flows without solids would not normally require mixing, while flows with significant levels of suspended solids, temperature or pH variations would benefit from mixing.

The *alternating flow diversion system* uses two or more basins (Figure 10.2). This approach is designed to collect the total effluent flow in one basin for a given period (typically 24 hours), while a second basin is discharging. The basins successively alternate between filling and discharging. The off-line basin's volume and pollutant characteristics vary throughout the fill process. Mixing should be provided so that when the off-line basin is ready for discharge, the contents have constant pollutant levels as the basin empties.

This type of equalization is often used with sequencing batch reactors (SBRs) which have two reactor basins. While this system provides a high degree of equalization, the land requirements and capital costs typically prohibit its use in industrial applications, except for two-basin SBR systems.

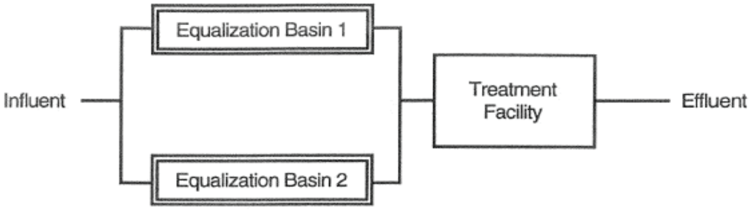


Figure 10.2 Alternating flow diversion equalization system

The *intermittent flow diversion system* is designed to allow any significant variance in wastewater parameters to be diverted to an off-line equalization basin for short periods (Figure 10.3).

The diverted flow is treated and bled back into the normal wastewater stream at a controlled rate. The rate at which the diverted flow is returned to the main stream depends on the diverted wastewater's volume and variance in addition to the level of treatment provided. Typically, the basin's contents would be sampled before discharge to determine the rate at which the basin can be emptied into the main process stream without harmful effects.

This type of equalization may be used when toxic or difficult-to-treat flows are anticipated as a result of certain plant operations. Industries that use this type of equalization include those with scheduled maintenance periods, refineries, metal-finishing operations with cyanide or hexavalent chromium batch operation and food and dairy operations during clean-in-place operations. High capital costs and land requirements make intermittent or off-line equalization unacceptable to many industries.

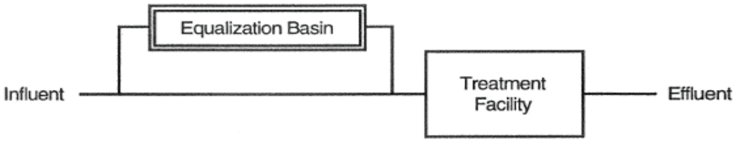


Figure 10.3 Intermittent flow diversion system

The *completely mixed equalization system* is designed to completely mix a single flow or multiple flow streams combined at the front end of the wastewater treatment facility (Figure 10.4) in an equalization basin that is on-line and receives flows continuously. This type of equalization is most often used by the industry. Completely mixed equalization can be used to reduce variances in each stream by thorough mixing with other flows. This system assumes that the flows are compatible and can be combined without creating more problems. This must be determined before using this system. For example, a metal-finishing operation should not equalize cyanide wastewater with acidic rinse water because toxic hydrogen cyanide gas would be generated. Instead, the cyanide waste should be segregated and treated first.

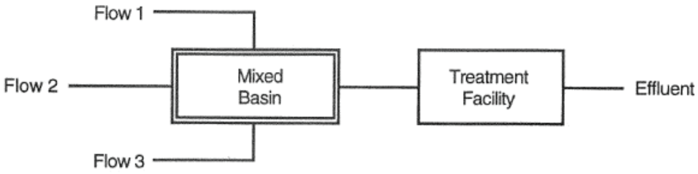


Figure 10.4 Completely mixed combined flow system

During the design of this equalization process, sufficient equalization capacity should be ensured. This is highlighted in an example of two different pumping controls in the same 750-m3 equalization tank (Figure 10.5).

In Situation A, with the pump start control set at elevation 590, all volume above the pump-start level represents *live storage.* This is the storage available when the influent flow rate exceeds the effluent flow rate. In such a case, the level rises at a rate of the difference in the inflow and outflow rates. All storage below the pump-start (300 m3) is *dead storage.* This is storage that does not handle higher inflows that can be pumped out of the tank by the existing pumps.

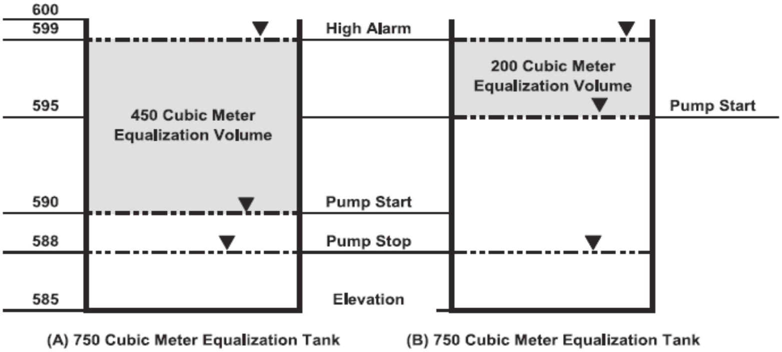


Figure 10.5 The pump placement's effect on capacity in a completely mixed equalization tank

In Situation B, with the pump start controls set higher in the same tank, the *live* storage volume available to equalize influent flows is reduced to 200 m^3. All storage below the pump-start (550 m^3) is dead storage, unavailable to equalize influent flows.

Therefore, within an effluent pump's suction requirements, lower pump-start elevations maximize a tank's equalization capacity.

10.6. Solids Separation and Handling

High suspended solids concentrations (more than 500 mg/L) can overload a POTW's grit chambers, primary sedimentation tanks and solids management processes. High levels of FOG (more than 150 mg/L) can accumulate in primary sedimentation tanks and biosolids digestion tanks, clog pumps and collector mechanisms, greatly reduce oxygen transfer rates in aeration basins and potentially lead to NPDES violations. FOG from refineries, industrial laundries or other manufacturers with petroleum-based products can cause toxicity problems in a POTW's biological processes.

High concentrations of settleable solids and FOG can also clog sewer lines and pumping-station wet wells. Besides being difficult and expensive to remove at this stage, these materials can cause objectionable odors if they are biodegradable. Suspended solids in industrial wastewater may be either organic or inorganic.

These solids are typically classified based on size and removal technique:

- Large solids at least 25 mm in diameter that will interfere with downstream flow and treatment operations;
- Grit and suspended matter such as sand, gravel, metal particles, plastic particulates, products of incomplete combustion, and other dense materials that settle more rapidly than organic solids;
- Settleable solids and materials with particles with diameters between 1 µm and 25 mm that settle out of wastewater during a standard Imhoff cone test; and
- Colloid particles with diameters between 10^{-6} and 10^{-3} mm (0.001 and 1 µm) and surface charges that must be neutralized to allow particle agglomeration, flocculation and settling.

Grit can enter industrial sewers via stormwater runoff and washing operations at pulp and paper operations, timber products-processing, food processing, chemical manufacturing, etc. Mill scale from steel-pickling operations has the characteristics of grit as it is an inorganic composition with high settling velocities. It is typically removed from wastewater using the same treatment processes.

Settleable solids and colloidal materials also may be organic or inorganic, depending on the process from which they originate. Dispersing agents (e.g., surfactants) may stabilize suspended solids, making them more difficult to remove. Such situations must be approached on a case-by-case basis. Chemical coagulation and flocculation with metal salts or synthetic polyelectrolyte are typically used to remove colloids.

Water and wastewater solids are called *residue*. The total residue is the material left after a sample has been evaporated and dried in an oven at a defined temperature. It includes both filterable residue and nonfilterable residue (the fraction that passes through the filter). Suspended solids are filterable residue; dissolved and colloidal solids are nonfilterable residue.

The amount of total suspended solids (TSS) is determined by filtering a sample through a defined filter medium, drying it in an oven, and then determining the residue's weight. The drying temperature is typically between 103 to 105 ^{0}C. Total suspended solids include both "fixed" and "volatile" fractions, which are determined by filtering the sample through a filter disk until 200 mg of residue are collected on the filter. The residue is dried, weighed and then ignited at a temperature of 550 ^{0}C. The weight of the residue after ignition is the fixed suspended solids fraction. The difference between the fixed and total suspended solids weights is the volatile suspended solids fraction.

Because of the high viscosity of sludge solids, its TSS and volatile suspended solids contents are determined by first calculating the total solids or total volatile solids for a particular sample. This will include both suspended and dissolved solids.

Suspended solids removal methods are chosen based on the initial concentration of solids in the wastewater, the desired final concentration, the size of the particles, settleability, thickening characteristics, and discrete or flocculent nature.

Jar and pilot testing of a specific waste stream are often necessary to determine its solids characteristics and compatibility with a particular treatment process. Techniques typically used to remove suspended material from waste streams with TSS concentrations less than 1% (10,000 mg/L) include straining, gravity separation and filtration.

10.7. Removal of Fats, Oil, and Grease

10.7.1. FOG Characteristics

Fats, oils and grease may be vegetable, animal, or mineral based. Fats are mixtures of various triglycerides (the glycerol esters of fatty acids). They are found in both plants and animals and are important components of the human diet. Chemists classify fats, oils and grease according to their average molecular weight and degree of saturation. Fats have low, nonspecific melting points which are lower when unsaturated fatty acid components predominate.

Oils are triglycerides that are liquid at room temperature. Common edible oils include cottonseed, palm, olive, corn, and soybean, while mineral oils include petroleum hydrocarbons (nonpolar FOG). Common fats are lard, tallow, and butter fat. Soaps are also included in typical FOG analyses. Soap is formed when animal fat or vegetable oil is boiled with sodium hydroxide to produce glycerine and sodium salts of fatty acids.

Waxes, which are the monohydroxylic alcohol esters of fatty acids, are much harder than fats at room temperature. Their biological function is typically to serve as a protective coating or structural material (e.g., beeswax). Natural waxes contain free acids, free alcohols, and some hydrocarbons. Waxes are included in typical FOG analyses.

Grease is a general classification for such materials as fats, oils, waxes, and soaps based on their physical (semisolid) forms or their effect on wastewater collection and treatment systems.

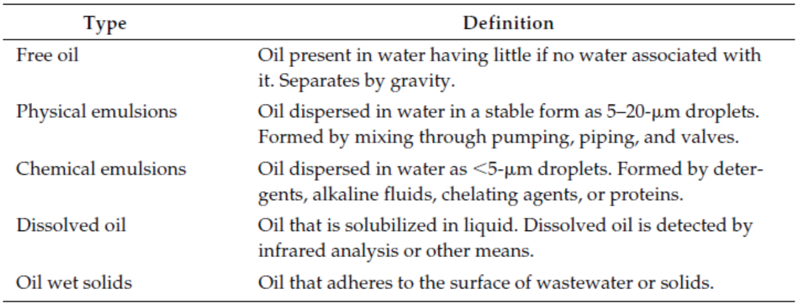
Many pretreatment programs require FOG control because industrial FOG can cause major problems at publicly owned wastewater treatment works (POTWs). FOG caused problems include:

- Blocked sewers;
- Excessive floating solids in pumping station wet wells;
- High scum concentrations in primary settling basins, causing carryover to downstream processes;
- Poorer performance of biological treatment processes;
- Coated multimedia and granular activated carbon filters;
- Difficulty thickening and dewatering biosolids; and
- Potential violations of NPDES permits, which prohibit discharges of visible oil sheens and floating solids.

Fats, oils, and grease are primarily regulated at the local level. Many sewer-use ordinances and WWTP discharge permits include FOG limits (either numerical or narrative).

Fats, oils, and grease may be present in wastewater either as free floating oil, in an emulsion or bound with solids (Table 10.1). Gravity will separate free-floating oils from water because their specific gravities are less than 1. Petroleum-based oils typically can be removed from wastewater by skimming them off the top of sedimentation basins. Such oils originate at refineries, petrochemical plants, steel manufacturers and industrial laundries.

Table 10.1 Types of oil in wastewater [8]



Type	Definition
Free oil	Oil present in water having little if no water associated with it. Separates by gravity.
Physical emulsions	Oil dispersed in water in a stable form as 5–20-µm droplets. Formed by mixing through pumping, piping, and valves.
Chemical emulsions	Oil dispersed in water as <5-µm droplets. Formed by detergents, alkaline fluids, chelating agents, or proteins.
Dissolved oil	Oil that is solubilized in liquid. Dissolved oil is detected by infrared analysis or other means.
Oil wet solids	Oil that adheres to the surface of wastewater or solids.

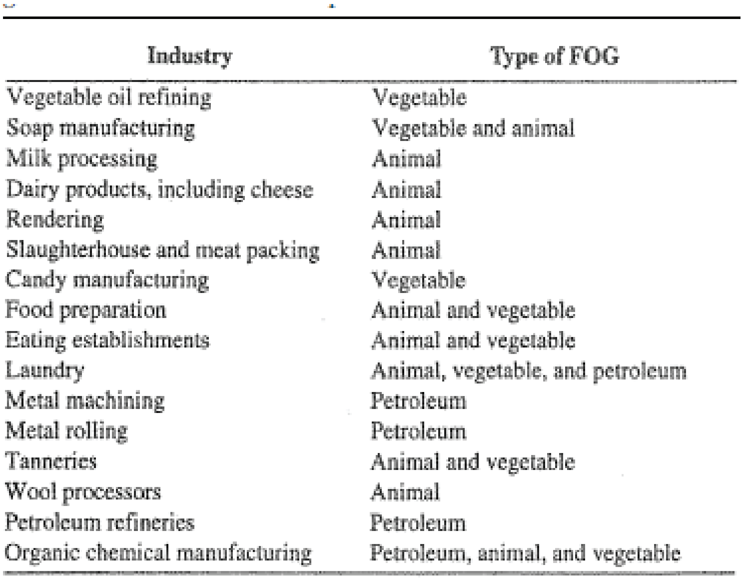
Emulsified oils are stable oil-water mixtures that typically will not readily separate by gravity without another influence (e.g., heat or de-emulsifying chemicals). Oil-water emulsions may be physical or chemical. Physical emulsions are mixtures of water and heavy oils or greasy materials which are typically insoluble in water and have been created mechanically (e.g., via high-speed, centrifugal pumping). They are less stable (more easily broken) than chemical emulsions and can be separated via heat or a coagulant [e.g., aluminum sulfate (alum)].

Chemical emulsions are typically found in metalworking fluids used to machine parts in the automotive and machine tool industries. These fluids are mixtures of immiscible liquids (mostly petroleum and mineral oils and water) that are stabilized by an emulsifying agent. To separate the oil and water, the emulsifying agent must be broken. This is often done with an acid salt (e.g., alum).

10.7.2. Sources of FOG

FOG typically averages 30 to 50 mg/L in domestic wastewater and represents as much as 20% of the organic matter measured as BOD. Industrial wastewater typically has higher FOG concentrations (Table 10.2).

Table 10.2 Industries that are major contributors of fats, oils, and grease to wastewater treatment plants [8]



Industry	Type of FOG
Vegetable oil refining	Vegetable
Soap manufacturing	Vegetable and animal
Milk processing	Animal
Dairy products, including cheese	Animal
Rendering	Animal
Slaughterhouse and meat packing	Animal
Candy manufacturing	Vegetable
Food preparation	Animal and vegetable
Eating establishments	Animal and vegetable
Laundry	Animal, vegetable, and petroleum
Metal machining	Petroleum
Metal rolling	Petroleum
Tanneries	Animal and vegetable
Wool processors	Animal
Petroleum refineries	Petroleum
Organic chemical manufacturing	Petroleum, animal, and vegetable

Potential sources of FOG in the food industry include meat processors and renderers, dairy processors, vegetable cookers and processors, edible oil producers, and nut and seed processors. Food-processing wastewater is largely due to cooking, cleanups (e.g., a cleanup shift) and changes in production (e.g., clean-in-place systems at milk producers). These flows often have high FOG concentrations and show significant variations in flow rate and pollutant concentration. Gravity separation, pH adjustment and coagulation are the most common types of FOG pretreatment in the food industry.

There are basically four types of metalmachining fluids (lubricants, coolants, and cutting oils):

- Straight oil (insoluble oils with little or no water);
- Soluble oils (oil-water emulsions);
- Synthetic metalworking fluids (an aqueous mixture of organic compounds); and
- Semi-synthetic metalworking fluids (a hybrid of synthetic metalworking fluid and soluble oil).

Oily wastewater can originate from various sources (e.g., machining plants, stamping plants, and machine shops). he metal pieces (i.e. from automobile manufacturing are frequently covered with machining fluids to cool and lubricate the cutting heads of the tools as well as to transport metal removed from the piece. Such fluids are settled or filtered to remove metal cuttings and then are typically reused. Metalworking wastewater consists of spent metalworking fluids, spent wash water, and spills. It is typically demulsified onsite before discharge to a municipal POTW.

Metalworking-fluid emulsions are typically treated by using an acid, an acid salt (e.g., alum) or a polymer to break the emulsion so oil and water can separate. Biological treatment would also de-emulsify such wastes. The treatment method depends on the metalworking fluid and is typically recommended by the fluid manufacturer.

Grease applied to metal surfaces for corrosion protection during storage and shipping can also end up in metalworking wastewater. Grease is typically removed via organic solvents or aqueous alkaline cleaning solutions. Vapor or immersion degreasing solvents (e.g., nonflammable chlorinated hydrocarbons or kerosene) can form emulsions or a floating film that may be toxic to microorganisms in POTWs. They also may be flammable or liberate toxic gases, so they cannot be discharged to public collection systems.

Petroleum refinery wastes include free and emulsified oil from leaks, spills, tank draw-off, etc.; chemical treatment-related emulsions; oil-laden condensate; water from distillate separators and tank draw-off; and oil-laden alkaline and acidic wastes and sludge. The combined refinery wastewater may contain crude oil, various crude oil fractions or suspended solids coated with oil, soaps, and waxy emulsions. Petroleum FOG also includes light hydrocarbons (e.g., gasoline and jet fuel); heavy hydrocarbon fuels; and tars (e.g., crude oils, diesel oils, lubricants, asphalt, and cutting fluids).

Other industries that typically generate significant amounts of FOG include industrial laundries, vehicle-washing facilities, iron and steel manufacturers, pharmaceutical manufacturers, aluminum can manufacturers and printed-wire board manufacturers.

10.7.3 Pretreatment techniques

In a pretreatment train designed to remove multiple pollutants, the FOG removal system should be installed as close as possible to the source to minimize the places where FOG can accumulate, and to reduce the size of downstream treatment units.

Emulsified FOG, however, stays in suspension and can be challenging to remove. To prevent free FOG from becoming emulsified, pretreatment system designers should avoid pumping oily wastewater (particularly with *centrifugal* pumps) wherever possible. When pumping is necessary, positive-displacement, *diaphragm* pumps should be considered to reduce the chance of creating physical emulsions. Designers also should avoid diluting FOG-laden wastes with non-FOG waste streams Before choosing a pretreatment process for emulsified FOG, system designers should characterize FOG and perform treatability studies.

There are two stages of FOG treatment. First-stage treatment separates free FOG from the waste stream. It removes fats, greases, and non-emulsified oils. Effective processes include gravity separation and gravity separation enhanced with coalescing media or parallel plates.

Second-stage treatment involves breaking emulsions and removing emulsified FOG. Emulsions can be broken via heating, distillation, chemical treatment and centrifugation, chemical treatment and pre-coat filtration, and filtration. Ultrafiltration also has been successfully used in cutting oil and fatty acid recovery systems. The most common second-stage system consists of gravity separation; chemical addition (e.g., alum, ferric sulfate, and ferric chloride); flocculation; and dissolved air flotation (DAF).

Gravity separators range from small packaged restaurant units to large industrial product-recovery systems. One first-stage treatment system is an oil interceptor (grease trap), which is used at commercial establishments with small, intermittent discharges of FOG (e.g., restaurants, hotels, and service stations). Grease traps are designed to collect and retain the FOG typically found in kitchens. They are installed in the drainage system between sink or floor drains and the building sewer and are readily accessible for cleaning and maintenance. Another first-stage system is a gravity separator with mechanical float removal and waste oil storage. It is used to treat industrial wastes from rendering plants, food processors, and oil refineries.

A gravity separator should provide enough area, quiescent conditions and time to allow the FOG to float out of the mixture. Because major flow changes will affect oil-removal efficiency, flow equalization may be required to avoid problems. If a steady flow is not anticipated because of other factors, the trap should be oversized to compensate for peak sustained flow rates.

When designing a gravity separator, the design engineer must consider the unit’s hydraulic capacity, the flow configuration and the ease and convenience of cleaning. The distance between the inlet and outlet should be adequate to prevent grease from escaping the trap via the outlet.

There are commercial devices that remove oil from wastewater by passing it through a medium with a large surface area. The medium, often called a coalescer, is typically an oleophilic plastic arranged in a honeycomb or parallel-plate configuration. This coalescing oil-water separator

(Figure 10.6) is typically best suited for fluid petroleum hydrocarbons with suspended solids concentrations less than 300 mg/L.

As oily water passes through the medium, the oil rises and coalesces on the underside of the plate. It then creeps up the side and ultimately rises to join the floating oil layer on the surface. The flow continues through another separation chamber before exiting the separator. The resulting larger oil globules are removed easily by gravity.

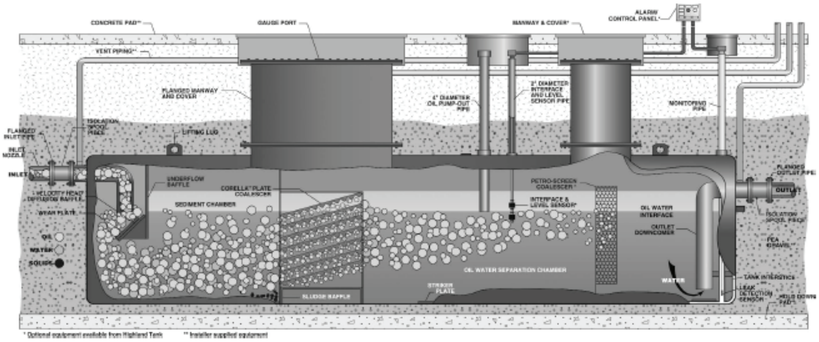


Figure 10.6 An illustration of a typical coalescing separator (Highland Tank Co.) [8]

The medium in the unit should be checked to ensure that it will not render the recovered oil unusable. If the captured oil is intended for human consumption or animal feed, the design engineer should ensure that the coalescer is a material approved by the corresponding Agency. Additionally, animal and vegetable oils, which are more polar than petroleum oils, may adhere to the plastic and foul the device.

Coalescing separators work best with light FOG loads and require more maintenance than simple gravity separators to keep the medium free of blockages. A number of coalescing separator manufacturers will size a separator based on flow data, oil type, and their own particular design. As a rule of thumb, a coalescing separator should be sized at an overflow rate approximately 0.762 $m^3/m^2 \cdot d$.

Emulsions are chemically treated to destabilize dispersed oil or destroy emulsifying agents. The process consists of rapidly mixing a coagulant with wastewater and then physically separating FOG from it via flocculation, flotation, etc.

The wastewater can be de-emulsified via coagulating salts (e.g., alum, polyaluminum chloride, ferric chloride and ferric sulfate); acids; organic polyelectrolytes; heat; or salts and heat.

Dissolved air flotation (DAF) is the physical separation process most often used to remove a chemically concentrated FOG. This process consists of pumping air into a waste stream under pressure and then releasing the air-charged stream to atmospheric pressure in a tank (Figure 10.7). The oil and small solids cling to the minute air bubbles and float to the surface, where they are removed via skimmers.

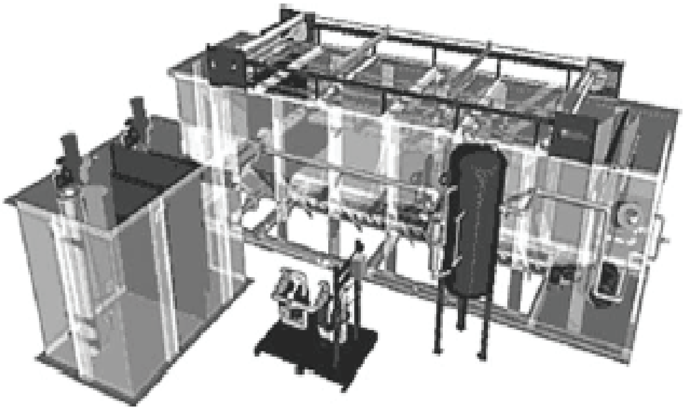


Figure 10.7 An illustration of a standard-rate dissolved air flotation unit (Ellis Corporation) [8]

When chemically generated floc particles do not separate well, a centrifuge can separate them more efficiently. Centrifuges require more maintenance and energy than other types of separators but can be used when space is limited or significant flows must be processed. Pilot testing is required to determine whether a centrifuge will remove the FOG effectively.

Centrifuges are typically used to process industrial sludges (including FOG removal) rather than industrial wastewater.

Hydrocyclones are an application of centrifuge technology that is becoming more popular at industrial facilities. They can be used to separate oil from heavier solids, oil from heavier water and even oil from heavier oil. Hydrocyclones rely on centrifugal force for separation, therefore needing less space than conventional oil-water or oil-solids separation techniques.

In a hydrocyclone system (Figure 10.8), fluid is pumped tangentially into the hydrocyclone. The hydrocyclone spins it to generate strong centrifugal forces that force the solid and liquid (or two immiscible liquids) to separate. The forces generated vary over the hydrocyclone's length. The heavier phase (e.g., water, heavier oil, or solids) is forced outward toward the wall of the hydrocyclone tube and down to the underflow. The lighter phase flows toward the center, where it forms a core and exits via the overflow. The typical detention time is 2 to 3 seconds. Other than pumping through the hydrocyclone, the process has no moving parts. Multi-hydrocyclone assemblies are used for higher flow rates.

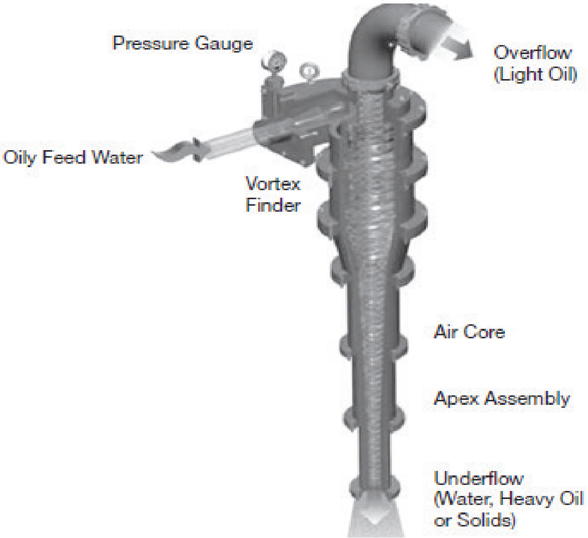


Figure 10.8. A schematic of a hydrocylone (FLSmidth Krebs) [8]

Hydrocyclones are typically used at refineries, offshore oil platforms, crude oil transfer facilities, vehicle washing stations, dairies, food processors, etc.

An ultrafiltration system uses a fine membrane to separate FOG from water and can treat emulsions as low as 0.005 μm. Ultrafiltration has been gaining popularity as membrane prices have dropped and works well for facilities that want to reuse water, recover the oil, or discharge directly to a receiving water rather than to a POTW.

In a typical ultrafiltration system (Figure 10.9), screened or filtered influent is pumped to the process tank. A pump forces the solution through the membrane, which separates the constituents. The permeate (clean water) is discharged, typically at atmospheric pressure. In a "cross-flow" configuration, the water that does not pass through the membrane is recirculated to the process tank and mixed with the influent. As the removed oil accumulates on the membrane, the differential pressure across the membrane rises and permeate throughput decreases. Once the membrane performance deteriorates to a prescribed level, the process is taken out of service and backwashed or chemically cleaned.

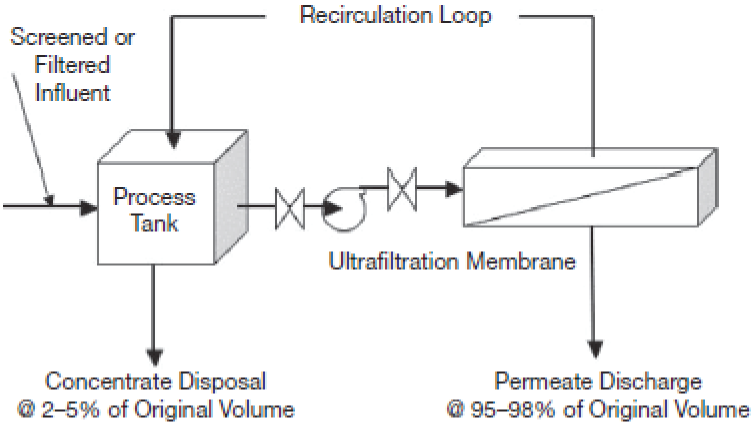


Figure 10.9 A schematic of an ultrafiltration process

Membrane filtration is typically preceded by gravity separation to reduce clogging and maintain a reasonable permeate throughput. Gravity separation may be followed by cartridge or bag filtration to reduce particle sizes to at least 5 µm.

Ultrafiltration breaks the oil-water emulsion but can only concentrate FOG, not remove it. Sometimes a gravity coalescing filter is used to remove the concentrated oil from the concentrate or reject stream. If this filter is impractical, the oil and water could be further separated via the addition of flocculants (e.g., alum and organic polymers). Also, heat can break oil-water emulsions at temperatures between 38^0 to 82^0C depending on the nature of the emulsion.

A major advantage of ultrafiltration is that the recovered FOG can be recycled or recovered. For example, it is currently used to recover machine oils in metalworking shops. The process's cost-effectiveness depends greatly on the value of the recovered material.

The disadvantages of ultrafiltration include high capital costs, pretreatment requirements and membrane cleaning and replacement costs.

The design of an ultrafiltration system is based on a number of factors, including the waste characteristics (e.g., oil content, salt content, suspended solids), other chemicals that may be incompatible with a membrane and other process conditions (pH, temperature, etc.) that may affect the process. Pilot testing is strongly recommended.

10.7.4. Options for using recovered FOG

There are many options for reusing FOG. For example, the oil recovered from edible oil refining, soap making, rendering, and meat processing can be salvaged and used in animal foods or diesel engines. Many restaurants collect the spent

FOG from frying vessels and sell it to rendering plants, where it is purified and then sold for industrial or animal feed use. Oil skimmed from gravity separators may be included or may be discarded with the restaurant's other solid waste and refuse.

Petroleum hydrocarbons with low water content can be used in refinery feedstock, reformulated for resale or sold on the fuel market. Likewise, waste oil from certain industries can be collected and sold to waste oil refiners. However, rising petroleum prices have made disposing such FOG less attractive.

There may be other uses for recovered FOG, depending on its pH and the type and percentage of oil, fat, waxes and foreign material present. To determine the potential marketplace, consult the industrial waste exchanges throughout the United States. Selling the FOG may help offset the process's operating costs.

10.8. Utilization of industrial wastewater and extracting valuable materials from them

When designing sewage and water treatment systems for industrial enterprises there are some basic questions that should be addressed:

- Possibility to reduce the amount and concentration of the wastewater;
- Maximum use of wastewater for industrial and other purposes without releasing them into the recipient; and
- Opportunities and ways extraction of valuable substances from wastewater.

Some kinds of industrial wastewater containing organic matter can successfully be utilized for irrigation. They are used alone or mixed with sewage water after previous specific treatment. Water from factories for starches, meats, fertilizers and tend to be the most suitable for irrigation.

Because of the high content of nitrogen, phosphorus and tin in these waters, their use for irrigation increases the fertility of the soil and agricultural yields by two to three times.

Wastewater from the mining industry contains a high percentage of minerals and is not suitable for irrigation because its nutrition is negligible and it contains toxic substances that can adversely affect the soil microflora. Moreover, high concentrations of substances disturb the soil structure.

Wastewater from leather tanning mills is dangerous regarding sanitation and its use for irrigation is not allowed.

Water with high concentrations of organic pollution in meat factories for example, should be diluted to some extent before use for irrigation. In some cases, they may require prior biological and mechanical treatment.

Water from starch factories and processing of fruits and vegetables becomes stale quickly, therefore it is diluted with lime. The utilization of wastewater for irrigation must be approved by the health authorities.

Wastewater from various industries may include metals, fats, chemical products, fibers, etc., which can be extracted through proper methods of extraction. Such extraction and re-utilization is an important process with positive economic impact.

From the wastewater that comes from factories for primary processing of wool, fat is extracted which is used to produce lanolin, a valued product for medical, electronic and other industries.

For extracting contaminants from wastewater, different methods can be applied: mechanical, physical-chemical and chemical.

10.9. pH Control

10.9.1. Introduction

Adjusting the pH of wastewater is one of the most common processes in an industrial pretreatment system. Because of various acids and bases used in industrial manufacturing, processing and cleaning operations, most facilities need to adjust the pH of their wastewater before discharging it to surface water or publicly owned treatment works (POTWs).

The optimum pH range is somewhat plant and process specific. For direct discharges, the effluent pH must be between 6.0 and 9.0 to protect the receiving water. For indirect discharges, the effluent pH must be between 5.5 and 10.0 to protect municipal collection systems from corrosion and POTW processes from upset or failure. If a facility's pretreatment system includes biological treatment processes, however, the wastewater's pH must be within a fairly narrow range, between pH 6.5 and 8.5, before entering the biological reactor. If the biological system is designed to nitrify, the optimum pH range is between 7.5 and 8.5.

These are the pH ranges typically used for biological treatment processes, however some processes operate effectively outside of these ranges. Also, the optimum pH range may change with differences in temperature, process configurations (e.g., batch processes versus continuous-flow processes) and technologies (e.g., aerobic treatment versus anaerobic treatment).

Acidic wastewater discharged into a collection system can trigger adverse chemical reactions. For example, when cyanide ions in wastewater come into contact with acidic industrial wastewater, the combination can produce a highly toxic hydrogen cyanide gas. Sulfides in wastewater may combine with acidic industrial wastewater to produce hydrogen sulfide gas. Both hydrogen cyanide and hydrogen sulfide are dangerous in low concentrations. In addition, hydrogen sulfide gas can be oxidized biologically to form sulfuric acid, which can corrode concrete pipes.

The term *pH*, which is used to describe a solution’s acidic or alkaline condition, is defined as the negative logarithm of the active hydrogen ion concentration ($[H^+]$) expressed in moles per liter:

$$pH = - \log[H^+]$$

or

$$pH = \log 1/ [H^+]$$

The pH scale runs from 0 to 14; the neutral point (pH = 7) is the pH of pure water at approximately 25 ^oC. Alkaline solutions have a pH above 7 and acidic solutions have a pH below 7. Because pH is a logarithmic function, a solution with a pH of 5 has 10 times more active hydrogen ions than one at pH 6. Similarly, a solution of pH 2 has 1000 times more active hydrogen ions than one of pH 5. A solution of pH 1 contains 1 $x10^{-1}$ mole/L of free hydrogen ions, while a solution of pH 13 contains 1 $x10^{-13}$ mole/L of free hydrogen ions.

The hydrogen ion concentration varies inversely to the free hydroxyl ion concentration $[OH^-]$ expressed in moles per liter, as noted in the following equilibrium equation:

$$[H^+][OH^-] = 10^{-14}$$

In a liter of pure water at 25 ^0C, approximately 1x 10^{-7} moles of water dissociate, producing identical concentrations of free hydrogen and hydroxyl ions. The negative logarithm of the hydroxyl ion concentration is called the *pOH.* The relationship between pH and pOH can be derived by taking negative logarithms of both sides to obtain:

$$pH + pOH = 14$$

Acids and bases dissociate in water, producing hydrogen and hydroxyl ions respectively. An acid is described as weak or strong depending on the number of hydrogen ions liberated when the acid is added to water. A base is also described as strong or weak depending on the number of hydroxyl ions liberated when the base is added to water. For example, nitric acid (HNO_3) is a strong acid because nearly all of its molecules dissociate in water to produce hydrogen ions and nitrate ions. Acetic acid (CH_3COOH), on the other hand, is a weak acid because its molecules dissociate very little, producing few hydrogen ions in aqueous solution.

If an acid is added to water, the concentration of hydrogen ions in the solution increases.

If $1*10^{-3}$ moles of a strong acid [e.g., hydrochloric acid (HCl)] are added to 1 L of pure water at pH 7, nearly all of the acid will dissociate, producing about 1×10^{-3} mole of hydrogen ions and a pH of about 3. If a base is added to water, it releases hydroxyl ions that react with the hydrogen ions to form water, thereby lowering the hydrogen ion concentration and raising the solution's pH. For example, if 1×10^{-2} moles of a strong base [e.g., sodium hydroxide (NaOH)] are added to 1 L of pure water at pH 7, the hydroxyl ion concentration will be about 1×10^{-2} moles/L (pOH = 2) and the pH will be about 12.

10.9.2. Acidity and alkalinity

Acidity and alkalinity are useful concepts for determining neutralization requirements. More than a pH measurement is required to adequately determine how much base is needed to neutralize an acid or how much acid is needed to neutralize a base [8]. In a nitric acid solution (strong acid), almost all of the acid's hydrogen ions are quantified by the pH measurement because the hydrogen ions are nearly completely dissociated. In an acetic acid solution, however, the acid's ions are available as both hydrogen ions and acetate ions (CH3COO–).

As free hydrogen ions combine with an added base's hydroxyl ions to form undissociated water, more of the acetic acid will dissociate to maintain the hydrogen ion concentration that existed when the solution was at equilibrium. Therefore, a pH measurement alone will not indicate how much base must be added to neutralize the acetic acid solution.

A strong acid solution may have a lower pH than a weak acid solution, even if equivalent amounts of acid were used to prepare both solutions. However, the total acidity of both solutions will be identical and equal amounts of a base will be required to neutralize the two solutions. Conversely, a dilute solution of a strong acid and a concentrated solution of a weak acid may have the same pH, but will require different doses.

Acidity is the measure of a solution's capacity to neutralize a strong base (e.g., NaOH) to a designated pH. It is expressed as an equivalent amount (in milligrams per liter) of calcium carbonate ($CaCO_3$). Acidity is a gross measure; it can be interpreted in terms of specific dissolved substances only when the solution's chemical composition is known. Strong mineral acids [e.g., sulfuric acid (H_2SO_4)], weak acids [e.g., carbonic (H_2CO_3) or acetic acids], and metal salts (e.g., ferrous or aluminum sulfate) contribute to a wastewater's measured acidity.

Alkalinity is the measure of a solution's capacity to neutralize a strong acid (e.g., H_2SO_4) to a designated pH. Like acidity, alkalinity is expressed as an equivalent amount (in milligrams per liter) of calcium carbonate. It is a gross measure and can be interpreted in terms of specific substances only when the solution's chemical composition is known. The alkalinity of many wastewater is primarily a function of their carbonate (CO_3^{-2}), bicarbonate (HCO_3^{-}), and hydroxide equilibria. The alkalinity is taken as an indication of the combined concentrations of these constituents (it may also include contributions from borates, phosphates, silicates, and other anions).

10.9.3. pH Measurement principles

A pH measurement device has three components: the pH sensor or probe, which includes a measuring electrode, a reference electrode and a temperature sensor; a preamplifier; and an analyzer or transmitter. The sensor components are typically combined into one probe. The measuring electrode is typically made of glass, however, recent developments have replaced glass with more durable solid-state sensors.

A glass measuring electrode has a pH-sensitive glass bulb at the end and a silver chloride wire in the center, which is surrounded by a potassium chloride (KCl) electrolyte solution. The reference electrode typically is a chamber that surrounds the measuring electrode. It contains a silver chloride wire surrounded by an electrolyte solution of potassium chloride saturated with silver chloride. A porous liquid junction in the reference electrode allows the electrolyte solution to make physical and electrical contact with the liquid being monitored and develop a potential (voltage) that the electrodes can measure [8].

The measuring electrode, which is sensitive to the hydrogen ion concentration, develops a potential directly related to that concentration. The reference electrode provides a stable potential for comparison. When immersed in a solution (e.g., wastewater), the reference electrode's potential remains constant, while the measuring electrode's potential changes in proportion to the hydrogen ion concentration.

10.9.4. Selection of neutralizing agents

The first question to answer is whether a base or acid (or both) will be needed to control pH. Both are often needed, especially when the waste stream characteristics are highly variable and the target pH range is narrow.

An economic evaluation of neutralizing agents should include several alternatives. For example, an acidic wastewater's pH can be raised by either a strong or weak base. The strong base will require a lower dose, but its reactions may be difficult to control within a narrow pH range. Also, the strong base may cost more per unit than the weak one. The overall chemical cost is a function of both the unit cost and the required dose. Related labor and maintenance costs must also be evaluated to compare total operating costs for each chemical.

When evaluating chemical costs, one appropriate comparison is the cost to provide a unit of alkalinity or acidity for each chemical. The following equation can be used for this evaluation:

$$C_{alk}/_{acid} = (C\text{bulk})(\text{EW})/[(P\text{bulk})(\text{EWCaCO}_3)]$$

Where

Calk/acid = cost per unit weight of alkalinity or acidity (as $CaCO_3$),
Cbulk = cost per unit weight of bulk chemical,
EW = equivalent weight of chemical,
Pbulk = fractional purity of bulk chemical,
EW_{CaCO_3} = equivalent weight of calcium carbonate =50.

The installation costs should include chemical storage tanks and buildings, pumping/metering equipment, construction materials, safety considerations and required instrumentation for process control.

The reaction time will affect the number, size and mixing requirements of the pH-control vessels. The system controls will also be affected by the reaction time.

The concentration of dissolved solids produced during neutralization depends on the type and amount of chemicals used.

The amount of solids generated during neutralization is typically a function of the wastewater’s composition, the reagent(s) and the wastewater’s final pH. Precipitated solids must either be discharged to downstream treatment processes (or a POTW) in suspended form, removed, processed or disposed.

Some chemicals must be handled with more caution than others. Any precautions needed to reduce skin contact, accidental eye contact and vapor inhalation should be considered during the selection process. The quantity of chemical(s) required affects storage and secondary containment requirements, which may raise other safety considerations.

Depending on the type and usage rates of the selected pH-control chemicals, these chemicals may be delivered in dry or liquid form. Dry forms include powdered and granular chemicals that must be wetted, mixed and stored in liquid form. Dry chemicals may be shipped in bags weighing up to several hundred kilograms, which are manually emptied into chemical mixing equipment or contained in “supersacks” that must be hoisted to a rack for emptying into the conveying equipment. Liquid chemicals may be delivered in drums, totes, truckloads, or railcars.

The type and quantity of chemicals selected determines the facilities required to receive, unload, store and deliver it to the pH-control system. Other chemical handling and storage issues include safety, freeze protection, dust control, construction materials and chemical-specific handling systems. For example, carbon dioxide is typically delivered by the truckload in liquid form and stored at low temperatures in a pressure vessel. A vaporizer is used to evaporate the carbon dioxide in gaseous form and this gas may then be added to wastewater via a gas-diffusion system.

The following bases are typically used to neutralize acidic wastes.

Lime is typically used to neutralize acidic wastewater because it is widely available and relatively inexpensive. The types of lime and limestone materials used to neutralize acid wastes include:

- High-calcium hydrated lime (slaked lime); and
- Calcium oxide (quicklime or unslaked lime)

Each form has a different reaction time, which will affect the size of neutralization tanks and therefore, the capital costs. Some also have a significant percentage of inert materials, which add to the quantity and type of solids produced.

Lime compounds dissolve and react slowly because they need relatively long contact times and high mixing power levels to function effectively. Their principal disadvantages are solids and scale production because of the formation of insoluble calcium salts, lime dust and its products, which is a nuisance and potential health concern. Solids must be removed via a clarifier or quiescent pond, dewatered and then disposed.

Limestone is typically one of the least expensive options for basic reagents. When used in beds through which the waste stream passes, it produces carbon dioxide which tends to gas-bind the beds. When limestone is used to neutralize sulfuric acid wastes, a calcium sulfate coating will likely form on the bed material and must be removed via mechanical agitation. Limestone reaction times may be 1 hour or longer, depending on the quality and size of the stones and the bed must be periodically replenished to maintain process effectiveness.

Sodium hydroxide (NaOH), also called *caustic soda*, is available in both solid and liquid forms. However, anhydrous NaOH is considered impractical in wastewater treatment applications because of safety concerns associated with its handling and dissolution. Because of this, the following discussion pertains to liquid NaOH.

Caustic soda is typically expensive but offers numerous advantages in capital, operation and maintenance costs when compared to lime and other bases. It is a strong neutralizing agent and reacts rapidly, thereby reducing tankage requirements. It is also a “clean” chemical to store and handle and it generates significantly less solids than lime-based compounds. Also, the sodium salts formed via caustic soda are highly soluble, therefore solids sedimentation is often not required after pH adjustment.

Caustic soda typically is co-produced with chlorine and because the chlorine supply and demand varies by region, making the price and availability of caustic soda potentially volatile. Other disadvantages of caustic soda include health and safety concerns as it is harmful to lungs and unprotected skin and a slipping hazard if spilled. Also, an overdose of caustic soda can rapidly raise a wastestream’s pH to more than 12 or higher, which can be a corrosively hazard.

A salt of weak carbonic acid (H_2CO_3), sodium bicarbonate ($NaHCO_3$)—also called *baking soda*—is a highly effective buffering agent. Because it is nearly pH neutral, it is quite useful for adding either alkalinity or acidity, acting primarily as a buffering agent. It is particularly effective for pH control in anaerobic biological treatment systems.

Sodium carbonate (Na_2CO_3; soda ash) has fewer and less extreme handling precautions than caustic soda and is less expensive than sodium bicarbonate. However, it typically is a less-effective neutralizing agent than either NaOH or $NaHCO_3$. Soda ash is a moderately fast-acting neutralizer, but it generates carbon dioxide which may cause foaming problems. Because of its low solubility in water, soda ash is most economically fed in slurry form in the same manner as hydrated lime.

Magnesium hydroxide [$Mg(OH)_2$] is a weak base that is relatively safe to handle and, unlike lime and caustic soda, is endothermic when dissolved in water. The chemical is very basic but does not react as rapidly as lime or caustic soda. Its solubility is low at ambient temperatures and decreases as the temperature rises. It also becomes insoluble at a pH of approximately 9.0, so an overdose will not make the wastewater's pH excessively high. Magnesium hydroxide is gaining acceptance as a cost-effective alternative for neutralizing acidic streams, especially when dissolved metals must be removed. It typically produces a low-volume metal hydroxide sludge, however this material can be more difficult to dewater than one generated via lime.

The following acids are typically used to neutralize alkaline wastewater.

Sulfuric acid (H_2SO_4) is the chemical most commonly used to neutralize alkaline wastewater. It is economical and requires conventional materials for storage and feeding under most conditions. However, special safety materials and handling precautions are needed because of its corrosiveness. If the wastewater contains high concentrations of sodium or calcium, the reaction will also produce soluble sodium salts or insoluble calcium salts, respectively. Under anaerobic conditions, the sulfate ion ($SO4^{2-}$) can be reduced to sulfide and then form hydrogen sulfide (H_2S), a corrosive and dangerous gas that tends to accumulate in collection systems. Under aerobic conditions, sulfide can be biologically oxidized back to sulfate and then form weak solutions of sulfuric acid that may corrode concrete pipes.

Compressed carbon dioxide (CO_2) gas has become fairly common for neutralizing alkaline wastewater. When dissolved in wastewater, CO_2 forms carbonic acid (H_2CO_3), a weak acid that reacts with alkaline wastes to lower the pH. Neutralization with CO_2 is most cost-effective when used to "fine tune" the wastewater's pH in a two or three stage neutralization process or when only minor pH adjustment is required. Depending on its availability, the use of flue gas to neutralize alkaline wastewater may be an economical method of CO_2 addition. The flue gas typically contains about 14% CO_2 and the neutralization principles are the same as those for compressed CO_2 gas.

Other acids (e.g., hydrochloric, nitric, and phosphoric acid) can neutralize alkaline wastewater in certain situations, but they are typically more expensive and difficult to handle than H_2SO_4.

10.9.5. Design of pH control systems

A pH-control system should consistently adjust the wastewater's pH to stay within acceptable permit or process-control limits. To do this, the system must:

- Add the proper amount of acid or base to the wastewater,
- Adequately mix the wastewater and the pH-control chemical(s),
- Provide enough time for the neutralization reaction to reach equilibrium or near-equilibrium conditions.

Nearly all wastewater varies over time, so the pH-control system must be able to measure the wastewater's pH and control the amount of chemical added to reach the target pH. Designing pH-control systems is complicated because pH is a logarithmic function of the hydrogen ion concentration. For example, let's say that adding *x* amount of base to a strong acid solution with a pH of 2 will increase the solution's pH to 3. Then, to increase the pH to 4, only approximately 10% of the original dose (*x*) may be required. Only 1% of *x* will be needed to increase the pH to 5 and only approximately 0.1% of *x* is required to reach pH 6. Therefore, adjusting a waste stream from pH 2 to 7 can be a difficult control problem. A large quantity of base may be required before any measurable change in pH is produced, but as the pH increases, the rate of pH change also increases until the solution reaches an equivalence point, which depends on the wastewater's composition.

Then, the rate of change decreases. To control pH precisely, an accurate and responsive control system is required. Neutralization-system designers must consider the effects of variations in wastewater flow rate, pH and buffering capacity. An industrial wastewater's pH often varies significantly over time (minute to minute, day to day, and month to month). Some wastewater (e.g., food-processing wastewater with both basic and acidic cleaning chemicals) can vary from 2.0 to 12.0 pH in a matter of minutes.

If a wastewater's pH varies significantly, an equalization process can reduce the necessity and size of the pH-control process. Equalization is often used in wastewater treatment to dampen variations in wastewater characteristics [e.g, flow, suspended solids, or biochemical oxygen demand (BOD)] and such equalization processes have relatively straightforward designs because these characteristics are typically conservative under normal conditions. However, pH is not a conservative substance, but a result of multiple complex chemical equilibria, which may change rapidly and significantly. A pH change of only two standard units (e.g., 2 to 4) represents a 100-fold change in the wastewater's hydrogen ion concentration. Other wastewater parameters rarely have changes of this magnitude.

Many industries generate both acidic and alkaline wastewater. Others only generate acidic wastewater, but may have neighbors that generate alkaline wastewater. When acidic and alkaline wastes are generated simultaneously or at neighboring locations, combining them can be a cost-effective neutralization method. Each waste may need its own storage tank so the wastewater can be blended at the proper ratios and slugs of acid or alkali can be avoided. Provisions should also be made to supplement the weaker waste stream, which may not be able to completely neutralize the stronger one.

Before blending waste streams from multiple facilities, however, design engineers should evaluate their overall compatibility by reviewing related material safety data sheets, contacting chemical suppliers and analyzing each flow. They should be particularly careful about blending a nonhazardous waste stream with a hazardous one, because any resulting solids must be handled and disposed as a hazardous waste in compliance with regulations. Also, if one waste stream will need more treatment (e.g., biological treatment), combining the wastewater may be undesirable because of the effects on downstream processes including sizing and other considerations.

The two main types of pH control systems are batch and continuous-flow systems. The major differences between the two systems are the control systems used and the hydraulic controls into and out of the pH-control vessel(s).

Batch pH-control processes are typically used at plants with intermittent or low volumes of wastewater. A maximum flow of 190 to 380 m3/d is often cited as applicable for batch control systems, though much larger batch-control systems have been successfully installed. Batch pH-control systems are typically simpler than continuous-flow systems and can be more reliable because each batch of wastewater can be adjusted to a target pH before being discharged.

Batch systems typically include multiple pH treatment vessels or a large equalization or holding tank upstream of a single batch tank (Figure 10.10). Because of the nature of the process, wastewater is typically pumped to the pH-control vessel. Control valves on the inlet side of the control tanks are used to determine which tank receives influent. Control valves on the tank outlets are used to discharge neutralized wastewater via gravity to downstream processes or a municipal collection system. A typical batch system design also includes tank level controls, pH-monitoring equipment, chemical-addition equipment and mixing equipment in the batch tanks.

Wastewater is pumped into one of the control tanks until it reaches a predetermined level. Depending on the raw wastewater's pH, the neutralizing chemical may be added during the filling period or after the tank is full. The neutralizing chemical is added until the target pH is reached. Once the target pH has been maintained for a period of time, the neutralized wastewater is discharged.

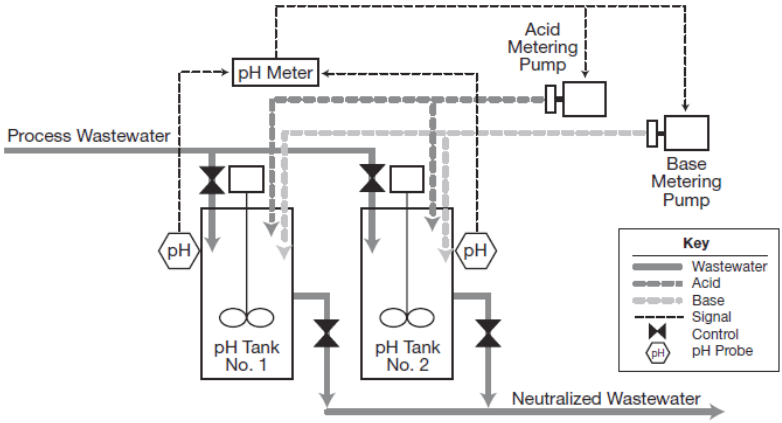


Figure 10.10 A batch pH control system schematic [8]

As one of the main advantages of a batch pH control system is its simplicity, the equipment and control systems should also be simple. Liquid control chemicals (e.g., sulfuric acid or caustic soda) typically are used for batch systems. Because the wastewater volumes are relatively low, the chemical use rate is typically minimal and chemical costs are rarely taken into consideration when selecting a chemical. The pH-control chemical typically is stored in a liquid-chemical storage tank and electronic or motor-driven metering pumps deliver it to the batch neutralization tank.

Continuous-flow pH control systems are typically used when the flow rate to be neutralized is more than about 380 m^3/d, though much smaller systems have been implemented. Continuous-flow systems typically require a more sophisticated pH monitoring and control system to consistently meet the effluent pH target.

Continuous-flow systems may consist of only one pH control vessel or have two or three tanks operated in a series (Figure 10.11). The number of tanks depends on the degree of pH adjustment required, the wastewater's buffering capacity and the target pH range. For wastewater with average buffering capacity that requires minimal pH adjustment, one tank may be enough. For widely variable wastewater, or wastewater requiring a large change in pH (e.g., from 2 to 7), multiple tanks are typically used. In this case, pH is grossly adjusted in the first tank and then "fine-tuned" in the second and subsequent tanks to meet the target. Each tank will typically have an independent pH-monitoring and chemical-addition system.

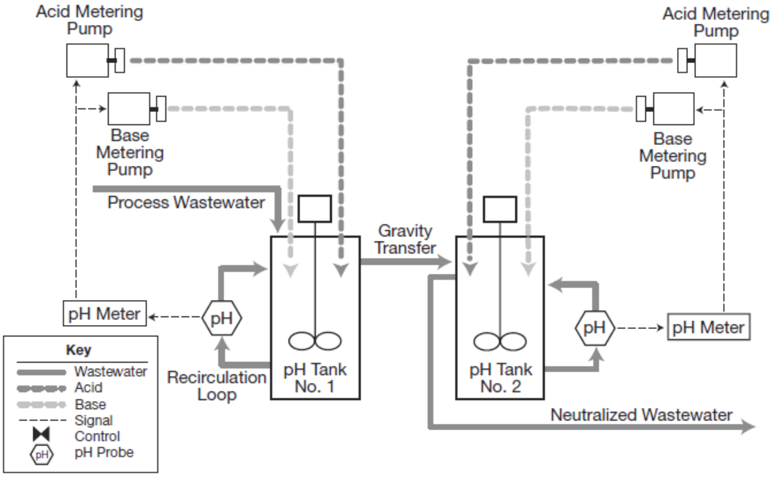


Figure 10.11 A continuous-flow pH control system schematic (two-stage) [8]

The target pH level in each tank can be approximated via titration curve analyses (Figure 10.12). In the first tank, the wastewater's pH is adjusted to the point at which the wastewater's buffering capacity has been nearly exhausted and adding more chemical would cause the pH to change rapidly. In the second tank, smaller amounts of pH-control chemical are added until the target pH level is reached.

Depending on the site and wastewater hydraulics, continuous-flow systems may be able to flow via gravity. More likely, however, a pumping station will be needed to lift wastewater to the first tank, after which the wastewater flows via gravity to the downstream tanks. Automatic control valves are typically unnecessary because the wastewater continuously flows in and out of the tanks.

Chemical storage and delivery systems may be similar to those used for batch-control systems. However, because continuous-flow systems are typically used for large wastewater flows, dry chemicals (and their associated mixing and delivery systems) may be less expensive than liquid ones.

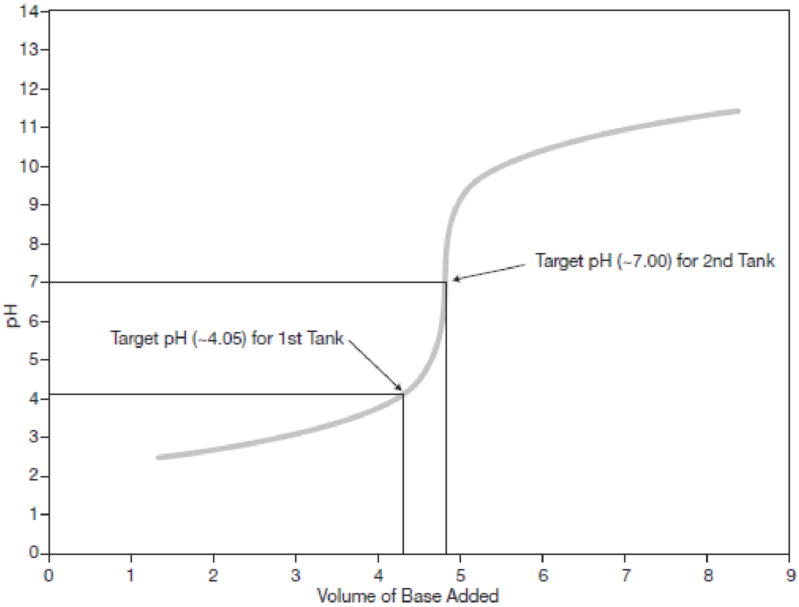


Figure 10.12 Two-stage pH control using titration curves [8]

A pH-control system's hydraulic detention time is calculated as the volume of the pH-control vessel(s) divided by the influent flow rate. The required detention time is a function of the neutralization reaction rate and the type and intensity of mixing provided. So, the pH-control vessels must be large enough to effectively control the wastewater's pH under the highest anticipated flow rates and the range of pH levels. Therefore, wastewater variability must be carefully determined before designing the system.

Minimum hydraulic detention times typically are set at 5 to 10 minutes less than worst-case conditions. Under average wastewater conditions, a hydraulic detention time of 15 to 30 minutes is common. For highly variable wastewater discharges, hydraulic detention times of 1 to 2 hours or more are used.

The hydraulic detention time is also depends on the pH-control chemical used. Liquid chemicals typically should have at least 5 minutes to neutralize wastewater. Solid chemicals (including slurries) may need at least 10 minutes. If dolomitic lime is used, the required detention time is as much as 30 minutes

For optimum mixing efficiency, a cylindrical reaction vessel's depth should be about equal to its diameter. A square tank should be approximately cubic (depth, width, and length should be equal). In continuous-flow systems, the inlet and outlet should be at opposite sides of the reaction vessel to reduce short-circuiting.

The reagent may be added at the reaction vessel inlet, to the influent before it enters the vessel or to a side stream-recirculation loop if a pump-based mixing system is used. If a vertical-turbine mixing system is used in a cylindrical tank, two or more wall baffles should be added to the tank to avoid a whirlpool effect. The baffle width typically is one-twelfth to one-twentieth of the tank's width. Square tanks provide for better mixing without the need for baffles.

10.10. Ion exchange

A significant disadvantage of the neutralization and subsequent precipitation process in conventional metal-finishing industries is that the facilities use a number of plating lines with different metals and batch dumps, causing significant variations in the waste streams. Even if the waste streams are equalized, finding an optimum pH for treatment is difficult and may change occasionally. In addition, the large quantities of hazardous materials (metals) involved make conventional neutralization processes less desirable than other technologies that produce less solids.

Given these factors and the rising cost of potable water, many metal finishers (both platers and printed-circuit-board manufacturers) have turned to other treatment technologies (e.g., ion exchange, activated carbon, membrane filtration, electrodialysis and evaporation) with higher metal removal rates and lower solids volumes. These technologies also produce reusable water, thereby reducing a facility's need for access to potable water. Most of these technologies are widely used to remove or recover metals in locations where recovered material benefits are high or local pretreatment standards are strict.

In the ion exchange process, a resin exchanges certain of its ions (e.g., sodium or hydrogen) for other ions with a similar electrostatic charge (e.g., metals dissolved in wastewater). Ion exchange can remove both cations (e.g., metals) and anions (e.g., nitrates and sulfates) from wastewater.

Figure 10.13 is a simplified schematic of an ion exchange process intended to remove heavy metals and nitrates. In the example, the positively charged metal ions are exchanged with hydrogen or sodium ions in the cation exchange column(s) and removed, leaving the anionic nitrate ions in the waste stream. The negatively charged nitrate ions are then exchanged for hydroxyl (OH-) ions in the anion exchange column.

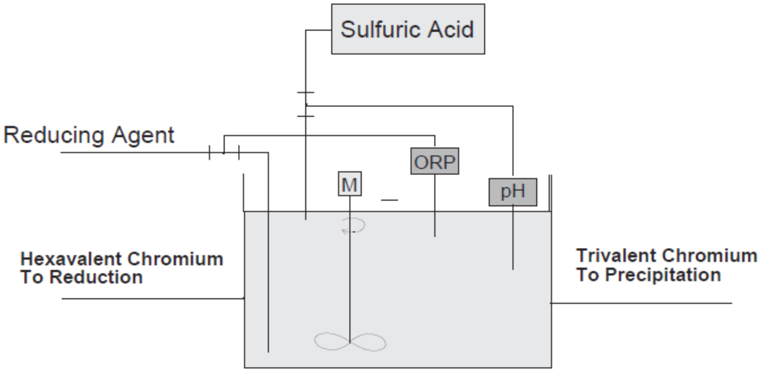


Figure 10.13 A schematic of a typical hexavalent chrome reduction system

When all or most of the resin's ions have been exchanged, it must be taken offline and regenerated. Cation exchange resins are typically regenerated by soaking them in an acid solution, which removes the metals and replaces them with hydrogen ions. Anion exchange resins are regenerated by soaking them in an alkali (e.g., sodium hydroxide), which removes the metals and replaces them with hydroxyl ions.

Increasingly, ion exchange resins are designed to target specific pollutants to improve pollutant removal efficiency while reducing regeneration requirements. Suspended solids, FOG, organics and high levels of total dissolved solids can interfere with ion exchange performance, increasing resin cleaning and regeneration/replacement frequency. Pretreatment is typically required upstream of an ion exchange system. Before ion exchange occurs, sedimentation and/or filtration are used to remove suspended solids and FOG while granular activated carbon treatment is used to remove high levels of organics. High levels of dissolved solids may require more ion exchange units to guarantee the desired removal efficiencies for chosen pollutants.

Ion exchange systems must be pilot-tested before implementation to determine the effects of competing ions and other interferences. Resin manufacturers typically perform or help with such testing. They can recommend specific resins, wastewater pH levels, regenerants and specific pretreatment requirements that will optimize system performance.

When designing ion exchange columns, the general hydraulic loading rate is approximately 235 to 350 m3/m2•d. Resin bed depths are typically 0.9 to 1.8 m. The resins are chosen based on the various ions present and design engineers should coordinate with the resin manufacturer to determine the optimal resin, projected performance, and expected regeneration rates.

Ion exchange is often used to recover precious metals (e.g., gold, silver, and platinum). Many photographic labs recover silver by passing the film-developing wastewater through ion-exchange columns and collecting the silver in the regenerating solution. Ion exchange also removes ionic mercury effectively.

Three types of resin are typically used for metals removal: a strong acid cation resin, a weak basic anion resin, and a strong basic anion resin (for cyanide and fluoride removal). For this treatment process to be effective, design engineers must understand the "order" in which metals are removed (Table 10.3), particularly if the wastewater contains a number of metals. The cations and anions at the top of the table are removed preferentially to those below them in the table.

Table 10.3 Order of cation and anion removal by ion exchange in order of decreasing preference [8]

Preference	Cation	Anion
↘	Barium	Phosphate
	Lead	Selenate
	Calcium	Carbonate
	Nickel	Arsenate
	Cadmium	Selenite
	Copper	Arsenite
	Zinc	Sulfate
	Magnesium	Nitrate
	Potassium	Bisulfite
	Ammonia Sodium	Chloride
	Hydrogen	Cyanide
		Bicarbonate
		Hydroxide
		Fluoride

Inorganic arsenic occurs in arsenite and arsenate forms. Before considering treatment for arsenic, the wastewater should be tested to determine which forms are present and in what quantities.

Arsenite is not readily removed by ion exchange. However, it can be oxidized by chlorine or other oxidants into arsenate, which can then be removed by ion exchange. Strongly basic anion exchange resins, which are regenerated by sodium salts, readily remove arsenate. Newer ion exchange products eliminate the need for regeneration, but require periodic resin replacement and proper disposal of the spent media. If the wastewater contains iron and sulfates as well as arsenic, the resin's exchange load and its regeneration frequency will increase.

The most common forms of selenium in water are selenite and selenate. Selenate (Se^{+6}) is much easier to remove via ion exchange than selenite (Se^{+4}). Before choosing a treatment approach, design engineers should determine which selenium form(s) are present and in what quantities. An oxidant (e.g., chlorine, sodium hypochlorite, or hydrogen peroxide) may be used to convert selenite to selenite before the ion exchange process. Strongly basic anion exchange resins are typically used to remove selenite. However, iron and sulfates will increase the resin's exchange load, so if they are present in the wastewater a different resin may be needed to focus on selenate removal.

Ion exchange systems treat ammonia effectively. The choice of resin depends on the other cations and anions in the wastewater that may interfere. Many ion exchange systems designed for ammonia use clinoptilolite, a naturally occurring zeolite that is highly selective for the ammonium ion. It is regenerated with salt or caustic soda, which strips ammonia easily, allowing the solution to be reused.

The optimum operating pH range is between 6 and 7, but ammonia removal is effective within the pH range of 4 and 8.

Outside of this range, the ammonia exchange capacity drops and ammonia leakage increases, leading to breakthrough. When the pH is above 9, the ammonium ion volatilizes and becomes ammonia gas, which is not removed via ion exchange.

Ammonia can also be removed by strong-acid cation exchange resins. These resins exchange sodium for ammonium ions and are regenerated via a strong acid. Virtually all nitrates are soluble and cannot be treated via neutralization or precipitation, but they can be removed via ion exchange. A strong-base anion resin is typically used; however, it will attract sulfates even more readily than nitrates (Table 10.3). This can be a capacity problem for nitrate removal if sulfate levels are high, so more selective nitrate resins should be used when this is the case. Both resins are regenerated with sodium or calcium salts.

Ion exchange systems remove radioactive materials (e.g., uranium, radium, actinium, thorium, and protactinium) from wastewater effectively. However, removing and transporting spent radioactive media from the site may require special security precautions or be left to the responsibility of the resin manufacturers.

Ion exchange columns are regenerated by first draining the column of wastewater. Then the resin is agitated by compressed air, backwashed with potable water and drained. Once backwashing is complete, cation resins are soaked in an acid solution (8 to 10% by volume concentration) to regenerate them, while anion resins are soaked in a caustic solution (4% concentration). The chemicals are then drained, potable water is added and rinsing continues until the proper pH is attained (pH 3 to 4 in cation column effluent and pH 10 to 11 in anion column effluent) before the column is ready for service. All water and chemicals used in the regeneration process must be treated for metals removal.

10.11. Adsorption

Adsorption is the adhesion of substances to the surface of a solid. The following sections covers brief descriptions of various adsorbents and their ability to treat inorganic compounds.

Activated carbon has long been used to remove organic substances from wastewater, but its use in treating inorganic compounds, particularly metals, is not well-demonstrated. Some metals removal occurs in activated carbon systems, but the removal efficiency is typically low and unpredictable. Activated carbon does remove free and combined chlorine residual successfully, but dechlorinating agents (e.g., sulfur dioxide and other reducing agents) do this more cost-effectively.

The most popular adsorbent is activated carbon because it is relatively inexpensive, adsorbs a wide range of organic and inorganic substances and can be made from several materials (e.g., wood, sawdust, fruit pits, coconut shells, coal lignite, and petroleum residues). To make activated carbon, the chosen material is carbonized and then activated with hot air or steam. The starting materials and treatment intensity give each activated carbon a different capacity and selectivity. The extensive pore structure provides an extensive adsorption surface, which can range from 600 to 1100 m2/g of active carbon.

Activated carbon's adsorption capacity ranges from as low as 0.007 kg/kg carbon for methanol to as high as 0.18 kg/kg for propylene dichloride. In general, the sorption capacity increases as the solute's molecular weight increases across a series of compounds with similar functionality. In wastewater treatment systems, multiple solutes often compete for adsorption sites on the activated carbon. Differences in carbon source, temperature swings and other system-specific variances require that the project team conduct pilot tests (e.g., batch isotherm data and column studies) before designing an activated carbon process. Some waste streams contain suspended solids, FOG, or other materials that must be removed before activated carbon treatment. A pilot study should identify these incompatible materials and suggest removal options.

Activated carbon is thought to remove a solute from solvent in three steps:

- Transfer across a liquid boundary,
- Sorption to the outer surface, and
- Migration into deep pores.

Scale-up models address these steps differently, if at all. In general, most highly sorbet solutes seem to be rate-limited by liquid boundary diffusion. A lesser number of solute systems seem to be rate-limited by pore diffusion. In the most common contact method of down flow fixed-bed, kinetic modeling is further complicated because sorption never reaches a steady-state.

Figure 10.14 shows a typical breakthrough curve for a fixed-bed adsorption process. The process's influent is highly concentrated with solute. When the first batch of wastewater contacts the first layer of resin, equilibrium is reached rapidly and the resin becomes saturated with solute. As the water moves downward, the remaining solute contacts fresh resin and a new equilibrium is formed until there is virtually no solute left in the water. The next batch of wastewater that enters the column immediately contacts saturated resin, and the solute is transported down to the next layer of resin until it reaches a layer that is able to adsorb it. Graphically, a concentration wave front forms with a characteristic shape influenced by hydraulic conditions, temperature, initial solute concentration, column dimensions and resin quality.

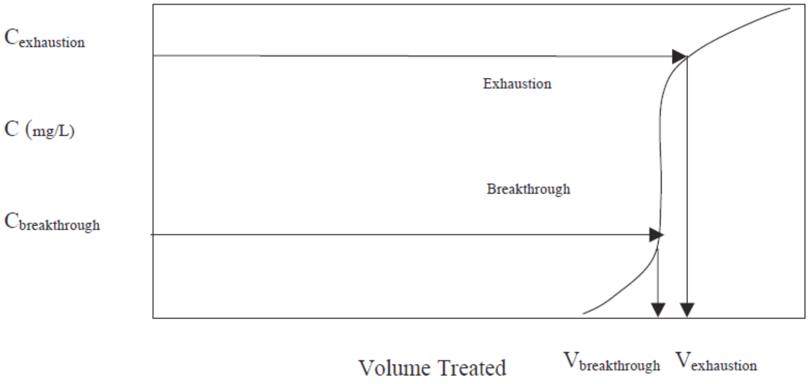


Figure 10.14 A graph of a typical activated carbon column run

At some point, the concentration exceeds the desired level, signaling breakthrough. An effective column run is defined by the run time until breakthrough. The resin's overall efficiency is roughly defined as the area of the curve to the left of the breakthrough point divided by the total area.

Because of the complexities of the sorption process and the inability to adequately predict the kinetics, researchers suggest that laboratory and pilot-scale design work are necessary whenever considering an adsorption process.

The tests should address the following questions:

- How much pollutant can be loaded onto the sorbent?
- How long will this loading take?
- How will desorption be done?
- What is the recapture efficiency?

The simplest scale-up model is a direct method in which a test column is operated at the same contact rate to be used in the full-scale design. The contact rate is typically two to three bed volumes per hour and the superficial rate is typically between 0.0013 and 0.0034 m3/s. A breakthrough curve is constructed from the test data (Figure 10.14). After breakthrough, the column must be regenerated by removing the adsorbed solute from the activated carbon. The regenerated carbon is then reused. Depending on the solute and carbon involved, the column may be regenerated via steam stripping, vacuum stripping or thermal regeneration.

Many full-scale designs incorporate two or three columns. In the two-column design, one column regenerates while the other is on-line. In the three-column design, two columns operate in series while the third regenerates. The first column in the series is allowed to reach breakthrough because the second one collects the pass-through solute. Once the third column is fully regenerated, it is valved to become the second in series. The second column is valved to become the first in series and the first is taken off-line for regeneration. This design substantially reduces the regeneration cost per unit volume of carbon.

Activated alumina is produced by controlled drying of aluminum hydroxide to create a crystal structure that is relatively water-free. The final structure of the alumina is a function of the final temperature and the starting product, resulting in a crystal phase that is mostly boehmite or unhydrated. The crystal may be produced to have the following properties: large specific surface area, high pore volume, defined pore size distribution, specific catalytic reactivity, specific adsorptive capacity and high crushing strength with low dust formation.

Activated alumina is used industrially as a catalyst to aminate alcohols and as a desiccant in air dryers. Activated alumina also has a high sorption capacity for arsenious acid, arsenate and fluoride and is used in the water treatment industry and home water systems to control these inorganic contaminants.

Some natural clays have a capacity for cation exchange. Organoclays are formed by the exchange of inorganic cations with organic cations (principally amines) containing long-chain organic tails. The organic fraction on the clay surface makes the clay hydrophobic to better adsorb organic compounds.

Synthetic resins can be constructed from polystyrene, phenolic esters, acrylic esters and polyaminated cellulose. These materials have seen broad use as ion exchange resins because they attract specific solutes and can be easily reversed for recharge.

SURFACE WATER POLLUTION FROM INDUSTRIAL WASTEWATER

11. SURFACE WATER POLLUTION FROM INDUSTRIAL WASTEWATER

Rapid industrial development generates industrial wastewater that represents a growing part of the total amount of produced wastewater. Industrial wastewater is generated by large, medium and micro-scale industries. The management, primary treatment and the discharge of industrial wastewater are critical issues considering the direct impact they may have on human health and the environment. High concentrations of heavy metals such as lead, cadmium, zinc, mercury, and nickel are found in industrial outlets and may be deposited in river sediment. Furthermore, there may be the presence of toxic organic substances such as polycyclic aromatic hydrocarbons, polychlorinated biphennyls and other threatening contaminants, such as endocrine disrupters, pesticides, food additives and pharmaceutical products. These contaminants can cause poisoning, mutations, reproductive disorders and immune suppression in aquatic animal forms and humans. In spite of this, almost the entire agricultural industry and commercial entities discharge wastewater without specific pretreatment directly into the sewer systems and nearby recipients, which in both cases is an offense punishable by law.

Various pollutants affect the quality of the water in different ways. Therefore, there should be a strict initial separation between industrial and urban wastewater. If industrial wastewater is released without prior treatment into watercourses that are treated in sewage treatment plants, waste products can overload the treatment system which depend on biological processes. Therefore, industries must pre-treat their wastewater to meet acceptable standards before discharge into municipal sewer systems or the environment. During the construction of wastewater treatment plants, wider national interest should always take precedence, including the protection of human health and the maintenance of ecological balance in aquatic systems with an emphasis on reasonable costs of maintenance and operation.

The main goal is to improve water quality. This implies that in the future, wastewater treatment plants will be put into operation in most municipalities. The idea is for these treatment plants to treat urban wastewater and most of the industrial wastewater. Industrial companies not connected to the municipal system for water treatment must treat their wastewater with their own equipment for pre-treatment or to build their own treatment plants. The main obstacle regarding the treatment of industrial wastewater is to ensure that the industrial water will be treated properly before it is directly discharged into drains or into rivers.

From a technical standpoint, the treatment plants are primarily designed to treat urban wastewater from households and little polluting industries. This means that the technology applied in the treatment plant is based on physical treatment and biological removal. For example, household wastewater is different from that of industry. The first is characterized by a high content of organic matter, while the second is characterized by a number of contaminants (heavy metals, acids, alkalis, toxic substances, etc.).

The biological part of the technology is very delicate and can easily be damaged by the presence of the above pollutants contained in industrial wastewater. To ensure proper treatment of industrial water as such, treatment plants need to have the necessary technology. Even the effectiveness of the operation of the treatment plant will be brought into question due to the existence of many industrial pollutants in the water.

The second reason as to why pretreatment is important for industrial wastewater is that before it reaches the treatment plant, the sludge from this plant can be used in the agriculture. This implies that sludge must meet certain minimum quality criteria in order not to be detrimental for agriculture. The presence of heavy metals or other toxic substances will prevent the usage of the sludge for agriculture and should instead be discarded in a landfill.

Improvement of industrial wastewater can be achieved through the following proposed EU measures:

- Treatment of wastewater from industrial production, according to Directive drainage and wastewater treatment (91/271/EEC);
- Cleaner production measures, through improving the performance and water consumption excess water usage can be reduced. This is related to the Directive on Integrated Prevention and Control of Pollution IPPC(96/61/EC).

Both methods should take into account the best possible technology and the most effective and advanced methods for the development of industrial activities designed to prevent and reduce emissions and environmental impact.

It is expected that the Directive on integrated prevention and control of pollution will be more appropriate and effective in the future regarding new industrial buildings. In such a case, it should provide that all new industrial facilities consider and implement measures to reduce wastewater, incorporate prior treatment, manage efficient spending of electricity and reduce the risk of contamination during their work.

Wastewater treatment at the end of the industrial process depends on the process in operation and may involve expensive equipment for pretreatment that requires large investments and has large operating costs. For new industrial facilities it is relatively simple to implement pretreatment with costs that will factor interest in the initial financial balance. However, already operating industries require additional investments to be directed to wastewater treatment.

For industrial enterprises with difficult economic situations, it can be expected that they will not be able to pay for it. Therefore, the short term loans are necessary to implement effective and financially acceptable measures to improve the quality of industrial wastewater. In this regard it is proposed not to insist pretreatment of industrial water with the best technology, but pretreatment to be performed in a manner that ensures good practice and management of resources.

11.1. Water Monitoring

Monitoring of industrial discharges is another problem. Measurements can show "satisfactory" results but fail to reflect the actual water pollution when carried out at a time different from the discharge of effluent, which occurs mostly during the night (when sampling is quite complicated).

The mentioned issues are the result of:

- Lack of will to invest in expensive technologies and a lack of awareness among economic operators of the need for pretreatment of wastewater prior to discharge;
- Limited or no monitoring of the discharge of wastewater by officials from the local government units;
- Relatively low penalties for infringements committed in the field of environmental pollution;
- Systematic monitoring of qualitative characteristics of surface water intended to give a complete picture of water quality data, including: the level and trend of pollution, which initiates a level of water protection and information on the nature and development of pollutants that have significant impact on water quality.

Modern laboratories with the newest and most efficient technologies are necessary to monitor industrial wastewater.

11.2. Methods to reduce the quantities and pollution levels in industrial wastewater

The main ways to reduce the amount of pollution and wastewater are:
Specialists from around the world are starting to pay more attention to implementing environmental technologies. These main tasks are associated with the development and adoption of such technologies and methods which permit complete elimination or significant reduction of water consumption. New technologies are created on the basis of full utilization of the output of raw materials.

Guidelines for developing and perfecting the technology and installation, depending on the type of wastewater are:

1. Water cooling to be replaced by air cooling,
2. Reduce the need of flushing water to wash or rinse as the output quality of raw materials and products are increased. Using new waterless technologies.
3. The water contained in the raw materials and output products is decreased by previous processes of their dewatering
4. Molasses solutions: technological processes implemented in dry assets, using "dry" means of getting the products (eg. Paper), multiple use molasses solutions etc.
5. Aqueous extracts and absorption liquids – are used many times, the water is replaced with waterless solutions, performed regeneration extragent and absorbent etc.
6. Other types of wastewater - are used multiple times, water wash installations are replaced by anhydrous solvents and others.

In many industrial enterprises, especially in chemical combinations, up to 85% of water consumption is used for cooling the product and equipment. In recent years, the technology is turning towards air cooling, which is better for the economics of water and the prevention of pollution.

11.3. Systems and schemes for sewage of industrial operators

There are two types of sewage systems:

- Internal and
- External sewage systems

Internal systems includes sewage networks and facilities located on the territory of an industrial facility:

- Sewage networks,
- Pump stations,
- Local wastewater treatment plants.

External sewage systems cover networks and facilities and are used jointly by several industrial operators:

- Sewage networks,
- Plants,
- Wastewater treatment plants.

When choosing a system and pattern of industrial sewage, operators should take into account:

1) The quantity, composition and properties of wastewater from individual plants and general industrial facilities as well as their mode of discharge (hourly load);
2) Possibility of reducing the amount of contaminated water from the facility with the rationalization of production technology;
3) Opportunities for the reuse of wastewater in the recirculation water supply system or for technological purposes in other types of production, which allows for the usage of water with lower qualities;
4) Efficiency in extracting and exploiting valuable substances contained in wastewater;
5) Possibilities for splitting the flows of production water in terms of reusing unpolluted water and purifying contaminated water;
6) Possibilities for increasing production capacities and thus the increasing the amount of polluted water;

7) Opportunities for effective water purification from more industrial enterprises and localities in the region;
8) Possibilities for using treated wastewater in technological processes in other industries and irrigation;
9) Efficiency of water purification from individual plants and industries in local water treatment plants;
10) Effectiveness of the application of one or another purification method; and

Industrial sewage is usually constructed as an entirely separate system. When the composition of wastewater allows and when there is a complex sewer system in the settlement, the principal of mixed sewage can be used.

Depending on the amount and degree of contamination, the water is drained through several *independent flows*:

Slightly contaminated water, consisting of one or more contaminants; acidic water; alkaline water; water containing toxic substances; strongly mineralized water; water containing oils and fats, fibers, surfactants, etc.

Sanitary water is drained and treated separately. When industrial water is close in composition to sanitary water, they can be treated together.

Rain water from unpolluted areas of industrial enterprises are drained independently and without treatment into the recipient. Rain water from polluted areas is drained together with polluted industrial water and purified in water treatment plants before entering the recipient.

Common treatment of sanitary water and industrial wastewater is not always possible. Water from the plants for electroplating, for example, contains chromium and cyanide. The production of acids have pH = 2 to 3, and water from the factory for wool contain fats, fibers and others. In such cases, there is a need to construct local water treatment systems, neutralizers, plants for impairment of chromium and cyanide, oil containment, oil, fiber and more. After local treatment, individual flows can be combined in one.

Separation of wastewater in separate streams may not be practical for various reasons, including sanitary requirements, fire hazard, risk of explosion, risk of fracture and blockage of canals and pipelines, etc. If water containing sulfuric acid with water containing lime, calcium sulphate is obtained, which is separated as sludge and causes blockage of the channels. Mixing the streams with temperatures above 40 ^{0}C creates the possibility of an explosive mixture.

Also, flows that contain a large amount of impurities of minerals, petroleum, oils and more are not to be mixed with sanitary wastewater. Such interference prevents the extraction of useful substances from wastewater and complicates the technology of purification. Therefore in most industrial companies (metallurgical, chemical, pulp and paper, food processing, etc.), sewerage is projected as individual. This means there are separate networks for production, sanitary and storm water. Unpolluted water after cooling can be included in the recirulating water supply system. Polluted industrial water can also be used in the recirculating system either partially or fully. Figure 11.1. shows the different sewer systems.

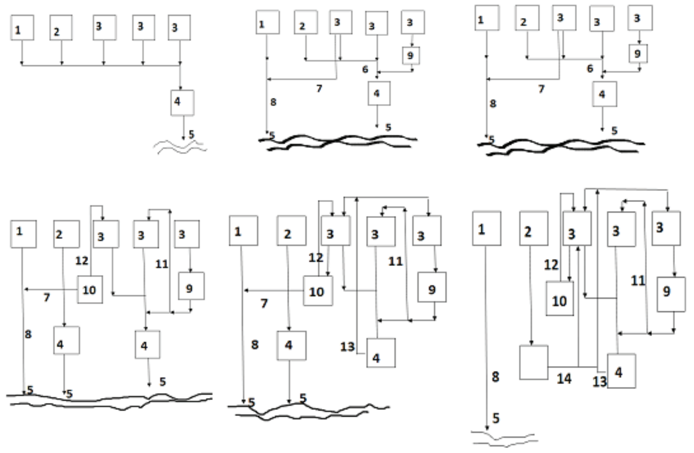


Figure 11.1. Scheme of sewerage systems of industrial enterprises

a- common sewer system, b- divided sewerage system and sanitary productive rain water sewer, c- divided system with rainwater and sanitary production network and local wastewater treatment plants, d- divided system with rainwater, sanitary and production network, local treatment systems and partly recirculated water use, e- divided sewer system with rainwater and sanitary production network and local water treatment systems and fully exploiting the recirculated water, f- divided sewer system without drainage for production and sanitary water.

1- rainwater, 2- sanitary water, 3- industrial water, 4 - treatment plants, 5 - discharge into recipient, 6- network of sanitary and industrial wastewater, 7- unpolluted production wastewater, 8- network for rain water, 9- local treatment plant, 10- plant for cooling unpolluted wastewater, 11-recirculated water supply network and local treatment of production wastewater, 12- network for the recirculated unpolluted cooling water from production, 13- network for recirculated wastewater water supply and treatment of industrial wastewater, 14 – network for the recirculated water supply and local treatment of sanitary wastewater.

11.4. Combined drainage and treatment of wastewater from industrial operators and settlements

When industrial operators are located in or near urban areas, the possibility of including wastewater in municipal sewage and combined treatment of industrial and municipal wastewater should be taken in consideration first.

In cases where industry operators are near to settlements and one another, there is a need to carry out techno-economic studies and comparisons of options for centralized and decentralized sewage system and construction of individual or combined treatment plants.

Combined drainage and treatment of industrial and municipal wastewater is only possible under certain conditions. It should be decided on a case to case basis.

To include industrial water in communal sewage, it should fulfill the following requirements:

1) Does not contain harsh and undissolvable impurities which may be deposited or swim and could have bad influence on the communal sewage;
2) Has no corrosive effect on the pipeline material and the units of the system;
3) Does not contain flammable materials (gasoline, oil, etc.), poisonous gases and impurities that may form explosive mixtures in the sewer network and plants; and
4) Does not exceed temperatures of 40 ^{0}C;
5) Does not contain bacterial contamination and other microorganisms causing diseases;
6) Does not contain radioactive and other toxic substances above the permitted concentrations; and

Production wastewater that does not meet these conditions is subjected to prior treatment to average the quantity and characteristics, neutralization, mechanical or physical-chemical cleaning, impairment and others.

To ensure normal operation of municipal wastewater treatment plants for combined treatment of industrial and municipal wastewater, the following conditions must be fulfilled:

- Combined water should have a temperature between 6 and 30 ^{0}C;
- Active reaction pH is 6.5 to 8.5;
- General salt concentration is below 10 mg / l;
- Biological oxygen demand (BOD) does not exceed 500 mg / l at the treatment biofilters and 100 mg / l at the treatment bio pool;
- The water does not contain undissolved oils, resins, oil and hard undissolvable active surface matter, which cannot be oxidized in biological purification plants;

- The chemical oxygen demand (COD) does not exceed 1.5 of the BOD; and
- To maintain a minimum ratio BOD: nitrogen: phosphorus = 100: 5: 1. If this ratio is maintained, obtained nutrient elements in the form of water, etc.

In common biological wastewater treatment, mechanical treatment can be common or separate. Separate is used where there is explosive hazardous industrial wastewater, chemical and mechanical treatment of industrial wastewater and when requires separate treatment of municipal and industrial wastewater.

STATE OF ART TREATMENT PLANTS

12. STATE OF ART TREATMENT PLANTS

Modern wastewater treatment plant operates with high efficiency and effectiveness nowadays in environmentally sound manner. There are two examples of such plans below, one in America and the other in Germany.

Location	**Kenosha, Wisconsin, USA**
Capacity	130.000 m^3/day
Population	110.000 People
Effluent discharge:	Lake Michigan
Project value	Approx. 10.000.000 USD
Starting of operation	2015
Sludge handling:	Thickening, Digesting, Disintegration during the digesting by hydrolyze, Dewatering, Drying
Innovation:	Hydrolysis: the chemical breakdown of a compound due to reaction with water.
System advantages:	» Higher gas production in existing digesters » Reduced Sludge viscosity allows for higher digester loading rates and shorter SRTs » Lower disposal costs through higher cake solids » Lower Polymer consumption » Reduced/eliminated digester foaming » Class A Biosolids

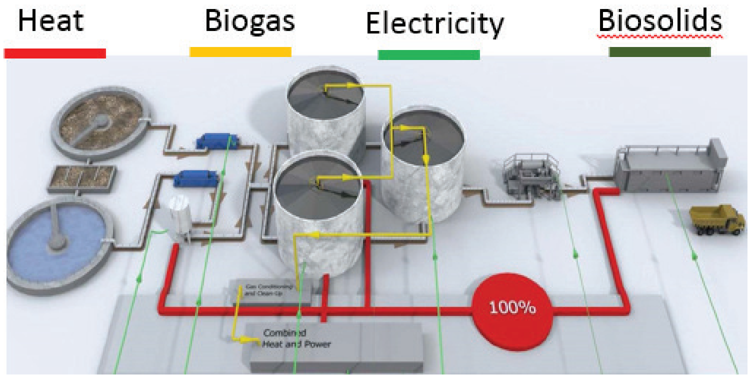


Figure 12.1 Municipal WWTP, Kenosha, Wisconsin, USA

Location	**Koblenz, Rhineland Pfalz, Germany**
Capacity	61.000 m³/day
Population	Approx. 130.000 People
Effluent discharge:	River Rheine
Project value	16.000.000 Euro
Starting of operation	2017
Sludge handling:	Thickening, Digesting (optimized by adding enzymes) Dewatering Drying Gasification
Innovation:	Syngas: 2 stage Pyrolysis, with a sophisticated air pollution system for producing synthase gas from dried sludge granulate.
System advantages:	» Additional energy by burning synthase gas: electricity and heat demand of the WWTP fully covered. » 90% less disposal costs, » Reduction of CO2 emissions » Decontaminated nontoxic ash, ready for further purposes such raw material for fertilizer industry or for recycling of phosphorous from sewage sludge.

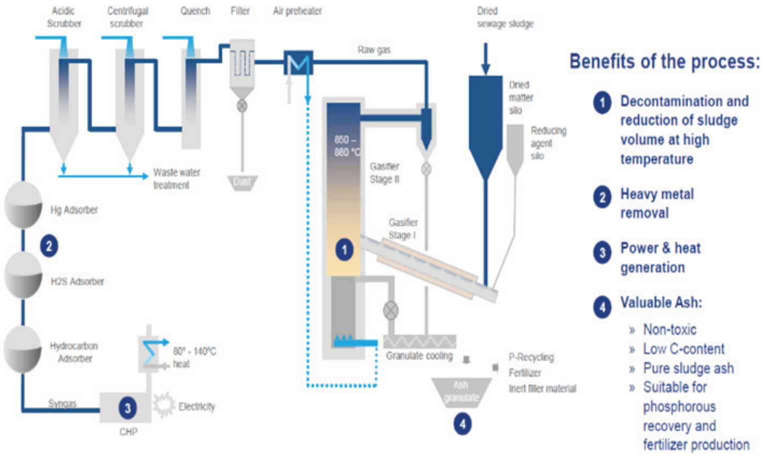


Figure 12.2 Municipal WWTP Koblenz, Rhineland Pfalz, Germany

BEST AVAILABLE TECHNIQUES

13. BEST AVAILABLE TECHNIQUES

13.1. Wastewater treatment techniques

13.1.1. Removal of sulphate and other pollutants using ultrasonic reactors

Description

Sulphate-rich wastewaters are treated using the following process steps:

1. Reaction of the sulphate in the water effluent with aluminium hydroxide chloride under acidic conditions (ideally with pH < 1.3). The quantity of aluminium hydroxide chloride that is required is proportional to the concentration of sulphate within the effluent.
2. Neutralisation with lime slurry or liquid lime (the optimum pH has been found to be 11.5).
3. Treatment in an ultrasonic reactor at a controlled rate where sulphate can precipitate. The amplitude and power of the ultrasonic vibrations are controlled to optimise the efficiency of sulphate removal. Within the ultrasonic reactor, the reaction chemistry and kinetics are altered so that calcium aluminium sulphate oxide is formed. This material is a very fine precipitate, almost colloidal in nature, and it has been found that flocculation is started by the addition of Epofloc L1-R (a heavy metal precipitant which is a carbamine). Not only does this ensure the removal of any heavy metals that are present, it also removes any excess aluminium. The material is flocculated using an anionic polyacrylamide. The resultant supernatant is clear and colourless. The precipitant produced in the process has been analysed using x-ray fluorescence and diffraction and has been identified as a type of zeolite.

4. Clarification where sludge is removed and treated in a filter press and can then be disposed of or reused/recycled.

The technique can be applied as an end-of-pipe technique or included within a wastewater treatment plant. An example of this is within a treatment plant, e.g. for chromium removal.

Achieved environmental benefits

The technique is used to remove the following contaminants from wastewaters:

- sulphate (up to 99.7 % reduction)
- COD (up to 55 % reduction)
- phosphate (up to 99.9 % reduction)
- heavy metals (up to 99.7 % reduction).

The resultant filter cake produced has a lower moisture content and is often non-hazardous and can be disposed of in a suitable landfill site. It can sometimes be reused in the following applications:

- as an alternative raw material in the cement industry
- as a treatment material for paint wastes, e.g. spray booth waste
- in waste stabilisation/solidification
- in the treatment of contaminated soils.

Cross-media effects

A side effect of this technique is the fact that the precipitate produced is fine and extremely slow to settle. This requires a settlement tank/clarifier that is designed for this purpose (often the settlement velocity is as slow as 0.18 m/h). Care should be taken with the addition of the Epofloc L1-R and flocculant so as to ensure that the flocculated particles settle in order to quickly leave behind fine particles of the calcium aluminium sulphate oxide.

The consumption of raw materials is as follows based on a flow rate of 5 m3/h, 10 hours a day, five days a week, with an input sulphate level of between 2 500 mg/l and 8 000 mg/l, normally around 5 000 mg/l:

- aluminium hydroxychloride: 1 300 kg/week
- liquid lime 18 wt-%: 4 000 kg/week
- Epofloc L1-R: 5 kg/week
- anionic flocculant: 3–5 kg/week.

The electrical consumption of the ultrasonic reactor is 120–140 watts. The filter cake production is 5 000–6 000 kg/week.

Operational data

The plant is operated automatically. The required pH values are achieved using digital dosing pumps and pH controllers. The 4–20 mA signal from the pH controller is input into the dosing pump so the dosing is proportional. The ultrasonic reactor is started and stopped on the flow through the system. The ultrasonic reactor has its own control unit for setting the amplitude and power. One consideration from an operational/maintenance perspective is the cleanliness of the pH electrodes. Since the efficiency of the removal process is affected by pH, regular cleaning of the electrodes is required. In practice, this can be achieved with self-cleaning electrodes.

Applicability

The technique can be applied to new or existing plants. If the technique is retrofitted, this often will involve adding some dosing pumps and the ultrasonic reactor. Assuming the settlement tank or clarifier is of a suitably size, the technique can be applied to large or small plants. In the case of large plants, several ultrasonic reactors may be required to handle the flow (normally only required for flow rates of > 40 m3/h).

Economics

The cost of the technique depends on the volume of wastewater to be treated and on the pollutants to be removed. Costs of ultrasonic reactors are normally in the range of GBP 22500–97500 (i.e. EUR 24500–108 000 assuming 1.11 EUR/GBP).

Whilst the capital cost is quite high, this should be compared to the cost of tankering the waste off site, which would be around GBP 460–1500 (i.e. EUR 510–1665 assuming 1.11 EUR/GBP) for a load of 20 tonnes, depending on the composition of the waste. This means that the payback time on the reactor is typically less than three months.

In addition to the payback time, there is an environmental benefit derived from the waste being treated at source.

Driving force for implementation

Whilst sulphate may not be seen as a pollutant with regard to the environment, it can generate problems with the sewer infrastructure, particularly the concrete sewers. This is a problem that is faced by industry discharging into water authority sewers throughout Europe.

Example plants

Rimex Metals Ltd, London, United Kingdom.

13.1.2. Photocatalytic oxidation with titanium dioxide

Description

The technique is a low-temperature system based on photocatalysis that can degrade a range of organic compounds as well as destroy microorganisms in aqueous effluents. A variation of the technique can also be used to treat gas effluents.

The technique is simple to operate and with few moving parts. It is also highly reliable and robust. The system is capable of being scaled to a variety of throughput requirements, from litres to cubic metres per day, and can be operated either on a continuous flow or a batch basis, depending on the target material to be treated.

The basic configuration can use either a suspended photocatalyst that can be recovered for reapplication, or an immobilised photocatalyst coated on an inert substrate. The latter approach has, in general, a lower destruction efficiency than the former, but it reduces the need for a recovery plant, and is therefore simpler to build and to use.

With a suspended catalyst, a mixture of the target material to be treated, the catalyst and water is passed as a thin slurry film over a series of plates and exposed to UVA light. If sufficient degradation of the target material occurs, then the treated mixture can be passed through a catalyst recovery system, after which the water and treated target material can be released into the environment by discharge through a conventional water treatment system; the catalyst can be recycled for further use in the process. If further processing is required before transferring the degraded pollutant stream into the water treatment plant, a continuous loop system can be operated or, if batch processing is required, then the process mixture can be put into a holding tank for further treatment prior to discharge.

With an immobilised catalyst, the process is clearly simpler, whether a batch or a continuous flow is used.

Achieved environmental benefits

The photocatalytic process can be applied to industrial wastewaters for:

- general organic pollutant destruction
- specific pollutant degradation such as a pharmaceutical- or pesticide-contaminated waters
- toxicity reduction

- biodegradability improvement
- BOD/COD removal
- odour and colour improvement.

Cross-media effects

Energy consumption (by the UV lamps as well as pumps to circulate the water effluents) is a cross-media effect associated with this technique.

No chemicals are consumed with the implementation of this technique.

The power consumption will be dependent on the reactor size and the energy requirement will depend on throughput. For a reactor suitable for treating ~2 200 l/d, or ~15 m3/week, 200 lamps of 80 W each will be needed and with a treatment time of approximately 1.5 hours, the energy consumption will be about 24 kWh.

Operational data

The effectiveness of the technique will obviously depend on the technical set-up of the equipment and the substances being treated, and, as with all techniques, trials will be required prior to full-scale implementation. However, high destruction efficiencies (> 99 %) have been reported. This technique is probably only applicable to small-scale specialist treatment.

In 2009, there was no known commercial application of this technique to the knowledge of the TWG for the review of this BREF document.

Applicability

Advantages and disadvantages of photocatalytic oxidation with titanium dioxide are given in Table 13.1.

Table 13.1: Applicability of photocatalytic oxidation with titanium dioxide to treat wastewater

	TiO2 slurry	**Immobilised TiO2**
Advantages	» Readily available » Relatively inexpensive » Highly photoactive » High surface area compared to immobilised TiO2 (50 m^2/g) » No mass transfer effects	» No need to replace the catalyst after photocatalysis » Easy to replace » No coagulation » Proprietary method for achieving high surface area of TiO2 coating
Disadvantages	» Need to remove slurry after photocatalysis » Can coagulate and lose activity	» Not readily available » Lower surface area than slurry » Problems of adherence and robustness

Economics

Indicative costs can only be given for a photocatalyst reactor system to treat micro-pollutants in wastewater. Treatment of a particular micro-pollutant would have to be estimated on the basis of trial runs and pilot studies. Typically though, for a system that would treat about 2 200 l/d, or ~15 m3/week, a capital cost for an installed basic plant without ancillary equipment, such as analytical tools, would be in the range of GBP 400 000–500 000 (i.e. EUR 444 000–555 000 assuming 1.11 EUR/GBP).

For the reactor mentioned above, the cost for treating about 140 litres will typically be GBP 1.20 (i.e. EUR 1.33 assuming 1.11 EUR/GBP) and the weekly bill for 15 m3 would be around GBP 132 (i.e. EUR 147 assuming 1.11 EUR/GBP). Using this energy cost on a constant basis, an estimate of operating costs can be made by incorporating amortisation over five years, overhead labour costs, consumables (including replacement catalyst, or catalyst plates, and lamps), and servicing. Then, excluding plant overheads such as rent, rates, property maintenance, etc., an annual operating cost is estimated to be about GBP 200 000 (i.e. EUR 222 000 assuming 1.11 EUR/GBP).

13.1.3. Combined electrochemical oxidation

Description

Electrochemical processes can be classified into two main groups:

- direct electrolysis (also called 'anodic oxidation', 'direct oxidation' or 'electrochemical incineration') by anodic oxidation in which the pollutant reacts at the anode surface with adsorbed hydroxyl radicals;
- indirect electrolysis where the pollutant reacts in the solution with an electrogenerated reagent produced at the anode (e.g. $O3$, $ClO-$, $Cl2$, $ClO2$) or at the cathode (e.g. $H2O2$).

Combined electrochemical oxidation processes combine electrochemical, photochemical and catalytic oxidation to achieve optimal results in the degradation of toxic and non-biodegradable organic substances.

The following combination can be used:

- anodic oxidation and cathodic generation of hydrogen peroxide ($H2O2$);
- cathodic generation of hydrogen peroxide and UV irradiation;
- catalytic electrochemical oxidation (in situ generation of hydrogen peroxide and specific catalysts);
- electrochemical generation of oxidising agents (e.g. $H2O2$, $O3$), UV irradiation and varied catalysts.

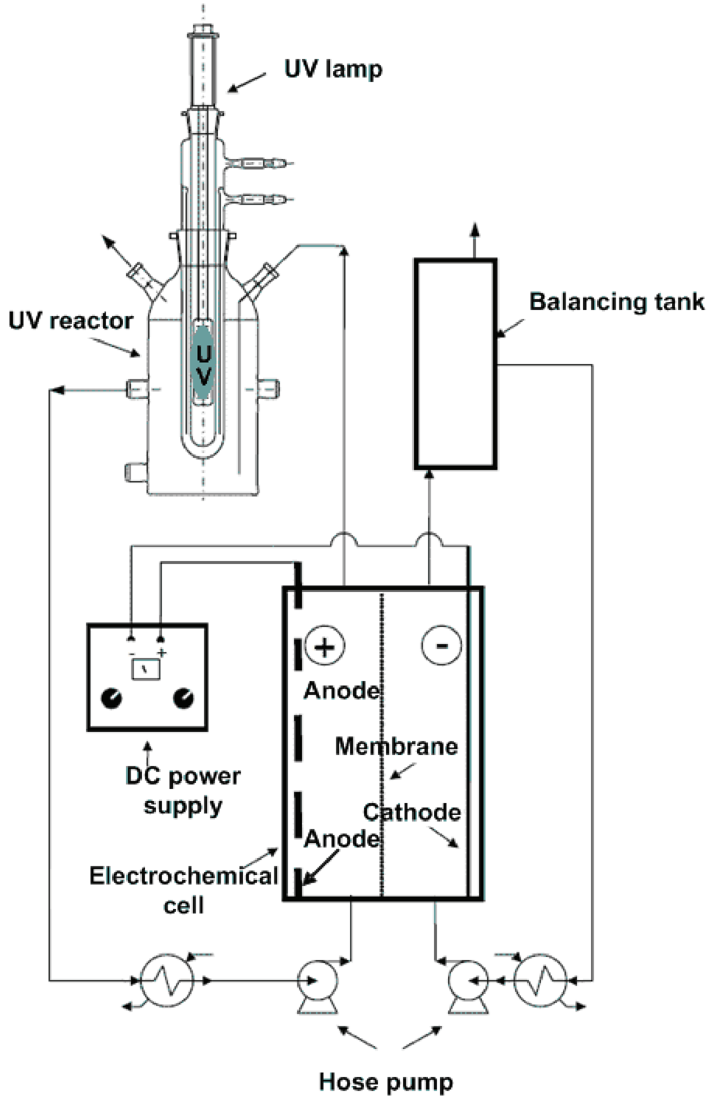


Figure 13.1. Example of a combined electrochemical oxidation process

The objective of these combined electrochemical oxidation processes is the creation of hydroxyl radicals, the ultimate cause of oxidation of the organic matter present in the wastewater. Identification of the most suitable electrode materials generally necessitates carrying out specific tests adapted to the nature of the wastewater that has to be treated.

Achieved environmental benefits

The technique allows toxic organic pollutants and non-biodegradable substances to be converted into more easily biodegradable organic components, or the total mineralisation of the organic pollutants (e.g. to convert them into water, salts and carbon dioxide). The environmental performance of the technique is not only measured by the TOC, COD or specific component reduction but also by taking into account the biodegradability improvement for further biological treatment. A major advantage of electrochemical wastewater treatment is the use of the wastewater as an electrolyte.

Cross-media effects

Energy (to carry out electrolysis) is considered to be the most important cross-media effect. Examples of consumables include:

- 9.2 kWh per m3 for wastewater with an incoming EDTA concentration of 500 ppm;
- reagents such as H2O2 are produced in situ.

Electrochemical methods are generally safe because of the mild conditions used (relatively low temperature and pressure) and the small amount and innocuous nature of the added chemicals.

Operational data

The nature of the electrode material strongly influences both the selectivity and the efficiency of the process.

Monitoring

A thorough monitoring of the following operating parameters is important:

- pH
- temperature

- TOC
- concentration of the organic compounds in treated wastewater
- energy consumption.

Applicability

Advantages and disadvantages associated with electrochemical oxidation are given in Table 13.2.

Table 13.2: Applicability of combined electrochemical oxidation

Advantages	Disadvantages
» Generally safe operation » Compared to techniques such as chemical oxidation, there is no transportation and storage of dangerous reactants (e.g. chlorine dioxide) » Relatively low consumption of energy (because of mild temperature and pressure to operate) » Can apply for treating wastewaters with TOC < 5 000 ppm	» Low reaction rate in case of electrode fouling (by reaction products)

The technique is reported to be applicable to treat wastewater loaded with persistent organic pollutants such as:

- pesticides and herbicides
- polycyclic aromatic hydrocarbons (PAHs)
- volatile organic compounds (VOCs)
- chelating agents.

These contaminants can be found in wastewaters from:

- pharmaceutical production
- hospitals
- the pulp and paper industry
- the oil and petrochemical industry
- municipalities. Applications include:
- disinfection of drinking water
- inactivation of bacteria and viruses

- odour control
- decolouration of dyestuffs
- landfill leachates.

Economics

The lifetime of the electrodes may constitute one of the key economic parameters [194, Martinez-Huitle and Ferro 2006].

Economics associated with combined electrochemical oxidation are given in Table 13.3.

Table 13.3: Economics associated with combined electrochemical oxidation

Type of costs	Costs	Comments
Invetsment/capital costs	EUR 100 000	For a wastewater treatment capacity of 1 m^3/h
Operating costs	EUR 2.50 per m^3	To mineralise wastewater with a concentration of 500 ppm EDTA
Source: [193, Austria 2009].		

Although investment costs for the equipment should be considered, the application for persistent wastewater with a TOC value below 5 000 ppm is economically reasonable.

Driving force for implementation

New water legislation is the driving force for the implementation of this technique.

Example plants

- Lovö Waterworks, Stockholm, Sweden
- VTU Technology, CoolOx water treatment plant, Graz, Austria.

13.1.4. Supercritical water oxidation

Description

Supercritical water oxidation (SCWO) is a special application of the high-pressure variant of wet air oxidation (see Section 3.3.2.3.3.3.3). The oxidation reaction takes place in the supercritical region of water, i.e. temperatures over 374 °C and pressures above 22.1 MPa.

Wastewater is brought to the supercritical pressure by a high-pressure pump before it enters the economiser, where the feed is preheated by the reactor effluent. At start-up, or if the organic concentration in the wastewater is less than 4 %, the feed has to be heated further to reach the supercritical temperature range. When oxygen is added to the feed, the temperature in the reactor will rise to about 600 °C.The reactor effluent flows into the economiser, then through a heat recovery steam generator and through an effluent cooler. Finally, a control valve drops the effluent pressure to atmospheric conditions and the liquid and gas phases are separated.

The organic wastewater content is reduced to carbon dioxide, water and nitrogen. Characteristics of SCWO are:

- complete solubility of organic compounds in supercritical water;
- complete precipitation of inorganic solids, such as salts;
- reaction time for complete destruction between 30 and 60 seconds, strongly dependent on the reaction temperature;
- reaction at about 25 MPa and 400–600 °C;
- complete conversion of the organic content, i.e.
  - organic carbon is converted to carbon dioxide
  - organic and inorganic nitrogen are converted to nitrogen gas

  - organic and inorganic halogens are converted to the corresponding acid
  - organic and inorganic sulphur are converted to sulphuric acid;
- destruction of volatile solids;
- oxidation of heavy metals to their highest oxidation state;
- separation of all inerts as fine, non-leachable ash.

Achieved environmental benefits

Abatement efficiencies associated with SCWO are given in Table 13.4.

Table 13.4: Abatement efficiencies associated with SCWO

Pollutant	**Abatement efficiency (%)**	**Comments**
Organic compounds	> 99	—
1,2,4-Trichlorobenzene	99.99 (1)	495 °C, 3.6 min
4,4-Dichlorobiphenyl	> 99.99 (1)	500 °C, 4.4 min
DDT	> 99.99 (1)	505 °C, 3.7 min
PCB 1234	99.99 (1)	510 °C, 3.7 min
PCB 1254	99.99 (1)	510 °C, 3.7 min
Dioxins	> 99.99 (1)	574 °C, 3.7 min
(1) [3, Environment Agency (UK) 1997].		

Cross-media effects

Depending on the wastewater influent, the gaseous effluent contains traces of nitrous oxide and acetic acid generated by the process, but also hydrogen halides as a degradation product of halogenated organic compounds, which need to be treated in downstream waste gas facilities. Inorganic solids need to be discharged if they cannot be recycled or used elsewhere.

The installation is a source of noise, relating to the pressure generation. To abate noise the equipment needs to be enclosed.

Monitoring

During the whole process, a thorough monitoring of operating parameters such as pressure, temperature and oxygen content should be carried out.

Applicability

SCWO is applied to contaminants with low biodegradability and/or high toxicity in the chemical, petrochemical and pharmaceutical industries. It also destroys dioxins and PCB, while the relatively low temperature range of 400–600 °C makes it unlikely to produce NOX (i.e. nitrogen oxides, excluding N_2O).

Another application field for SCWO is the treatment of industrial and municipal sludge to destroy toxic organic compounds, including dioxins.

Advantages and disadvantages are described in Table 13.5

Table 13.5: Advantages and disadvantages associated with SCWO

Advantages	Disadvantages
» All organic content, irrespective of its properties, is destroyed » Very high destruction efficiency is achieved at relatively low temperatures, resulting in NOX-free emissions » No dioxins are generated » Very short reaction time is necessary, resulting in short residence time and thus in low reactor volume » Can be combined with other downstream treatments	» Traces of nitrous oxide (N_2O) and acetic acid are likely to be found » Inorganic solids precipitate and might cause corrosion » Elevated chloride concentrations lead to increased corrosion thereby requiring specific types of steel

Economics

Operating costs are primarily determined by the energy costs associated with pumping the influent and compressing the air or oxygen. Costs between EUR 30/t and 100/t have been reported [63, VITO 2010].

Driving force for implementation

Driving forces for implementation include relieving the subsequent biological treatment of COD/AOX loads that could have a disturbing, inhibiting or toxic effect.

13.1.5. Membrane distillation

Description

Membrane distillation (MD) is a thermally driven process in which only vapour molecules are transported through porous hydrophobic membranes. The liquid feed to be treated by MD must be in direct contact with one side of the membrane and does not penetrate the dry pores of the membranes. The hydrophobic nature of the membrane prevents liquid solutions from entering its pores due to the surface tension forces. As a result, liquid/vapour interfaces are formed at the entrances of the membrane pores. In MD, the membrane itself acts only as a barrier to hold the liquid/vapour interfaces at the entrance of the pores and it is not necessary to be selective as required in other membrane processes such as pervaporation. The main requirements for the MD process are that the membrane must not be wetted and only vapour and non-condensable gases must be present within its pores. The pore size of the membranes used in MD lies between 10 nm and 1 µm. The MD driving force is the transmembrane vapour pressure difference that may be maintained with one of the four following possibilities applied in the permeate side.

1. An aqueous solution colder than the feed solution is maintained in direct contact with the permeate side of the membrane giving rise to the configuration known as direct contact membrane distillation (DCMD). The transmembrane temperature difference induces a vapour pressure difference. Consequently, volatile molecules evaporate at the hot liquid/vapour interface, cross the membrane in the vapour phase and condense in the cold liquid/vapour interface inside the membrane module.
2. A stagnant air gap is interposed between the membrane and a condensation surface. In this case, the evaporated volatile molecules cross both the membrane pores and the air gap to finally condense over a cold surface inside the membrane module. This MD configuration is called air gap membrane distillation (AGMD).
3. A cold inert gas sweeps the permeate side of the membrane carrying the vapour molecules and condensation takes place outside the membrane module. This type of configuration is termed sweeping gas membrane distillation (SGMD).
4. A vacuum is applied in the permeate side of the membrane module by means of a vacuum pump. The applied vacuum pressure is lower than the saturation pressure of the volatile molecules to be separated from the feed solution. In this case, condensation occurs outside the membrane module. This MD configuration is termed vacuum membrane distillation (VMD).

The advantage of the MD process in comparison to the conventional separation processes is that it relies on a lower operating temperature and hydrostatic pressure. Feed solutions having temperatures much lower than their boiling point under pressures near atmospheric can be used. In contrast to pressure-based membrane processes, MD in principle does not require additives like acids or antiscalants because the membranes are a lot less sensitive to concentration polarisation or membrane pollution. Thus, MD does not require the supply mix to be subjected to a specific pretreatment.

Achieved environmental benefits

Separation/concentration of non-volatile components (e.g. ions, acids, colloids, macromolecules) from aqueous flows and the removal of trace amounts of VOCs like benzene, chloroform and tri-chloroethylene from water are the achieved environmental benefits of membrane distillation.

Cross-media effects

Cross-media effects include: relatively low permeate flux in comparison with pressure-based membrane processes such as RO, permeate flux decay due to concentration and temperature polarisation effects, membrane fouling and total or partial pore wetting, and high thermal energy consumption.

Operational data

At the time of writing this document (2011), no industrial scale application of the MD process has been reported.

Applicability

The MD process has been successfully applied on laboratory scale for the separation of non- volatile components from water like ions, colloids, macromolecules; for the removal of trace volatile organic compounds from water such as benzene, chloroform, trichloroethylene; and for the extraction of other organic compounds such as alcohols from dilute aqueous solutions. It has been applied for water desalination, environmental waste clean-up, water reuse and food processing. MD offers potential for water purification in the pharmaceutical, chemical and textile industries, for the concentration of fruit juices and milk processing, and in biomedical applications like the removal of water from blood. It could also be applied for separating azeotropic aqueous mixes (alcohol-water), for the concentration of cooling liquids (glycols), non-volatile acids and oil-in-water emulsions and in applications where high-temperature processing causes thermal degradation of the process flow. With the discharge of less harmful waste flows in mind, MD offers greater potential in the textile industry where wastewater is contaminated with dyes.

Economics

Due to the use of very low pressures, which are associated with a low-cost installation (thinner piping, etc.) and fewer operational problems, investment and maintenance costs for MD are considerably lower than those of pressure-driven membrane processes like ultrafiltration (UF) and reverse osmosis (RO). If one assumes that MD technology is fully developed, the total production cost of a hypothetical DCMD desalination plant with 30 % internal heat recuperation for the production of clean water at 3 800 m^3/h can be estimated at EUR 0.55/m^3, which is clearly lower than the cost of a RO installation with the same capacity (EUR 0.89/m^3).The expected cost for drinking water production in a large-scale MD desalination plant can currently be estimated at EUR 0.43–0.70/m^3 (EUR 0.27–0.36/m^3 when using residual heat). Further cost reductions are expected when the technique gets more mature. The cost efficiency of MD is to a great extent determined by the use of residual heat flows and/or alternative energy sources. In contrast to conventional separation processes like distillation and RO, the MD process is carried out at a lower working temperature and pressure which results in lower energy costs. By using residual heat or alternative energy sources (solar, wind, etc.), the energy efficiency of a MD plant can be increased significantly.

Driving force for implementation

The driving force for implementation in comparison to the conventional separation processes is the requirement for a lower operating temperature and hydrostatic pressure.

Example plants

Despite the broad potential for application and the favourable cost estimate, MD is not yet generally accepted as a separation technique and is still not being implemented within industry on a large scale. The most recent developments tend to indicate an industrial breakthrough of MD for low-cost and sustainable desalting of sea water.

13.1.6. Naturally improved microorganisms to treat refractory TOC/COD

Description

The technique consists of the use of naturally improved microorganisms (e.g. prokaryotic cells or bacteria, photosynthetic bacteria or eukaryotes such as yeasts, fungi and photosynthetic microalgae) to treat wastewaters loaded with refractory TOC/COD.

The technique consists of a three-step process:

- selection of naturally occurring microorganisms;
- generation of microbial variants with enhanced characteristics to treat the targeted pollutants in wastewaters;
- introduction of the improved microorganisms into the water treatment process.

» The technique is an alternative to other techniques such as chemical oxidation or incineration to treat wastewaters which contain COD/TOC.

Achieved environmental benefits

A reduction of TOC/COD levels in water effluents is the environmental benefit of the technique.

Refractory TOC/COD abatement efficiencies associated with naturally improved microorganisms is given in Table 13.6.

Table 13.6: Abatement efficiencies associated with naturally improved microorganisms to treat refractory TOC/COD

Characteristics of the wastewater treated	Abatement efficiency (% of TOC or COD removed)	Comments
100 g/l of TOC-containing acrylic acid polymers, metacrylic acid polymers and hydroquinone	70–97 TOC	Pilot scale
Effluent loaded with dimethylformamide	98 COD	Laboratory development
Effluent loaded with metformin	60 COD	2 days retention time on effluent which contain 95 % COD of metformin
Effluent loaded with methyl cyanide	98 TOC	—
Effluent loaded with sulfanilic acid and chloride from a pharmaceutical production plant	90 TOC	11 days retention time and chloride content of 32 g/l
Effluent loaded with aliphatic acids and phthalic acid derivatives	Up to 100 TOC	—

Cross-media effects

There are no significant cross-media effects associated with this technique.

Operational data

The generation of microbial variants is carried out in ‘continuous’ cultures, where the culture environment is constantly diluted, thus making it possible to maintain multiplying cell lines over long periods of time at a constant cell density. This is known as the ‘turbidostat’ principle. Within a turbidostat, a constant elevated growth rate fosters the appearance of greater numbers of spontaneous mutations. The ‘variants’ produced tend to split more actively than other cells do,or to better utilise the resources available within the environment. Moreover, if they are maintained in suspension for as long as possible, their rate increases over time within the culture population, thus making them detectable and easier to isolate.

Applicability

The technique is generally applicable to new and existing installations in the industrial or municipal sectors.

Economics

Investment costs are made up of the treatment tank and the decanting system. The technique can provide significant savings compared to incineration. At a plant producing acrylate resins in France, the total cost reduction is evaluated at 50 %. The return on investment is expected to be < 2 years.

Driving force for implementation

The cost savings at installations with high incineration costs for treating wastewater which contains refractory TOC/COD is the driving force for implementation.

Example plants

» TOTAL, France: effluent loaded with acrylic acid (industrial pilot phase)

» CIBA, Germany: effluent loaded with 4,4’-dinitrostilbene-2,2’-disulfonic acid (laboratory phase)

» Pharmazell, Germany: effluent loaded with sulfanilic acid (industrial pilot phase)

» Solvay, Belgium: effluent which contains phthalic acid (industrial pilot phase).

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