Kentucky
Operator Certification
Program

WASTEWATER TREATMENT

Plant Operator Certification Manual

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ENERGY AND ENVIRONMENT CABINET
CERTIFICATION AND LICENSING BRANCH
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Certification and Licensing Program

Mission

Promote responsible environmental stewardship.

Goal

Provide operators with the basic knowledge required to manage drinking water, wastewater, and solid waste systems.

The Certification and Licensing Branch is home to the solid waste, drinking water and wastewater certification programs. Through education and certification exams, these three programs help ensure that the people charged with dealing with community solid waste, drinking water and wastewater are knowledgeable and capable of handling the responsibilities required of those positions.

Hotline and Website for regulatory, technical, or operational concerns:

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Chapter 1

Certification Purpose and Process

In this chapter, you will learn what you need to know and what you need to do to get certified to perform the important work of a **wastewater** operator.

1.1 Purpose: Why do we need you to do this important job?

Have you ever wondered why it doesn't stink when you walk outside in the morning, or why you have never had to drive through **sewage** on your way to the grocery store or your favorite restaurant? Have you ever wondered why we can fish, swim, and boat in our rivers and creeks, without having to worry about getting a life-threatening illness?

It is because of wastewater treatment plant workers. Everyday life, especially in cities and townships, would be miserable and sickly without you. You provide a critical service to your community. Thank you!

It takes knowledgeable and conscientious people to deliver clean water and ensure that wastewater is treated before being returned to the environment. Only operators that are certified by the Kentucky Certification and Licensing Branch can oversee the operation of a wastewater treatment plant.

The formal regulations that relate to wastewater treatment plant operators are contained in **401 KAR Chapter 11**. The main points of the regulations are summarized in this chapter.

1.2 System Classifications

The classification of a treatment plant will depend on how much wastewater it can process. Larger plants will require operators with more experience because such plants are usually more complicated. Wastewater treatment plant operators can achieve five different levels of certification or proficiency (Class I through Class IV and Limited). To operate a Class I wastewater treatment plant, you must have a Class I certification and so on. The five wastewater treatment plants by size are summarized in Table 1.1.

Table 1.1 Five Major Wastewater Treatment Plants by Size

Class I	A wastewater treatment plant that can process less than or equal to 50,000 gallons per day.
Class II	A wastewater treatment plant that can process more than 50,000 gallons per day but less than or equal to 2,000,000 gallons per day.
Class III	A wastewater treatment plant that can process more than 2,000,000 gallons per day but less than or equal to 7,500,000 gallons per day.
Class IV	A wastewater treatment plant that can process more than 7,500,000 gallons per day.
Limited	School systems can hold a class I, II, III, IV or Limited certification.

1.3 Certification Process

In order to be able to operate a wastewater treatment plant in the state of Kentucky you must have a valid operator's license. The wastewater operator certification process required to obtain a license in Kentucky is outlined in **401 KAR Chapter 11:050**. In brief, the educational and experience requirements to become a certified operator include:

1) Meet the required education and experience as specified in Table 1.2.

Table 1.2 Minimum Education and Experience Requirements to Become a Certified Operator

Class I	High School Diploma or GED and 1 year of acceptable operation of a wastewater treatment plant.
Class II	High School Diploma or GED and 2 years of acceptable operation of a wastewater treatment plant.
Class III	High School Diploma or GED and 3 years of acceptable operation of a wastewater treatment plant, as well as 1 year of experience in a wastewater treatment plant that can process more than 50,000 gallons per day.
Class IV	A baccalaureate degree from a regionally accredited college or university in engineering, or biological, environmental, physical, or chemical science, or equivalent and at least three (3) years of acceptable operation of a wastewater treatment plant. Two (2) years of the required experience shall be in a wastewater treatment plant with a design capacity greater than two (2) million gallons per day and at least one (1) year of **primary responsibility** shall be in a wastewater treatment plant with a design capacity greater than two (2) million gallons per day.
Limited	A minimum level of education and experience shall not be required.

   a. The Kentucky Division of Water (KDOW) now allows for some formal education to substitute for the required experience needed to achieve different levels of operator certification.
      i. KDOW currently accepts academic degrees in science and math for substitution of up to 50% of the experience required for an operator’s license.
      ii. KDOW will also now accept degrees outside of science and math to count towards the experience requirement, however they cannot substitute for more than 25% of the experience requirement.

2) Submit the appropriate completed documents to the Kentucky Energy and Environment Cabinet (KYEEC).
   a. Operator Classifications I – IV:
      i. **Registration Form for Exams and Training**.
      ii. **Education and Experience Documentation Form**.
      iii. The application fee ($250, if paper add $50) in accordance with 401 KAR 11:060.
   b. OIT Designations Classifications I – IV (Program details are contained in Section 1.3):
      i. **Registration Form for Exams and Training**.
      ii. **Education and Experience Documentation Form**.

        iii. The application fee ($250, if paper add $50) in accordance with 401 KAR 11:060.
        iv. A **mentor letter** with the commitments listed in Section 1.4. A template is in the DEP Forms Library.
3) Once submitted, the individual will be assigned an Agency Interest Number (AI#). The AI# is a database file number provided to each entity that conducts any activity with the Kentucky Department for Environmental Protection (KDEP) including the Division Water, Division for Air Quality, Division of Waste Management, and Division of Enforcement.
4) The application will be reviewed by Kentucky Certification and Licensing Branch (CLB) staff to determine if the applicant meets the requirements. All Class IV applications are reviewed by the Kentucky Wastewater Operators Certification Board which makes recommendations for approval. If approved, the applicant will be notified of the scheduled examination date.
5) A final grade or score of at least a 70% is required to pass the certification exam. The applicant will be notified of the results of the exam by mail. Additionally, exam results are posted using your agency interest number at the **OCP Exam Result website** or by using the KDEP **E-Search** tool.
    a. If the applicant passes the exam, a certificate and wallet card shall be issued designating the certification classification for which the operator has demonstrated competency.
    b. If the applicant fails to pass the exam, the applicant may reapply following the steps listed above.
6) If a system office is available at the wastewater treatment plant or within the sewer service area, the operator’s certificate shall be prominently displayed on the wall.

Information about exam preparation and future exam dates can be found on the **Kentucky Operator Certification Program** website.

1.4 Operator-in-Training (OIT) Program

Kentucky’s operator workforce is maturing rapidly causing a shortage in properly certified operators. The Operator-in-Training (OIT) program provides an accelerated career path for qualified individuals to gain valuable experience working at a wastewater treatment plant or collection system. The OIT program allows employees without the required experience to begin working at a wastewater collection system, under the direct supervision of a mentor. A mentor is a certified operator that must have an active certification, have a certification level that is equal to or higher than required to have primary responsibility of the facility, and be located at the same facility. The steps to obtain the OIT designation are:

1) Apply for the OIT program.
2) Be approved to take the exam requested.
3) Pass the exam.
4) Gain the required experience while working under the supervision of a mentor.
5) Apply to upgrade the OIT designation to a certification.

The OIT designation can be upgraded to a certification of the equivalent level once the required experience is obtained. The OIT designation can also be renewed without examination as discussed in Section 1.5 of this Chapter.

Anyone can apply for an entry-level OIT (Class I-OIT) if he or she has a high school diploma or equivalent. The application process to obtain an OIT designation is the same process as to obtain a certification (outlined in Section 1.3 of this chapter) with one addition. The applicant is required to submit a letter from the mentor. The mentor’s letter must include the following:

- A commitment to overseeing the applicant's work.
- A commitment to mentor the applicant if the applicant is under the mentor's direct responsible charge.
- Confirmation that the mentor has an active certification that is equal to or greater than the certification level required to have primary responsibility of the facility where both are working.

After passing the Class I exam, the applicant will receive a certificate with the Class I-OIT designation. Experience attained from that point forward will count toward the upgrade of the OIT designation to a certification. Once the Class I-OIT meets these requirements, the OIT designation can be removed.

To remove or upgrade an OIT designation for any level, the person with the OIT designation must acquire the minimum experience required for that certification level, satisfy the requirements of **401 KAR 11:050** Section 3 (1)(a) and (b), and submit a letter from the mentor that recommends the removal of the OIT designation. Once approved, the KYEEC will issue a new certificate with the appropriate classification. A certified operator with an OIT designation who is unable to comply with the requirements to upgrade or renew may apply to retake the certification exam to upgrade their certification.

An operator with a Class I-OIT designation may not be in responsible charge of a facility. However, an operator with a Class II, III, or IV-OIT designation can have primary responsibility for a facility if they meet the requirements otherwise spelled out in the regulations governing staffing of wastewater facilities.

The program also allows an operator who has successfully qualified for and passed the certification exam to apply for an OIT license that is one level higher than the type of certification that the individual currently holds. All OIT applicants must pass the operator certification exam for which they are seeking the OIT designation and work under the responsible charge of a mentor. In other words, an operator with a Class I active license is eligible to apply for the Class II-OIT designation. This also means a Class I may also apply for the Class II-OIT designation and take the Class II operator certification test prior to completing the mandatory year of experience as part of the requirements to obtain a Class II-OIT certificate.

Applicants for a Class II-OIT, Class III-OIT, and Class IV-OIT must have successfully qualified for and passed the certification exam of the same type of classification at one level lower than the OIT designation being pursued. This means a Class I or a Class II-OIT may also take the Class II operator certification test prior to completing their mandatory two years of experience. Similar

OIT certifications are also available for Class II-IV facilities. Table 1.3 outlines the requirements for each OIT designation to obtain an active operator certification.

Table 1.3 OIT Designations

Class	Required Education	Designation Requirements	To Obtain Certificate
I-OIT	High school diploma or GED certificate.	Experience not required. Must have mentor and pass Class I exam.	One year of experience operating a wastewater collection system, letter from mentor.
II-OIT	High school diploma or GED certificate.	Experience not required. Must have a Class I certification, a mentor, and pass Class II exam.	Two years of operating a wastewater collection system and letter from mentor.
III-OIT	High school diploma or GED certificate.	Experience not required. Must have a Class II certification, a mentor, and pass Class III exam.	Three years of operating a wastewater collection system with one year having been in a collection system that transports wastewater to a treatment plant with a design capacity > 50,000 GPD.
IV-OIT	Equivalent to Class IV requirement.	Experience not required. Must have a Class III certification, a mentor, and pass Class IV exam.	At least three years of operating a wastewater collection system with two years having been in a collection system that transports wastewater to a treatment plant with a design capacity > 2 MGD.

1.5 Certification Renewal

Upon issuance of a certificate by KYEEC, the operator's license is considered active. All wastewater treatment operators must renew their certifications by June 30 of each odd-numbered year (e.g., 2023, 2025). The only exception to this rule is if you received your certification between January 1st and June 30th of the renewal year. For example, if you receive your certification sometime between January 1st and June 30th in 2023, then you will have until June 30th, 2025, to renew. If you received your certification in 2024, then you must renew it by June 30th, 2025.

If your certification expires, you may file for renewal through December 31st of the same odd-numbered year, however, a late fee is required as listed in **401 KAR 11:060**. If approved, your certification will be returned to the status of active. If you do not renew your certification by the deadline of December 31st, your certification is terminated. In other words, you will lose it.

To become an active certified operator again, you will have to formally reapply for certification, as described in section 1.3, and take and pass the certification exam. Certified operators with expired certificates shall not be in responsible charge of a wastewater facility.

There are two options an active operator may use to renew their certification:

1. Electronically (currently unavailable for those with an OIT designation) through the cabinet website using the **E-Search** page.
2. By submitting required documents to the Certification and Licensing Branch, 300 Sower Blvd., Frankfort, KY 40601. All paper applications will incur a $50 additional processing fee.

The required documents are as follows:

- Certified operators:
    - The **Application for Certification Renewal**.
    - The appropriate fee. The current renewal fee is $200 per license. If submitted by mail, add $50. If submitted after June 30 of the renewal year but no later than December 31 of the renewal year, add $250.
- OIT designated certified operators must also submit the following documents:
    - A letter of recommendation from their mentor.
    - The **Education and Experience Documentation** documenting that they have earned the required years of training hours. An operator designated as an OIT may renew their certification without examination if they have accumulated the required training hours for their classification during the two-year period immediately prior to the certificate expiration date (see Section 1.6). For example, to renew a Class II Collection, a Class II Treatment, or a Class II-OIT certificate with an expiration date of June 30, 2021, twelve hours of approved training must be completed between July 1, 2019, and June 30, 2021.

In **E-Search**, you can enter the AI#, your name, or your certification number (if certified) to electronically check your exam status, the status of your license, find out how many continuing education hours you have, and register for a continuing education training event. Additional information on certification renewals as well as applicable fees can be found on the **Kentucky Operator Certification Program** website.

1.6 Operator Continuing Education Requirements

Prior to applying for certification renewal or to return a certificate to active status, a certified operator must complete a required number of approved training hours. Operators holding both a treatment and a collection system certificate must complete the required number of approved training hours for the highest certificate held instead of completing the required number of continuing education hours required for each certificate. Training hours earned prior to the initial certification are not allowed to be counted toward renewal. Additionally, only training hours completed during the two-year period immediately prior to the certificate expiration date can count toward renewal as indicated in Table 1.4.

Table 1.4 Wastewater Certificate Continuing Education Requirements

Classification	Required CEUs	Date Obtained
OIT Designations	Same as Class Level	During the two-year period immediately prior to the certificate expiration date (July 1 to June 30 in odd years).
I	12 hours	
II	12 hours	
III	24 hours	
IV	24 hours	
Limited	12 hours	

Training hours can be obtained by taking courses offered by the CLB or by authorized service providers. The CLB maintains a list of approved training courses and their providers on the CLB website. Prior to signing up for a training course, check with the CLB website to confirm that the training has been approved.

1.7 Other Resources

Certification and Licensing Branch, Department for Environmental Protection, Kentucky Energy and
Environment Cabinet. **Kentucky Operator Certification Program.**
Kentucky Administrative Regulations, **401 KAR Chapter 11**.

Chapter 2

Ethics

Our actions affect more than just us, especially when we work in a field like wastewater treatment that directly impacts the health, safety, and welfare of the public and the environment. Because of the potential impact of an operator's actions on the public and the environment, it is important that an operator makes sure that all their decisions are consistent with the highest level of ethical behavior.

2.1 Definition

Merriam-Webster defines ethics as, "the discipline dealing with what is good and bad and with moral duty and obligation." What does this really mean? Ethics is about right and wrong. Professionals (like a certified operator) are recognized as being capable of making judgments, applying skills, and reaching informed decisions in their field of experience and expertise. Professions which provide service to the public often define ethics in terms of concepts such as honesty, integrity, transparency, accountability, confidentiality, objectivity, respect, lawfulness, and loyalty. Regulations often define the standards of professional conduct and ethics for certified operators (Ref. 1).

2.2 Mandatory Ethics for all Operators

An operator's job is important to the safety, health, and welfare of the public and the environment. Therefore, it is highly important to be professional and have integrity. The minimum ethical standards of practice for this job are set forth in **401 KAR Chapter 11:020.** A certified operator shall:

- Protect the safety, health, and welfare of the public and the environment.
- Use reasonable care and judgment in the performance of operational duties.
- Inform the employer of the possible consequences if a certified operator's judgment is overruled by an employer when the safety, health, and welfare of the public or the environment are endangered.
- Be objective, truthful, and complete in applications, reports, statements, and testimony provided to the cabinet.
- Ensure the integrity of the samples that the operator collects, prepares, or analyzes so that results shall be a true representation of water quality.

Because it is so important for operators to follow the standards of practice, certified operators who violate the standards in **401 KAR Chapter 11:020** could be subject to one or more of the following disciplinary actions outlined in **401 KAR 11:050 Section 6**:

- Probation of the operator's certification for a specified period, not to exceed one (1) year.
- Suspension of the operator's certification for a specified period, not to exceed four (4) years, during which the certification shall be considered void.
- Revocation of the operator's certification.

- Civil or criminal penalties.
- A combination of the disciplinary actions listed above.

2.3 Case Studies for Thought

Perhaps the best way to consider ethics is to look at an actual case study from a real-life experience.

2.3.1 Weston Wastewater Treatment Plant

Richard Madison was the operations supervisor at the Weston Wastewater Treatment Plant (Ref. 2). He had worked at the plant for nearly 15 years. On August 21, 1991, he attended a meeting at City Hall with the mayor of Weston. In this meeting, Madison accused three men, the plant superintendent (employed under a contract by a consulting laboratory), the plant maintenance supervisor, and the plant testing and quality control supervisor, of several environmental law violations. Specifically, he stated that on several occasions since early 1990, he had seen them tampering with collected samples to be tested for compliance with **biochemical oxygen demand (BOD)** standards. The water from the wastewater treatment plant discharges into the Weston River, which is a source of drinking water for several downstream communities.

Additionally, Madison stated that the three men had used high pressure hoses to wash sewage directly from tanks into the river. Madison stated he had informed the director of public works, a political appointee and close ally of the mayor, in May but no actions had taken place. All four denied the claims.

In the days following the meeting, the mayor appointed a committee to investigate the charges and fired the director on August 21. The committee hired another lab to provide testing and consulting services. The USEPA also announced that it was beginning a criminal investigation.

A newly elected mayor fired Madison in March 1992 citing poor job-performance. Madison sued the city for wrongful termination claiming that he was fired for whistleblowing. The city denied the charge. During the next two years, Madison sent out over 600 resumes and was interviewed 25 times but was unable to find a job. In March 1994, a jury eventually ruled in Madison’s favor and awarded him $163,800.

In July 1992, the USEPA charged the superintendent, the maintenance supervisor, and the quality control supervisor with four counts of violating the Clean Water Act (CWA). The indictment charged that they had ordered the discharge of at least 14 tons of **sludge** into the river and had filed incomplete and inaccurate test reports. USEPA compared compliance results submitted by the utility from May 1989 to August 1991 to results from the consulting lab from September 1991 to February 1992. USEPA’s analysis determined tampering might have begun possibly by diluting the sample as early as November 1989. One thought was that personnel could have been concerned the plant was not operating properly possibly because of poor maintenance. The data also indicated that the tampering ended in June 1991, after Madison had informed the director of his suspicions.

In November, the superintendent was acquitted. The other two were convicted and each received 15-month sentences for which they entered a federal prison in February 1994.

Ethical Questions

1) More than a year passed between Madison observing the illegal behavior and reporting it to the authorities. Does this affect the ethics of his behavior?
    - Waiting more than a year suggests his motives might not have been completely noble. There may have been events or relationships that changed in early 1991 that caused him to stop overlooking the tampering and other actions.
2) There were numerous suggestions regarding Madison's motives for blowing the whistle. What might his motives have been? Do his motives affect the ethics of whistleblowing?
    - Perhaps he had a falling out with the others, believed that he should have received recognition, advancement, or compensation, or had political reasons for not initially reporting the actions.
    - It does not appear that his motives affect the fact that he acted properly in blowing the whistle, to the director or the mayor. If he was acting unethically prior to blowing the whistle, it was better that he acted properly at that point. It is not clear that he needed to inform the mayor of the actions. Based on the historic test data, informing the director of his allegations stopped the tampering. Of course, that may have been temporary and would still have resulted in the wrong doers going unpunished.
3) How else might Madison have behaved in this situation? What are the pros and cons of each alternative course of action?
    - Alternative courses of action could have included confronting the supervisors, sending an anonymous letter to EPA, letting the director take care of it, making sure that he was physically present during sample taking, telling plant workers that they should never hose out a sludge tank unless he was there, or other approaches.
    - One con of the approach he did take is that it appears that the tampering ended after he told the director, yet he still destroyed his career.
4) Suppose that Madison had not seen the illegal actions but had based his charges on evaluating the test results submitted to USEPA. Would it have been ethical to report his charges to the mayor and USEPA?
    - It would probably take more convincing statistical data to justify whistleblowing in the absence of personally seeing the illegal behavior. Without definitive data, Madison could have risked ruining the careers of others without being able to prove his allegations.

2.3.2 Local Restaurant Discharge

In early 2001, the wastewater treatment plant in Tinsel Town received a large influx of **grease** into the plant which damaged the skimmers and rakes preventing the **clarifiers** from effectively removing the solids. The wastewater treatment plant operator notified the proper city authorities and an investigation into the source of the grease commenced. The city hired an outside environmental consultant to come in and investigate all the restaurants in town, checking cleaning records and looking at their grease traps.

One of the locally owned restaurants got wind of the survey and called in a septic service to clean out their grease trap prior to the technicians arriving on-site. Restaurant personnel falsified records by backdating the service. The restaurant was owned by a relative of the mayor. Due to this, no one was found to be in violation of their grease trap capacity and no fault was found. The city handed out a “slap on the wrist” to all the restaurants, telling them to be sure to clean out their grease traps regularly. About a year later, it happened again. This time, the operator suggested the survey start with the locally owned restaurant and found that they had not cleaned the grease trap since the last survey. There is a significant cost in both time and money to the city when the plant goes down due to grease in the clarifier.

Ethical Questions

1) What ethical issues are present in this situation and what standards are in question?
    - It is not unethical to start the survey with the restaurant since they were suspected of falsifying records previously. The operator seems to have used reasonable care and judgment in the performance of his operational duties.
2) As an operator, how would you wish this to be handled to protect the integrity of your plant?
    - To protect the safety, health, and welfare of the public and the environment, the operator could inform the city officials of the significant cost in time and money when the wastewater treatment plant is not operating because of grease in the clarifier and the cost and time to fix the clarifier. The operator could request that the city take formal action against the restaurant and inform the restaurant owner of the cost associated with their violations and the impact upon the plant.
    - If the city officials choose to not enforce against the restaurant, the operator could explain the possible consequences if a certified operator’s judgment is overruled by an employer when the safety, health, and welfare of the public or the environment are endangered. For example, if the wastewater treatment plant is not functioning and the permit limits cannot be met when the plant discharges into the river, then the city could receive a Notice of Violation from the state. Depending upon the extent of the exceedance, the city could be required to pay a penalty.

2.3.3 It is Just One Sample…Right?

A local manufacturer continually discharges liquid waste into the sanitary **sewer** line to the Tinsel Town Wastewater Treatment plant. The discharge limit for arsenic is 0.95 mg/L. This manufacturer samples their discharge weekly to ensure that their discharge does NOT exceed the allowed concentration of arsenic. Their permit indicates that they are required to halt all discharge if the sampling indicates that they exceeded the allowable limit, and a report must be filed with wastewater treatment plant. For the past 5 years, the weekly sampling has shown that the manufacturer has met the arsenic standard. During this week’s sample it is found that the discharge from the plant is more than the 0.95 mg/L arsenic limit. The process has not changed, and the company decides not to notify the plant as required. The plant manager and the wastewater treatment plant operator are friends, and it comes up during their conversation that the manufacturing plant exceeded the arsenic allowable limit, the plant did not stop discharging, and the notification report was NOT filed as the permit required.

Ethical Questions

1) What would you do as the wastewater treatment plant operator?
    - Since the plant manager told his friend the operator about the incident and that it was not reported, by doing nothing, the operator may not be protecting the safety, health, and welfare of the public and the environment. Additionally, if the company 'gets away with' not reporting the exceedance and continuing to discharge wastewater in exceedance of allowable limits, they may decide to repeat their actions in the future or possibly stop sampling for arsenic entirely.
    - The operator should take some care in deciding how to proceed. The plant manager's job and friendship may be in jeopardy if the operator starts accusing the company of wrongdoing without proof. Additionally, the plant manager may have a grudge with the company or personal reasons to retaliate against the company.
2) What are alternative courses of action that could be used to handle this situation?
    - The operator could investigate the incident or request that the manufacturer submit results of their weekly samples for the timeframe in question. The operator could recommend that the city issue a letter of warning or take more formal actions depending on the level of cooperation and documented information from the manufacturer.
    - Alternatively, the operator could have confronted the plant manager when he initially disclosed the violation and informed him that he was ethically, if not legally, required to report the incident since he could potentially be held liable for having such information and not acting on it. At a minimum, he should inform the manager of the seriousness of the issue and insist that such an incident should never occur in the future. As an added precaution, he could take steps to randomly sample from the plant **effluent** to independently ensure compliance and then report any future violation.

2.4 References

1. BOMI International. *The Importance of Ethics in the Workplace*. Retrieved from **https://fmlink.com/articles/the-importance-of-ethics-in-the-workplace/**
2. Fletcher, D. (2019). *Weston Wastewater Treatment Case*. Retrieved from **http://ethics.tamu.edu/wpcontent/uploads/sites/7/2017/04/Weston-Wastewater.pdf**

2.5 Other Resources

Kentucky Administrative Regulations, 11 C.F.R. **§ 020** and **§ 050**.

Chapter 3

Introduction to the Clean Water Act

3.1 The Importance of Clean Water

Our personal health, communities and the economy thrive when clean water is available. Our economy requires water for multiple purposes, including manufacturing, farming, and energy production. We also need water for cleaning, cooking, drinking, and waste disposal. Healthy ecosystems provide wildlife habitat and recreation. When water is heavily polluted it becomes difficult to use for any of the things listed.

While the importance of clean water should be self-evident, for many years, some industries in the United States would dump their waste into available streams and lakes in an attempt to remove the waste from the area. For a long time, the mantra, "The solution to pollution is dilution," was quite common. As you can imagine, this resulted in some of the waters of the US becoming heavily polluted. In 1948, Congress passed the Federal **Water Pollution** Control Act as a first attempt to address this problem (Ref. 1). Unfortunately, this law was not sufficient as streams and rivers continued to become more polluted. Perhaps the most striking example of this was in 1969 when the Cuyahoga River in Cleveland, Ohio, caught fire for the 13th time because of all the pollutants in the river (Ref. 2). In response, Congress created the US Environmental Protection Agency (EPA) in 1970 and then passed what eventually became known as the Clean Water Act (CWA) in 1972.

The CWA did many things, including:

- Maintained existing requirements to set water quality standards for all contaminants in surface waters.
- Gave the EPA authority to implement pollution control programs such as setting wastewater standards for industry.
- Established the basic structure for regulating pollutant discharges into the waters of the United States by creating a formal pollutant discharge permit program. This is formally known as the National Pollutant Discharge Elimination System (NPDES) and the permit associated with this program is known as a NPDES permit.
- Made it unlawful for any person to discharge any pollutant from a point source into navigable waters unless a permit was obtained under its provisions.
- Funded the construction of sewage treatment plants under the construction grants program.
- Recognized the need for planning to address the critical problems posed by nonpoint source pollution.

The Clean Water Act establishes the federal guidelines by which states can draft laws and regulations and create programs to fulfill this mandate (Ref. 3). Because the EPA does not have the resources to implement all these programs across the country, they have given this responsibility to the individual states. Thus, the federal NPDES program for Kentucky is managed by the KDOW Kentucky Pollutant Discharge Elimination System (KPDES) Branch and the associated permits that they issue and manage are called KPDES permits.

While individual states cannot implement instream water quality standards less stringent than those of the federal government (i.e., EPA), they can implement more stringent standards. In Kentucky, the regulations that govern pollutant discharges into streams of the Commonwealth are found in Title 401 of the **Kentucky Administrative Regulations**, Chapters 5, 10, and 11 (Ref. 4).

Some of Kentucky's water quality standards apply to all streams in Kentucky while other standards are dependent upon what the stream is used for, or what is called its "designated use." By default, all streams in Kentucky are designated to support the life of warm water aquatic species as well as primary (e.g., swimming) and secondary (e.g., boating and fishing) water contact. If water is being withdrawn from a stream for use as a public water supply, the state has additional water quality standards that must be met. Examples of water quality standards that apply to all Kentucky streams (see **401KAR Chapter 10:031**) are shown in Tables 3.1, 3.2, and 3.3.

Table 3.1 Example of Water Quality Standards That Apply to All Kentucky Streams

Parameter	Lower Limit	Upper Limit
Temperature	N/A	31.7°C (89°F)
pH	6.0	9.0
Un-ionized ammonia	N/A	0.05 mg/L

Table 3.2 Examples of Bacterial Standards That Apply to All Kentucky Streams

Parameter	Chronic Conditions – the average of five or more samples collected within 30 days shall be less than:	Acute Conditions - 80% of the samples collected within 30 days shall be less than:
Fecal Coliform	200 cfu/100 mL*	400 cfu/100 mL
E. coli	130 cfu/100 mL*	240 cfu/100 mL

*Note: These averages are based on geometric mean, which involves a special mathematical calculation which you will not be tested on.

Table 3.3 Minimum Allowable Dissolved Oxygen Levels

Parameter	Instantaneous	Daily average
Minimum dissolved oxygen	4 mg/L	5 mg/L

In order to make sure the water quality of the rivers and streams in Kentucky are ultimately protected, the KDOW uses two different strategies:

1) Pollutant discharge permits.
2) Stream water quality standards.

As a wastewater operator, you are part of the first strategy. To protect the streams, the KDOW sets limits on how much of a pollutant a wastewater treatment plan can discharge into a receiving stream. The term pollutant is broadly defined as anything that is introduced into the environment that has undesired effects, or adversely affects the usefulness of a resource, or technically, its "designated use". For our purposes, this is any type of industrial or municipal, waste (including heat) discharged into water. It should be pointed out, that in most cases the wastewater treatment plant is not required to eliminate 100% of all the wastes entering the plant, but only to those levels that when discharged into the stream would not exceed the instream water quality standards associated with the designated use of the stream. What are those levels and where do I find them? These levels are specified in your **KPDES discharge permit**. Examples of discharge limits for most wastewater treatment plants with **secondary treatment** (i.e., biological treatment) are provided in Table 3.4. In addition to these values, the **pH** of the discharge must be between 6.0 and 9.0. Most secondary treatment facilities are also required to provide at least 85% removal for both BOD_5 and TSS. The discharge limits for ***Escherichia coli* (*E. coli*)** are the same as those for the instream water quality standards shown in Table 3.2.

Table 3.4 Typical Discharge Limits for Wastewater Treatment Plants with Secondary Treatment

Parameter	7-Day Average	30-Day Average
5-Day BOD (biochemical oxygen demand)	45 mg/L	30 mg/L
TSS (total suspended solids)	45 mg/L	30 mg/L
Chlorine Residual	0.019 mg/L	0.011 mg/L

The KDOW sets the discharge limits for your facility based on what have been found to be nationally applicable "technology based" limits for certain types of pollutants. They then continue to monitor downstream of your facility to make sure the water quality standards for the stream are still being met (this is the second part of their strategy). Where technology-based limits are not adequate to achieve water quality standards for one or more parameters and designated use, the KDOW can impose additional facility-specific "water quality based" limits. KDOW has a professional staff that uses monitoring data and computer models to set these limits. Such limits include values for **dissolved oxygen (DO)** and ammonia, although neither parameter can exceed the water quality standards shown in Table 3.3. Regardless of the source, each of these limits will be listed in your facility specific KPDES discharge permit.

3.2 Why Do I Need a Permit?

The Clean Water Act made it unlawful to discharge any pollutant from a point source into navigable waters unless a permit was first obtained. As stated in **401 KAR Chapter 10,** it is the policy of the Commonwealth:

1) To conserve the waters of the Commonwealth for public water supplies, for the propagation of fish and aquatic life, for fowl, animal wildlife and arborous growth, and for agricultural, industrial, recreational and other legitimate uses; to provide a comprehensive program in the public interest for the prevention, abatement and control of pollution; to provide effective means for the execution and enforcement of such programs; and to provide for cooperation with agencies of other states or of the federal government in carrying out these objectives.
2) To safeguard from pollution the uncontaminated waters of the Commonwealth; to prevent the creation of any new pollution of the waters of the Commonwealth; and to abate any existing pollution.

Industrial, municipal, and other facilities must obtain permits if their point source discharge flows to surface waters. Point sources are single identifiable sources of pollution. Examples include publicly owned treatment works (POTWs), industrial process wastewater discharges, certain mining operations, and discharges from concentrated animal feeding operations (CAFOs.) While Municipal Separate Stormwater Systems (MS4s) may also contain specific points of discharge into a stream, these are currently treated somewhat differently through a more general (and not point specific) MS4 permit. For municipal systems that include Combined Sewer Overflows (CSOs), they must also obtain a CSO permit. Similar to MS4 permits, these permits are also usually not point specific but typically include all the CSOs within the collection system.

In summary, you may think of a KPDES permit as a license for a facility to discharge limited amounts of pollutants into **receiving waters** under certain conditions.

3.3 References

1. EPA. (August 8, 2017). ***History of the Clean Water Act***.
2. Collaborative on Health and the Environment. ***"The River Caught Fire": The Cuyahoga River Fire of 1969***.
3. EPA. (2016). Clean Water Rule.
4. Kentucky Administrative Regulations, **Title 401**.

3.4 Other Resources

EPA. **Introduction to the Clean Water Act**. *Watershed Academy Web.*

Chapter 4

Kentucky Pollutant Discharge Elimination System

All discharges into streams in Kentucky require a permit through the Kentucky Pollutant Discharge Elimination System (KPDES). Wastewater discharges require a KPDES permit according to regulation 401 KAR Chapter 5:055 (Ref. 1)**.** Below is a discussion about obtaining a permit and how to read the permit.

4.1 Obtaining a Permit

To obtain a KPDES permit for municipal wastewater discharge, the applicant must submit two forms to the Kentucky Division of Water (KDOW) (Ref. 2). Each required form also has a complete set of instructions for completion of the permit application.

1) Form 1 is required to be submitted for all new applications and contains general questions regarding the facility location, operator information, environmental registrations, and type of permit being requested.
2) Form A is required for wastewater discharges. It asks questions that are more specific to the operation itself about things such as the collection system, the average flow rate, treatment of the effluent, discharge location, discharge characteristics, etc.

Other types of systems, such as non-discharge systems or stormwater systems require different types of KPDES permits and thus will need different types of forms.

These forms and the required permit fees must be submitted at least 180 days before discharge is scheduled to begin or 180 days prior to permit renewal. Once the required paperwork and fees have been submitted to the Division of Water (DOW), a formal review process will begin, and the applicant will be notified in writing if there are deficiencies that need to be corrected or if the application is deemed complete.

Once the application is considered technically complete, a draft permit will be issued for public comment. At this point you have the opportunity to review and provide feedback on your permit requirements.

4.2 Elements of a KPDES Permit

All wastewater treatment plants must have a KPDES discharge permit. Some example pages of a typical permit are provided in Figures 4.1 and 4.2. A typical KPDES permit will contain the following information:

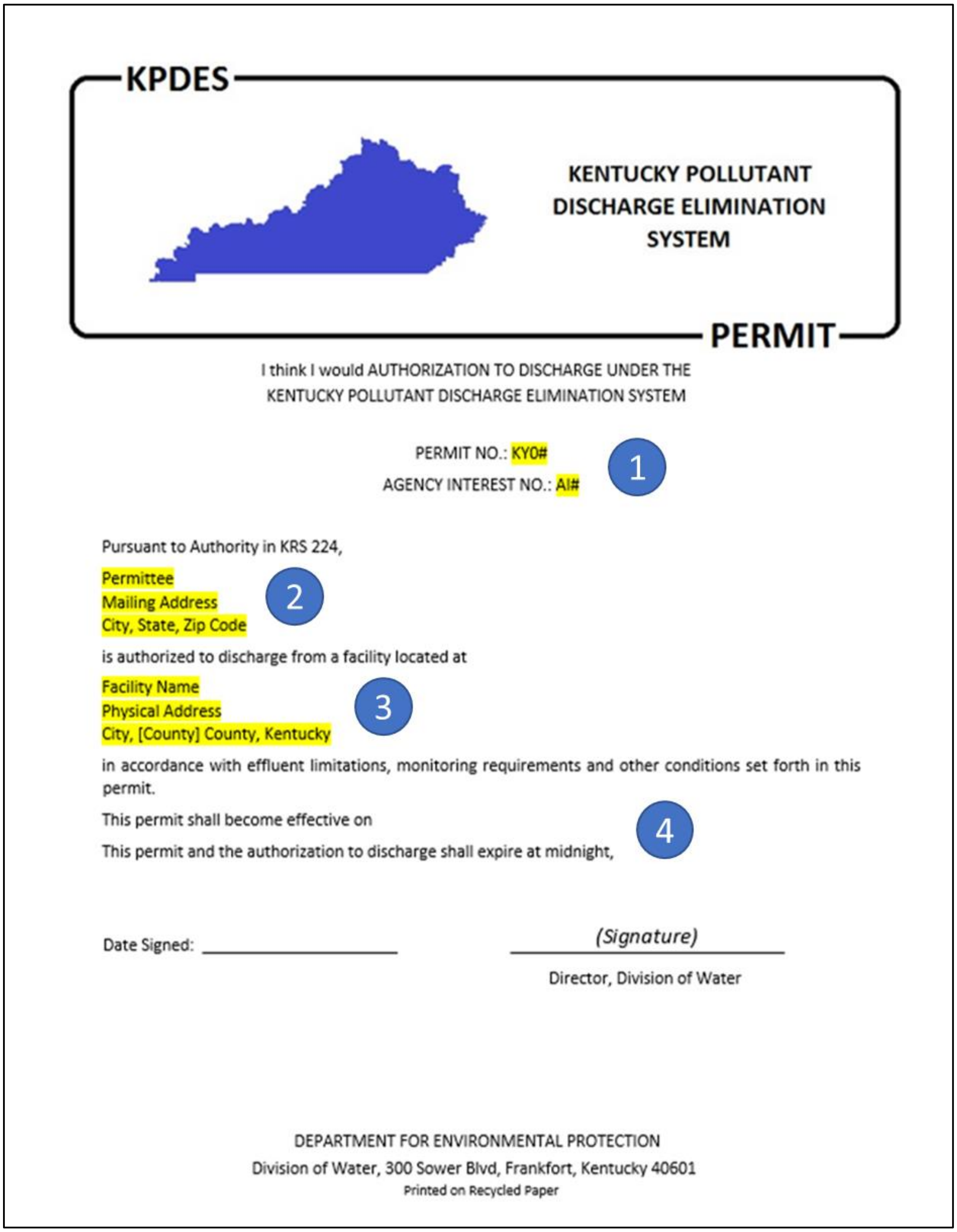
- Cover Page**:** Contains the name and location of the permittee, a statement authorizing the discharge along with the location of the discharge facility, and a listing of the stream or water body into which the discharge is authorized (Figure 4.1).
- Effluent Limitations**:** This information is listed on the effluent limitations and monitoring requirements section of the permit (Figure 4.2) The pollutant limitations are developed based on the existing technology used by the plant to clean the water and the nature of

the receiving stream. The permit will identify the pollutant, the loading limits, and the monitoring requirements.

- Monitoring and Reporting Requirements**:** This information is also listed on the effluent limitations and monitoring requirements section of the permit (Figure 4.2). The data collected from the monitoring is used to characterize waste-streams and receiving waters, evaluate wastewater treatment efficiency, and determine compliance with permit conditions.
- Standard Conditions: Pre-established conditions that apply to all KPDES permits and delineate the legal, administrative, and procedural requirements of the KPDES permit.
- Special Conditions: Conditions developed to supplement numeric effluent limitations. Examples include additional monitoring activities, special studies, best management practices (BMPs), and compliance schedules.

Figure 4.1 Cover Page of KPDES Permit

Front page should contain: (1) permit number and agency interest number, (2) the name and location of the permittee, (3) name and location of the specific facility, and (4) the beginning and ending dates of the permit.



KPDES

KENTUCKY POLLUTANT
DISCHARGE ELIMINATION
SYSTEM

PERMIT

I think I would AUTHORIZATION TO DISCHARGE UNDER THE
KENTUCKY POLLUTANT DISCHARGE ELIMINATION SYSTEM

PERMIT NO.: KY0#
AGENCY INTEREST NO.: AI#

Pursuant to Authority in KRS 224,

Permittee
Mailing Address
City, State, Zip Code

is authorized to discharge from a facility located at

Facility Name
Physical Address
City, [County] County, Kentucky

in accordance with effluent limitations, monitoring requirements and other conditions set forth in this permit.

This permit shall become effective on

This permit and the authorization to discharge shall expire at midnight,

Date Signed: ____________________

(Signature)
Director, Division of Water

DEPARTMENT FOR ENVIRONMENTAL PROTECTION
Division of Water, 300 Sower Blvd, Frankfort, Kentucky 40601
Printed on Recycled Paper

Figure 4.2 Effluent Limitations and Monitoring Requirements

1. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

1.1. Compliance Monitoring Locations (Outfalls)

The following table lists the outfalls authorized by this permit, the location and description of each, and the DOW assigned KPDES outfall number:

① ② ③ ④

TABLE 1.					
Outfall No.	**Outfall Type**	**Latitude (N)**	**Longitude (W)**	**Receiving Water**	**Description of Outfall**
XX	External/Internal	XX.XXXXXX’	XX.XXXXXX’	XX	Domestic Wastewater from a Publicly Owned Treatment Works which Includes an Approved Pretreatment Program
XX	External	XX.XXXXXX’	XX.XXXXXX’	XX	Untreated CSO [or Storm Water] from [name] CSO

1.2 Effluent Limitations and Monitoring Requirements

Beginning on the effective date and lasting through the terms of this permit, discharges from Outfall XX shall comply with the following effluent limitations:

⑤ ⑥ ⑦ ⑧

TABLE 2.									
EFFLUENT LIMITATIONS								**MONITORING REQUIREMENTS**	
Effluent Characteristics	**Units**	**Loadings (lbs/day)**		**Concentrations**				**Frequency**	**Sample Type**
		Monthly Average	**Maximum Weekly Average**	**Minimum**	**Monthly Average**	**Maximum Weekly Average**	**Maximum**		
Flow, Effluent	MGD	Report	Report[1]	N/A	N/A	N/A	N/A	XX	XX
Flow, Influent	MGD	Report	Report[1]	N/A	N/A	N/A	N/A	XX	XX
pH	SU	N/A	N/A	6.0	N/A	N/A	9.0	XX	Grab
$CBOD_5$[2], Effluent	mg/l	XX	XX	N/A	XX	XX	N/A	XX	24-Hr Composite[3]
$CBOD_5$[2], Influent	mg/l	N/A	N/A	N/A	Report	Report	N/A	XX	24-Hr Composite[3]
$CBOD_5$[2], Percent Removal[4]	%	N/A	N/A	N/A	85	N/A	N/A	1/Month	Calculated
TSS[5], Effluent	mg/l	XX	XX	N/A	30	45	N/A	XX	24-Hr Composite[3]
TSS[5], Influent	mg/l	N/A	N/A	N/A	Report	Report	N/A	XX	24-Hr Composite[3]
TSS[5], Percent Removal[4]	%	N/A	N/A	N/A	85	N/A	N/A	1/Month	Calculated[4]
Ammonia (as mg/l NH_3N)	mg/l	N/A	N/A	N/A	XX	XX[1]	N/A	XX	24-Hr Composite[3]
May 1 - October 31	mg/l	N/A	N/A	N/A	XX	XX[1]	N/A	XX	24-Hr Composite[3]
November 1 – April 30	mg/l	N/A	N/A	N/A	XX	XX[1]	N/A	XX	24-Hr Composite[3]
Dissolved Oxygen	mg/l	N/A	N/A	XX	N/A	N/A	N/A	XX	Grab

The specific sections of the KPDES permit are identified by the reference numbers in Figure 4.2 and are summarized below:

- Column 1 contains the identification number associated with each outfall identified by the permit. All discharge locations should be identified in this column.
- Column 2 is the outfall type as identified by the permit application.
- Column 3 identifies the named stream, river, lake, pond, etc., that is receiving the effluent from the plant.
- Column 4 is a description of the type of effluent (e.g., Domestic Wastewater from a Publicly Owned Facility).
- Column 5 column identifies the characteristics of the effluent including flowrate, physical characteristic (e.g., pH and dissolved oxygen) and pollutant type (CBOD, TSS, ammonia) by characteristics allowed by the permit.
- The two columns labeled 6 contain the monthly average and maximum weekly average discharge limits in lbs/day for the different effluent parameters.
- The four columns labeled 7 identify the minimum allowable, monthly average, maximum weekly average, and maximum allowable concentrations for the different effluent parameters. You will notice that some cells contain a number (e.g., 30, 45, 85) which are the same for all permits, some cells contain XX, which means the specific number will be dependent upon the facility, and some cells contain N/A which is shorthand for Not Applicable.
- The last two columns labeled 8 explain how frequently a water quality parameter should be sampled or monitored and what type of sample should be collected (e.g., grab or 24-hour composite). Each of these types of sample collection will be discussed in more detail in the next chapter.

Following the Effluent Limitations and Monitoring Requirements section of the permit, the KPDES permit will contain two additional sections:

1) A set of standard conditions that outline details regarding the need to reapply for a permit, the proper operation and maintenance of the plant, inspection, and entry, the keeping of monitoring records, reporting requirements, etc.
2) A set of special conditions that apply to the wastewater treatment plant (WWTP) you operate. It is important that all operators be familiar with the provisions of your facility permit, especially if any special conditions are applicable.

4.3 References

1. Kentucky Administrative Regulations. **401 KAR Chapter 5**.
2. KEEC. ***Wastewater Discharge Permits***.

4.4 Other Resources

KEEC. (2016). ***General Procedures for Limitations Development***.
KEEC. (2019). ***KPDES General Instructions.***

Chapter 5

Discharge Monitoring Reports

In order to ensure that a wastewater treatment plant is meeting its permitted discharge limits, each facility is required to monitor and sample the discharge from its plant and report the results of the associated readings and laboratory analyses to the KDOW via a formal report known as the **Discharge Monitoring Report** (DMR) (Ref. 1).

5.1 DMR Submittal

The KPDES permit will identify the specific reporting requirements for each discharge point identified in the permit. Section 3.3 in the KPDES fact sheet for your permit outlines the specific effluent and monitoring requirements for your permit. The results of your sampling are reported via your facility Discharge Monitoring Report (DMR). All DMRs must now be submitted electronically through an online entry portal called NetDMR on, or before, the 28th day of the month following the monitoring period end date.

5.1.1 NetDMR

According to the Kentucky Energy and Environment Cabinet (KEEC), "NetDMR is a national tool for regulated Clean Water Act permittees to submit Discharge Monitoring Reports (DMRs) electronically via a secure internet application to the EPA through the Environmental Exchange Network. To access NetDMR, users must have a CDX account. CDX is an agency user account creation and management tool used for accessing several different EPA systems for electronic reporting with a single sign in."

By using a registered account, the security of the information being transmitted can be preserved and the amount of paperwork and errors can be reduced since the entered data is validated prior to a timely submission. Detailed instructions on the NetDMR process are provided in the **Kentucky Discharge Monitoring Report Manual**. To login or register for a Central Data Exchange (CDX) account, visit the **NetDMR 2017 Upgrade Registration and Log-in Page**.

Once logged into the NetDMR account, an operator will be able to view, create, sign, and submit DMR by following the steps. The individual parts of NetDMR are detailed in Section 5.1.2.

First, you will need to search for your permit and then select "Edit DMR."

- Once your DMR portal opens, you need to verify that the Permit ID, Permittee, Facility Location, Address, and Monitoring Period are correct.
- You also need to verify each permit requirement and ensure that the information you are reporting is in the correct units.
- If there has been no monitoring or discharge for any of the required reports for the entire monitoring period, you will need to select the appropriate No Data Indicator

(NODI) code. There are several options available for this response and you should carefully review the list before making a choice.

If there has been flow and monitoring during the DMR period, you will record the data for each parameter sampled. You should keep the following things in mind when inputting your data into the NetDMR system:

- Average is normally the arithmetic average of all sample measurements for each parameter obtained during the monitoring period.
- Unlike the average for most measurements, the average for **bacteria** (e.g., *E coli*) is expressed in terms of a geometric average (mean) – see Appendix B.
- Maximum and minimum are the high and low measurements obtained during the monitoring period.
- If the result of only one measurement is being reported, enter the same value in EVERY column for which limitations are specified in the permit.
- ALL sample measurement spaces available must be completed.
- You can enter either a monitored value or a No Data Indicator (NODI) code for a required parameter but not both.

The NetDMR system will notify you if you input erroneous data or attempt to input monitoring data that exceeds your permit limits. Should an error show up, double check the information and correct it or provide the required explanation. Additional help on using NetDMR can be found at the **KDOW NetDMR website.**

5.1.2 Parts of the NetDMR

The NetDMR is divided into different reporting sections that are identified by the reference numbers in Figure 5.1 and summarized below:

- ① KPDES Permit ID, Permittee and Facility Information:
    - Verify that the correct name and mailing address are shown in NetDMR.
- ② Permitted Feature:
    - The permitted feature refers to a particular pipe or outfall. Each DMR corresponds to a specific outfall. Make sure you are recording data for the correct outfall on your DMR.
- ③ Discharge:
    - The discharge refers to the specific limits set and discharge type for the outfall. Each DMR corresponds to a specific outfall and limit set. Make sure you are recording data for the correct outfall and limit set on your DMR.
- ④ Monitoring Permit:
    - The first and last days of the monitoring period are displayed in MM/DD/YYYY format. Since the monitoring period for each permit is different, the permittee should check to be certain that the monitoring period specified on the DMR corresponds to the permit requirement.

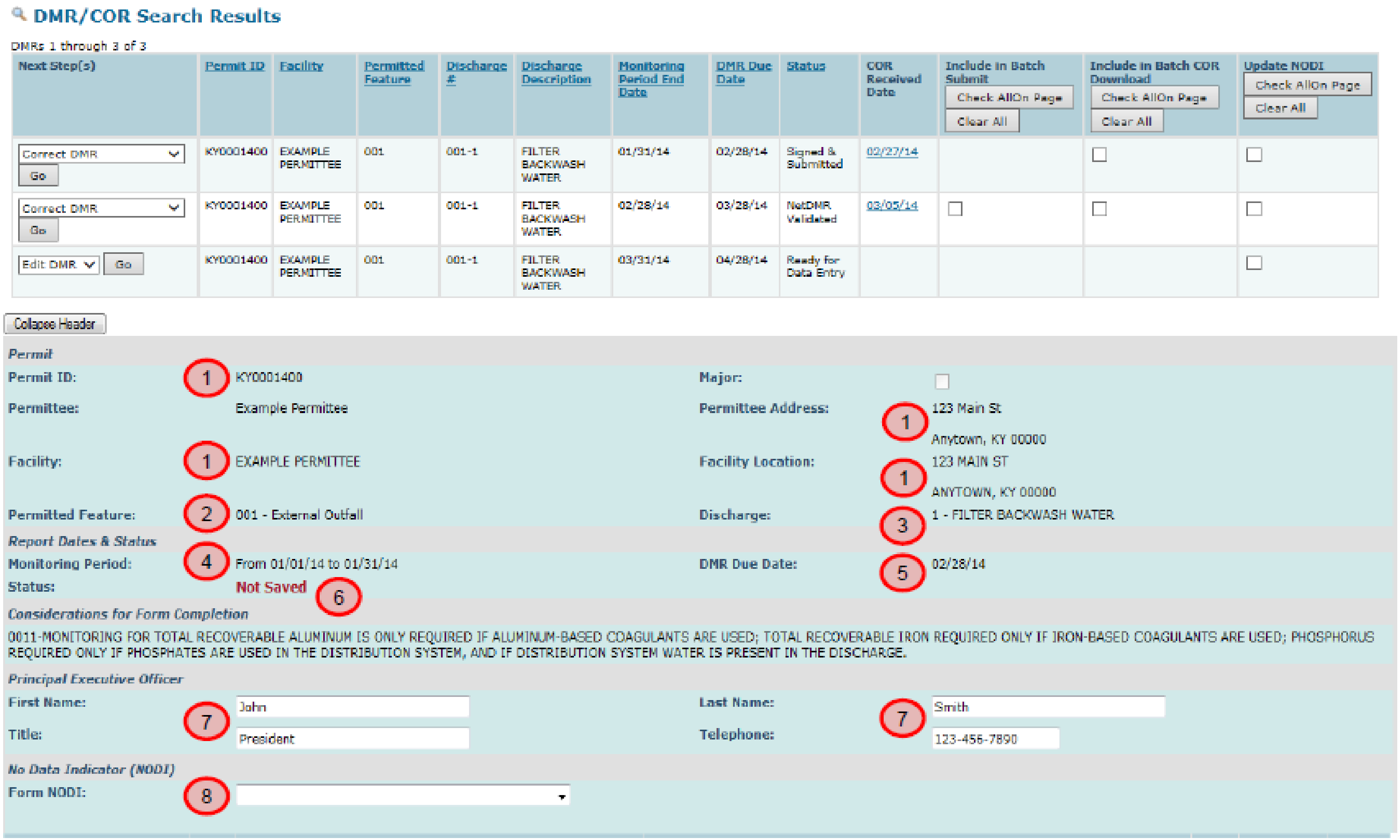
- ⑤ DMR Due Date:
    - Displays the date by which the DMR submission must be completed to avoid violation of the permit requirements.
- ⑥ Status:
    - Displays the status of the DMR submission (Not Saved, NetDMR Validated, Submitted, etc.).
- ⑦ Name/Title of Principal Executive Officer or Authorized Agent:
    - The name, title and phone number of the responsible person should be filled out in the header section of the DMR.
- ⑧ No Data Indicator (NODI):
    - If there is no discharge or data available for the entire DMR for the monitoring period, select the appropriate NODI code from the dropdown box. No other entries for parts 9-17 are required. It is important to note that you should never force a discharge in order to take a sample during the monitoring period. The intent of the monitoring program is to be representative of the operations of the wastewater treatment system.
- ⑨ Parameters:
    - Verify that each parameter specified in the permit is listed one per box in the far left column of the form.
- ⑩ DMR Value Qualifier:
    - Equals (=) will pre-populate in the qualifier dropdown box unless you manually choose a different option. Select the appropriate DMR value qualifier from the dropdown list based on the values reported by your laboratory.
- ⑪ Sample Measurement:
    - Enter the analytical data for each parameter under “Quantity or Loading” and “Quality or Concentration” in the appropriate box result in NetDMR. “Quantity or Loading” values are referred to as Q1 and Q2 and “Quality or Concentration” values are referred to as C1, C2 and C3 in NetDMR.
        - Average is normally the arithmetic average (geometric mean for bacterial parameter) of all sample measurements for each parameter obtained during the monitoring period. pH is never averaged.
        - Maximum and minimum are normally the high and low measurements obtained during the monitoring period.
        - If the result of only one measurement is being reported, enter the same value in EVERY column for which limitations are specified in the permit.
        - ALL sample measurement spaces available must be completed. A value box cannot be left blank (see 18. Edit Check Errors below).

    - You cannot enter both a value and a NODI code for a required parameter and value type (see 18. Edit Check Errors below).

- ⑫ Permit Requirement:
  - Verify each permit requirement for each parameter under Quality and Quantity as specified in the permit.
- ⑬ Units:
  - The parameter units are prepopulated based on your permit requirement. Unless the units are changed, there is no need to fill in this column. If your laboratory report shows different units than listed on your permit, you must convert to the permit listed units (preferred) or select the appropriate units from the dropdown list.
- ⑭ Number of Exceptions:
  - The “# of Ex.” field indicates how many times a limit was not met during the monitoring period. To complete this field, count and then enter the number of sample measurements that does not conform to the maximum (or minimum) limit for the parameter for both “Quantity or Loading” and “Quality or Concentration”. Do not count the results for the average “Quantity or Loading” and “Quality or Concentration” as exceptions.
    - Some permits and parameters specify the maximum (or minimum) results as “weekly averages” instead of a “daily maximums”. In these instances, count and report the number of “weekly averages” that did not conform to the permit limit, not the number of individual sample results.
- ⑮ Frequency of Analysis:
  - The frequency of analysis is prepopulated based on your permit requirement. Unless the frequency is changed, there is no need to fill in this column. If you did not collect the permit required number of samples, select the actual frequency of sampling during the monitoring period from the dropdown list. For example, enter “99/99” for continuous monitoring, “1/7” for once per week, “1/30” for once per month and “1/90” for once per quarter. See the Appendix D for frequency of analysis codes and explanations.
- ⑯ Sample Type:
  - The sample type is prepopulated based on your permit requirement. Unless the sample type is changed, there is no need to fill in this column. If a different sampling method was used, select the method used to collect the actual sample from the dropdown list. See Appendix E for sample type codes and explanations.
- ⑰ Parameter Specific NODI Code:

    - If there is no data available for the specific parameter for the monitoring period, select the appropriate NODI code from the dropdown box.
- ⑱ Edit Check Errors:
    - If any "errors" are listed, they must be either corrected or acknowledged by clicking the checkbox under acknowledge. Examples of errors are a DMR value exceeding the permit limit, entering both a value and a no discharge code for a required parameter, or leaving a required parameter blank. The error listing will provide the parameter and specific value (Q1, Q2, C1, C2, C3) on which the error occurred.
- ⑲ Comments and Explanation of Any Violations:
    - This block is required to explain and discuss any permit violations that occurred during the monitoring period. If you require additional space, please attach a brief explanation. The explanation in both the comment box and any attachments should detail the cause and corrective actions taken in addition to referencing each violation by date.
- ⑳ Add Attachment:
    - This feature is used to attach additional files that may be relevant to your DMR such as laboratory reports, data, letters of explanation, etc. Most document formats (PDF, MS WORD, MS EXCEL, JPG) are acceptable.
- ㉑ Report Last Saved By:
    - This information shows who last edited and saved information on the DMR. It will not update when the DMR is submitted if no edits are made prior to DMR submission.
- ㉒ Save Options:
    - When you have finished making changes to the DMR, you must save your edits. Click Save and Continue if you want to remain on the current DMR and screen or Save and Exit if you want to return to the available DMR listing screen. Once the DMR is saved, the DMR Status (6) and Edit Check Errors (18) will update to display the current status and potential required edits. Saving the DMR does not complete your permit required DMR submission.
- ㉓ Sign and Submit:
    - After the DMR has been saved, if all edit check errors (18) have been cleared or acknowledged and the DMR status (6) shows NetDMR validated, the DMR can be submitted. Submitting the DMR completes your permit required DMR submission.

Figure 5.1 Example of NetDMR



DMR/COR Search Results

DMRs 1 through 3 of 3

Next Step(s)	Permit ID	Facility	Permitted Feature	Discharge #	Discharge Description	Monitoring Period End Date	DMR Due Date	Status	COR Received Date	Include in Batch Submit Check AllOn Page Clear All	Include in Batch COR Download Check AllOn Page Clear All	Update NODI Check AllOn Page Clear All
Correct DMR Go	KY0001400	EXAMPLE PERMITTEE	001	001-1	FILTER BACKWASH WATER	01/31/14	02/28/14	Signed & Submitted	02/27/14		☐	☐
Correct DMR Go	KY0001400	EXAMPLE PERMITTEE	001	001-1	FILTER BACKWASH WATER	02/28/14	03/28/14	NetDMR Validated	03/05/14	☐	☐	☐
Edit DMR Go	KY0001400	EXAMPLE PERMITTEE	001	001-1	FILTER BACKWASH WATER	03/31/14	04/28/14	Ready for Data Entry				☐

Collapse Header

Permit

Permit ID:	① KY0001400	**Major:**	☐
Permittee:	Example Permittee	**Permittee Address:**	① 123 Main St Anytown, KY 00000
Facility:	① EXAMPLE PERMITTEE	**Facility Location:**	① 123 MAIN ST ANYTOWN, KY 00000
Permitted Feature:	② 001 - External Outfall	**Discharge:**	③ 1 - FILTER BACKWASH WATER

Report Dates & Status

Monitoring Period:	④ From 01/01/14 to 01/31/14	**DMR Due Date:**	⑤ 02/28/14
Status:	Not Saved ⑥		

Considerations for Form Completion

001-MONITORING FOR TOTAL RECOVERABLE ALUMINUM IS ONLY REQUIRED IF ALUMINUM-BASED COAGULANTS ARE USED; TOTAL RECOVERABLE IRON REQUIRED ONLY IF IRON-BASED COAGULANTS ARE USED; PHOSPHORUS REQUIRED ONLY IF PHOSPHATES ARE USED IN THE DISTRIBUTION SYSTEM, AND IF DISTRIBUTION SYSTEM WATER IS PRESENT IN THE DISCHARGE.

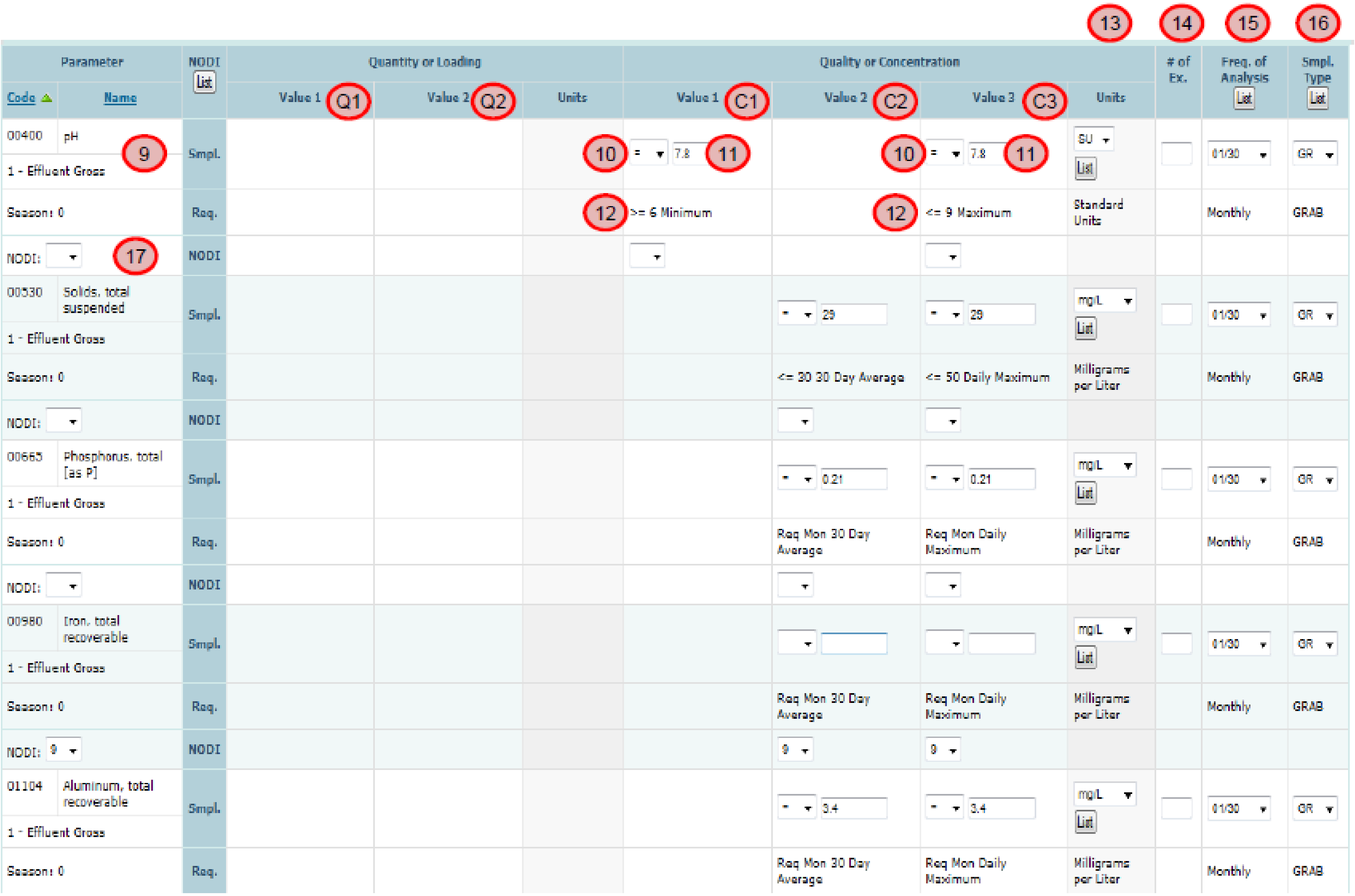
Principal Executive Officer

First Name:	⑦ John	**Last Name:**	⑦ Smith
Title:	President	**Telephone:**	123-456-7890

No Data Indicator (NODI)

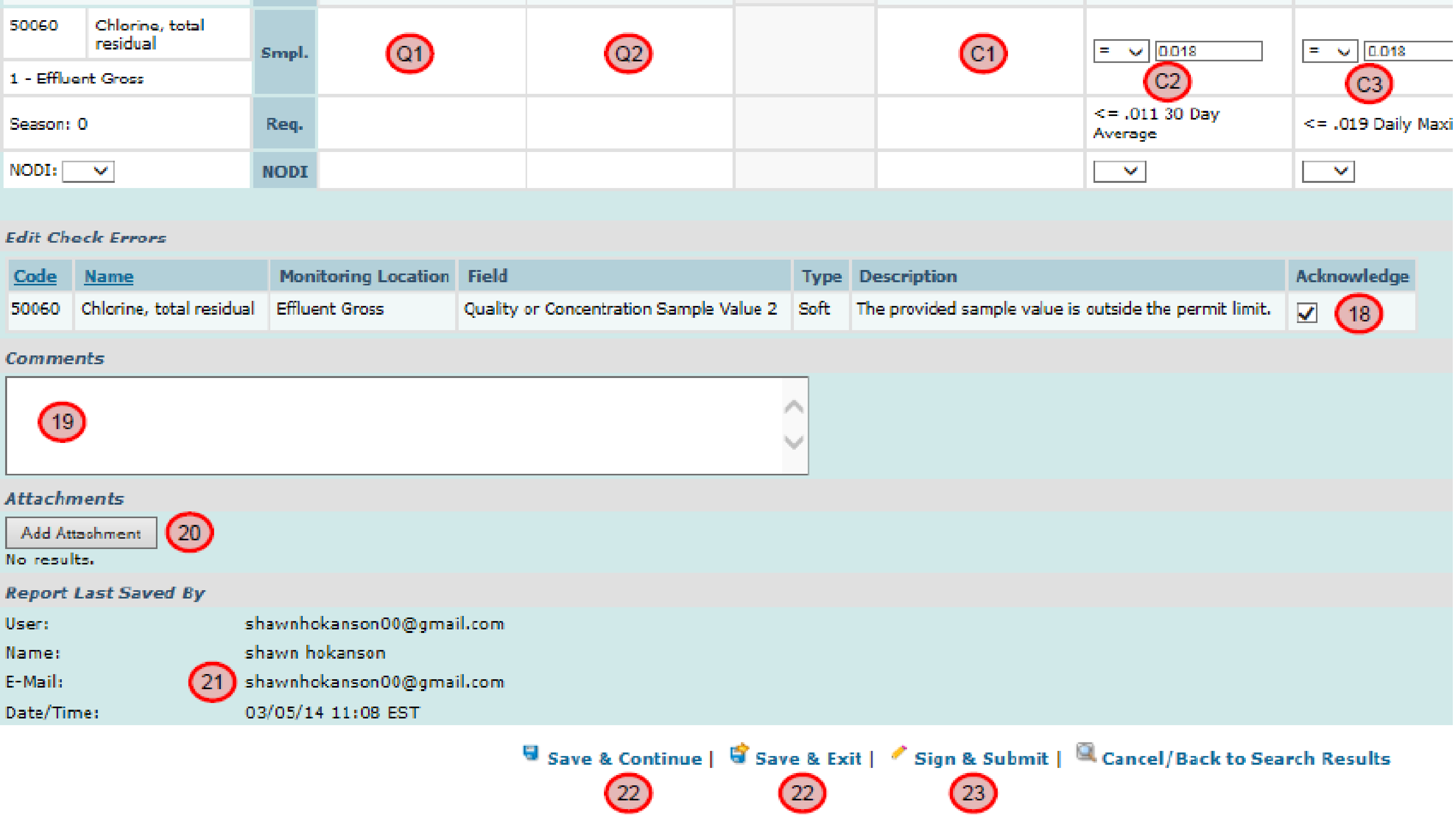
Form NODI: ⑧

Figure 5.1 (Continued) Example of NetDMR



Parameter		NODI List	Quantity or Loading			Quality or Concentration				# of Ex.	Freq. of Analysis List	Smpl. Type List
Code	Name		Value 1	Value 2	Units	Value 1	Value 2	Value 3	Units			
00400 1 - Effluent Gross	pH	Smpl.				= 7.8		= 7.8	SU List		01/30	GR
Season: 0		Req.				>= 6 Minimum		<= 9 Maximum	Standard Units		Monthly	GRAB
NODI:		NODI										
00530 1 - Effluent Gross	Solids, total suspended	Smpl.					= 29	= 29	mg/L List		01/30	GR
Season: 0		Req.					<= 30 30 Day Average	<= 50 Daily Maximum	Milligrams per Liter		Monthly	GRAB
NODI:		NODI										
00665 1 - Effluent Gross	Phosphorus, total [as P]	Smpl.					= 0.21	= 0.21	mg/L List		01/30	GR
Season: 0		Req.					Req Mon 30 Day Average	Req Mon Daily Maximum	Milligrams per Liter		Monthly	GRAB
NODI:		NODI										
00980 1 - Effluent Gross	Iron, total recoverable	Smpl.							mg/L List		01/30	GR
Season: 0		Req.					Req Mon 30 Day Average	Req Mon Daily Maximum	Milligrams per Liter		Monthly	GRAB
NODI: 9		NODI					9	9				
01104 1 - Effluent Gross	Aluminum, total recoverable	Smpl.					= 3.4	= 3.4	mg/L List		01/30	GR
Season: 0		Req.					Req Mon 30 Day Average	Req Mon Daily Maximum	Milligrams per Liter		Monthly	GRAB

Figure 5.1 (Continued) Example of NetDMR



50060	Chlorine, total residual	Smpl.					= 0.018	= 0.018
1 - Effluent Gross								
Season: 0		Req.					<= .011 30 Day Average	<= .019 Daily Maxi
NODI:		NODI						

Edit Check Errors

Code	Name	Monitoring Location	Field	Type	Description	Acknowledge
50060	Chlorine, total residual	Effluent Gross	Quality or Concentration Sample Value 2	Soft	The provided sample value is outside the permit limit.	☑

Comments

Attachments

No results.

Report Last Saved By

User:	shawnhokanson00@gmail.com
Name:	shawn hokanson
E-Mail:	shawnhokanson00@gmail.com
Date/Time:	03/05/14 11:08 EST

5.2 Consequence of Falsifying Reports

The Clean Water Act clearly states that anyone who falsifies a DMR, or knowingly causes monitoring devices to collect inaccurate data, can be punished with a maximum $10,000 fine and/or up to 2 years in prison for the first conviction. The punishment can double if an operator has more than one conviction (Ref. 2).

5.3 Sampling

The sampling of wastewater is one of the more important aspects of the wastewater operator's job. These samples verify that the wastewater treatment plant is operating as intended and meets the requirements of its KPDES permit. If the samples are not properly collected the sample results will not be representative of the plant conditions. There are three main types of samples that are collected at a wastewater treatment facility: continuous samples, grab samples, and **composite samples**. Since continuous samples are typically collected automatically through instrumentation, we will focus on the types of sampling that involve the direct collection by operators.

5.3.1 Grab Sampling

Grab samples are, as the name suggests, grabbed at a specific point in time. A grab sample is like taking a photograph of something, in this case the water quality of the wastewater at a given point in time. This means that the grab samples are representative of the system at a specific instant and may not be representative of typical operating outflow (Ref. 3). These samples can be a single sample, or a set of individual samples collected over a period less than 15 minutes in duration (Ref. 4).

Grab samples are appropriate when the sample is needed to (Ref. 5):

- Represent an outflow that does not always discharge into a body of water.
- Provide information about the concentration of a pollutant at a specific point in time.
- Provide a specific sample volume, such as for *E. coli.*
- Monitor parameters where grab samples are required.
    - pH
    - Temperature
    - Dissolved oxygen
    - Chlorine
    - Oil and grease
    - Coliform
    - Other samples as specified by the KPDES permit

Figure 5.2 Grab Sample

When taking a grab sample by hand, always wear protective gloves and hold the sample bottle well away from its mouth. If flow conditions at your plant are too low to sample effectively, or even zero flow, then do not take the sample and note the low flow conditions on your DMR.

Never artificially increase flow just to take a sample! However, if flow seems to be very low, double check that the flow measurement is accurate. Remember, if a sample can be taken, then it should be taken.

If the places where you need to take samples are difficult to reach you may use a sample apparatus (Figure 5.2). However, the same considerations apply when using an apparatus that apply when taking a grab sample by hand. You do not want to pour from a reused container into your sample bottle, so an apparatus that holds your bottle securely is a better choice. Also, the apparatus should not hold the bottle too close to the mouth in order to prevent cross contamination from the apparatus which will typically be reused.

5.3.2 Composite Sampling

A composite sample is a sample collected over time, formed either by continuous sampling, or by mixing individual grab samples collected at specific intervals over the specified time frame (Ref. 4). Composite samples reflect the average characteristics during the sampling period and are considered more representative samples (Ref. 6).

Composite samples are to be taken when specifically stipulated in a permit or when:

- The water or wastewater stream is continuous.
- Analytical capabilities are limited, where the lab may not have the capacity to analyze a large number of samples.
- The average pollutant load or concentration over a specific period is desired.
- It is necessary or useful for calculating mass/unit time loadings (Ref. 5).

There are two ways that composite samples can be generated. The permit will specify which of the following ways to use:

- Time composite samples.
    - Time composite samples are based on a constant time interval between samples. A time composite sample can be collected manually or with an automatic sampler. This type of composite is composed of discrete samples (normally the same sample volume) collected in one container at constant time intervals. This method provides representative samples when the flow of the sampled wastewater stream is constant (Ref. 5).
- Flow proportional samples.
    - Flow proportional samples can be collected automatically with an automatic sampler and a flow measuring device. In this case the sample can be taken at constant time intervals where the sample volume will be proportional to the observed flow. Alternatively, the samples can be collected incrementally at constant or variable volumes, where the sampling interval will be proportional to a given flow volume (Ref. 5).

If an automatic sampling device is used, it is important that the manufacturer’s instructions are followed precisely. This includes following all recommended maintenance and service guidelines. Be sure that your autosampler can take the samples required by your KPDES permit and that it is setup correctly to do so. Be sure to follow the manufacturer’s instructions to successfully set up the sampler for the correct type of sampling, either composite or grab.

Because composite samples are intended to show the average plant operation, it is important to ensure that the individual samples are mixed well with the existing composite. This will ensure that it is a representative sample which describes the plant performance accurately.

5.3.3 Labeling of Sample Containers

Sample containers should be carefully labeled prior to use to ensure that samples do not get mixed up. Today most labs use bar codes or QR codes to label and track sample containers. If not, the sample containers may be labeled with permanent marker or a printed label (Figure 5.3). To ensure that a paper label remains attached, it is often useful to cover it with a large piece of clear postal packing tape that wraps around the entire bottle. Be sure that your label contains all useful information such as:

- The KPDES number for the sampled effluent.
- The name of the sample or a unique identification number.
- What test this container is for (e.g., DO, pH, BOD, *E. coli*, etc.).
- The name of your treatment plant or company.
- The date and time of collection.
- Name of the person who collected the sample.

When giving the time of collection, it is normally preferable to use military time exclusively to avoid possible confusion between AM and PM (e.g., 1:30 PM = 13:30).

Figure 5.3 Example of a Sample Bottle Label

KPDES Number: ______________________

Sample name or ID: __________________

Analysis to be performed: _____________

Entity requesting analysis: ____________

Date: _____________________________

Time: _____________________________

Collected by: _______________________

Typically, samples are taken just after the flow exits the plant's final treatment step and before the treated water is released into the environment (effluent sampling). However, some permits require samples to be taken of the **raw wastewater** entering the plant (influent sampling). If you need to do influent sampling, be sure to take the sample before the first form of water treatment, such as the bar screen (Ref. 4).

Your KPDES will clearly identify the locations (sometimes by an ID) at which samples should be taken. Your treatment plan should have signs throughout the facility that identify the sampling locations.

5.4 Reporting

Your KPDES permit specifies the quality of the water that you are permitted to discharge back into your designated receiving water. To ensure that you are meeting your permit requirements, you are required to sample your wastewater, record the results, and then report the results back to the KDOW through your discharge monitoring report (DMR). The quality is measured by taking measurements of different pollutants and water quality parameters associated with your treated wastewater. These include:

- Pollutants:
  - Solids that can negatively impact aquatic life and the treatment process.
  - **Organic matter**, that when decomposed can lead to a reduction in available oxygen.
  - **Nutrients** such as phosphorus, **nitrogen** – including ammonia.
  - Bacteria which are usually assessed using an indicator organism like *E. coli*.
  - Metals which can be toxic to the environment and the bacteria used in the treatment process.
- Parameters:
  - Flow rate (normally represented by the letter Q).
  - pH (a measure of how acidic (<7) or basic (>7) a water is).
  - **Alkalinity** (a measure of the capacity of water or a solution to buffer changes in pH).
  - Dissolved oxygen (needed by most bacteria and aquatic life to survive).

5.4.1 Reporting Units

Pollutants and parameters are frequently reported in a range of different reporting units. Some of the most common units are summarized below:

Table 5.1 Common Reporting Units for Parameters

Parameter	Reporting Term	Abbreviation
Flowrate (Q)	Million gallons per day	MGD
Flowrate (Q)	Gallons per day	GPD
Flowrate (Q)	Gallons per minute	GPM
Volume (V)	Million gallons	MG
Volume (V)	Cubic feet	ft^3
Volume (V)	Liter	L
Area (A)	Square feet	ft^2
Area (A)	Acres	ac
Concentration (C)	Milligrams per liter	mg/L
Concentration (C)	Parts per million	ppm
Load (L)	Pounds per day	lbs/day

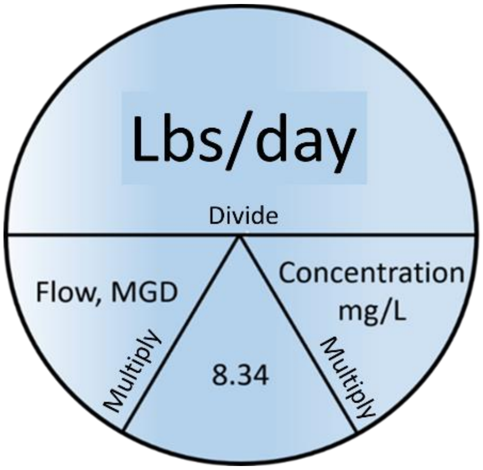
In reporting pollutant loads, an operator is frequently required to convert the concentration of a pollutant measurement measured in units of mg/L into an equivalent load in units of lbs/day. This can be done using the following equation:

$$[1]\ (Pollutant\ load, lbs/day) = (pollutant\ flow, MGD)\ x\ 8.34\ x\ (pollutant\ concentration, \frac{mg}{L})$$

Note: 8.34 is the weight of 1 gallon of water and is used as a conversion factor.

Another way to visualize this equation, is by using the pound "pie" diagram shown in Figure 5.4.

Figure 5.4 Load/Concentration Calculation Diagram



This figure can be used to solve for any one unknown, whether it be load (lbs/day), flowrate (MGD), or concentration (mg/L). To use the diagram, cover with your finger the one section of the diagram that you don't know but want to know. Then use the uncovered parts of the diagram to solve the unknown.

Example 5.1

The discharge from a wastewater treatment plant is 1.0 MGD. If the measured concentration of total suspended solids (TSS) is 10 mg/L. what is the daily pollutant load of TSS in units of lbs/day?

Solution:

Since we are looking for the load in lbs, cover up the top part of the pie chart which has lbs in it. This leaves (Flow, MGD), 8.34, and (Concentration, mg/L) all in the bottom part of the figure. You will note that each of these pie segments in the bottom have the word multiply separating them. This then means that we should multiple all three terms in the bottom to get what we have covered up – lbs. This then yields:

$(Load, lbs) = (Flow, MGD)\ x\ 8.34\ x\ (Concentration, mg/L)$ or

$(Load, lbs) = (1.0\ MGD)\ x\ 8.34\ x\ (10\ mg/L) = 83.4\ lbs/day$

Conversely, if we were given lbs and wanted to know the concentration, then we would multiple the (Flow, MGD) x 8.34 and then DIVIDE both into the value of the known (Load, lbs).

$(Concentration, mg/L) = (Load, lbs)\ /\ (Flow, MGD)\ x\ 8.34)$ or

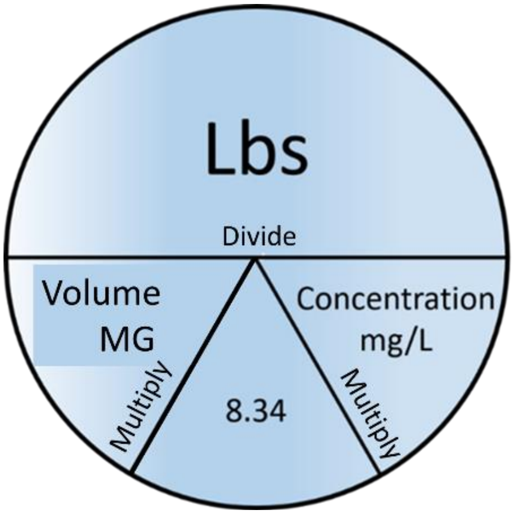
$(Concentration, mg/L) = 83.4\ lbs\ /\ ((1\ MGD)\ x\ 8.34) = 10\ mg/L$

In addition to converting a concentration and a flow rate into a pollutant loading, an operator may also on occasion need to covert the volume of a pollutant (typically expressed in MG) and its concentration (typically expressed in mg/L) into a pollutant load. Similar to equation [1], this can be calculated using equation [2] below:

$$[2]\ (Pollutant\ load, lbs) = (volume, MG)\ x\ 8.34\ x(pollutant\ concentration, \frac{mg}{L})$$

Like equation [1], this equation can also be solved using a similar “pie” diagram as shown in Figure 5.5.

Figure 5.5 Load/Concentration Calculation Diagram



5.4.2 Conversion Factors

When converting any measurement from one system of units to another, the operator will usually need to employ a conversion factor. A list of some of the most common conversion factors is given below in Figure 5.6.

Figure 5.6 Common Unit Conversion Factors

Area
1 acre = 43,560 ft^2
1 ft^2 = 144 in^2

Flow
1 MGD = 694.5 gpm
1 MGD = 1.55 ft^3/s

Power
1 hp = 0.746 kW

Pressure
1 psi = 2.31 ft of water
1 ft of water (head) = 0.433 psi

Time
1 day (24 hours) = 1440 minutes

Volume
1 ft^3 =7.48 gallons
1 yd^3 = 27 ft^3

Weight
1 gallon water = 8.34 lbs
1 ft^3 water = 62.4 lbs
1 ton (US)* = 2,000 lbs

Concentration (and Solutions)
1 ppm = 1 mg/ml
1% solution = 10,000 mg/L

* Note a US ton is different from an English or Imperial ton and a metric ton.

5.5 Pollutants

For the purpose of implementing the NPDES program, the US EPA divided pollutants that are expected to be discharged from point sources into the following categories:

- Conventional pollutants: These pollutants are typical of municipal sewage, such as BOD, TSS, fecal **coliform bacteria**, oil and grease and pH (see **40 CFR §401.16**).
- Non-Conventional pollutants: These are all pollutants that are not included in the list of conventional or toxic pollutants listed in 40 CFR Part 401 and include **chemical oxygen demand** (COD), total organic carbon (TOC), nitrogen, and phosphorous.
- Toxic pollutants: These are pollutants, or combinations of pollutants which after discharge and upon exposure, may cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions, or physical deformations (see **40 CFR §401.15**). The list of toxic pollutants includes disease-causing organisms as well as 129 priority pollutants identified by the EPA, pursuant to Section 307(a) of the Clean Water Act, or any pollutant listed under Section 405(d), which relates to sludge management.
- Priority pollutants are of principal importance for control under the Clean Water Act. A list is included in the Clean Water Act as **Appendix A to 40 CFR Part 423**.

In addition to the classification system outlined above, pollutants are also categorized by their ability to be changed or degraded within the environment or treatment process. The two terms commonly used are:

- Conservative Pollutants – Pollutants that are not normally physically or chemically transformed to non-toxic substances in the receiving water. Conservative pollutants tend to be stable, long-lived compounds that persist within the environment. These include, but are not limited to, salts and metals.
- Non-Conservative Pollutants – Pollutants that are transformed to non-toxic substances through physical, chemical, or biological processes in the receiving water. Non-conservative pollutants can be transformed or degraded into other compounds, but the rate of transformation depends on the physical, chemical, and biological conditions occurring within the environment of the receiving water. Non-conservative pollutants include biochemical oxygen demand (BOD), ammonia (nitrogen), and certain other organic compounds.

5.5.1 Total Solids

Total Solids (TS) include all the solids that exist in wastewater (Ref. 7). Total solids can be divided into Total **Suspended Solids** (TSS) and Total **Dissolved Solids** (TDS), therefore TS = TSS + TDS (Ref. 8). TSS is one of the parameters that must be monitored and reported on the KPDES permit.

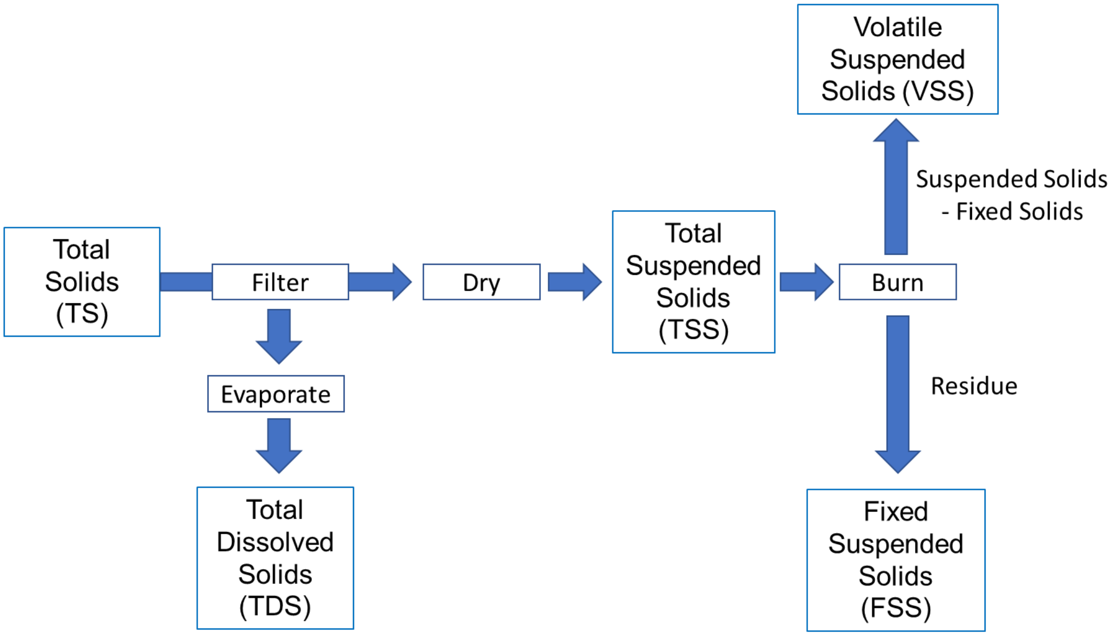
1) Total dissolved solids (TDS) are the portion of the total solids that are not physically retained on a filter (i.e., they pass through the filter) with a specific pore size (typically 2.0 mm or less) when passing a sample of the wastewater through the filter.

2) Total suspended solids (TSS) are the portion of the total solids that are physically retained on a filter with a specific pore size (typically 2.0 mm or less) when passing a sample of the wastewater through the filter (Ref. 9).

Total suspended solids can be further divided into volatile suspended solids (VSS) and fixed suspended solids (FSS). Volatile simply means the solids will burn up when heated to 550 °C. While the fixed solids will not burn up. In general, volatile solids are comprised of organic matter and fixed solids with inorganic matter (Ref. 8).

Wastewater operators also usually calculate another solids parameter called **settleable solids**. Settleable solids represent the amount of the total solids that will settle out in one hour when 1 liter of sample is placed in a special cone shaped flask called an Imhoff cone. The results of this test are reported in units of mL/L. This test can be used to anticipate the type of settling characteristics of the wastewater and the possible performance of the clarifiers. Typically, about 60 percent of the suspended solids in municipal wastewater are settleable.
The different types of solids in a water quality sample can be determined through a series of laboratory tests as shown in Figure 5.7.

Figure 5.7 Classification of Total Solids



5.5.2 Total Dissolved Solids

Total dissolved solids are measured by filtering a well-mixed sample of wastewater through the same standard glass fiber filter used in the TSS test (see above). The filtrate is then placed in a pre-weighed dish which is then placed in oven at 180^{o}C for one hour or until the water in the sample has evaporated leaving behind the dissolved solids. The increase in the weight of the dish containing the dissolved solids represents the total dissolved solids which can be calculated as follows in equation [3] (Ref. 8):

$$[3]\ (TDS, mg/L\ ) = \frac{(weight\ of\ dry\ solids\ \&\ dish, g) - (weight\ of\ dish, g)}{(sample\ volume, mL)} x\ 1{,}000{,}000$$

Note: We multiply by 1,000,000 to convert the result from g/mL into units of mg/L.

5.5.3 Total Suspended Solids

Total Suspended Solids (TSS) represents the dry-weight of particles (measured in milligrams per liter (mg/L), or its equivalent – parts per million (ppm)) that are not dissolved in a sample of water (Ref. 9). To measure the TSS in a sample of wastewater, a specified volume of wastewater (measured in mL) should be filtered through a glass filter (typically a 24 mm diameter filter with a 2.0 µm pore size). Prior to use, the filter is first cleaned with deionized water to remove any unbound fibers or material, dried at 105°C, cooled to room temperature in a desiccator and weighed (this will be the weight of crucible and filter). The glass filter is then placed in a pre-weighed glass cup, called a Gooch crucible, which is attached to a filter flask into which a specific volume of sample (in mL) is poured into the crucible and pulled through the filter using vacuum. The crucible cup, filter, and associated residue are then placed in a drying oven at a temperature of 105°C to a constant weight, then cooled in a desiccator to room temperature. The filter, crucible and residue are weighed and the difference in weight before and after the sample has been collected is determined (Ref. 8). This process is illustrated in Figure5.8. TSS (mg/L) can then be calculated using equation [4]:

$$[4]\ (TSS, mg/L) = \frac{(wt. of\ crucible, filter\ \&\ solids, g) - (wt. of\ crucible\ \&\ filter, g)}{(sample\ volume, mL)} x\ 1{,}000{,}000$$

Note: We multiply by 1,000,000 to convert the result of g/mL into units of mg/L.

Example 5.2

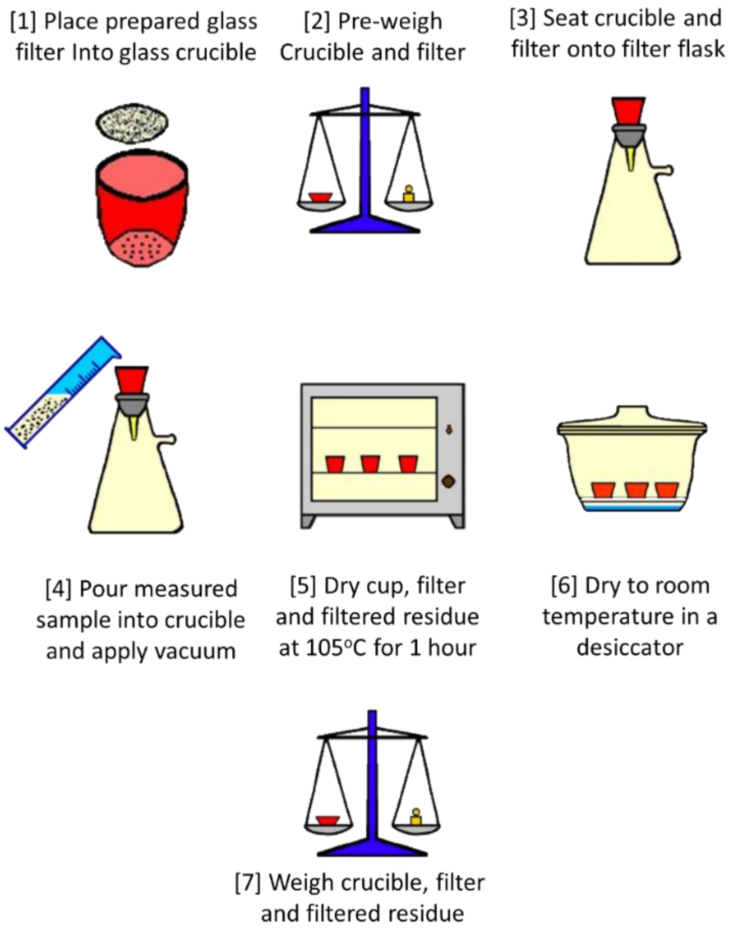
A 50 mL sample was collected for TSS. The weight of the filter and crucible was 21.5308 g. The weight of the filter, crucible, and dry solids after drying was 21.5447 g. What is the TSS in mg/L?

Solution:

Because the weights are in units of grams, and the sample size is in mL, we can use equation [4] to calculate TSS.

$$(TSS, mg/L) = \frac{(21.5447\ g) - (21.5308\ g)}{(50\ mL)}\ x\ 1{,}000{,}000 = (278\ mg/L)$$

Figure 5.8 Calculation of Total Suspend Solids (TSS)



In addition to expressing TSS in terms of its concentration (i.e., mg/L), it is also sometimes important to express the amount of TSS in terms of a daily loading (i.e., lbs/day). This can be calculated using equation [1] but solving for TSS in pounds per day instead of pollutant load in pounds per day.

$$[1]\ Pounds\ of\ TSS\ per\ day = (Flow, MGD)\ x\ 8.34\ x\ (TSS, mg/L\ )$$

Note: 8.34 is the weight of 1 gallon of water and is used as a conversion factor.

Example 5.3

The concentration of TSS in a wastewater sample was determined to be 278 mg/L, and the influent flow is 1.5 MGD. How many pounds of TSS is in the influent per day?

Solution:

The flow is (1.5 MGD). So, equation [1] becomes:

$$Pounds\ TSS\ per\ day = (1.5\ MGD)\ x\ 8.34\ x\ (TSS, mg/L\ )$$

The TSS concentration was determined to be 278 mg/L, so, equation [1] becomes:

$$Pounds\ of\ TSS\ per\ day = (1.5\ MGD)\ x\ 8.34\ x\ (278\ mg/L)$$

Using a calculator to multiply the three numbers yields:

$$TSS\ loading = (3{,}477.78\ lbs/day)$$

Note: 2 places of decimals are presented in the answer.

The amount of TSS in wastewater is determined using a composite sample, preserved by cooling to less than or equal to 6°C for a maximum holding time of 7 days**.** Limits on the quantity of TSS allowable in your wastewater discharge can vary for each plant and can be found on your KPDES permit. Typical limits for TSS include 45 mg/L based on a 7-day average and 30 mg/L based on a 30-day average (Table 3.3).

5.5.4 Volatile Suspended Solids (VSS)

From a wastewater operator's perspective, we are primarily interested in just the volatile part of the total suspended solids (i.e., VSS), since this will approximate the concentration of organic material in the sample (i.e., either the organic waste load to primary clarifier, or the total active biological mass – including bacteria, in the **aeration** tank or the secondary treatment system (Ref. 8)). The total weight of volatile solids is used to calculate the food to microorganism ratio or F/M ratio, an important operational parameter to optimize treatment (covered in more detail in Chapter 14). To measure the VSS of the wastewater, the residue from the TSS test is combusted in an oven at a temperature of 550°C until a constant weight is achieved. This process is illustrated in Figure 5.9. The weight lost on combustion is called VSS and is calculated using the following equation:

$$[5]\ (VSS, mg/L) = \frac{(wt. of\ crucible\ \&\ filter\ \&\ ash, g) - (wt. of\ crucible\ \&\ filter, g)}{(sample\ volume, mL)}\ x\ 1{,}000{,}000$$

Note: We multiply by 1,000,000 to convert the result of g/mL into units of mg/L.

Example 5.4

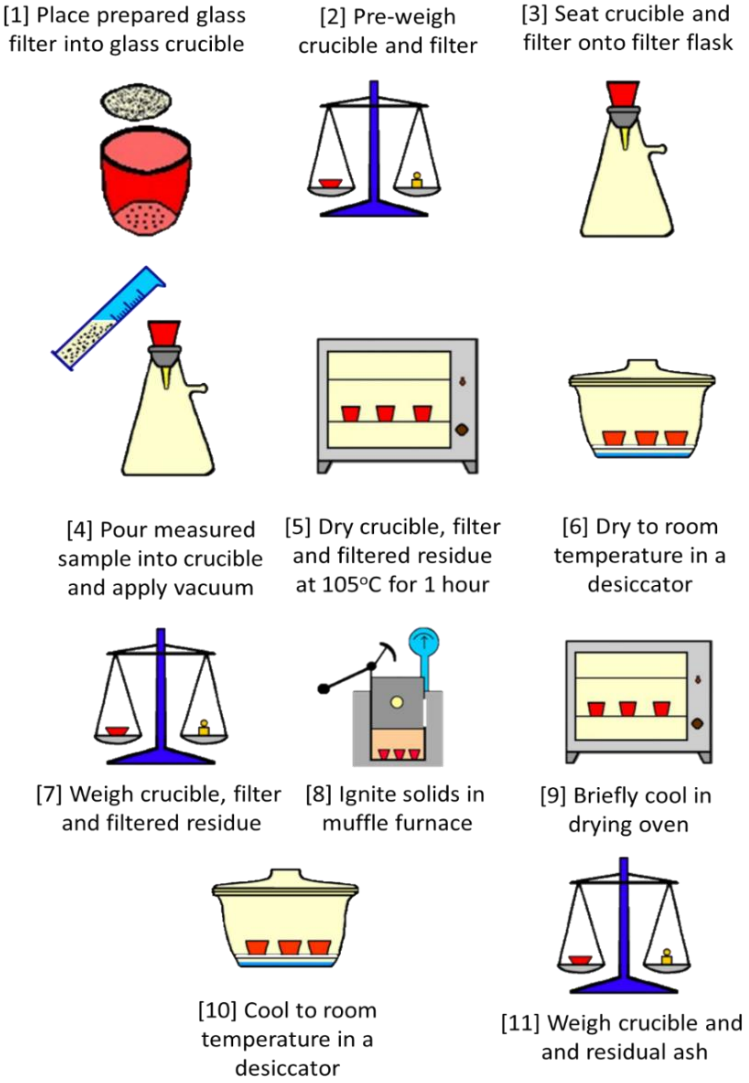
A 50 mL sample was collected for VSS. The weight of the filter and crucible was 21.5308 g. The weight of the crucible, filter and ash after combustion was 21.5349. What is the VSS in mg/L?

Solution:

Because the sample and dish weight are in units of grams, and the sample size is in mL, we use equation [5].

$$(VSS, \frac{mg}{L}) = \frac{(21.5349\ g) - (21.5308\ g)}{(50\ mL)}\ x\ 1{,}000{,}000 = (82\ mg/L)$$

Figure 5.9 Calculation of Volatile Suspend Solids (VSS)



5.5.5 Fixed Suspended Solids (FSS)

Fixed suspended solids are the weight of solids that remain once you have burned off or ignited the total suspended solids in an oven at 550˚C (Figure 5.9). The fixed suspended solids will normally represent the amount of **inorganic material** in the total suspend solids (Ref. 8). Mathematically, the fixed suspended solids can be calculated as follows:

$$\boxed{FSS = TSS - VSS}$$

5.5.6 Total Settleable Solids

Total settleable solids represent the material that settles out of suspension within a defined period. The amount of total settleable solids coming into a plant can be useful to an operator in optimizing the operation of the primary clarifier. The most common method for determining settleable solids is to fill a 1-liter Imhoff cone with a well-mixed sample of influent (Figure 5.10). The material in the cone is then allowed to settle for 45 minutes. After 45 minutes, the sample should be gently agitated with a rod. The sample should then be allowed to continue to settle for an additional 15 minutes. The final volume of settleable solids should be measured using the gradations on the side of the cone. This volume should be recorded as mL/L (Ref. 8).

Figure 5.10 Pictures Of An Imhoff Cone Empty And Showing Settleable Solids.

5.5.7 Measurement of the Organic Strength of Wastewater

If wastewater which contains a significant amount of organic matter is discharged from a treatment plant into a stream, **aerobic bacteria** in the wastewater and/or stream will use the oxygen in the stream to degrade this organic matter. If the oxygen level in the stream drops too low, then aquatic life in the stream such as fish may not be able to survive. As a result, the DOW limits the concentration of the organic matter in wastewater to ensure that the dissolved oxygen levels (DO) will not be depleted below certain minimum levels (i.e., 4 mg/L DO for instantaneous or acute conditions and 5 mg/L DO for average or chronic conditions).

The amount of organic matter in a wastewater can be measured in three ways (Ref. 10):

1) Directly as the total organic carbon (TOC).

2) Indirectly as the chemical oxygen demand (COD).
3) As a 5-day biochemical oxygen demand (abbreviated as BOD_5).

COD represents the amount of oxygen that is used in chemically breaking down organic matter (typically using an oxidizing chemical such as dichromate). As such, COD is used as an indirect measure of the amount of organic matter in the wastewater. BOD_5 represents the amount of oxygen that is used by bacteria to break down the organic matter (over a 5-day period) (Ref. 10). As such, BOD_5 is used as an indirect measure of the amount of organic matter in the wastewater that is biodegradable.

Most municipal wastewater treatment plants will use BOD_5 as a measurement of the organic strength of the wastewater while most industrial treatment plans will use COD as a measure of the organic strength of wastewater.

5.5.7.1 Total Organic Carbon

Total organic carbon (TOC) includes all the different forms of carbon in a wastewater. This includes COD and BOD_5 as well as any carbon compounds that are not chemically oxidized or cannot be broken down by **microorganisms**. For most municipal wastewater treatment plants, the values of TOC in the wastewater will range from 80 to 260 mg/L (Ref. 11). TOC is measured instrumentally using various methods which convert organic carbon into carbon dioxide which is then measured by an electronic analyzer. In this way, there is a direct relationship between the amount of measured carbon dioxide and the amount of organic carbon. In recent years, the TOC test has become more accepted and used because it only takes 10 to 15 minutes to complete the test and obtain a value. Also, newer continuous online methods can measure concentrations of TOC in the parts per billion range (ppb). Measurement of TOC can also be used to estimate BOD_5 and COD if a long-term relationship between the three is developed for a particular wastewater treatment plant. The ratio of TOC/BOD_5 for most untreated wastewater ranges from between 1.2 to 2.0 parts TOC to 1-part BOD_5 (Ref. 11). The results of a TOC analysis are reported in units of mg/L.

5.5.7.2 Chemical Oxygen Demand

Instead of measuring the amount of organic carbon in a wastewater directly (i.e., by measuring TOC), the amount can be indirectly measured using the chemical oxygen demand (COD). COD measures the amount of oxygen that is consumed when the organic matter in the wastewater reacts with an oxidizing agent (typically potassium dichromate in a 50% sulfuric acid solution). In the past, some methods used silver and mercury containing compounds in the process which would result in toxic byproducts that needed to be disposed of safely, however, modern methods have been developed that do not require these **heavy metals**. A typical COD test can take anywhere from 1 1/2 hours to 3 hours, which still makes this a rapid test. Like TOC, COD values are expressed in mg/L of oxygen. The ratio of BOD_5/COD for most untreated wastewater ranges from 0.3 to 0.8 parts BOD_5 to 1-part COD (Ref. 11)

5.5.7.3 Biochemical Oxygen Demand

The biochemical oxygen demand (BOD) is a measure of the amount of oxygen needed by aerobic bacteria to break down organic compounds which contain carbon and nitrogen. By measuring the amount of dissolved oxygen consumed during the 5 day test we can infer the amount of organic carbon or nitrogen in the wastewater (Ref. 8). Technically, BOD can be divided into two different categories depending upon the type of waste being reduced (i.e., organic carbon or reactive nitrogen). Different species of bacteria are responsible for reducing either the carbonaceous material or nitrogenous material. While bacteria that break down carbon typically use 1.5 parts of oxygen for each part of carbon removed, nitrifying bacteria typically use 4.6 parts of oxygen for each part of nitrogen removed.

When bacteria encounter organic carbon in the treatment plant, they will immediately start to break down organic material and use up oxygen dissolved in the water. Over time, the amount of oxygen used can be measured and plotted as a carbonaceous biochemical oxygen demand curve as shown in Figure 5.11. Approximately 68% of the total oxygen will be used in the first 5 days of the decomposition process of organic material. Nitrifying bacteria, however, typically do not start processing the reactive nitrogen until day 5 to day 8 of the test. Over time, the amount of reactive nitrogen available will decrease as more oxygen is used, just as with the bacteria that are breaking down carbon organic material. This nitrogenous biochemical oxygen demand curve can also be plotted and added to the carbonaceous biochemical oxygen demand curve show in Figure 5.11. Thus, the total BOD contained in the wastewater at any given time will simply be the sum of the two curves.

5.5.7.4 Five-Day Biochemical Oxygen Demand

As can be seen from Figure 5.11, it can typically take several weeks for the bacteria to consume all the oxygen needed to break down both the carbon and reactive nitrogen material in the wastewater sample. However, if we are only interested in the amount of oxygen needed to break down the organic carbon in the wastewater, then we don't need to run a laboratory analysis over several weeks to estimate that demand. In fact, it was found that a reliable determination of carbonaceous BOD (CBOD) in the wastewater could be obtained by measuring the BOD after five days of analysis, i.e., BOD_5 (Ref. 8). The ultimate CBOD can then be approximated from a BOD_5 analysis using the following relationship:

$$\boxed{CBOD\ (ultimate)\ =\ 1.47\ x\ BOD_5}$$

Another practical reason for calculating the BOD after five days (i.e., BOD_5) is that this will typically represent the BOD load before nitrogenous bacteria start to use up additional oxygen in breaking down any reactive nitrogen in the wastewater. While the previous equation provides a way to estimate the ultimate CBOD, most water quality regulations for wastewater plants are based on BOD_5, so this is what operators should focus on.

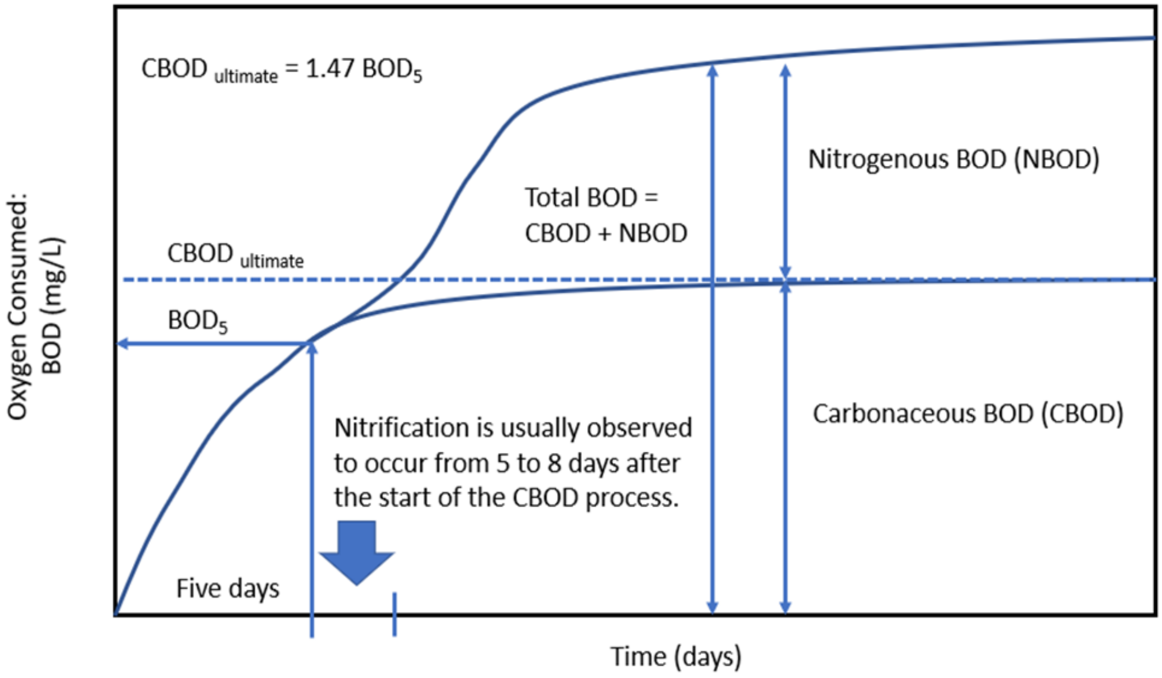
The relationship between the amount of oxygen consumed in the breakdown of the organic carbon and organic nitrogen over time is shown in Figure 5.11. As can be seen from the figure, approximately 70% of the BOD is consumed by the bacteria within the first five days. This quantity is called the five-day BOD or BOD_5. At about the same time (5 to 8 days), organic nitrogen will also start to be consumed by any nitrifying bacteria present in the wastewater sample. Eventually both the CBOD curve and the NBOD curves will flatten out as all the organic materials is consumed.

There are several different ways to calculate the BOD_5 associated with a wastewater:

1) The use of dilution bottles and incubator (see Figure 5.12).
2) A manometric method, which measures the change in pressure in a sample bottle as oxygen is consumed and carbon dioxide is produced (see Figure 5.13).
3) The use of a BOD electrolytic respirometer (Ref. 11).

Essentially each method uses different ways to measure the amount of oxygen at the beginning of the test and the amount of oxygen remaining at the end of the test. The final BOD_5 value from the test will normally be expressed in units of mg/L of oxygen.

Figure 5.11 Plot of CBOD and NBOD versus Time



When sampling wastewater for a BOD_5 test, the operator will normally collect a composite sample from either the influent stream or the effluent stream and place the sample in a plastic or glass container while preserving the sample on ice to less than 6°C for no more than 48 hours. The sample is placed on ice to prevent bacteria from growing in the sample and consuming organic matter before the test has begun.

Typically, the test determines the amount of dissolved oxygen consumed per liter of sample over a 5-day period with the sample kept at 20°C. The result is expressed in mg/L of oxygen (Ref. 11).

Figure 5.12 BOD Dilution Bottles

Figure 5.13 BOD Manometric Bottles

The BOD$_5$ of a sample is typically found by using the following equation (Ref. 8):

$$[6]\ (BOD_5, mg/L) = (Initial\ DO, mg/L - Final\ DO,\ mg/L\ )\ x\ \frac{(Volume\ of\ BOD\ bottle, mL)}{(sample\ volume, mL)}$$

Example 5.5

The initial DO of a 15-mL sample was 7.1 mg/L and the final DO was 4.1 mg/L after 5 days of incubation at 20^{0}C in a 300-mL sample bottle. What was the BOD$_5$ in mg/L?

Solution:

All the information we need is in the correct units, so all we do is plug in our information into equation 6.

$$BOD_5 = (7.1\,mg/L - 4.1\,mg/L)\ x\ \frac{300\ mL}{15\ mL} = 60\,mg/L$$

The primary measure of a wastewater plant's success is in the efficiency of the removal of BOD$_5$ through the treatment process. This success is measured using the removal efficiency, which looks at the concentration of BOD$_5$ entering the plant and the concentration of BOD$_5$ leaving the plant. Removal efficiency is calculated using equation [7] as follows (Ref. 8).

$$[7]\ Removal\ Efficiency\ (\%) = \frac{influent\ BOD_5 - effluent\ BOD_5}{influent\ BOD_5}\ x\ 100\%$$

The Removal Efficiency equation can be used to measure the efficiency of many parameters. The influent and effluent units can be pounds, gallons, MGD, etc. If the units on the influent and effluent are the same, the calculation can be performed without unit conversions.

Example 5.6

If the influent BOD_5 concentration is 51.6 mg/L and the effluent BOD_5 concentration is 3.12 mg/L. What is the removal efficiency of the plant?

Solution:

Since the influent and effluent units are the same, no conversion is needed, and we can just plug our values into equation 7.

$$Removal\ Efficiency\ (\%) = \frac{51.6\, mg/L - 3.12\, mg/L}{51.6\, mg/L}\ x\ 100\% = 93.9\ \%\ removal$$

5.5.8 Ammonia/Nitrogen

Similar to BOD, nitrogen is an essential nutrient for the growth of bacteria. The breakdown of nitrogen compounds such as ammonia to nitrites can also result in a decrease in available dissolved oxygen. As with BOD, it is important that large quantities of nitrogen be removed from wastewater before the wastewater is discharged into a receiving stream. Nitrogen occurs in nature in several different forms (Ref. 12):

- Nitrogen gas (N_2).
- Organic nitrogen – molecules which contain both nitrogen and carbon.
- Ammonia – NH_3 (also called un-ionized ammonia).
- Ammonium ion – NH_4^+ (also called ionized ammonia).
- Nitrites (NO_2^-).
- Nitrates (NO_3^-).

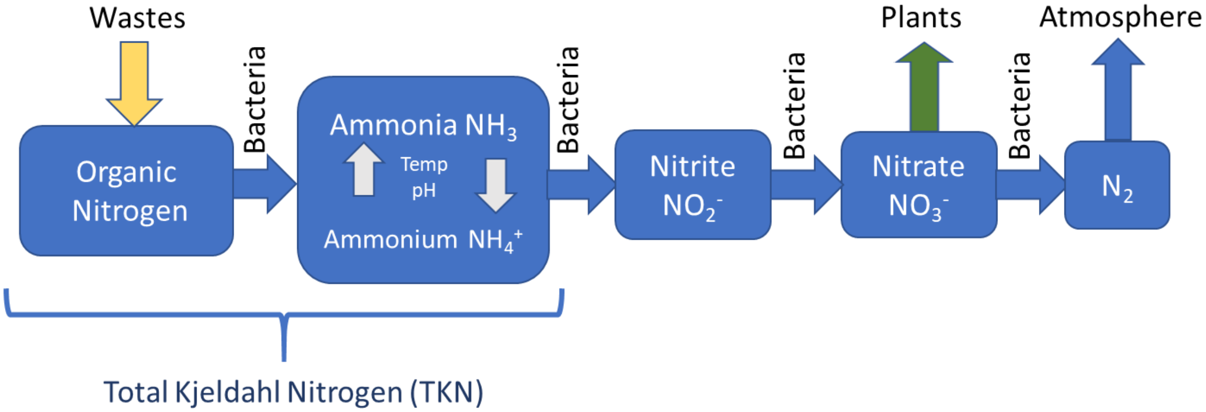
These different forms of nitrogen are used by bacteria in a sequence of reactions shown in Figure5.14. As can be seen from the figure, organic nitrogen (molecules that contain both nitrogen and carbon atoms) enters the wastewater mainly through domestic waste. Organic nitrogen is then broken down into either ammonia (NH_3) or ammonium (NH_4^+). Depending upon the temperature and pH of the water, these two forms can change back and forth into the other form. Together, the total amount of nitrogen contained in organic nitrogen and ammonia and ammonium is called Kjeldahl Nitrogen or TKN. Ammonia and Ammonium can then be broken down into nitrite (NO_2^-) which can then be broken down into nitrate (NO_3^-) before being converted and released back to the atmosphere as nitrogen gas (N_2). The different forms of nitrogen are associated with one another through the following relationships (Ref. 11):

$$Organic\ Nitrogen\ =\ Nitrogen\ contained\ in\ decaying\ organic\ matter$$

$$Total\ Kjeldahl\ Nitrogen\ (TKN)\ =\ Organic\ Nitrogen\ +\ Ammonia\ (NH_3)\ +\ Ammonium\ (NH4+)$$

$$Total\ Nitrogen\ =\ Total\ Kjeldahl\ Nitrogen\ (TKN)\ +\ Nitrite\ (NO2-)\ +\ Nitrate\ (NO3-)$$

Figure 5.14 Relationship Between the Different Forms of Nitrogen



Ammonia and the ammonium ion can switch between each other's form depending upon the temperature and the pH of the water (Ref. 12). When the temperature and pH of the wastewater increases, the amount of ammonia (NH_3) will increase as the amount of ammonium ion (NH_4^+) decreases. Conversely, as the temperature and pH of the wastewater decreases, the amount of ammonium ion (NH_4^+) will increase as the amount of ammonia (NH_3) decreases (Figure 5.14).

While nitrogen is essential to life, certain forms of nitrogen, such as ammonia, can be harmful to human and aquatic life (Ref. 12). Like BOD, ammonia in wastewater discharges can also lead to a decrease in oxygen in the stream as nitrifying bacteria use oxygen to break down the ammonia into nitrite (NO_2^-) and nitrate (NO_3^-). In a wastewater treatment plant this demand for oxygen can be offset by adding oxygen to the treatment process using mechanical aerators. However, in a stream natural aeration may not be sufficient to offset this demand.

As a result, it is important that the concentration of ammonia be decreased before the treated wastewater is discharged into the environment. A KPDES permit will have a limit for ammonia. Laboratories frequently report ammonia results as either NH_3 (mg/L) or NH_3-N (mg/L). In the first case, the milligrams (mg) being reported will refer to the total mass of the ammonia molecules present (that is one nitrogen atom and three hydrogen atoms per molecule). In the case of NH_3-N, the milligrams (mg) being reported only refers to the mass of the nitrogen atoms present. Sometimes this is referenced as "ammonia as N". As a result, when comparing or reporting ammonia concentrations, an operator should always make sure they are using the right convention.

As with TSS, when determining the concentration of ammonia in wastewater it is necessary to convert the concentration into a total load in pounds. Since this will normally involve multiplying the concentration by the plant discharge in units of MGD, the resulting load will be expressed in terms of pounds/day.

Example 5.7

The concentration of ammonia as N is 6 mg/L. The plant discharges 0.25 MGD into the stream. How many pounds of ammonia as N are in the effluent?

Solution:

$$[1]\ Pounds\ of\ ammonia = (flow, MGD)\ x\ 8.34\ x\ (concentration\ of\ ammonia, \frac{mg}{L})$$

Since we know the concentration in mg/L and the flow in MGD, all we need to do is plug the information into equation [1].

$$Pounds\ of\ ammonia = (0.25\ MGD)\ x\ 8.34\ x\ (6\, mg/L) = 12.51\ lbs$$

5.5.9 Phosphorus

Phosphorus is an essential element for all life since it is a major component of DNA, our genetic material, and ATP, the energy molecule of the cell. Phosphorus will stimulate the growth of aquatic plants and algae in water bodies if discharged in excessive concentrations as effluent. Too much phosphorus can lead to an increase of algal growth known as **eutrophication**. Excess nitrogen (as fertilizer) also contributes to eutrophication (Ref. 8).

Algae are single-celled plants, or simple plants, that can pose significant problems to other aquatic life and humans if allowed to grow unchecked in bodies of water. Aquatic life will typically utilize inorganic forms of phosphorus in wastewater to promote cell growth. The most common form of inorganic phosphorus available for use by most plants is **orthophosphate** (Ref. 11). Thus, sometimes water quality laboratories will run samples for both total phosphorus (TP) and orthophosphate.

While phosphorus is necessary for normal plant growth, too much phosphorus can lead to an overgrowth of algae (Ref. 13). When too much algal growth occurs, it can choke a stream by forming large green mats and cause taste and odor problems in drinking water. More importantly, algae release oxygen into the stream and remove carbon dioxide during the daytime through the process of photosynthesis. However, at night they remove oxygen from the water and release carbon dioxide (due to cellular respiration). As a result, they can sometimes cause the dissolved oxygen in a stream to drop below the minimum required level to support aquatic life, which can then lead to fish kills. Normally, the lowest value of dissolved oxygen in the stream will occur right before sunrise. Excessive growth of algae can also change the pH of the water during a 24-hour period. This is more of a challenge to drinking water treatment than wastewater treatment, but if a wastewater treatment plant discharges upstream of the intake of a water treatment plant, this could lead to additional water treatment requirements.

Some recent scientific studies in the Floyds Fork watershed near Louisville, Kentucky, have suggested that algae blooms can occur with total phosphorus concentrations as low as 0.2 mg/L. In some streams in central Kentucky, the natural streams themselves can have background levels that high. Typical wastewater influent can have total phosphorus concentrations as high as 10 mg/L, so you can begin to see some of the challenges associated with wastewater treatment. Unfortunately, most typical wastewater treatment plants with secondary biological treatment can only remove about 20% of the phosphorus. To remove additional phosphorus requires either advanced improvements in biological treatment, the use of chemicals (which produces a lot of additional sludge) or the use of more sophisticated and expensive treatment technologies such as reverse osmosis.

Kentucky, like many states, has not yet established statewide numerical limits for total phosphorus or orthophosphate, although state officials are currently working toward a standard. In the interim, new plants and plants with expansions of more than 50% are required to meet a target of 0.5 mg/L Total Phosphorous, expressed as an annual average mass effluent limit on their KPDES permit. For all plant expansions that are less than 50% of capacity or design, the plant is required to meet a target of 1.0 mg/L Total Phosphorous expressed as an annual average mass effluent limit on its KPDES permit. Operators should check their current KPDES permit to see if their plant has any explicit phosphorus limits. At a minimum, the current Kentucky Water Quality Standards state that "nutrients shall not be elevated in a surface water to a level that results in eutrophication problem."

Like other water quality parameters, special precautions must be taken when collecting samples for use in testing for phosphorus. When sampling for Total Phosphorous the sample must be acidified with sulfuric acid (H_2SO_4) to a pH of less than 2 standard units and cooled to less than 6^0 C with a holding time of 28 days.

While it is difficult to remove phosphorus from our wastewater, certain actions have been taken to reduce the amount of phosphorus in wastewater. In the 1960s, detergent manufacturers reduced or stopped putting orthophosphates into laundry detergent. Later, dishwasher detergents were made phosphorus free. This resulted in a significant decrease in the amount of phosphorus that ended up in streams from wastewater treatment plants. Another remaining source of phosphorus is from domestic sewage, which for obvious reasons cannot be significantly lowered, which brings us to an example problem.

Example 5.8

45,000 people live in our community and each person contributes 0.0048 lbs of phosphorus to the wastewater per day. What is the concentration (mg/L) of phosphorus in the water if the plant receives 5.5 MGD?

Solution:

The pounds equation is used.

$$[1]\ (Pounds\ of\ Phosphorus, \frac{lbs}{day}) = (flow, MGD)\ x\ 8.34\ x\ (concentration, \frac{mg}{L})$$

The equation can be rearranged and solved for the concentration of the material as follows:

$$[1']\ (Concentration\ of\ Phosphorus, \frac{mg}{L}) = \frac{(pounds\ of\ phosphorus, lbs)}{(flow, MGD)\ x\ 8.34}$$

From the number of pounds each person will contribute and the population the number of pounds of phosphorus can be calculated.

$$Pounds\ of\ Phosphorus = (45{,}000\ people)\ x\ (0.0048\ \ lbs/person)\ \ = 216.0\ lbs/day$$

Now plug these numbers into the equation to get:

$$[1']\ (Concentration\ of\ Phosphorous, \frac{mg}{L}) = \frac{(216.0,\ \ lbs)}{(5.5\ MGD)\ x\ 8.34} = 4.71\ mg/L$$

5.5.10 Heavy Metals

Heavy metals can be defined as those metals that have a high atomic weight or are toxic to life at relatively low concentrations. This distinguishes them from metals such as sodium, calcium, potassium, and iron that are essential to all life. While a few of these heavy metals are necessary for human health, above certain levels they all become toxic. Heavy metals are one of the most persistent pollutants in wastewater (Ref. 14). It is very hard to remove them through conventional treatment methods. As a result, many of them will pass through a conventional wastewater plant. Heavy metals such as mercury, cadmium, and chromium (common pollutants from certain industrial processes) can be toxic to the bacteria in the plant that are used to break down organic matter and ammonia. As a result, many industries that may release these metals into a sewer system are required to have their own KPDES permit that regulates what they can discharge which should include a **pretreatment** plan prior to discharge to a wastewater treatment plant.

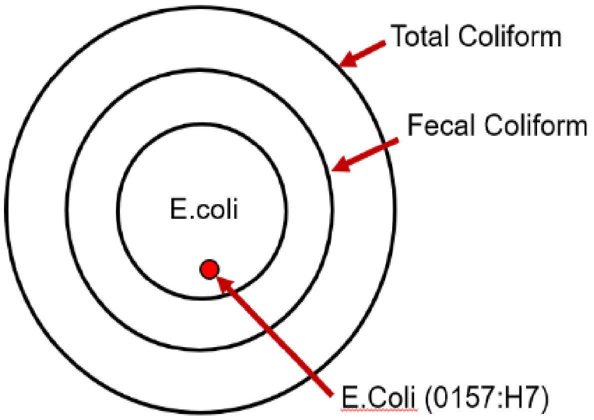
The most common metals in wastewater include arsenic (technically a metalloid, but it tends to occur with other metals, so we typically lump it together), lead, mercury, cadmium, copper, nickel, silver, chromium, and zinc. These pollutants can come from natural sources like soil erosion and urban runoff, but they are most likely to come from industrial sources like metal finishing, mining extraction, textile factories, and technological waste (Ref. 14).

All metals, except for mercury and chromium VI, are preserved with nitric acid (HNO_3) to a pH of less than 2 and stored at less than or equal to 6^0C for no more than 28 days (Ref. 15).

5.5.11 Coliform Bacteria

Coliform bacteria are microorganisms that are present in wastewater and the environment and in the fecal matter of most vertebrate animals. Though the bacteria that inhabit warm-blooded animals (which includes humans) are of greater concern. Coliform bacteria, as a group, will not likely cause illness to humans. However, their presence may indicate that disease-causing microorganisms (called pathogens) could be in wastewater. Because it is easier to test for coliform bacteria instead of specific pathogens (such as *E. coli*), we typically use coliform bacteria as an indicator of the possible presence of pathogens (Ref. 16). The broader family of coliform bacteria can be subdivided into subgroups that provide a greater ability to determine whether the coliform comes from a human or non-human source.

Figure 5.15 Different Kinds of Coliform Bacteria



As can be seen in Figure 5.15, fecal coliforms are a subset of total coliforms, and *E. coli* are a subset of fecal coliforms. Many health alerts in the news that refer to an *E. coli* outbreak (normally associated with produce such as lettuce) where several people get sick. Such reports are not associated with the typical *E. coli* strains that are found in most wastewaters, but a more virulent strain called O157:H7. As can be seen in the figure this represents a very small subset of the *E. coli* family.

Tests for fecal coliform and *E. coli* are cheap and reliable. Results are typically reported as colony forming units (cfu) per 100 milliliters of sample (cfu/100 mL) (Ref. 17). A colony forming unit is assumed to represent a single viable bacterial cell in the sample. The results may also be reported as MPN, which stands for Most Probable Number and refers to a method that uses dilution cultures and a probability calculation to determine the approximate number of viable cells in a volume of sample. For example, 50 MPN/100 mL means that the Most Probable Number of viable cells in 100 mL of sample was 50.

Originally, most wastewater treatment plants checked for the possible presence of pathogens in their discharge by sampling for fecal coliforms. As we saw previously in Table 3.2, the average geometric mean, and maximum values for fecal coliform for surface water are 200 cfu/100 mL and 400 cfu/100 mL respectfully. Later, in 1986, the EPA determined that *E. coli* would be a better indicator of contamination from human sources. Also, there were improvements in analysis that allowed for a more rapid, reliable, and accurate identification of *E. coli* in wastewater samples. As a result, many wastewater treatment plants have switched from fecal coliform to *E. coli,* which has an average geometric mean limit of 130 cfu/100 mL and a maximum of 240 cfu/100 mL. It is important to check your facilities KPDES permit to see what type of samples should be collected, analyzed, and reported. Bacteriological sampling is conducted using a grab sample. Sample collection and preservation is extremely important in obtaining accurate results for bacteriological sampling. The samples must be collected with a sterile collection apparatus and then preserved at a temperature of less than 6^0C for no longer than 6 hours before analysis (Ref. 16).

5.6 Parameters

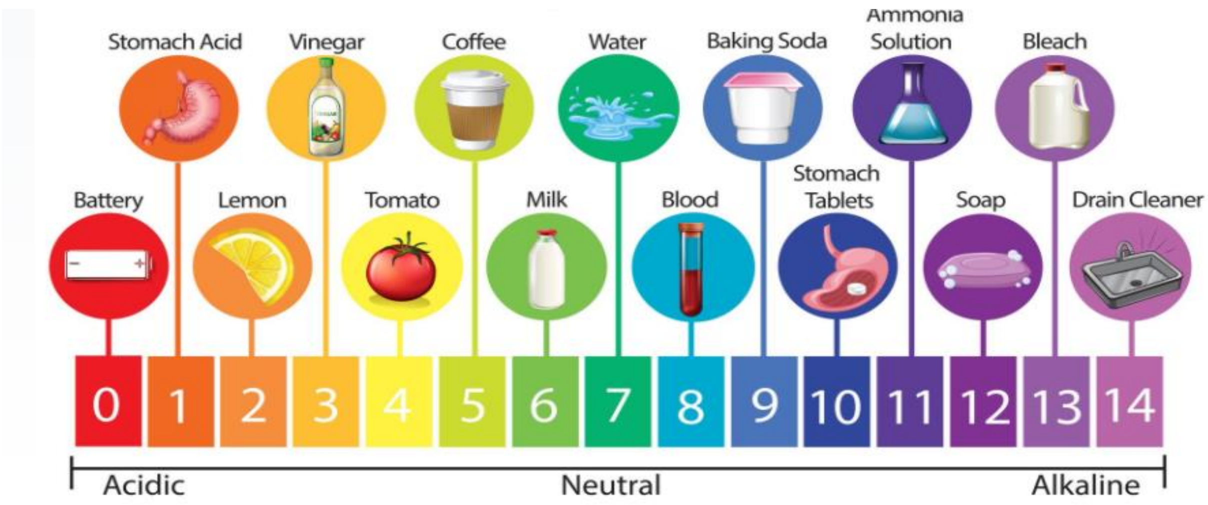
5.6.1 pH

pH is a measure of the hydrogen ion (H^+) concentration in a solution in standard units (SU). pH is used to describe or measure the acidity or basic nature of wastewater (Ref. 18). Basic solutions are also called **alkaline**. An acid is any chemical that releases hydrogen ions (H^+) when dissolved in water (e.g., hydrochloric acid), lowering the pH below a reading of 7 (i.e., pH < 7.0)**.** A base is a substance that produces hydroxide ions (OH^-) when dissolved in water (e.g., ammonia), raising the pH above a reading of 7 (i.e., pH > 7.0). Examples of the pH of different substances are shown in Figure 5.17.

The term alkalinity is also used to describe the buffering capacity of a solution, or of wastewater. It is important to distinguish which definition of alkalinity is used. It may be less confusing if solutions with a pH of greater than 7.0 were simply called basic.

The pH scale goes from 0 to 14. At a pH of 7.0, the solution is neutral, it is neither acidic nor alkaline. While most scales, like a ruler, are linear (i.e., 2 inches is twice as long as 1 inch, 4 inches is twice as long as 2 inches, etc.) the pH scale is different – it uses a logarithmic scale. This means that a pH of 3.0 will be 10 times more acidic than a pH of 4.0 and a pH of 2.0 will be 100 times more acidic than one with a pH of 4.0. This is true for the other end of the scale, a pH of 12.0 will be 10 times more basic than a pH of 11.0 and so on (Ref. 18).

Figure 5.16 The pH Scale



The pH of a water or wastewater sample can be determined in the field using a field meter (Figure 5.17) or in the lab using a lab meter (Figure 5.18). Before sampling for pH, the meter must be calibrated according to manufacturer's instructions. Calibration is a process where we place the probe into a solution of known pH to see if the meter matches that value. If it does, then we can be confident the meter is calibrated and can be used to test samples. If it does not, then it needs to be re-calibrated according to the manufacturer's instructions. This is a very important process to follow, and most protocols would recommend daily calibrations. Always record the calibration in the calibration logbook along with the date, time, and your name.

Figure 5.17 Example of a Field pH Meter

Figure 5.18 Example of a Lab Bench pH Meter

5.6.2 Alkalinity

Alkalinity is a property of water that is dependent upon the presence of certain chemicals such as bicarbonates, carbonates, and hydroxides. As we have mentioned, technically, alkalinity is the buffering capacity of a solution or body of water. It is a measure of the ability a solution of water to maintain a stable pH. In the lab, it is calculated by measuring the amount of sulfuric acid that must be added to a sample of water until the pH reaches 4.2. The final result is then reported in terms of mg/L of calcium carbonate ($CaCO_3$) (Ref. 11).

5.6.3 Hardness

Hardness is a measure of the total concentration of the cations Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) in the water. As with alkalinity, it is reported in terms of its concentration in mg/L of its equivalency to calcium carbonate. "Hard" water is generally associated with concentrations in the range of 150 to 300 mg/L, while "Soft" water is generally associated with concentrations less than 70 mg/L. Concentrations over 300 mg/L are generally considered to be "Very Hard", while concentrations between 75 to 150 are considered to be "Moderately Hard" (Ref. 8). When hard water is heated, calcium carbonate will precipitate out of solution and form solid deposits in pipes or on the surfaces of appliances such as kettles and water heaters. However, studies have shown that harder water can reduce the leaching of toxic metals such as lead and copper in the water by forming deposits on the inside of pipes. The challenge is to try and maintain the right level of hardness in water to prevent leaching of metals but not reducing the capacity of pipes or efficiencies of appliances. The hardness of a water can be reduced by treating the water with a combination of slaked lime (calcium hydroxide $Ca(OH)_2$) and soda ash (sodium carbonate or washing soda (Na_2CO_3)). The calcium will precipitate out as $CaCO_3$ and the magnesium will precipitate out as $Mg(OH)_2$. These solids can then be collected in a clarifier.

5.6.4 Specific Conductance

Specific conductance is a measure of the ability of water to pass an electrical current. It is measured using a meter and is expressed in terms of units of mho (or the reciprocal of the associated resistance) or microsiemens per cm (μS/cm). Conductance is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (atoms that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (atoms that carry a positive charge). As a result, conductance can sometimes be used to estimate the amount of total dissolved solids (TDS) in the water (Ref. 11). In general, the TDS concentration of the water in mg/L will typically vary between 50% to 70% of the specific conductance reading in μS/cm.

5.6.5 Turbidity

Turbidity is a measure of the cloudiness or the haziness of a water sample, which is usually caused by a large number of individual particles that are generally invisible to the naked eye (Ref. 11). Turbidity can be measured in a tank by using a 20-cm diameter disk called a Secchi disk (Figure 5.19). The disk is lowered into the water until it just disappears from sight. The depth at which the disk disappears is called the Secchi depth and is recorded in meters.

A less subjective measurement of turbidity can be obtained using a device called a turbidimeter (Figure 5.20). In this case, a sample of the water is placed in a small vial which is then placed into the device. Light is shone through the sample and the scattering of the light by the sample is measured and recorded. This scattering of light is converted to a digital scale which is then reported via a display or through a printed output. The measure of turbidity is usually reported in units of Nephelometric Turbidity Units (NTUs). In general, the TSS concentration of the water in mg/L can be expressed in terms of the measured turbidity in units of NTUs.

Figure 5.19 Example of a Secchi Disk

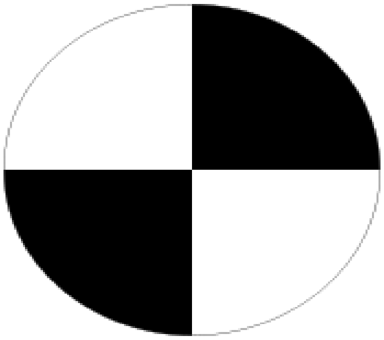


Figure 5.20 Example of Turbidimeter

5.6.6 Dissolved Oxygen

Dissolved oxygen (DO) is the amount of oxygen in the water available for aquatic organisms. The dissolved oxygen level required in the wastewater effluent is set by the permit and will typically be greater than or equal to the in-stream water quality standards shown in Table 3.3. For reporting purposes, the lowest observed DO value during the sampling period is typically reported.

DO is tested as a grab sample that is analysed immediately. There is no preservation or holding time for these samples. Similar to a pH meter, a DO meter should always be calibrated prior to use in accordance with the meter manufacturer's specifications.

5.6.7 Chlorine

Chlorine is used to disinfect wastewater to lower the number of pathogens to an acceptable level. Because it involves one of the major steps in the wastewater treatment process, it will be discussed in more detail in Chapter 16. However, because chlorine is toxic to the environment, a discharge limit is set in the permit (Table 3.4).

Total Residual Chlorine (TRC) is the amount of measurable chlorine remaining after treating water with chlorine, i.e., the amount of chlorine left in water after the chlorine demand has been satisfied (Ref. 2). To calculate TRC, you should use equation [8] as follows:

$$[8]\ (TRC, mg/L) = (Dosage, mg/L) - (Demand, mg/L\ )$$

Example 5.9

The effluent flow from a wastewater treatment plant is 4.5, MGD, the chlorinator is set on 350, lbs/day and the chlorine demand of the wastewater is 9.0, mg/L. What is the total residual chlorine in mg/L?

Solution:

First, determine the concentration of the chlorine added to the wastewater. For this, equation [1'] is used.

$$[1']\ (Dosage,\ mg/L) = (Chlorine\ Applied,\ lbs/day)\ /\ (Flowrate,\ MGD)\ x\ 8.34$$

Or: $(Dosage,\ mg/L) = (350\ lbs/day)\ /\ (4.5\ MGD)\ x\ 8.34 = 9.33\ mg/L$

Therefore,

$$[8]\ (TRC\frac{mg}{L}) = (9.33\ \frac{mg}{L}) - (9.0\ \frac{mg}{L}) \ = 0.33\ mg/L$$

5.7 Summary of Water Quality Sampling Specifications

A summary of the specifications for the various types of parameters that will need to be sampled and analyzed for reporting on the DMR are provided in Table 5.2. The table summarizes the types of containers, preservative needed and holding time for each pollutant. This table will indicate if you can use a plastic (P) or glass (G) container. The table also indicates if the sample needs to be kept cool, if the pH needs to be altered, or if some other type of preservative needs to be added. The table also indicates the holding time which is the maximum amount of time between sampling and starting the analysis of the sample not simply getting the sample to the laboratory. It is worth noting that an *E. coli* sample has a holding time of only 6 hours.

Table 5.2 Water Quality Sampling Specifications

Summary of Sampling Information			
Parameter	**Container**	**Preservative**	**Holding Time**
E. coli	P, G	Cool, < 6°C	6 hours
Hydrogen ion (pH)	P, G	None required	Analyze immediately
Ammonia	P, G	Cool, <6°C H_2SO_4 to pH < 2	28 days
Alkalinity	P, G	Cool, <6°C	14 days
Biochemical oxygen demand (BOD_5)	P, G	Cool, <6°C	48 hours
Biochemical oxygen demand, carbonaceous (CBOD)	P, G	Cool, <6°C	48 hours
Kjeldahl and organic nitrogen	P, G	Cool, < 6°C H_2SO_4 to pH < 2	28 days
Residue, non-filterable (TSS)	P, G	Cool, <6°C	7 days
Oxygen, dissolved probe (DO)	G	None required	Analyze immediately
Phosphorus, total	P, G	Cool, < 6°C H_2SO_4 to pH < 2	28 days
Oil and grease	G	Cool, <6°C H_2SO_4 to pH < 2	28 days
Phosphorus	P, G	Cool, < 6°C HNO_3 to pH < 2	28 days
Metals except chromium IV, Cr^{VI}, and mercury, Hg	G	Cool, < 6°C HNO_3 to pH < 2	6 months

5.8 References

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Chapter 6

Recordkeeping

One very important job of an operator at a wastewater treatment plant is to make sure that all records are up to date and complete. Recordkeeping allows a utility to:

- Track plant performance so that performance can be either maintained or improved.
- Provide the data necessary for completing important reports.
    - DMRs
    - Annual Reports
- Demonstrate evidence of compliance with regulatory agencies.

Examples of important records are shown below:

- Sample Logs.
- Sample Chains of Custody.
- Calibration Logs.
- Laboratory/Analytical Results.
- Equipment Maintenance/Failure Logs.

Many of these are considered legal documents which can be inspected by the Commonwealth of Kentucky or the EPA. There is often a minimum time that records must be kept for regulatory purposes. Always remember, from a legal or regulatory perspective, if you don’t write it down, it didn’t happen!

6.1 Sample Logs

The KPDES permit identifies several pollutants and water quality parameters that must be sampled and analyzed. The operator must keep a record or log of all the samples that are collected. The sample logs should include the following information:

- Dates, times, and locations of sampling.
- Sample(s) collected.
- Sample techniques.
- Name of sampling personnel.

These records can be maintained in a bound logbook or in an electronic database and must be retained for a minimum of 3 years. Sample logs for sludge data must be kept for a minimum of 5 years. An example of a log sheet for water quality samples is shown below in Figure 6.1.

Figure 6.1 Example of Data Log Sheet for Water Quality Samples

Sample ID	Sample Description	Date	Time	Type	# Contain	Preserve

Type: **G** = Grab, **C** = Composite

Contain = number of containers

Preservative: **IC** = Ice; **HC** = HCL; **HS** = H_2SO_4; **HN** = HNO_3; **HP** = H_3PO_4; **OH** = NaOH
ST = Sodium Thiosulfate; **AA** = Ascorbic Acid

6.2 Chain of Custody

The **chain of custody** is a document that records the path of sample transfers from the time of collection to the time of analysis. This record identifies, who had the sample, when they had it, who they gave it to, and when it was transferred or collected. This document will ensure that the required sample hold times are met, and it also verifies who had the sample at any specific time (Ref. 1). A sample chain of custody is shown in Figure 6.2.

Figure 6.2 Example Chain of Custody Form

Customer:	Project:
Address:	Contact:
	Phone:

Sample ID	Source	# Contain	Preserve	Required Tests

Relinquished By:	Received By:	Receipt Company (Print)	Date	Time

Source: **N** = influent; **F** = effluent; **S** = stream
Preservative: **IC** = Ice; **HC** = HCL; **HS** = H_2SO_4; **HN** = HNO_3; **HP** = H_3PO_4; **OH** = NaOH
ST = Sodium Thiosulfate; **AA** = Ascorbic Acid

6.3 Calibration Logs

Calibration is the process where adjustments of the physical or digital components of a piece of equipment are made so that that the equipment performance or measurements accurately reflect the true parameter value. Regular calibration was discussed for pH and DO meters, but any measuring device will need calibration (Ref. 2).

With time, all equipment readings will tend to drift until the measurements will no longer be accurate. In order to make sure that the data we get represents the true condition of the wastewater in the plant, it is important to properly calibrate instruments on a recommended schedule, or if the performance of the equipment does not seem to be working properly (Ref. 3). The procedures for calibrating the equipment can be found in the operations manual for each piece of equipment.

To prevent any questions as to the validity of the data collected or submitted, the operator of the plant should maintain logs that clearly identify the dates, times, and readings that are obtained each time equipment is calibrated. If a question surrounding a particular reading should occur, the operator can go back through the calibration logbook to verify the last time the meter was calibrated. This record can potentially identify if any particular drift can be observed in the meter over time. If the drift becomes too severe and the machine cannot be recalibrated, the machine will need to be repaired or replaced (and then recalibrated). Similar to sample logs, calibration logs should be maintained for a period of 3 years. An example of an instrument calibration log is shown if Figure 6.3. A typical calibration log will identify the type of instrument being used, the manufacturer and model number, the standard being used for calibration, and the reading from the instrument (i.e., the calibrated reading). In documenting the calibration process of a pH meter for example, the operator will normally place the meter probe into different glass beakers each containing a different pH standard and then adjust the meter until the meter output records the actual standard pH. The actual meter reading is then recorded in the "calibrated reading" column of the calibration log since the meter reading may be slightly different than the actual standard.

Figure 6.3 Instrument Calibration Log

Date:				Instrument:
Project:				Manufacturer:
Calibrated by:				Model #:
Verified by:				Manual #:
Time	STD Conc.	Reading	Units	Remarks

STD Conc. = Standard Concentration

Units: pH (SU); Conductivity (umhos/cm); Turbidity (NTU); ORP (150 MV)

6.4 Laboratory/Analytical Reports

Any samples sent to a laboratory for testing will generate a laboratory report that confirms the parameter/pollutant sampled, the date and time the sample was received by the lab, and the date and time the sample was analyzed. The report will also contain the results of the analysis, the units of the analysis, the method used in performing the analysis, and the initials of the analyst.

These analytical reports are the evidence that the discharge monitoring reports submitted are accurate and that samples have been taken on time and sampled correctly.

In addition to the results, a lab should also provide a quality control/quality assurance (QA) document. This QA document should contain information about the blank value (a sample that should have no pollutants) and the results of the test on a laboratory control sample (a known value). Figure 6.4 is an example of what the report may look like.

Figure 6.4 Example of a Laboratory Report for Physical Parameters and Nutrients

Project ID:	**Sample ID:**
Project Account:	**Submitted Date:**
Sample Field ID:	**Collection Date/Time:**
Sample Collector:	**Site Reference:**

Parameter	Results	Unit	MDL	RL	Qualifier
Chlorine	11.3	mg/L	1	3.18	
Conductivity	515	mg/L	0.004	0.13	
Hardness	276	mg/L	1	3.18	
Nitrate (NO_3)	7.01	mg/L	0.1	0.32	
NO_3-N	1.58	mg/L	0.02	0.06	
Sulfate	13.9	mg/L	5.00	15.9	
Total Nitrogen	1.6	mg/L	0.6	1.91	
Total Recoverable Phosphorous	0.40	mg/L	0.006	0.02	
Turbidity	2.3	mg/L	0.08	0.25	

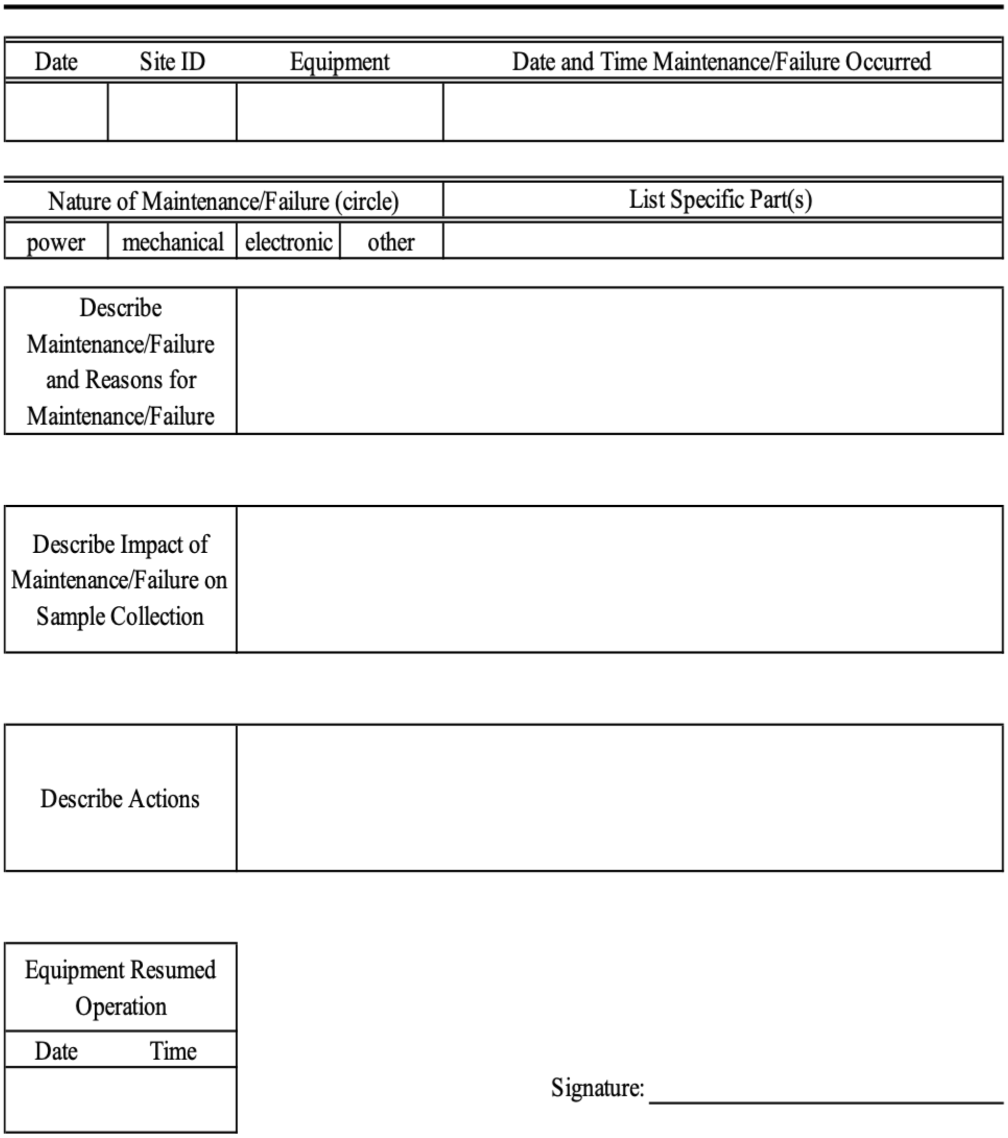
MDL = minimum detection limit; RL = recovery limit

Qualifiers are notes attached to data to give detailed information such as work sub-contracted out by the lab, estimations, and matrix interferences. These notes can also include whether the sample was not received at proper temperature or labelling issues. These are basically notes entered by the analyzing laboratory. Each lab has their own system and will provide a key explaining what each qualifier means.

6.5 Equipment Maintenance/Failure Log

It is important for plant operators to keep a log that documents when plant equipment is taken out of service for maintenance or failure. The information from these logs can be useful in identifying emerging problems with the equipment or documenting the need for replacement and/or repair. This information can also be useful in preparing annual operation budgets for the plant or long-term capital improvement needs. An example of a typical equipment maintenance/failure log is provided in Figure 6.5 below.

Figure 6.5 Equipment Maintenance/Failure Log



Date	Site ID	Equipment	Date and Time Maintenance/Failure Occurred

Nature of Maintenance/Failure (circle)				List Specific Part(s)
power	mechanical	electronic	other	

Describe Maintenance/Failure and Reasons for Maintenance/Failure	

Describe Impact of Maintenance/Failure on Sample Collection	

Describe Actions	

Equipment Resumed Operation	
Date	Time

Signature: ______________________________

6.6 References

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6.7 Other Resources

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Chapter 7

Management Plans and Procedures

In addition to being responsible for proper operation and maintenance of the system, an operator is also responsible for being familiar with and implementing several different management plans. Each of the following plans is discussed in this chapter:

- Standard Operating Procedure (SOP)
- Emergency Response Plan (ERP)
- Capacity, Management, Operations and Maintenance Program (CMOM)
- Asset Management Plan (AMP)
- Sewer Overflow Response Protocol (SORP)
- Best Management Practices (BMPs)
- Groundwater Protection Plan (GPP)

7.1 Standard Operating Procedure

Each wastewater facility should have a plan that includes standard operating procedures (SOP) for each component, piece of equipment, or analytical procedure. The plan should include easy to understand, step-by-step detailed instructions for all routine operations such as start-up, operation, and shutdown of equipment as well as guidance for access in confined spaces.

The objective of a SOP is to have written uniform instructions for a particular task such that any qualified person can successfully and safely complete the task. The SOP allows the operator to successfully maintain consistency in performance, quality control, worker safety, and production, while reducing miscommunication and failure to comply with regulations. The operator should be familiar with the procedures and know where to locate each SOP in case of an emergency.

7.2 Emergency Response Plan

Each wastewater utility should also have a formal Emergency Response Plan (ERP) that includes detailed guidance and procedures for dealing with different kinds of emergency conditions. These could include natural disasters (e.g., floods, fires, tornadoes), operational disasters (e.g., explosions, toxic releases, chemical spills), accidents, terrorism, sabotage, and power or equipment failure. The document should include emergency contact information at both the local and state level. The operator should be familiar with the different parts of the ERP and know where to physically locate or access the document in case of an emergency.

The ERP should be updated at least annually and exercised periodically. If your utility has not yet developed an ERP, two excellent templates have been developed by the **Rural Community Assistance Partnership (RCAP)** and the **Kentucky Rural Water Association (KRWA)**.

7.3 Capacity, Maintenance, Operations, and Management

The Capacity, Maintenance, Operations, and Management (CMOM) program is a framework of self-assessment and practices that help a sewer system manage, operate, and maintain their collection systems; investigate and provide adequate collection system and treatment plant capacities; and respond to and prevent unauthorized discharges such as sanitary sewer overflows (SSOs) and other non-compliance (Ref. 1). The goals of the CMOM program are:

- To better manage, operate, and maintain the collection system.
- Proactively prevent or minimize inflow and infiltration into the collection system.
- Prevent unauthorized discharges of toxic chemicals into the collection system.
- Investigate capacity constrained areas of the collection system and treatment plant.
- Proactively prevent or minimize unauthorized discharges (i.e., SSOs).
- Respond to overflow events and other non-compliance.
- Proactively prevent or minimize the potential for the release of pollutants from associated activities through treatment plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from storage areas.

KPDES requires that publicly owned treatment works (POTWs) complete a CMOM self-assessment using the checklist in the *Guide for Evaluating Capacity, Management, Operation, and Maintenance (CMOM) Programs at Sanitary Sewer Collection Systems* (Ref. 2) to determine the appropriate CMOM programs for the POTW. Once the **checklist** is completed, the POTW can develop a plan of action based on that assessment. This must be completed within one-year of receiving the KPDES permit and continuously maintained at the wastewater treatment plant.

The CMOM Plan of Action and associated CMOM program documentation should be updated whenever there are changes in the collection systems or treatment plants which materially affect the information specified in the applicable documents. If any element of the CMOM program proves to be ineffective in achieving the general objective of preventing and eliminating unauthorized discharges, such as SSOs, then the permit and/or specific CMOM initiative should be modified to address deficiencies. If at any time following the issuance of the permit any element of the CMOM program is found to be inadequate pursuant to a state or federal site inspection or review, the affected CMOM initiative and documentation should be modified to incorporate appropriated changes necessary to resolve regulatory concerns.

The elements that must be included in the CMOM Plan of Action are:

- Self-assessment summary (including recommended improvements and schedules).
- Collection system map or diagram (preferably in an electronic form such as a GIS coverage) that identifies:
    - A scale.
    - A north arrow.
    - Date the map was drafted and most recent revision.
    - Street names.
    - Surface waters.
    - Service area boundaries.
    - Manholes and other access points.
    - Sewer lines.
    - Pump stations.
    - Wastewater treatment plants.

    - Permitted discharge points or outfalls, including CSOs.
    - Locations of recurring SSOs within the last five years prior to the effective date of the KPDES permit.
- Sewer Overflow Response Protocol (see Section 7.5).
- Best Management Practices (BMPs) (see Section 7.6).
- Any other constituent programs necessary to achieve the goals of the CMOM program.

7.4 Asset Management Plan

For wastewater utilities, asset management is a process used to make sure that planned maintenance can be conducted and capital assets (e.g., pumps, motors, pipes, etc.) can be repaired, replaced, or upgraded on time and that there is enough money to pay for it (Ref. 3). It allows the utility to manage infrastructure capital assets to maintain a desired level of service at the lowest life cycle cost (Ref. 4). Lowest life cycle cost refers to the best appropriate cost for rehabilitating, repairing, or replacing an asset.

Asset management is implemented through an asset management program, which typically includes a written asset management plan (AMP). An AMP is a strategic plan for tracking and managing the infrastructure and other assets owned by a utility. An infrastructure asset is any long-lived capital asset that is operated as a system or network, such as a sewer collection system. The sewers, manholes, and pump stations are the primary asset components of the collection system. Buildings that are integral to the function of the network, such as pump station houses, are also considered part of the infrastructure asset. Key elements of the AMP should be implemented by everyone in the organization, including management, financial, engineering, administrative, and field staff.

Wastewater systems need an asset management program to (Ref. 5):

- Address aging water infrastructure assets before they fail.
- Keep assets productive, and not allow them to become disruptive liabilities.
- Treat all decisions as investment decisions to maximize limited financial resources.
- Make costs transparent to support financial decisions.

Asset management requires:

- Support and involvement of local officials who have the authority and willingness to commit public resources and personnel to maintain community assets.
- A commitment of time and money to make cost-effective asset decisions (e.g., spending some money in the short-term to save more money over the long-term).
- A team made up of key decision makers.

A sustainable wastewater utility provides a safe and reliable collection system while managing infrastructure assets to maximize their useful life. An AMP will help “tell the story” of the system’s assets to the community in a way that is understandable. Small systems that have simple AMPs can benefit as much as large systems that have complex plans. Asset management will enable the system to:

- Have more efficient and focused operations.
- Select capital projects that meet the system’s true needs.

- Base sewer system service rates on sound operational decisions.
- Improve its financial health.
- Reduce environmental violations due to failed or poorly performing assets.
- Improve the security and safety of infrastructure assets.

Although operational personnel are not owned by the utility, the development of employees to build a successful team takes significant time and effort and can be considered a component of a successful wastewater utility. Therefore, utilities are strongly recommended to create and maintain a framework to identify key personnel positions needed to ensure regulatory compliance that supports the organization's mission. The framework should, at a minimum, track the employee, the knowledge and training required for key positions, the employee's current operator certification status, the operator's certification renewal requirements, and information necessary for promotion.

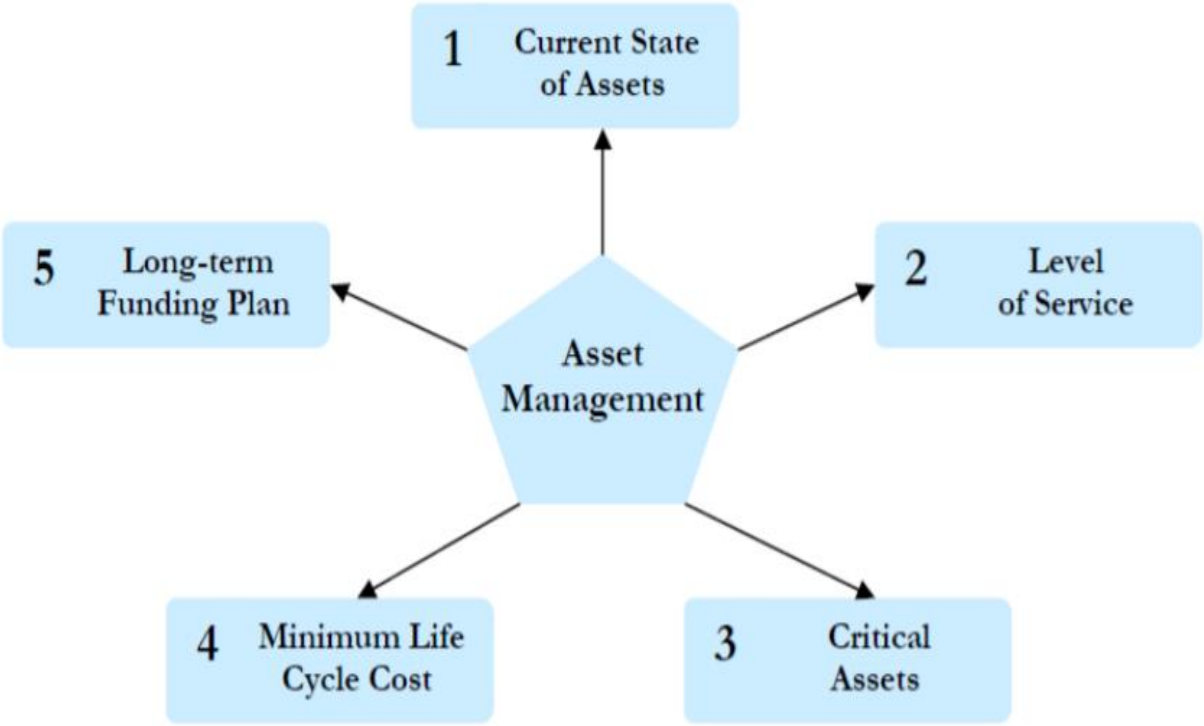
7.4.1 Core Framework Questions

The following five questions are a good starting point for any system to establish a core framework and address some of the major activities associated with asset management.

1) What is the current state of the system's assets?
    - Your wastewater system's assets are part of your community's total assets. A decline in the value of your infrastructure indicates insufficient funding of asset management.
2) What is the required "sustainable" level of service?
    - Knowing the required "sustainable" level of service will help implement an asset management program and communicate to stakeholders what the utility is doing. The required level of service provides the basis for justifying utility user rates.
3) Which assets are critical to sustained performance?
    - Identifying critical assets will help managers make decisions about resource allocation and about maintaining or improving the utility's sustainable level of service.
4) What is the life-cycle cost?
    - Knowing the answer to this question will help guide the system from a passive "fix-it-when-it-breaks" posture and move the system to an active program of preventive maintenance and timely asset replacement.
5) What is the best long-term financing strategy?
    - Knowing the full economic costs and revenues generated by the system will help determine its financial viability. A financial forecast can then provide needed information in making decisions regarding long-term funding strategy.

Figure 7.1 provides a flow chart that shows the relationship and dependencies between each core framework questions.

Figure 7.1 Five Core Questions of Asset Management Framework



It is important to remember that publicly owned treatment works (POTWs) are owned by a state, municipality, special sewer district, or other publicly owned and financed entity. POTWs are required to meet the requirements of the Governmental Accounting Standards Board's Statement #34 (GASB 34). Kentucky governmental entities (e.g., municipalities, fiscal courts, Commonwealth of Kentucky) are required to conduct an annual audit within six months of their fiscal year on each financial fund of the county. Most Kentucky governmental entities that own a POTW will include the funds of the POTW in their audit. However, some do not. As a collection system certified operator, you should be familiar with GASB 34 but are not required to be an expert on the subject. The following section provides a detailed overview of GASB 34 as it relates to POTWs.

7.4.2 Governmental Accounting Standards Board's Statement #34 (GASB 34)

The Governmental Accounting Standards Board's Statement #34 (GASB 34) details the accounting and financial reporting practices for state and local governmental entities including POTWs (Ref. 5). If the system is publicly owned, GASB 34 requirements will need to be followed to obtain a "clean opinion" (i.e., a good credit rating) from an auditor. Without a clean opinion, utilities may face higher interest rates on loans and bonds and may be more closely scrutinized by regulators and public officials. When following GASB 34 standards, the POTW is required to report the value of infrastructure assets and the cost of deferred maintenance. An accurate and up-to-date AMP will help a utility comply with this requirement.

GASB 34 provides collection system owners with an option of documenting the value of the system assets using the full historical cost, rather than reporting depreciation, if certain requirements are met. These requirements include maintaining the system at or above a condition level specified by the government, and managing the system using an asset management program that meets certain requirements. Under this option, known as the "modified approach," maintenance and preservation costs are expensed and only additions and improvements to the system are capitalized. This option is appropriate for utilities that use asset management activities to preserve the service life of the system over time. When an alternative method called depreciation accounting is used, a portion of the historical cost over an estimated useful life is steadily written off. This method is more appropriate for assets that are used up over a finite life.

To use the modified approach, the asset management program must inventory the system assets, perform a condition assessment, and estimate the annual amount of money needed to maintain and preserve the system assets at the established condition level. The condition assessment must be performed at least every three years. As required supplementary information, the POTW must present a schedule of the assessed condition of the assets for the three most recent condition assessments, the estimated financial resources needed to maintain and preserve the system, and the amount of money expensed for the last five years.

Sewer collection utilities can demonstrate to customers, lending institutions, and regulators a commitment to maintaining the assets for which they are responsible. This commitment can symbolize a utility's dedication to delivery of excellent service, proper use of public funds, and compliance with environmental and health laws. In addition, the POTW can benefit from an asset management program with lower capital replacement costs, smoother system operations, less resistance to needed rate increases, and better commercial lending terms.

7.4.3 Asset Management Program Components

Asset management is a continuous process that provides information on the use, acquisition, and disposal of infrastructure assets to optimize the delivery of services while minimizing costs over the useful life of the asset. Below is a list of the key components of an asset management program.

- <u>Level of service</u>. For most collection systems, the basic level of desired service will be to deliver reliable sewer collection services at a minimum cost, consistent with applicable environmental and health regulations. Level of service criteria should be system-specific while also addressing CMOM and GASB 34 requirements, particularly in areas where improvements are most needed and will yield the greatest benefits. Examples include:
    - Ensuring adequate system capacity for all service areas.
    - Eliminating system bottlenecks due to pipe blockages.
    - Reducing peak flow volumes through I&I controls.
    - Providing rapid and effective emergency response service.
    - Minimizing cost and maximizing effectiveness of CMOM programs.
- <u>Performance measurements</u>. Performance measurements include specific metrics designed to assess whether the level of service objectives is being met. Some examples of performance measurements:

  - Annual performance goals for sewer system inspection, cleaning, maintenance, rehabilitation, and capital improvement.
  - Correlations of grease control education and enforcement measures with expected reductions in the number, distribution, and severity of grease blockages.
  - Maximum hourly and monthly peak flow volumes.
  - Maximum emergency response time to emergency calls, tracking customer complaints and claims for private property restoration.
  - Cost-benefit analysis of key completed activities, considering expected vs. actual outcome and budgeted vs. actual cost.
- Data requirements. The electronic information system needed to implement an asset management program must be carefully considered by each utility. The selection criteria may include variety of factors such as asset management goals, performance measures, regulatory requirements, and collection system size, complexity, and condition.
  - Begin with an evaluation and documentation of existing information systems. For each data stream, questions to answer include:
    - How much data is collected?
    - How is the data collected, stored, and managed?
    - How frequently is the information collected?
    - How thorough are the records?
    - Is the data available to other information systems and/or other users?
- Asset identification. This process involves identifying and numbering the primary components in the sewer system. Once the components are assigned unique identifiers, the utility can link information systems and aggregate data for financial, economic, technical, and management use. The identification process typically begins with architectural or engineering maps and as-built construction or repair records, which may exist in paper or electronic format. Information from these records should be transferred to an electronic database, such as a spreadsheet, relational database, or asset management software program.
  - Each component record includes fields for relevant information. For instance, sewer main segments would be identified by location, length, material, size, slope, burial depth, beginning and ending manholes, and approximate or actual age. Usually, the component numbering system should be based on manholes, with the sewer segments labeled according to their relationship to the beginning and ending manholes.
- Failure impact evaluation and risk management. The potential impacts from sewer line failures should be assessed on a system-wide basis. The goal is to identify those areas of the system that will have the greatest impact if a failure occurs and focus asset management resources to minimize that risk. Failure severity impact factors normally considered include: the location within the system, intended service function, burial depth and access barriers, proximity to public areas or environmental resources, hydrogeological features such as soil type, depth to groundwater, seismic activity, etc. Critical areas can be classified by zones, individual segments, or subnetworks within the sewer system.

    - As an example, a community may have established an association between a certain acidic soil type and a higher-than-average failure rate of ductile iron pipe. A high failure impact rating can then be applied to all areas where these soils occur and where ductile pipe is known to exist. Similarly, a high rating might also be applied to sewer lines running under occupied structures in a commercial or residential district since any needed replacement would likely involve additional complexity, cost, and risk of private property damage.
- Condition assessment. Once the assets have been identified, it is important to identify any assets that are underperforming, determine the reason for the deficiency, predict when failure is likely to occur, and determine what corrective action is needed and when.
    - The GASB 34 modified accounting option requires that the condition assessment be based on an up-to-date inventory of assets, and that the methods used be documented in such a way that the same results could be obtained by someone else performing the same assessment. A condition level measurement scale should be used, and a minimum acceptable condition should be established and incorporated into the administrative rules governing the operation of the collection system (e.g., municipal ordinance, state, or county statute).
    - Currently, the condition level of the collection system is often left to the discretion of the individual utility. Whatever benchmarks are chosen, they should refer primarily to the physical condition of the system and its components. For instance, an established condition level for a sewer collection system could include ensuring that no more than 10% of main sewer lines can degrade below a fair condition during any 12-month period.
    - There are many different measurement systems in use by sewer utilities in the United States. Table 7.1 is an example of a simple grading system used by the Kentucky Infrastructure Authority in their **Water Resources Information System (WRIS)** database (Ref. 6).

Table 7.1 Asset Codes used for the WRIS

ASSET CODES	
Level	***Description***
Condition Codes	
1	New or Excellent – None or minor defects.
2	Good – Defects that have not begun to deteriorate.
3	Fair – Moderate defects that will continue to deteriorate.
4	Poor – Severe defects that will collapse/break in near future.
5	Inoperable – Defects need immediate attention.
Performance Codes	
1	Exceeds/Meets all performance targets.
2	Minor performance deficiencies.
3	Considerable performance deficiencies.
4	Major performance deficiencies.
5	Fails to meet performance targets.
Priority Codes	
0	Not a priority.
1	It would be nice to have.
2	Improved system operation & maintenance (O&M) efficiency.
3	Internal safety concern or public nuisance.
4	Potential public health, safety, or environmental concern.
5	Existing threat to public health, safety, or environment.

- Rehabilitation and replacement plan. Proactive rehabilitation and replacement planning provide the best opportunity for capital cost savings. By rehabilitating or replacing sewers and other components before they fail, the utility automatically avoids costs such as emergency contractor fees, staff overtime, unplanned repairs, and SSO cleanup costs. Additional savings can be achieved through coordination of sewer construction with other construction projects, replacing longer segments, and phasing construction over a period of years. Proactive planning also allows the utility to assess the relative economic costs and benefits of rehabilitation vs. replacement.
- Capacity plan. An assessment of a system's capacity to accommodate future expansion is fundamental to the CMOM approach. Capacity planning should be based on:
    - Review of operational, SSO, and peak flow data for evidence of existing capacity constraints.
    - Analysis of predicted demand for sewer service, based on regional growth patterns. Where possible, sewer planning should be linked to regional land use and/or watershed management planning activities.
    - Identification of current and future capacity shortfalls.
    - Identification and evaluation of alternatives for correcting the deficiencies, focusing first on those that are contributing to SSOs or peak flow violations at the treatment plant.

- Maintenance analysis and planning. An effective maintenance program keeps the sewer system running smoothly and helps prevent premature deterioration of components. Planning should be performed annually and updated throughout the year as needed to address changing conditions. Maintenance activities are either planned (e.g., inspecting all major lines in the system every 15 years, cleaning all major lines on a rotating basis every five years) or unplanned (e.g., defect repair, emergency blockage removal).
    - The asset management goal is to maximize planned maintenance and minimize unplanned maintenance. Planned maintenance is more cost-effective because it is performed on a non-emergency basis, is coordinated with other system operation activities, and provides more opportunity to value engineer activities during the planning process.
    - Maintenance planning is improved by evaluating the patterns of failures leading to unplanned maintenance to see if they were related to timing (e.g., the line failed before the next cleaning was scheduled); ineffective maintenance methods (e.g., repeatedly clearing sediment blockages in a sagging line, rather than correcting the sag); or advanced deterioration or improper design. It is important to document the assumptions, methods, and information used to support maintenance planning analysis.
    - Field crews should be integrally involved with maintenance planning. This gives management the benefit of field crews' on-the-ground expertise and achieves buy-in from the staff. As the maintenance program proceeds, field staff should be encouraged to provide feedback on which strategies are working and which are not, to allow mid-course corrections if necessary.
    - Training is also essential. Informal on-the-job training for new employees often allows improper procedures and mistaken assumptions to be passed on. New employees should be trained on how to perform standard procedures, coordinate with other public works and private utility crews, operate equipment, and observe health and safety protection requirements.
- Financial management system. The goal of sewer system financial management is to identify how much money will be needed to meet level of service goals and maintain the system at or above the identified minimum condition; forecast when the money will be needed; and use the information to set user fees, other revenues, and debt financing.
    - Financial forecasting should be performed over a period of five to 10 years and should be updated annually. The annual estimate of the cost to maintain the system is included in the utility's annual financial report, along with a full accounting of cash flows, debt financing, and financial reserve activity.
    - The better the supporting data, the more reliable the financial forecast. Support data includes:
        - Asset identification and valuation.
        - Condition assessment.
        - Performance monitoring.
        - Current and future capacity assessments.

    - Where gaps in the data exist, reasonable assumptions must be used as a basis for financial forecasting.
- Continuous improvement processes (CIP). CIP are based on periodic review of systems against performance measures to identify any problems or deficiencies. Performance measures can be related to level of service goals, condition maintenance goals, or asset management program goals.

7.5 Sewer Overflow Response Plan

All collection systems should have a sewer overflow response plan (SORP). The SORP is a component of the CMOM Plan of Action as referenced in Section 7.3. The SORP is used to ensure that in the event of a sanitary sewer overflow, the proper reporting has been performed and any adverse effects are minimized (Ref. 1). The plan should be developed to protect public health and the environment, meet permit requirements, protect wastewater personnel, and ensure the safety and proper functioning of the wastewater system.

The SORP should be maintained along with the CMOM and, at a minimum, contain:

- An overflow response procedure including designated responders for the POTW, response times, and cleanup methods.
- A public advisory procedure.
- A regulatory agency notification procedure.
- A manhole and pump station inspection schedule.
- A procedure for addressing discharges to buildings caused by blockage, flow condition, or any other malfunction in sewer infrastructure owned or operationally controlled by the POTW.
- A requirement to include the structure ID for reported incidents along with an estimate of the time and duration of the overflow and volume of the overflow.

7.6 Best Management Practices

Best Management Practices (BMPs) are schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to ensure compliance with the limits listed in the KDPES permit for POTWs. BMPs are components that may be required in plans and programs to address industry practices or standards for treatment requirements, operating procedures, and practices to control treatment plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw materials storage.

BMPs are often used in correlation with an AMP. Examples of what the BMPs may address include:

- Design and construction for O&M.
- Knowing the system inventory and physical attributes.
- Knowing where the system is (maps and location).
- Assessing the condition of the system.
- Planning and scheduling work based on the condition and performance of the system.

- Repairing, replacing, and rehabilitating system components based on their condition and performance.
- Managing timely, relevant information to establish and prioritize appropriate CMOM activities.
- Training personnel.

7.7 Groundwater Protection Plan

A groundwater protection plan (GPP) defines the BMPs that will be put in place to protect the regional groundwater from leakage or spills from the collection system into the groundwater aquifer (Ref. 7). This is important because groundwater recharge provides water to our streams, lakes, ponds, rivers, and wetlands. In addition, groundwater aquifers serve as a water supply source for many water utilities.

401 KAR 5:037 requires that wastewater treatment plants maintain a GPP if any of the following activities are occurring at the utility:

- Collection or disposal of pollutants in an industrial or commercial facility using floor drains that are not connected to on-site sewage disposal systems, closed-loop collection or recovery systems, or a waste treatment system permitted under the Kentucky Pollutant Discharge Elimination System (KPDES).
- Impoundment or containment of pollutants in surface impoundments, **lagoons**, pits, or ditches.
- Land treatment or land disposal of a pollutant.
- Storage, treatment, disposal, or handling of hazardous waste, solid waste, or special waste in landfills, incinerators, surface impoundments, tanks, drums, or other containers or in piles.
- Pesticide or fertilizer storage and handling for commercial purposes or distribution to a retail sales outlet.
- Pesticide or fertilizer application for commercial purposes, public right-of-way maintenance, or institutional lawn care.
- Commercial or industrial storing or related handling in bulk quantities of raw materials, intermediate substances, or products, finished products, substances held for recycling, or other pollutants held in tanks, drums, or other containers or in piles.
- Transmission in pipelines of raw materials, intermediate substances or products, finished products, or other pollutants.
- Installation or operation of on-site sewage disposal systems.
- Storing or related handling of road oils, dust suppressants, or deicing agents at a central location.
- Application of related handling of road oils, dust suppressants, or deicing materials.
- Mining and associated activities.
- Installation, construction, operation, or abandonment of wells bore holes, or core holes.
- Commercial or industrial transfer, including loading and unloading, in bulk quantities of raw materials, intermediate substances or products, finished products, substances held for recycling, or other pollutants.

401 KAR Chapter 5, Section 3, also requires that a wastewater utility maintain records to show compliance with the plan for a minimum of six years. A GPP is valid for three years, or whenever the protective practices or personnel change. A copy of the GPP and any changes are required to be submitted to the DOW by either mail or email. The contact information, frequently asked questions, examples of generic GPPs, and guidance documents are located on the EEC website at the following link: **https://eec.ky.gov/Environmental-Protection/Water/GW/Pages/GWGPP.aspx**

Please note that while the operator is not responsible for the development of the GPP, they are responsible for making sure that the conditions laid out by the GPP are met.

7.8 References

1. KEEC. **Capacity, Management, Operation, and Maintenance (CMOM).**
2. EPA. (2005). ***Guide for Evaluating Capacity, Management, Operation, and Maintenance (CMOM) Programs at Sanitary Sewer Collection Systems*** (EPA 305-B-05-002).
3. EPA. **Asset Management for Water and Wastewater Utilities**.
4. EPA. (2002). ***Fact Sheet: Asset Management for Sewer Collection Systems*** (833-F-02-001).
5. EPA. (2008). ***Asset Management for Local Officials***. (EPA 816-F-08-015).
6. Kentucky Infrastructure Authority. (2021). **Water Resources Information System**.
7. KEEC. **Ground Water Protection Plans**.

7.9 Resources

EPA. **CMOM Program Self-Assessment Checklist**.
EPA. **Sanitary Sewer Overflow (SSO) Additional Resources**.

Chapter 8

The Source and Characteristics of Wastewater

For a long time in early history, human waste and wastewater were disposed of directly on the land surface. In cities, it was common to dispose of human waste in chamber pots which were then dumped into gutters and ditches on the sides of the roads. This situation created some significant problems with diseases and odors. Rains were counted on to flush the waste away. Later, development of latrines or outhouse facilities continued until underground collection systems were eventually developed. Early health concerns led to the building of pipe collection systems to convey the human waste away from homes, usually to a river, stream, or other body of water. This improved public health but transferred the problem to receiving water streams.

8.1 Sources

Wastewater is generated from the water that flows from toilets, sinks, and drains into a sewer system. It comes into the treatment plant from various sources: household or domestic, industrial commercial and institutional (e.g., schools, hospitals). In addition to the used water, water from rain or groundwater can also get into the collection system due to cracks and leaks in the sewer pipes and manholes or from direct connections into the system such as from connected downspouts (which is typically prohibited or illegal). Older systems often had **combined sewers** where excess stormwater would flow into a sanitary sewer and overwhelm the wastewater treatment plant.

Domestic/household activities that generate wastewater include (Ref. 1):

- Human excreta such as feces and urine, that is often mixed with used toilet paper or other wipes.
- Washing water from sinks, dishwashers, washing machines, etc.
- Bathing water from tubs and showers.
- Surplus food preparation waste (e.g., drinks; cooking fats, oil, and greases (FOG); food scraps; detergents).

Industrial activities that generate wastewater include (Ref. 2):

- Industrial site drainage (e.g., silt, sand, chemical residues).
- Industrial cooling waters (e.g., heat, slimes, silt).
- Industrial processing waters.
- Organic waste from hospitals, creameries, food factories, etc.
- Difficult to treat organic waste from pharmaceutical and pesticide manufacturing.
- Acidic or alkali waste from manufacturing.
- Toxic waste from metal plating, cyanide production, etc.
- Solids and emulsions from paper mills, factories.

In addition, wastewater can sometimes include urban runoff from roads, parking lots, etc., that contain oils, animal feces, gasoline, rubber, de-icing salts, and other waste compounds if the sewer system is connected to places where stormwater can enter the system, as in combined sewer systems (a system which combines both sewage flows and stormwater). In these cases, it could also theoretically contain agricultural product pollution used in urban and rural settings (Ref. 1).

Rainwater can also enter the system through inflow and infiltration into the collection system. Inflow is water that enters the sewer system through illicit direct connections or through breaks or defects in the sewer pipes or associated components. Inflow normally enters the sewers as soon as there is significant rainfall and subsides quickly when the rain stops. Infiltration will increase flow into the collection system if the groundwater is high. Some of the common sources of inflow/infiltration are:

- Low lying manholes in roads or ditches that are subject to flooding during storm events.
- Defects or cracks in manholes.
- Buried manholes. Uncapped lateral lines.
- Roof down spots that are connected to the sewer.
- Sump pumps and foundation drains that are connected to the sewer.
- Gutters that are connected to the sanitary sewer.
- Cracks and offset joints in the sewer lines.

Inflow/Infiltration (I/I) can cause sewer systems to exceed their capacity and result in sanitary sewer overflows. This can also cause treatment problems in the wastewater treatment plant by increasing flows into the primary clarifiers and **activated sludge** basins. Too much flow into the treatment plant can wash out solids resulting in a reduction of plant efficiency. Some systems may have equalization basins where large increases in flow can be diverted and stored until after a storm event when the flows can then be released and treated. Ideally, sources of I/I should be identified and eliminated. In some cases, the federal standard will require such a study before loaning a municipality the additional funds to expand their treatment facilities.

8.2 Conveyance

Clean or potable water that can be used in the household for drinking, cooking, and cleaning is provided by the water supply system and is discharged through drains or flushing the toilet. The now “used” water flows through the waste pipes in the building to the wastewater collection system. From there, the wastewater is transported through gravity sewers, lift stations and pressurized force mains into the treatment facility. The wastewater is then treated by various processes before it is discharged back into the environment (Ref. 2).

8.3 Characteristics of Wastewater

Approximately 99% of wastewater is water. The remaining 1% consists of anything that can go down a drain or be flushed down a toilet. Common items found in wastewater are microorganisms (e.g., bacteria, viruses, etc.); organic matter (e.g., food, paper, etc.); fats, oil, and grease (FOG); inorganic matter (e.g., metals, minerals, etc.); solids that will not degrade or dissolve (e.g., plastic); and gases (Ref. 3).

8.4 References

1. Wikipedia. (2021). **Wastewater.**
2. WDNR. (2011). ***Introduction to General Wastewater Study Guide*.**
3. Heaton, L. (2000). ***As a Citizen, What Do You Know about Wastewater?*** University of Kentucky Cooperative Extension Service: IP-67.

Chapter 9

Industrial Pretreatment Programs

Pretreatment programs allow local governments and treatment plants to require permitting and enforcement responsibilities on industries that discharge into the publicly owned sanitary sewer system that then transport their wastes to the municipal wastewater treatment plant. The purpose of a pretreatment program is to reduce the levels of toxic pollutants that could come from industries and negatively impact the operation of the municipal plant.

9.1 Standards and Requirements

The Clean Water Act forbids the discharge into the municipal sewer system of any pollutants that could either pass through untreated or cause interference with the working of a treatment plant (Ref. 1). Essentially this means that any pollutant limited by the KPDES permit is not allowed to pass through the system and create a water quality violation, nor can it interfere with the treatment process by disrupting the wastewater treatment plant operations.

9.1.1 General and Specific Prohibitions

The **National Pretreatment Program** prohibits the discharge of (Ref. 1):

- Any pollutants that will create a fire or explosion hazard.
- Any pollutants that are considered toxic to the environment or the wastewater treatment process.
- Any pollutants that will cause corrosive structural damage to the wastewater treatment system.
- Any pollutants that will cause obstruction of flow in the municipal works or collection system (e.g., FOG).
- Heat, in amounts that will cause an increase in temperature, that can create problems for the activated sludge system.
- Petroleum products, and other oils, that will pass through or cause problems for the wastewater system.
- Pollutants that will result in the presence of toxic gases, vapors, or fumes that can create health and safety problems for the workers.
- Any pollutants hauled and illegally dumped into the system.

9.1.2 Categorical Pretreatment Standards

The National Pretreatment Program has developed specific industrial effluent guidelines for industries that fall under Title III of the Clean Water Act. For a list of affected industries and the requirements for them you can visit the EPA **Industrial Effluent Guidelines**. This website lists and outlines the national standards for industrial wastewater.

9.1.3 Local Limits

Each municipality must evaluate the treatment facility's capability to treat the water coming into the system and establish local limits to protect it from receiving wastes that could pass through untreated or create problems with plant operations (Ref. 1).

Local limits are to be set for any non-domestic dischargers. These limits can be a specific numeric limit that can be enforced at the point of discharge into the sewer system, or they can involve narrative limits that include best management practices. These local limits must be re-evaluated every time a KPDES permit is reissued.

9.2 Roles and Responsibilities

The following authorities or users have the responsibility for developing and implementing a pretreatment program.

9.2.1 Approval Authorities

For most pretreatment programs, the EPA authorizes the state to regulate the National Pretreatment Program. The state then issues the permit conditions to the individual municipalities. The responsibilities of the approval authorities are (Ref. 1):

- To determine when and where pretreatment programs need to be developed.
- Set schedules for sampling and other specific requirements for the pretreatment program.
- Review and approve requests for a pretreatment program.
- Provide technical guidance for the control authorities.
- Review and approve requests for site-specific variances.
- Review and receive annual pretreatment reports.
- Evaluate pretreatment implementation via audits and inspections.
- Initiate enforcements against noncompliant municipalities or industries.

9.2.2 Control Authorities

When a pretreatment program has been approved, the publicly owned treatment works becomes the control authority for the pretreatment program. It then becomes the job of the local wastewater utility to administer and enforce the pretreatment standards developed to ensure compliance within their pretreatment program. The responsibilities of the control authority or the wastewater utility include (Ref. 1):

- To develop local limits, standard operating procedures, and an enforcement response plan to establish and maintain an approved pretreatment program.
- Issue limits, conduct monitoring and inspection, receive and review reports, review requests for variance, evaluate compliance, and take action to enforce the pretreatment program for the industrial users.
- Submit regular reports to approval authorities for monitoring of the pretreatment program.

A pretreatment program is developed by submitting specific protocols and documents to the state for approval. To get a pretreatment program established the municipality must submit (Ref. 1):

- Evidence of legal authority that they can implement a pretreatment program.
- A description of how the program will be implemented.
- A demonstration that they will have enough money to implement the proposed program.
- Local limits, as well as a schedule of re-evaluation of those limits.
- Enforcement response plans.
- A comprehensive list of the industrial users.

The individual treatment works is then responsible for enforcing the permit and required to:

- Identify and locate all industrial users subject to pretreatment programs.
- Identify the pollutants and their volumes discharged to the system.
- Notify industrial users of applicable pretreatment standards and requirements, applicable limits, and monitoring requirements.
- Receive and analyze reports and notices from the industrial users.
- Sample and analyze industrial user discharges.
- Evaluate industrial users, and require measures for controlling accidental discharges, that might either cause interference or pass-through treatment plants untreated or violate the Publicly Owned Treatment Works (POTW) regulations.
- Investigate industrial user noncompliance, developing and using an Enforcement Response Plan.
- Provide sufficient funding, resources, personnel to carry out the requirements.
- Develop and enforce local limits or demonstrate that they are not necessary.
- Submit an annual report to the approval authority.

9.2.3 Industrial Users

The industrial users of the wastewater treatment system must comply with all the pretreatment requirements. This means that the industrial users, as well as the parent municipal system, must perform self-monitoring, provide reports to the municipality, and maintain relevant records. In the event of accidental or unexpected discharges that could be problematic for the treatment system, the industrial user must notify the municipality immediately. Failure to do so, could result in significant safety hazards to the workers in the collection system and at the plant, or could result in a breakdown of the treatment process which eventually may result in untreated discharges of wastewater resulting in notices of violations and fines.

9.3 References

1. EPA. National Pretreatment Program.

Chapter 10

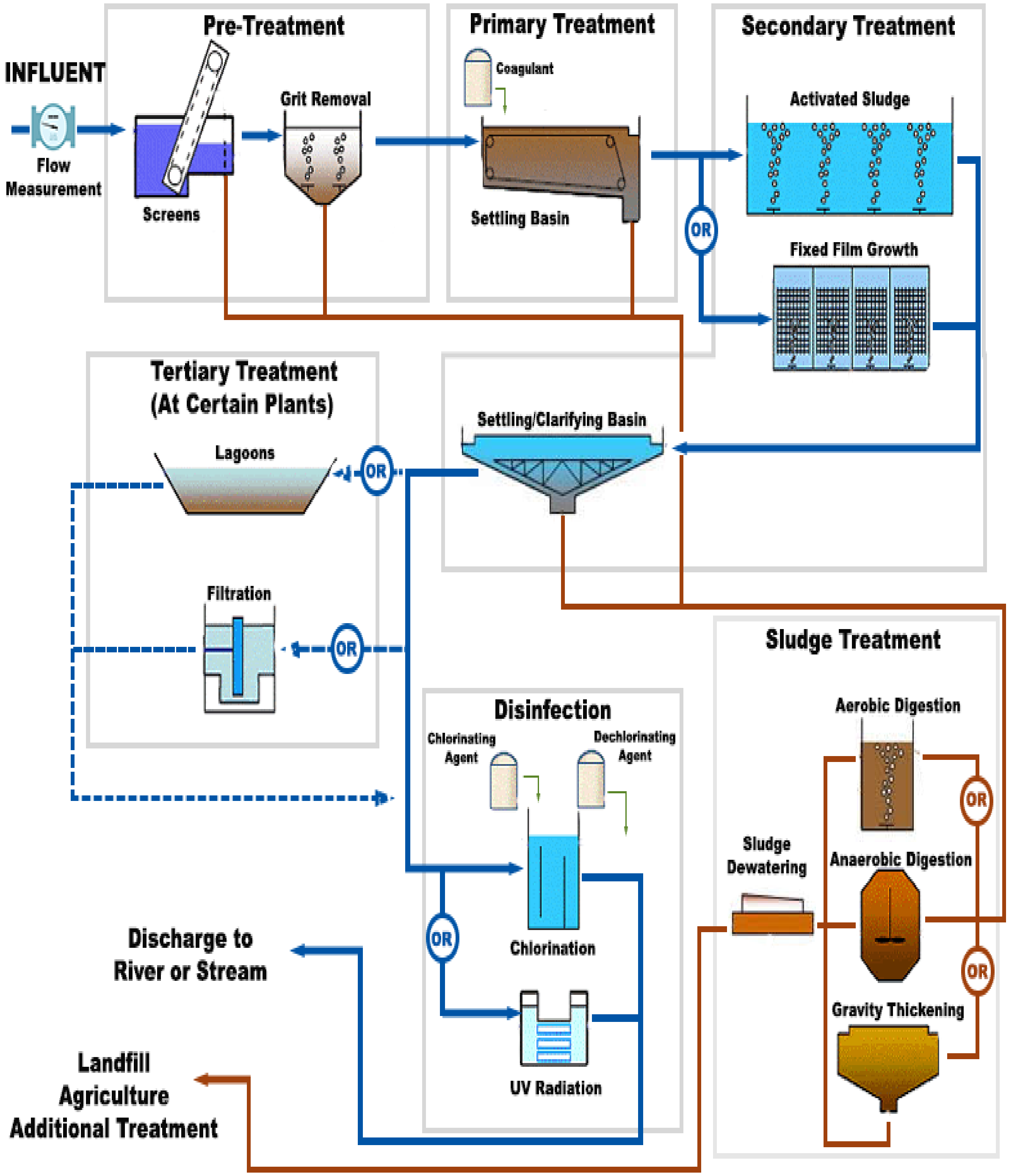
Wastewater Treatment

The treatment of wastewater (commonly known as sewage) has evolved into a complex process involving several different physical, chemical, and biological processes designed to reduce the load of organic wastes discharged into the environment. A picture of a typical wastewater treatment plant is provided in Figure 10.1. As can be seen from the picture, a typical wastewater treatment plant is made up of several different structures or tanks, each with a specific purpose as the wastewater flows through the facility.

Figure 10.1 The Central Wastewater Treatment Plant, Nashville, Tennessee

The various steps or stages involved in the treatment of wastewater can be visualized by using the flow chart or a process flow diagram shown in Figure 10.2. This diagram shows the various steps or stages used in treating wastewater for a traditional activated sludge treatment plant. As can be seen, some plants use slightly different components in the different stages of treatment (which may be the case with your plant) and so their process flow diagrams may look slightly different, but essentially all plants will include these basic stages.

Figure 10.2 Process Flow Diagram of a Typical Wastewater Treatment Plant



Legend: Blue lines show the passage of treated water. Brown lines show the passage of sludge.
Source: Adapted from Onondaga County Department of Water Environment Protection diagrams.

10.1 Wastewater Characteristics

The wastewater that enters the wastewater treatment plant has certain physical, chemical, and biological characteristics (Ref. 1). These can vary considerably throughout the day and from day to day over the course of a given week. One of the most common problems with older plants was they were originally designed based on average flowrates and average BOD loadings, with little consideration for peak conditions. In many communities, peak flow rates and BOD and TSS loadings can range two or more times the average design values. In fact, most modern plants being designed today are probably set up to handle future peak flows and loadings, so they are larger than they need to be. Over time, the operator should learn what to expect to be in a better position to operate the facility. Some general ideas of the typical wastewater discharged by individuals on a dry weight basis in units of lbs/person-day are provided in Table 10.1. Likewise, typical concentrations of wastewater constituents in untreated domestic wastewater are provided in Table 10.2 (Ref. 2).

Table 10.1 Quantity of Waste Discharged by Individuals

Constituent	Range, lbs/person-day
BOD_5	0.11 - 0.26
TSS	0.13 - 0.33
Free Ammonia as N	0.011 - 0.26
Organic Nitrogen as N	0.009 – 0.022
Total P as P	0.006 - 0.010
Oil and Grease	0.022 - 0.088

Table 10.2 Typical Composition of Untreated Domestic Wastewater

Constituent	Range, mg/L
BOD_5	110 - 350
TSS	120 – 400
Free Ammonia	12 - 45
Organic Nitrogen as N	8 - 25
Total P as P	4 - 12
Oil and Grease	50 - 100
Fecal Coliform	10^3 to 10^8 CFU/100 mL

10.2 Flow Measurement

To be able to properly operate a wastewater treatment plant, it is important to know how much sewage is flowing into the plant at a given point in time. These flows can be measured using either simple volumetric methods, where how long it takes to fill a container of known volume is measured, or hydraulic methods, where typically the depth of flow over a weir or through a flume is measured and then converted into a flow rate using standard hydraulic equations.

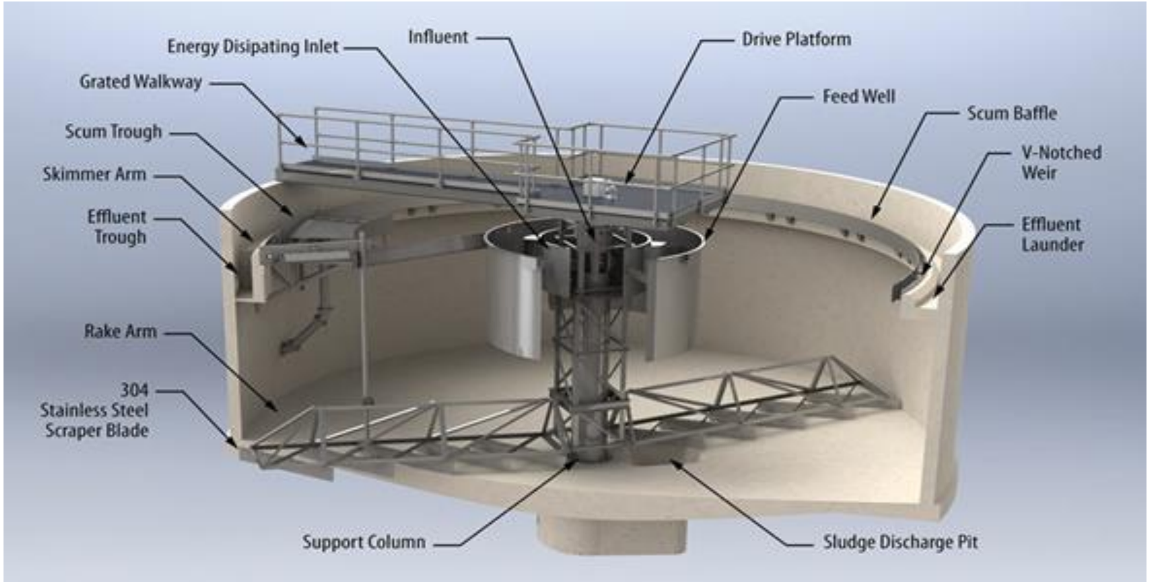
10.3 Pretreatment

Wastewater that flows into a treatment plant will most likely contain a lot of other things beside sanitary sewage. These items may include paper and plastic products; **grit** (which may include sand, gravel, cinders, and other heavy materials); and fats, oils, and grease (FOG). The treatment process will work much better if these items are removed from the wastewater prior to treatment. The pretreatment process in most wastewater treatment plants will include different types of equipment such as coarse and fine screens, grit chambers and grinders to remove these types of material.

10.4 Primary (First Level) Treatment

Once extraneous items have been removed from the wastewater, there is a significant amount of organic material (e.g., BOD) along with nitrogen and phosphorus remaining in the wastewater to be treated. This wastewater typically has high concentrations of TSS and may also have residual FOG. The first step in the treatment process will typically involve processes designed to settle out as much of the solids in the wastewater as possible and skim off the FOG. The removal of these materials is typically done in a series of sedimentation basins or primary clarifiers (Figure 10.3). The solids that settle to the bottom of the tank are then scrapped off and diverted into sludge discharge pits, which are then pumped to a sludge treatment and disposal process (to be discussed shortly). The FOG is skimmed off the surface of the water in the clarifier into a scum trough for collection and processing. The remaining wastewater then either flows by gravity or is pumped to the secondary treatment system. Between 50% to 80% of solids are typically removed by the primary clarifier treatment (Ref. 1).

Figure 10.3 Primary Sedimentation Tank



10.5 Secondary (Second Level) Treatment

Once most of the solids and the fat and grease have been removed, the next step is to reduce the amount of organic material in the wastewater which is associated with the BOD loading. This is typically accomplished using bacteria and protozoa that can use the organic material as food. To help in the process, the bacteria must be provided with a home in which to live and grow and sufficient oxygen to promote the breakdown of the food. There are two different ways that this can be done (Ref. 1):

1) Using fixed-film or attached growth systems like **trickling filters** (Figure 10.4), bio-towers or rotating biological contactors (Figure 10.5).

Figure 10.4 Trickling Filter

Figure 10.5 Rotating Biological Contactors

2) Suspended-growth systems include activated sludge aerated systems and lagoons where the wastewater is slowly moved through large tanks which hold millions of bacteria and protozoa that decompose the organic material (Figure 10.6).

Figure 10.6 Activated Sludge Facility

If the **activated sludge process** is designed properly, the bacteria can also be used to remove some of the nitrogen out of the water through a process known as **nitrification**. For most fixed film systems, oxygen is provided to the microorganisms through direct contact with the air, while in suspended-growth systems the oxygen is provided through aeration or mechanical mixing of the wastewater. Once the microorganisms are given sufficient time to degrade the organic material in the wastewater, the wastewater then flows over a weir into a second sedimentation tank (sometimes called a secondary clarifier) where the solids produced during the secondary treatment are allowed to settle out.

10.6 Tertiary (Third Level) Treatment

Some, but not all, wastewater treatment plants will employ a third level of treatment called **tertiary treatment**. The level of treatment will typically depend on the specific types of pollutant levels of the wastewater. For example, systems with extremely high levels of TSS may incorporate sand filtration to remove much of the residual suspended matter. Other systems may employ ponds or lagoons to achieve additional sedimentation and biological treatment. Finally, other systems may employ more sophisticated physical, biological, or chemical methods to remove additional nitrogen and phosphorus.

10.7 Fourth Level Treatment

In more rare cases, treatment plants may employ a fourth level of treatment to remove difficult to treat pollutants such as pesticides or pharmaceutical pollutants that may persist in the environment. For these types of pollutants, treatment plants may employ advanced **oxidation** with ozone followed by **adsorption** to granulated activated carbon. The oxidation tends to break down the molecules whose fragments are then adsorbed onto the carbon.

10.8 Disinfection

After removing the TSS, BOD and nutrients from the wastewater, it is necessary to disinfect the water before discharge to reduce the numbers of potential pathogens that have survived the treatment process. Common methods for **disinfection** include chlorine, sodium hypochlorite, peracetic acid, ozone, and ultraviolet light. While each method has its own advantages and disadvantages, most systems in Kentucky still employ chlorine or sodium hypochlorite as a disinfectant.

For some of the methods that add chemicals to the water (e.g., chorine and sodium hypochlorite) either as a liquid or a gas, the residual chlorine concentrations must be reduced below the regulatory limit (i.e., 0.019 mg/L in Kentucky, 7-day average, Table 3.3) before the water can be ultimately discharged. The de-chlorination process will usually involve the addition of another chemical such as sulfur dioxide (typically as a gas) which is used to neutralize the chlorine. In each case, the wastewater is routed through a contact chamber in which the dechlorinating chemical is added, and enough contact time maintained to ensure both sufficient disinfection and de-chlorination. Chapter 16 provides detailed information on disinfection and de-chlorination (Ref. 3).

10.9 Sludge Treatment and Disposal

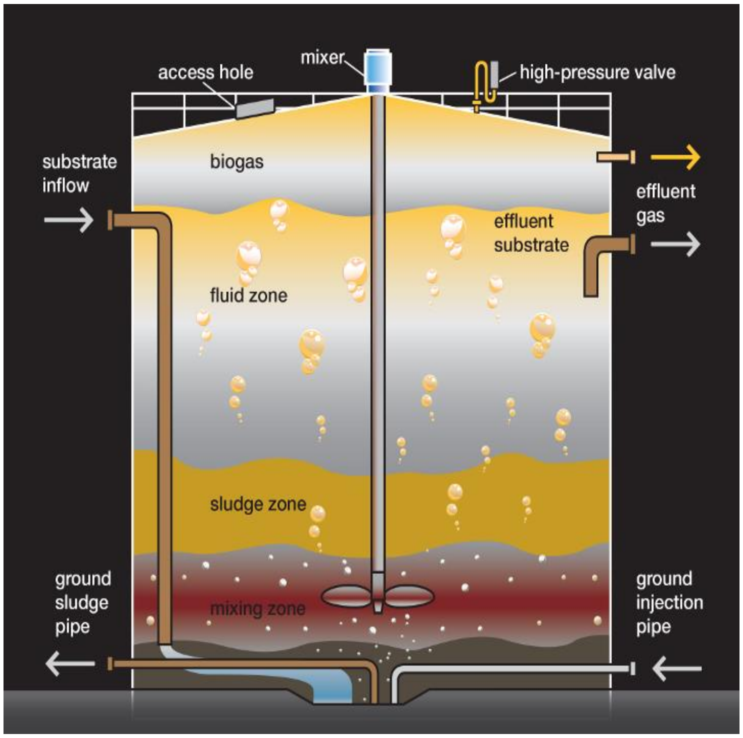
Wastewater treatment processes involve multiple steps that employ sedimentation (e.g., primary and secondary clarifiers). The sedimentation process can generate significant amounts of solids, which must be treated and disposed of in a safe manner. These settled solids (called sludge) accumulate and are separated from the liquid treatment stream and must be treated prior to disposal. This treatment is essential because raw sludge contains pathogens, is not fully digested and can be further broken-down emitting foul odors. This sludge must be treated to reduce weight, volume, and the potential health risks from the waste.

Many types of sludge are produced after going through the solids-treatment process. The three types of wastewater sludges which are characterized by their source in the liquid treatment stream are:

- Primary sludges from primary clarifiers are usually gray and slimy and may have an extremely offensive odor.
    - They can be readily digested under suitable operational conditions in aerobic and **anaerobic** digesters.
- Biological or activated sludges are generally brown and look like the texture of wool.
    - The darker the color, the more septic the condition of the sludge.
    - The lighter the color, the solids tend to settle slowly due to possibly being under-aerated.
    - The sludge when in good condition has an inoffensive odor but tends to become septic quickly. It can be readily digested alone or mixed with fresh sewage solids.
- Chemical sludges are usually black, though the surface may be red if they contain much iron. The odor may be offensive but not as bad as sludge from primary **sedimentation tanks**.
    - The sludge is slimy but will become gummy if water compounds containing iron or aluminum are present.
    - If left in the sedimentation tank, it will decompose like primary sludge but at a slower rate.
    - Large amounts of gas are emitted, and the density will increase by standing.

The most common strategies to treat sludges include anaerobic **digestion** (using bacteria that do not need oxygen), aerobic digestion (using oxygen consuming bacteria), or composting. A schematic of an anaerobic digester is provided in Figure 10.7. As can be seen from the figure, the digester is essentially a closed **reactor** in which special kinds of bacteria provide a further reduction in the organic matter in the sludge. This type of digestion results in the release of methane (CH_4) and carbon dioxide (CO_2) along with other gases such as hydrogen sulfide (H_2S). By removing the CO_2 and the H_2S, the resulting CH_4 can then be used as a renewable energy source to provide power or heat.

Figure 10.7 Diagram of an Anaerobic Digestor



While the digestion process can lead to a significant reduction in the amount of remaining organic matter, some residual sludge will remain. This remaining sludge is drawn out of the digester and thickened by passing it through a variety of dewatering equipment such as a centrifugal sludge thickener, a rotary drum sludge thickener, or a belt filter press (Figure 10.8). Depending upon the final composition of the sludge once the sludge has been thickened into fragments of sludge it can then be disposed of in landfills or used as fertilizer. However, before it can be land-farmed it must pass various tests such as a Paint Filter Test, Toxic Characteristic Leaching Procedure (TCLP) and a pathogen removal test.

Figure 10.8 Example of a Belt Filter Press

Chapter 17 provides detailed information on digestion and digesters. Chapter 18 provides detailed information on dewatered sludges.

10.10 References

1. Lin, S. (2001). Chapter 6: Wastewater Engineering. In *Water and Wastewater Calculation Manual*. pp. 1941 New York, New York: McGraw Hill.
2. Metcalf & Eddy. (2003). *Wastewater Engineering: Treatment and Resource Recovery* (4th ed.). pp. 182-186 New York, New York: McGraw Hill.
3. Mines, R., & Lackey, L. (2009). Chapter 10: Domestic Wastewater Treatment. In *Introduction to Environmental Engineering*. pp. 473-871 New York, New York: Prentice Hall.

Chapter 11

Flow Measurement

The efficiency of the wastewater treatment process will be dependent upon several factors. These factors include how long the wastewater resides in the different stages of the treatment process, how long the organic matter is in contact with the bacteria or protozoa, or how long any remaining bacteria or pathogens are in contact with the final disinfection agent. These factors will all be dependent upon the volumes of the treatment units and the amount of wastewater that is flowing into and through the plant. Because of these factors, it is important to know how much wastewater is entering the treatment plant. The measurement of this influent flow should be taken prior to all recycled water streams within the plant.

Most treatment plants will direct all wastewater entering the system through a single channel or pipe. Some type of flow measuring device is used to determine the instantaneous flowrate entering the plant. By summing the incremental flow readings over time, the total volume of water entering the plant in a given period (e.g., hours, days, weeks, or months) can then be determined. Each wastewater treatment plant is required to have a flow measuring device capable of measuring the anticipated flow, including variations within an accuracy of plus or minus ten percent (+/- 10%).

For treatment facilities of greater than 50,000 gpd capacity, an instantaneous, recording, and totalizing flow-measuring device is required. To ensure that accurate readings are being recorded, all flow meters should be recalibrated:

- On a regularly scheduled basis.
- Whenever accuracy is in question.
- Before adding chemicals to the flow.
- After any maintenance, repair, or replacement.

When reporting flows, consistency must be used when reading charts and totalizers. In other words, to get a 24-hour flow, the meter should be read at the same time each day. As a back-up, staff gauge installations are recommended so that instantaneous head (depth) readings can be used to compute a flowrate (using a rating curve). These readings are a useful check on the accuracy of the flow meters.

There are three basic ways that flows can be measured in a wastewater treatment plant:

- Volumetric measurement.
- **Open channel** flow measurement.
  - Weirs
  - Flumes
- Pipe flow measurement.

11.1 Volumetric Flow Measurements

During inspections or field studies, volumetric flow measurements might be taken using various techniques that involve measuring the length of time it takes to fill a container of known volume. There are a couple of methods by which this can be done.

One method for calculating flowrates is made by observing the difference in water levels in a sump of pit when the pumps cut on and off and calculating the volume of water contained between the high and low level of the sump. This volume will depend on the size and shape of the sump or pit. By measuring this change in level over the course of several pumping cycles and the time taken between cycles you can get a good estimate of the flow entering the treatment plant (Ref. 1).

Another method for doing a quick flow calculation in the field is to use a bucket and a stopwatch (or the timer on your cell phone). Assuming the flow is small enough so that it can be funneled through a single pour point, a bucket of known volume can be placed into the waste stream and the time recorded for how long it takes to fill to the bucket. By doing this a few times (at least 3) and averaging the results, you should be able to find a good estimate of flow entering the plant (Ref. 1).

11.2 Open Channel Flow Measurements

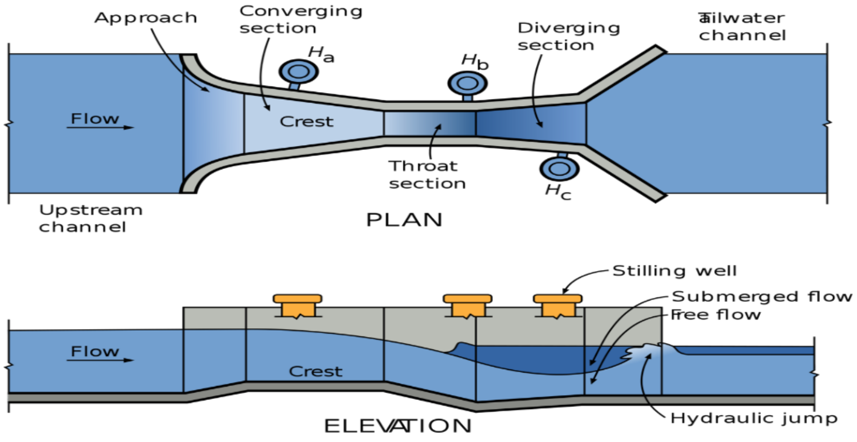
Measurement of wastewater in open channels is very common. An open channel is defined as any device that conveys water with the water surface open to the air. Measurement of flow in open channels is performed by directing the water through a section that has a known cross-sectional shape and then calculating the volume based on the height of the water flowing through the section. This is commonly done by using flumes and weirs (Ref. 2).

11.2.1 Flumes

Flumes can measure a wide range of flows and are preferable for many existing open channel applications where the available head or water level is limited. Flumes are also good at handling flows containing solids (wastewater influent) because of the high velocity through the flume tends to make it self-cleaning. The major disadvantage is that a flume installation is typically more expensive than a weir.

Flumes are designed with a known depth vs. flow relationship. The depth of water in the flume is measured at a location determined by the manufacturer. The depth of water is compared to tables that are provided with the equipment that then show the corresponding flow (Ref. 3).

Figure 11.1 Parshall Flume



The Standard conditions or requirements for Parshall flumes (Figure 11.1) are as follows:

- Flow shall be evenly distributed across the channel and should be turbulence free.
- The converging throat section of the flume should have a level bottom (see crest).
- Throat walls shall be vertical.
- The head (depth of water through the flume) measuring point shall be located upstream at 2/3 the length of the converging sidewall (stilling well H_a).
- Flow through the flume should be free from any blockages.

11.2.2 Weirs

Weirs are the simplest and least expensive type of primary measuring device. However, since the weirs force flow through a very specific area and over a plate, weirs can accumulate solids behind the plate which compromise the effectiveness of the weir as a flow measuring device. This can make them inappropriate for use in influent water streams.

The most common weirs (Figure 11.2) are:

- Contracted rectangular weirs (with end contractions).
- Suppressed rectangular weirs (without end contractions).
- Triangular weirs, also called V-Notch weirs.
- Trapezoidal weirs.

Figure 11.2 Weir Shapes

Suppressed Rectangular Weir

Contracted Rectangular Weir

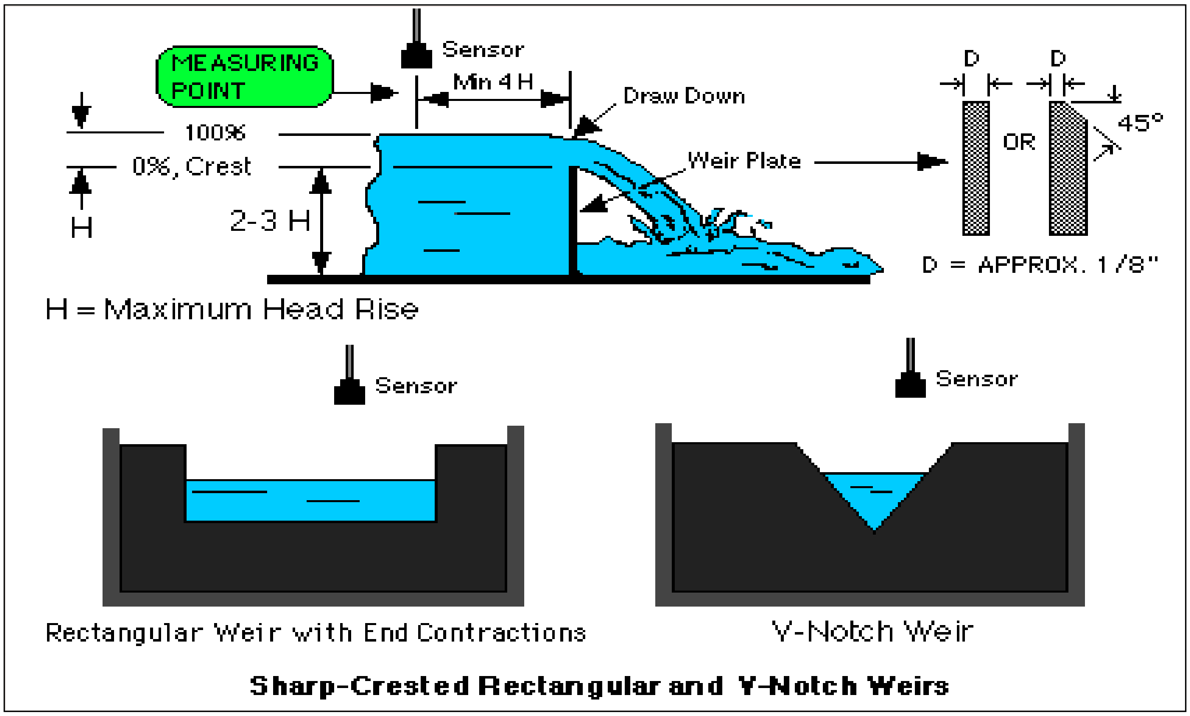
Triangular Weir

Trapezoidal Weir

While suppressed rectangular weirs are used for measuring larger flows, contracted rectangular weirs, triangular (or V-notch) weirs, and trapezoidal weirs are typically used for measuring smaller flows. In the case of the latter three, the flow reading will only be accurate if the water level is still contained within the notched section (shown in light blue in Figure 11.2).

Like flumes, each type and model of weir will come from the manufacturer with a table or chart that will provide the corresponding flow for a given depth upstream the lowest point where water is flowing over the weir (the weir plate). In some cases, the weir will have markings on it upstream of the lowest point so you can look at the weir and read the depth of the flow. Thus, by either observing or measuring the depth manually, you can determine the flow. Alternatively, some plants may have installed an electronic water depth sensor that measures the depth continuously and then sends the signal to an onsite gauge or back to a central computer room where the depth can then be converted by the computer to a digital flow reading. In either case, the flow is actually being tied back to a measured depth and a depth-flow relationship from the manufacturer (see Figure 11.3).

Figure 11.3 Calculating Flows Over Weirs



The standard conditions or requirements for Sharp-Crested Weirs are as follows:

- The weir should be installed so that it is perpendicular to the axis of flow. The weir plate should be level. The sides of rectangular contracted weirs should be truly vertical. V-notch weir angles must be cut precisely.
- The thickness of the weir crest should be less than 0.1 inch (or 1/8 inch). If the weir plate is thicker the downstream edges of the crest or notch should be relieved by chamfering at a 45° angle.
- The distance from the weir crest to the bottom of the approach channel should not be less than twice the maximum weir head and never less than one foot.
- The distance from the sides of the weir to the sides of the approach channel should be no less than twice the maximum head and never less than one foot (except for the suppressed rectangular weir).
- All the flow must pass through the weir and no leakage at the weir plate edges or bottom should be present.
- The nappe (overflow sheet of water) should touch only the upstream edges of the weir crest or notch.
- Air should circulate freely under, and on both sides of, the nappe.

11.3 Pipe Flow

In some cases, flows entering the plant may be coming through a pressurized pipeline. In this case the flow entering the plant can be measured by placing a flow meter in the pipe. While there are different kinds of in-line flow meters, magnetic meters and sonic meters are the most commonly used, most meters work similar to a Parshall Flume. That is, as the flow moves through the valve, the value will measure the drop in pressure and then convert the pressure drop to an equivalent flow based on the physical configuration and dimensions of the meter. These are not often used in wastewater conveyance.

11.4 Flow Calculations

Very often flow values are provided in units other than the ones that are needed (Ref. 4). This means that a conversion from one flow rate to another is required. Examples 11.1 and 11.2 are common conversions that will be encountered.

Example 11.1

The flow into a wastewater treatment plant is 435,000 GPD. How many MGD is this?

Solution:

Recall that GPD stands for gallons per day and MGD stands for million gallons per day.

$$435{,}000\ GPD\ x\ \frac{1\ million\ gallons}{1{,}000{,}000\ gallons} = 0.435\ MGD$$

Example 11.2

The waste sludge flow to a digester is 41 GPM. What is the flow in GPD?

Solution:

Recall that GPM stands for gallons per minute, so convert to gallons per day.

$41\ GPM\ x\ 1440 = 59{,}040\ GPD$

Where 1 *GPM* = 1440 *GPD*

11.5 References

1. Salguero, L., Deatrick, J., & Johnson, H. (2015). ***Wastewater Flow Measurement***.
2. Teledyne. (2016). ***ISCO Open Channel Flow Handbook***.
3. Open Channel Flow. **Parshall Flumes.**
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Chapter 12

Pretreatment

Pretreatment is used to remove items from the wastewater that could interfere with the treatment process, such as paper and plastic products, grit, and FOG. Typical equipment that are used to remove such items include:

- Coarse and fine screens followed by grit removal.
- Grit removal devices followed by grinders and/or comminutors.

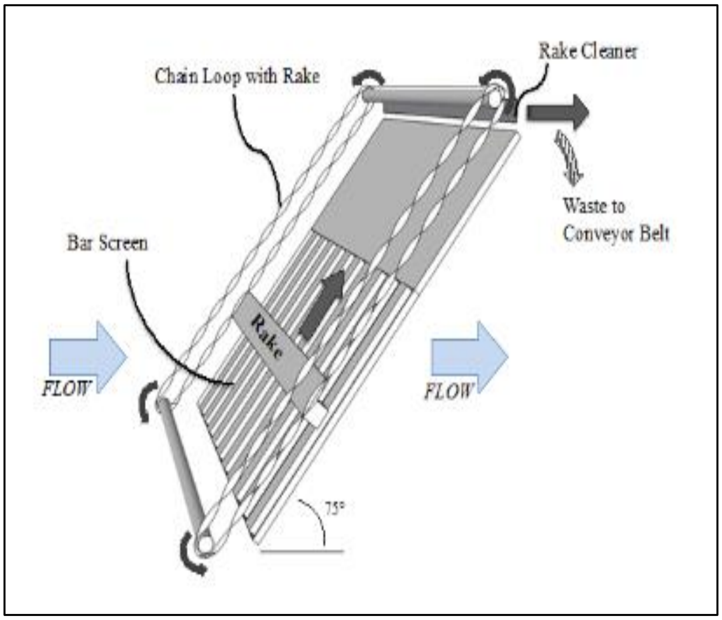
12.1 Screens

The screens found at treatment plants are used to remove trash and other large solids (e.g., wood, cloth, paper, plastics, etc.). Screening is intended to remove solid materials that could damage equipment in the plant such as pumps and valves, and materials that could reduce efficiency of the system or contaminate waterways if they pass through untreated. Screening devices may consist of parallel bars, gratings, wire mesh, or perforated slots (Ref. 1). Depending on the nature of the wastewater, a treatment plant may utilize either coarse or fine screens, or both.

12.1.1 Coarse Screens

Coarse screens have openings that range from ¼ in. to 6 in. They are designed in such a way that water and debris move through the screens without clogging them and are easy to clean. Cleaning screens can be done by hand or through mechanical means. The water should travel through the screen relatively slowly so that material can accumulate on the bars as shown in Figure 12.1 and not be forced through the screen. The screen should be placed perpendicular to the flow (Ref. 1).

Figure 12.1 Example of a Bar Screen



12.1.2 Fine Screens

Fine screens have openings that are less than ¼ in. These smaller openings are intended to capture materials that may create problems with operations such as very small pieces of plastic and other suspended solids which can't be broken down by the bacteria in the activated sludge tanks. There are several different types of fine screens - static wedge wire screens, drum screens, and step type screens (Ref. 1). The fine mesh of these types of screens needs to be inspected and cleaned regularly (typically once or twice a day depending on flow volume).

Figure 12.2 Example of a Fine Screen

12.2 Grinders/Comminutors

Grinders or comminutors are devices that are used to grind up large pieces of debris into smaller particles that can then be removed during the primary clarification process (Figure 12.3). They are equipped with a motor on the top that turns a series or pair of grinders through which the wastewater flows. Typically, these devices can be used to grind the materials roughly into particles that are ¼ to ¾ inches in size. For grinders to retain their function, they need to be properly maintained. The cutting teeth need to be inspected and sharpened or replaced regularly to allow for consistent operation.

Figure 12.3 Grinder/Comminutor

12.3 Grit Chambers

These units are designed to remove mostly inorganic material such as grit, sand and other solid material that are substantially larger and heavier than those of the organic solids that can be broken down in wastewater treatment.

Removing the grit helps to prevent damage to downstream equipment such as pumps. Grit removal also reduces the amount of volume required by subsequent sedimentation basins, thereby increasing the treatment capacity of those units.

Whatever system is used to remove grit, washing of the solids may be necessary to remove associated organic material so that potential odors from the breakdown of this organic material are not a nuisance.

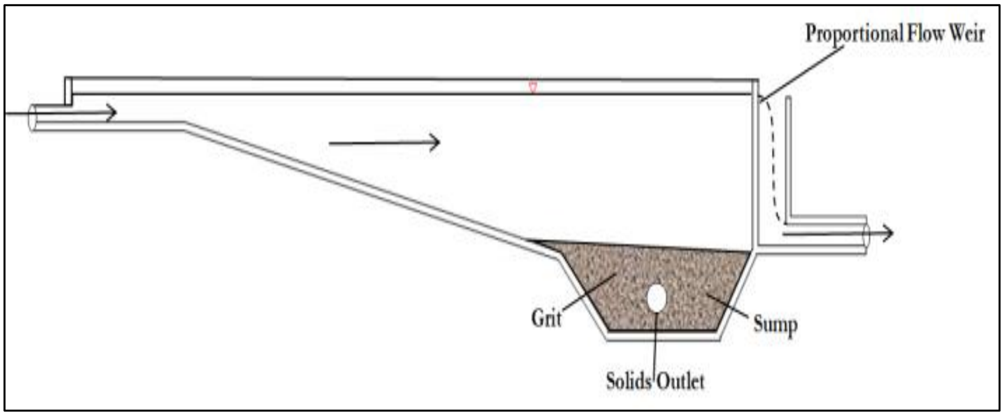
There are three general types of grit chambers as described in the next three sections:

- Horizontal flow.
- Aerated.
- Vortex.

12.3.1 Horizontal-flow channels

In many ways a horizontal grit chamber is a type of settling basin in which the velocity of the wastewater is reduced to 1-1.5 fps (feet per second) so that the grit will settle while the organic material remain in suspension (Figure 12.4). The velocity is controlled by either special influent distribution gates, dimensions of the unit, or special weir sections at the effluent end of the channel.

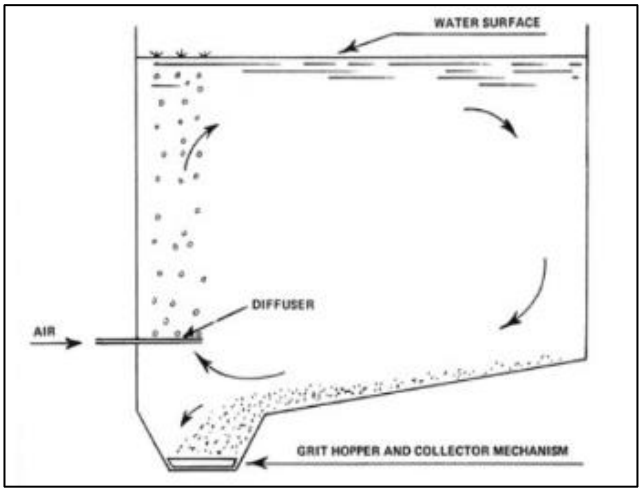
Figure 12.4 Horizontal Grit Chamber



12.3.2 Aerated Type

Although specific kinds of aerated grit chambers may vary, generally an aerated grit chamber uses injected air to help move the grit to a centralized collection chamber, shown here at the bottom of figure 12.5. By controlling the rate at which the air is injected, the operator can also keep the lighter organic matter from settling out and ensure that it passes on to the next level of treatment. Typical detention times (the amount of time the wastewater is kept or detained in the chamber) typically vary from 3 to 5 minutes at design peak hourly flows. Aeration also has the benefit of adding oxygen to the wastewater to help the breakdown of organic material by bacteria later in the treatment.

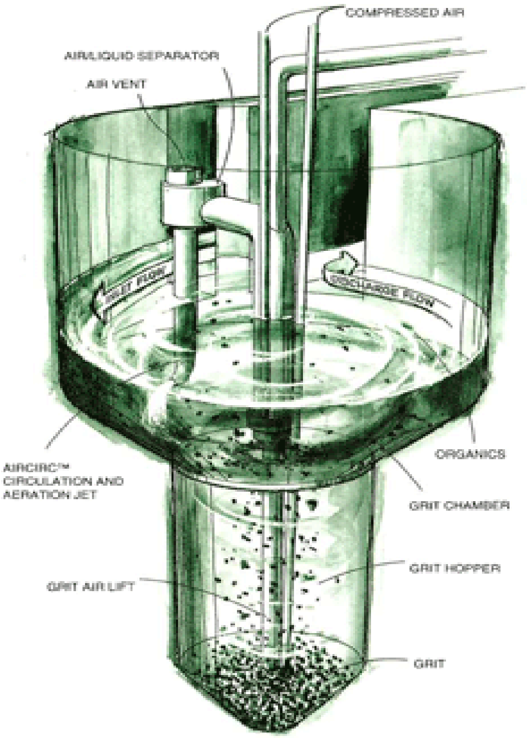
Figure 12.5 Aerated Grit Chamber



12.3.3 Vortex Type

The vortex-type of grit chamber consists of a cylindrical tank in which the flow enters from the side and then shoots around the edges creating a vortex-flow pattern similar to a whirlpool (Figure 12.6). This allows the wastewater and the lighter organic material to keep to the outside of the chamber, while the heavier grit falls to the center as a result of gravity and is collected and removed.

Figure 12.6 Vortex Type Grit Chamber



12.4 References

1. Metcalf & Eddy. (2003). Chapter 5: Physical Unit Operations. In *Wastewater Engineering: Treatment and Resource Recovery*. New York, New York: McGraw Hill.
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Chapter 13

Primary [First Level] Treatment

Primary treatment allows for the removal of large materials from the wastewater that could clog the pipes in the wastewater treatment plant, as well as for the settling out of large sludge particles to reduce the loading on the secondary treatment (Ref. 1). In most treatment plants, primary treatment removes about 60% of TSS and 35% of the BOD (Ref. 2).

13.1 Primary Clarifier

Primary clarifiers are typically built using either a circular tank design (Figure 13.1) or a rectangular tank design (Figure 13.2). In either case the purpose of a primary clarifier is to create an area of slow-moving fluid which allows the heavier solids in the wastewater to settle to the bottom of the tank as sludge, while the FOG and other floatables that were not captured by pretreatment rise to the top as scum. The sludge is removed from the bottom of the clarifier using either a large rotating scraper blade or a series of scraper blades that are attached to a drive motor. The scum is skimmed from the top into a trough while the clear water is moved onto the next stage of treatment in the plant (Ref. 3). Typical dimensions for circular and rectangular primary clarifiers are provided in Table 13.1.

Figure 13.1 Circular Primary Clarifier

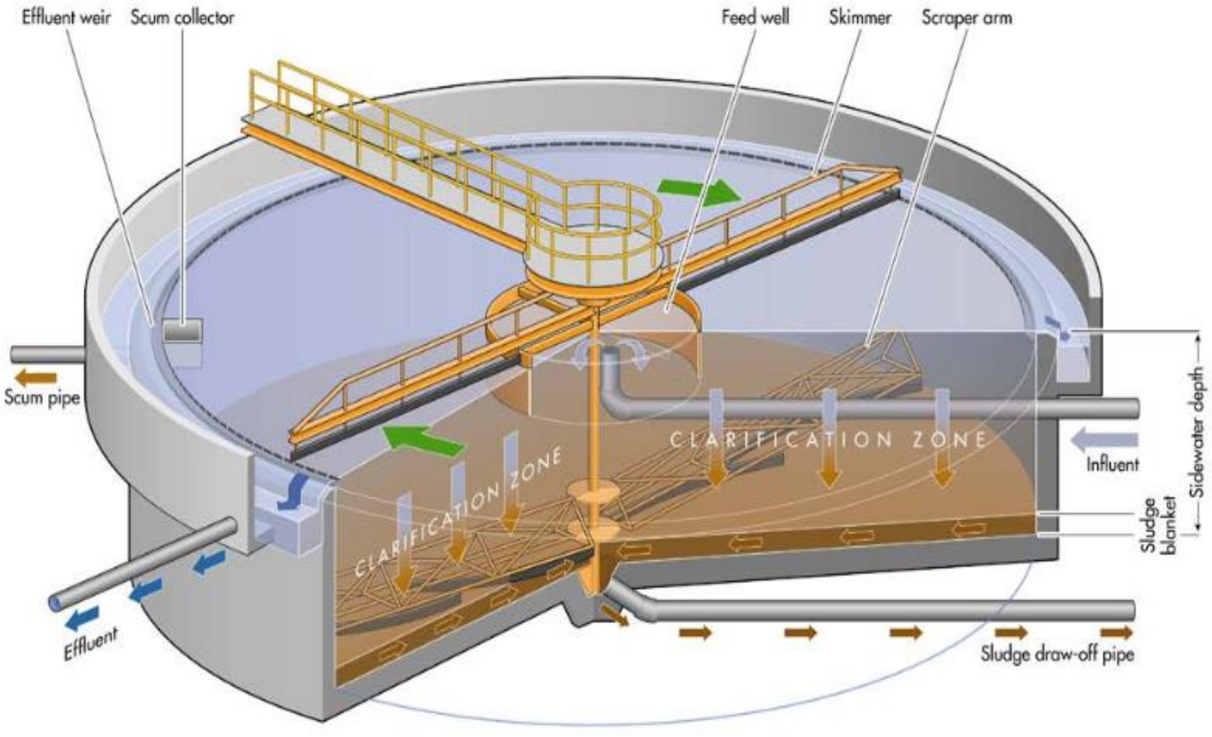


Figure 13.2 Rectangular Primary Clarifier

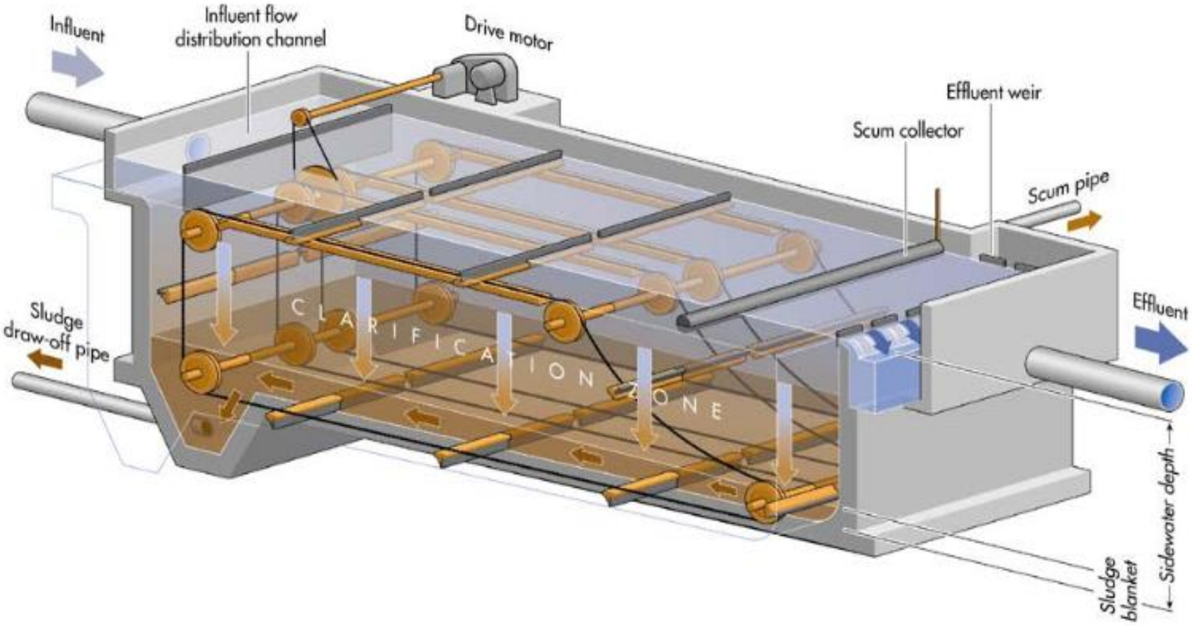


Table 13.1 Typical Dimensions for Primary Clarifiers

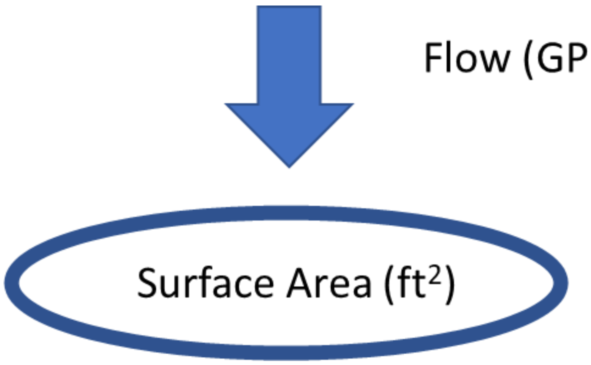
Item	Range	Typical
Circular Basin		
Depth	10 - 16 feet	14 feet
Diameter	10 - 200 feet	40 - 150 feet
Bottom Slope	¾ inch in 2 feet	
Flight Speed	0.02 - 0.05 rpm	0.03 rpm
Rectangular Basin		
Depth	10 - 16 feet	14 feet
Length	50 - 300 feet	80 - 130 feet
Width	10 - 80 feet	16 - 32 feet
Flight Speed	2 - 4 ft per minute	3 ft per minute

13.2 Operational Considerations for Primary Clarifiers

Primary clarifiers are used to remove solids and associated BOD from the wastewater that has passed through pretreatment but before it moves onto secondary treatment (Ref. 4). This is done by passing wastewater through a rectangular or circular basin where the velocity of wastewater is reduced. This slowing of the water allows particles in the wastewater to settle out of the water column (Ref. 5). The efficiency of the primary clarifier is normally determined using either the Surface Loading Rate (i.e., the flow entering the basin divided by the surface area of the basin) or by the Hydraulic Retention Time, also known as Detention Time (i.e., the volume of the basin divided by the flow entering the basin).

13.2.1 Surface Loading Rate

The hydraulic or surface loading rate (SLR) is a design value for the plant and can be a guide to how much water can be processed by each clarifier per day. Surface loading rates that are too high can lead to problems with settling, allowing solids to leave the clarifier and go downstream. Surface loading rates that are too low may lead to excess sludge build-up.



The surface loading rates may be calculated using the following equation (Ref. 6):

$$[9]\ (SLR, gpd/ft^2) = \frac{(flow, gpd)}{(clarifier\ surface\ area, ft^2)}$$

Or with the formula to calculate surface area of a circle:

$$[9]\ \ (SLR, gpd/ft^2) = \frac{(flow, gpd)}{(0.785\ x\ diameter\ x\ diameter, ft^2\ )}$$

Example 13.1

The flow to two 100 ft diameter clarifiers is 8.9 MGD. What is the surface loading rate?

Solution:

First, we need to calculate the surface area of the clarifiers. Since these are circles, recall that the area is:

$$Area\ (ft^2) = 0.785\ x\ \textit{diameter, ft}\ x\ \textit{diameter, ft}$$

Thus,

$$Surface\ Area\ for\ one\ clarifier\ (ft^2) = 0.785\ x\ 100\ ft\ x\ 100\ ft = 7{,}850\ ft^2$$

Since there are 2 clarifiers, we will need to multiply the surface area for one clarifier by 2.

$$Total\ Surface\ Area\ (ft^2) = 2\ x\ 7{,}850\ ft^2 = 15{,}700\ ft^2$$

Now, convert MGD to gpd.

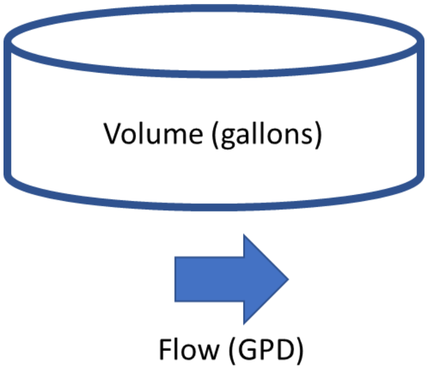
$$gallons\ per\ day = 8.9\ MGD\ x\ \frac{1{,}000{,}000\ gallons}{1\ MG} = 8{,}900{,}000\ gpd$$

Thus,

$$[9](Surface\ loading\ rate, gpd/ft^2) = \frac{8{,}900{,}000\ gpd}{15{,}700\ ft^2} = 567\ gpd/ft^2$$

13.2.2 Hydraulic Retention Time of the Primary Clarifier

The **hydraulic retention time** (HRT), also known as detention time, is simply the average time it takes for the wastewater to move through the clarifier (Ref. 7). The HRT is both a design parameter used by engineering in sizing the clarifier and an operations parameter to ensure that the wastewater spends sufficient time in the clarifier to permit proper settling of the settleable solids.



The HRT can be calculated using one of the following equations:

$$[10]\ (HRT, days) = \frac{(Tank\ Volume, MG\ )}{(Flow, MGD)}$$

If the tank volume is reported in ft^3, then HRT can be calculated using:

$$[11]\ (HRT, days) = \frac{(Tank\ Volume, ft^3\ x\ 7.48\ )}{(Flow, gpd\ )}$$

If HRT is to be reported in hours, then multiply the HRT in days by 24:

$$[11]\ (HRT, hours\ ) = \frac{(Tank\ Volume, ft^3\ x\ 7.48\ )}{(Flow, gpd)}\ x\ 24$$

Example 13.2

A clarifying tank has a volume of 30,000 ft^3. The flow through the wastewater treatment plant is 0.75 MGD. Calculate the hydraulic retention time (detention time) in the clarifying tank.

Solution:

First, convert the flow rate from million gallons a day (MGD) to gallons per day (GPD) by multiplying by 1,000,000.

$$0.75\ MGD\ x\ 1{,}000{,}000 = 750{,}000\ gpd$$

Since everything is in the correct units, the HRT can be calculated using equation 11.

$$[11]\ HRT, hrs = \frac{30{,}000\ ft^3\ x\ 7.48}{750{,}000\ gpd}\ x\ 24 = \ 7.2\ hours$$

13.2.3 TSS and BOD$_5$ Removal

The percent removal of total suspended solids (TSS) and biochemical oxygen demand (BOD) from a primary clarifier will depend directly on the hydraulic retention time or detention time of the clarifier. Typical removal efficiencies as a function of detention time are shown in Table 13.2 below. Typical detention times range from 1.5 hours to 2 hours (Ref. 8). Table 13.2 shows that detention times longer than 2 hours do not significantly increase the amount of TSS and BOD collected in the clarifier, while shorter detention times will remove less TSS and BOD leaving a greater level of these components to be treated in later parts of the system.

Table 13.2 Typical TSS and BOD Removal Percentages in Primary Clarifiers

	Detention Time, hrs					
	0.5	**1**	**1.5**	**2**	**2.5**	**3**
Percent Removal of TSS	35	47	52	56	58	61
Percent Removal of BOD	18	26	31	35	37	38

13.2.4 Typical Design Parameters for Primary Clarifiers

The typical design parameters for primary clarifiers will depend upon whether the clarifiers are followed by secondary treatment (see Table 13.3) or receive return flow from an activated sludge aeration tank (see Table 13.4).

Table 13.3 Primary Clarifiers Followed by Secondary Treatment

Parameter	Range	Typical
Detention Time, hours	1.2 - 2.5	2
Average Overflow Rate, gal/ft^2/day	800 - 1200	1000
Peak Hourly Overflow Rate, gal/ft^2/day	2000 - 3000	2500

Table 13.4 Primary Clarifiers Followed by Activated-Sludge Return

Parameter	Range	Typical
Detention Time, hours	1.2 - 2.5	2
Average Overflow Rate, gal/ft^2/day	600 - 800	700
Peak Hourly Overflow Rate, gal/ft^2/day	1200 - 1700	1500

Example 13.3

The flow to a 75 feet diameter clarifier with a 10 feet water depth is 2 MGD. What is the detention time in hours?

Solution:

First, we need to calculate the volume of wastewater in the clarifier.

$$(Volume\ of\ cylinder, ft^3) = 0.785\ \ x\ 75\ ft\ x\ 75\ ft\ x\ 10\ ft = 44{,}156.25\ ft^3$$

Next, we convert the flow from MGD to gpd.

$$Flow\ (gpd) = 2\ MGD\ x\ 1{,}000{,}000 = 2{,}000{,}000\ gpd$$

Now, we can use our equation for detention time (hours).

$$[11]\ Detention\ time, hours = \frac{44{,}156.25\ ft^3}{2{,}000{,}000\ GPD}\ x\ 7.48\ x\ 24 = 4\ hours$$

13.3 Primary Clarifier Performance

Average efficiencies in the removal of TSS and BOD in a primary clarifier were summarized in Table 13.2. Although a basin can be designed to accomplish these efficiencies using the parameters provided in Tables 13.3 and 13.4, these efficiencies can be reduced if the hydraulic retention times are decreased by short-circuiting. Short-circuiting occurs when the wastewater flows more rapidly through some parts of the basin than others or when water does not flow through parts of the basin at all, due to the presence of uneven currents though the basin (Ref. 2). Short circuiting can be caused by several factors:

- The presence of eddy currents can be formed from the momentum of the incoming fluid.
- Wind induced circulation patterns.
- Temperature induced convection currents.
- Cold or warm water induced density currents, where colder denser water moves along the bottom of the tank and warmer, less dense water moves across the top of the tank. This can occur when the temperature of the incoming wastewater is normally colder than the water in the basin (during summer) or warmer than the wastewater in the basin (during winter).

The operator should always be on the lookout for possible short-circuiting in the clarifier. This can sometimes be detected if there seems to be excessive solids flowing over the clarifier weirs. The operator can also keep an eye on the difference in temperatures between the incoming wastewater and the temperature at different depths in the basin. Temperature related short-circuiting can sometimes be controlled by using baffles in the inlet zone to force warmer water to the bottom of the basin or colder water to the top of the basin.

13.4 Sludge Removal

Over time, clarifiers will accumulate solids in the bottom of the basin. This accumulated residue is called sludge (or biosolids) (Ref. 9). Both circular and rectangular basins are equipped with mechanical devices that scrape the bottom of the basins and divert the sludge into a collection hopper where the sludge can then be pumped out of the basin (Ref. 4). The sludge is then typically pumped to a digester, drying beds, or to a de-watering facility, where it can be dewatered and then processed for disposal or land application (Ref. 10). As would be expected, the operator needs to monitor the buildup of the sludge in the clarifier to coordinate the frequency of the pumping. An excessive buildup of sludge could affect the path of the flow of wastewater through the basin, lead to short-circuiting, and affect the removal efficiency of the basin. Sludge could also be scoured and be re-suspended by water’s velocity. If the sludge becomes too old, it could become anaerobic in the bottom of the clarifier and could lead to anaerobic decomposition resulting in gas bubbles of methane, carbon dioxide, and hydrogen sulfide breaking the water surface. The release of hydrogen sulfide can be detected by the presence of a strong rotten egg.

The best way to ensure that sufficient quantities of sludge are being removed is to determine sludge blanket depth. This can be measured with either a sludge judge, sludge core taker, or sludge blanket finder. The depth of sludge that is at the bottom of a clarifier is typically less than three feet, though this will depend on how the plant is run. Over time, the operator should be able to determine the depth of sludge that is typically associated with the best level plant operation and then use this as a target when pumping sludge out of the clarifiers. When pumping sludge, it is important not only to know how many gallons pumped but the concentration of solids in the sludge. By measuring the concentration of sludge and the gallons pumped, the pounds of sludge transferred to the digester, drying bed, or de-watering facility can be determined.

$$[12]\ (Pump\ rate, gpm) = \frac{(Volume\ of\ sludge\ pumped,\ ft^3\ x\ 7.48)}{(pump\ time, \text{min})}$$

Example 13.4

Two 45 ft by 30 ft rectangular drying beds were filled with 1 ft of sludge from a clarifier in 2 hours and 10 min. What is the pump rate in gallons per minute?

Solution:

First, we can find the volume of sludge that was pumped by calculating the area of the drying beds and multiplying by the depth of sludge placed in the bed.

$$Volume\ of\ sludge\ on\ drying\ bed, ft^3 = 45\ ft\ x\ 30\ ft\ x\ 1\ ft = 1{,}350\ ft^3$$

Because two (2) 45 ft by 30 ft drying beds were filled we need to multiply the resulting volume by two.

$$Volume\ of\ sludge\ pumped = number\ of\ drying\ beds\ x\ volume\ of\ sludge\ per\ drying\ bed$$

Thus,

$$Volume\ of\ sludge\ pumped = 2\ x\ 1{,}350\ ft^3 = \ 2{,}700\ ft^3$$

The time it took to pump the sludge into the drying beds was 2 hours and 10 minutes. To convert this total time to minutes we do the following:

$$Time\ (minutes) = 2hr\ x\ 60 + 10min = 130\ min$$

Now we have all the information we need to calculate the pump rate.

$$[12]\ pump\ rate, gpm = \frac{2{,}700\ ft^3\ x\ 7.48}{130\ min} = 155\ gpm$$

13.5 Pumped Sludge

The typical characteristics of the sludge (or biosolids) that accumulates in a primary clarifier are summarized in Table 13.5.

Table 13.5 Physical Characteristics of Sludge Produced from Primary Clarifiers

Specific Gravity of Solids	Specific Gravity of Sludge	Dry Solids, lbs/gal Range	Dry Solids, lbs/gal Typical	Solids Conc. % Dry solids Range	Solids Conc. % Dry solids Typical
1.4	1.02	0.9 - 1.4	1.25	5-9	6

If we know the concentration of solids in our sludge from the clarifier, then we can calculate the pounds (lbs) of solids being pumped using an application of equation [2] as follows:

$$[2]\ (solids\ pumped, lbs) = (sludge\ pump\ volume, MG\ x\ 8.34\ x\ concentration, \frac{mg}{L})$$

Example 13.5

How many pounds of sludge will be loaded onto two rectangular 50 ft by 25 ft drying beds, if the sludge is 1.5 ft deep and has a solids concentration of 22,500 mg/L?

Solution:

First, we need to find the volume of sludge being pumped:

$$(Volume\ on\ drying\ bed, ft^3) = 50\ ft\ x\ 25\ ft\ x\ 1.5\ ft = 1{,}875\ ft^3$$

Since there are 2 drying beds:

$$(Total\ sludge\ volume, ft^3) = 2\ x\ 1{,}875 ft^3 = 3{,}750\ ft^3$$

To use our equation, we need to calculate the sludge volume in MG (million gallons per day):

$$(Total\ sludge\ volume, MG) = 3{,}750\ ft^3\ x\ 7.48\ x\ \frac{1\ MG}{1{,}000{,}000\ gal} = 0.02805\ MG$$

Now we can use our equation to calculate the weight of the sludge:

$$[1]\ Solids\ pumped, lbs = 0.02805\ MG\ x\ 8.34\ x\ 22{,}500\ mg/L = 5{,}264\ lbs$$

13.6 Operational Guide to Primary Clarifiers

The four main keys to ensuring the proper operation of a primary clarifier are (Ref. 11):

1) Ensure an appropriate surface loading rate (Table 3.1) by maintaining a fairly uniform and consistent flowrate to the basin.
    - Is the daily influent flowrate consistent in order to minimize potential hydraulic surges?
    - Is there excessive scum or grease on the water surface?
2) Ensure an appropriate hydraulic retention time (Table 3.2) by looking for evidence of short-circuiting and making necessary operation changes such as baffle placement.
    - Are solids floating on the surface?
    - Are solids escaping over the overflow weirs?
3) Ensure proper sludge removal to prevent the formation of anaerobic conditions.
    - Are any gas bubbles appearing on the water surfaces?
    - What is the sludge depth?
4) Ensure that the equipment is operating properly by conducting regular preventive maintenance:
    - Check for broken scrapers and or flights.
    - Are the speed reducer gears moving freely?
    - Check for blocked weirs.
    - Check that the rakes are in good condition and working properly.
    - Check sludge pumps are operating properly.

13.7 References

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13.8 Other Resources

MEDEP. ***Troubleshooting Activated Sludge Processes.***

Chapter 14

Secondary [Second Level] Treatment

The purpose of secondary treatment is to remove as much of the remaining BOD from wastewater as possible. Secondary treatment takes advantage of microorganisms that break down the organic material in wastewater to use as a food and energy source, very similar to the way humans and animals need food to survive. Most of these microorganisms also need oxygen to convert food into energy and grow.

The bacteria develop a sticky layer of slime around the cell wall that enables them to clump together to form bio-solids or sludge that is then separated from the liquid phase. The successful removal of wastes from the water depends on how efficiently the bacteria consume the organic material and on the ability of the bacteria to stick together, form **floc**, and settle out of the bulk fluid. The **flocculation** (clumping) characteristics of the microorganisms in activated sludge enable them to amass to form solid masses large enough to settle to the bottom of the settling basin. As the flocculation characteristics of the sludge improves, so is the improved settling and improved wastewater treatment. The flocculation process can be assisted by adding different types of compounds or polymers to the wastewater which can then help the particles stick together through a process called **coagulation.**

Historically two major different types of systems have been developed as secondary treatments:

1) Suspended growth systems where waste flows around and through free-floating microorganisms in a large tank where oxygen us pumped into the water and gathers into biological flocs that settle out of the wastewater. This process is called activated sludge.

2) Fixed-film or attached systems where the microorganisms grow on solid media (e.g., rocks, redwood, plastic surfaces) and sewage is then passed over them. Examples of fixed-film systems include trickling filters, bio-towers, roughing filters, or rotating biological contactors (RBC).

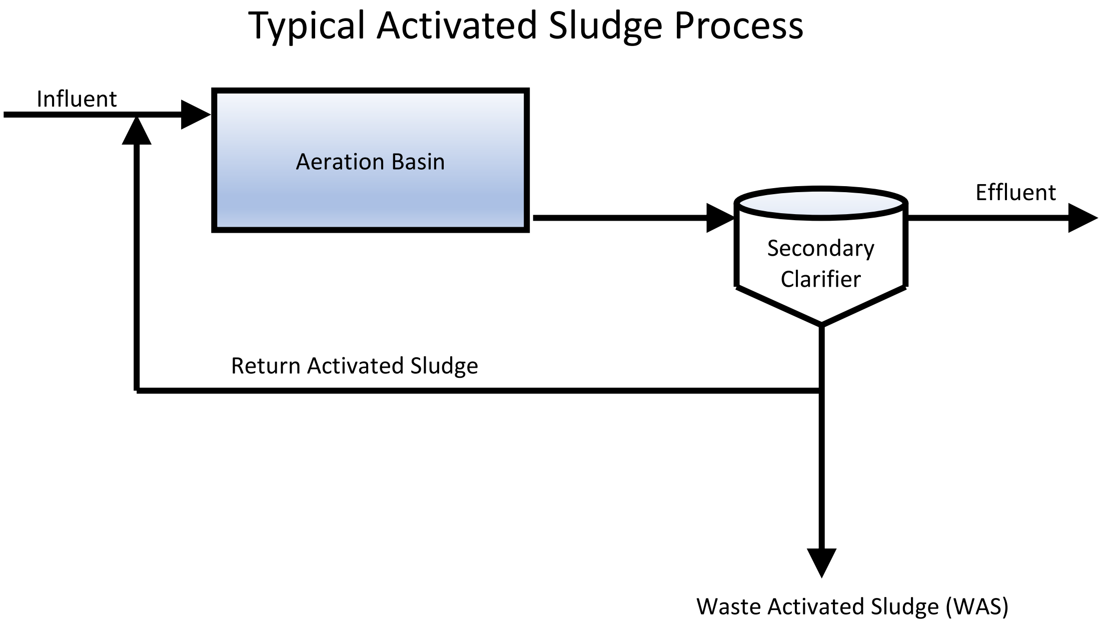
14.1 Activated Sludge Process

When wastewater enters a sewage treatment plant, it brings with it both a significant amount of organic waste material (e.g., BOD) as well as a wide range of microorganisms. The activated sludge process uses those microorganisms as well as those in **return activated sludge** (RAS) to break down and consume the organic matter, thereby reducing the BOD load. This process requires a hospitable environment, with enough oxygen in which the microorganisms can grow and reproduce. In the activated sludge process, this environment is accomplished using an **aeration basin** (Figure 14.1).

Figure 14.1 Example of an Aeration Basin in an Activated Sludge Process

Once wastewater enters the aeration basin, solids are kept in suspension by pumping air continually into the basin. Aeration promotes mixing of the microorganisms with the wastewater so that they have a greater opportunity to come into contact with each other. The higher concentration of oxygen allows the microorganism to metabolize the organic material. When wastewater leaves the aeration basin, the liquid moves to the secondary clarifier where the solids can settle out of the liquid. Some of these solids are typically recycled back to the front of the aeration basin as return activated sludge (RAS) while the **waste activated sludge (WAS)** is diverted or wasted to a digester or some type of dewatering facility. A schematic of a typical activated sludge process is shown in Figure 14.2.

Figure 14.2 Schematic of a Typical Activated Sludge Process



The flow coming into the aeration basin is called the influent, while the flow leaving the basin is called the effluent**.** Under normal operating conditions the influent flow should equal the effluent flow. The contents of the aeration basin are commonly called an activated sludge because the microorganisms are primed and ready, or ‘activated’, to break down the organic matter (Ref. 1). Activated sludge is also referred to as **mixed liquor** because it contains a mixture of the organic material in the wastewater and the accompanying microorganisms. When the mixed liquor is passed on to a secondary clarifier, some of the associated solids settle out as sludge. Some sludge is returned to the aeration tanks as return activated sludge (RAS) while the portion of it that is wasted is called waste activated sludge (WAS).

As was introduced earlier in Chapter 5, equations [1] and [2] are used to determine the mass or weight of pollutant loading into, or residing in, an aeration basin.

$$[1](\,Pollutant\ load, \frac{lbs}{day}) = (Flow, MGD)\ x\ 8.34\ x\ (Pollutant\ conconcentration, \frac{mg}{L})$$

Example 14.1

A TSS sample of 278 mg/L was collected from the influent to an aeration basin with a flowrate of 1,042 gpm. What was the total daily load, in lbs/day of suspended solids to the aeration basin?

Solution:

First, convert the flow of 1,042 gpm to a flow of MGD.

$$(Flow, MGD) = \frac{1{,}042\ gpm}{1{,}000{,}000}\ x\ \ 60\ x\ 24 =\ 1.50\ MGD$$

Using equation [1],

$$(Load, lbs/day) =\ 1.50\ MGD\ x\ 8.34\ x\ 278\ \ mg/L =\ 3{,}478\ lbs/day$$

If the actual amount in pounds rather than pounds per day needs to be calculated, a variation of equation [1] can be used. The equation [2] is the same except rather than flow in MGD, the volume of the tank in million gallons (MG) is used. This distinction will be introduced again when **mean cell residence time** (MCRT), **sludge age**, is covered.

$$[2]\ (lbs\ of\ constituent) = (Volume, MG)\ x\ 8.34\ x\ (Concentration, mg/L)$$

Example 14.2

A TSS sample of 278 mg/L was collected from an aeration basin with a volume of 70,000 ft^3. What is the total mass of TSS in lbs in the aeration basin?

Solution:

First, convert the volume of 70,000 ft^3 into MG.

$$(Volume, MG) = 70{,}000\ ft^3 x\ 7.48 = 0.524\ MG$$

Using equation [2],

$$(Load, lbs) = 0.524\ MG\ x\ 8.34\ x\ 278\ mg/L = 1{,}214.9\ lbs$$

14.2 Different Types of Activated Sludge Processes

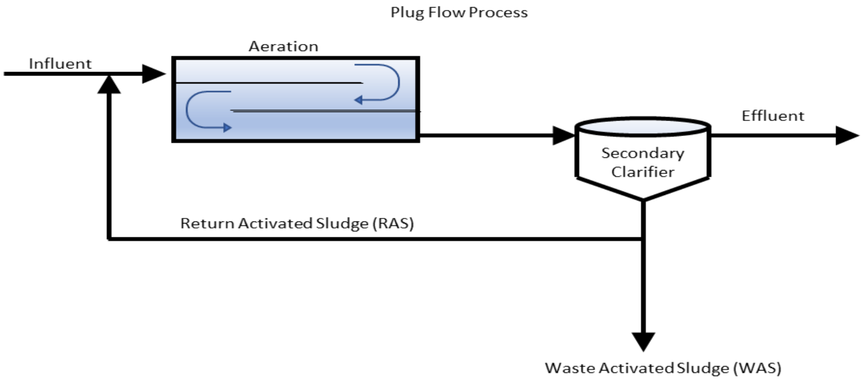
Examples of activated sludge treatment processes include:

- Conventional Plug Flow (Figure 14.3).
- **Extended Aeration** (Figure 14.4).
- Step Feed (Figure 14.5).
- Contact Stabilization (Figure 14.6).
- Complete Mix (Figure 14.7).
- Sequencing Batch Reactors (Figure 14.8).

14.2.1 Conventional Plug Flow Reactor

In a conventional plug flow activated sludge process, the influent and return activated sludge (RAS) are mixed together and enter at the beginning of an aeration tank (definition of plug flow). The contents travel through the tank at a constant rate (velocity) to the point of discharge. After discharge from the aeration basin the water flows into a secondary clarifier. The part of the sludge from the clarifier that is pumped back to the beginning of the tank is the return activated sludge (RAS) and the wasted activated sludge (WAS) is pumped to a digester and thickener for final disposal. Conventional plug flow reactors will have a high length-to-width ratio as shown in Figure 14.3. The sludge age is usually best from 3 to 15 days (Ref. 2).

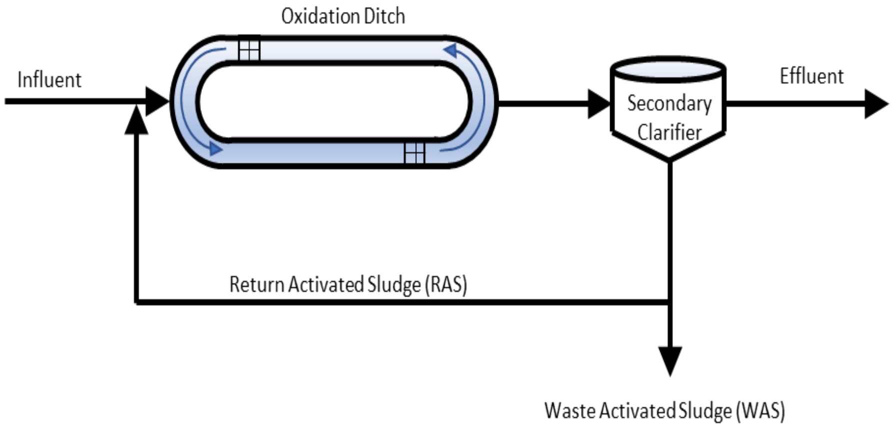
Figure 14.3 Conventional Plug Flow Activated Sludge Treatment



14.2.2 Extended Aeration

An extended aeration process is similar to a conventional plug flow reactor in that it uses plug flow hydraulics (influent and return activated sludge are mixed before flowing into the aeration tank), but the system is designed with larger aeration tanks to provide longer hydraulic retention times (e.g., 15 to 30 days). This results in a higher pollutant removal efficiency and less waste sludge. An oxidation ditch, as an example of an extended aeration process, is shown in Figure 14.4. An advantage of an oxidation ditch is that the levels of oxygen can be controlled to allow for biological removal of nitrogen and phosphorus.

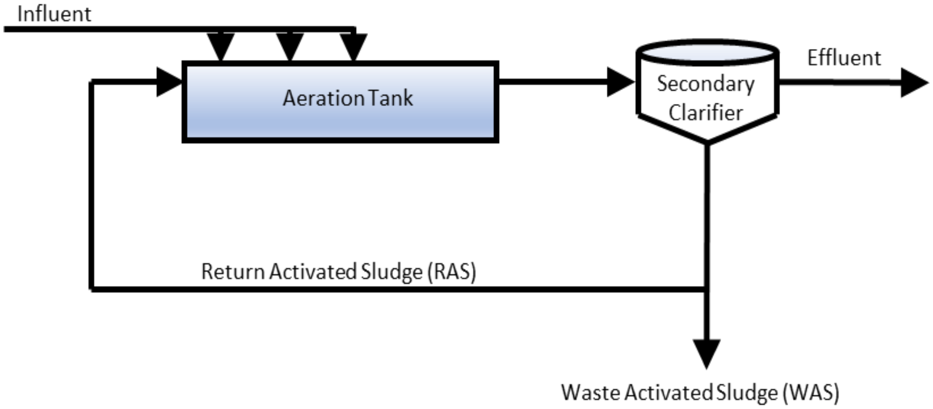
Figure 14.4 Extended Aeration Activated Sludge Treatment



14.2.3 Step Feed Aeration

A step feed process is very similar to a conventional plug flow design except that the influent is injected into the aeration tank at multiple points as shown below in Figure 14.5. This design distributes the organic load throughout the process and balances the oxygen uptake throughout the length of the system. This type of design also allows for better control in systems that may experience frequent shock loads to the system and typically produces a lower **mixed liquor suspended solids (MLSS)** load to the secondary clarifier.

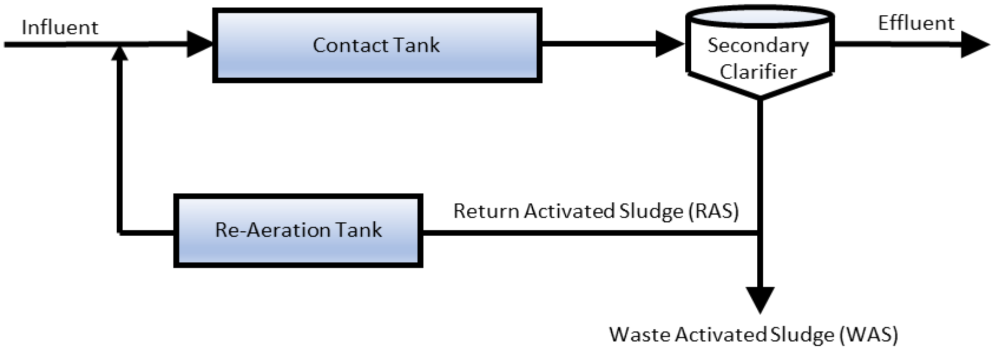
Figure 14.5 Step Feed Activated Sludge Process



14.2.4 Contact Stabilization

A contact stabilization system (Figure 14.6) uses two aeration basins (an initial contact basin and a second re-aeration or stabilization basin) in which the second basin is used to re-aerate and stabilize the return activated sludge (RAS) using a much longer detention time of between 4-6 hours, compared to about 1 hour in the primary contact basin. The main advantage of the contact stabilization process is that it requires less total volume than a traditional process and it tends to reduce the potential loss of MLSS through washout. Unfortunately, it can sometimes be more difficult to achieve more strict effluent limits using this system.

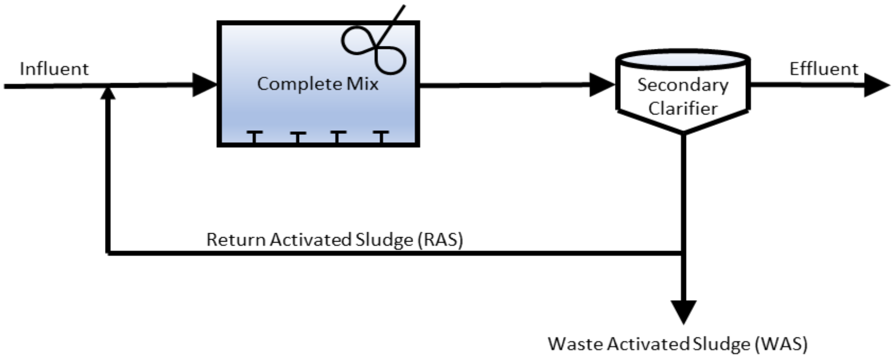
Figure 14.6 Contact Stabilization Activated Sludge Process



14.2.5 Complete Mix Reactor

In a complete mix treatment process (Figure 14.7), the characteristics of the microorganisms are similar throughout the aeration basin. Because the length to width ratio is small, as compared to a more conventional plug flow reactor, the tank contents are identical throughout the basin due to mixing. As a result, there is a very low level of food available at any time to a large mass of microorganisms. This low food to microorganism ratio is an advantage in handling surges in organic loadings without producing a change in effluent quality. A disadvantage of this system is that the lower level of available food makes it more prone to the growth of filamentous bacteria that can cause sludge bulking problems. **Bulking sludge** occurs when the sludge fails to separate out in the sedimentation tanks. The bulking of sludge decreases the efficiency of the treatment process by reducing the amount of sludge that settles.

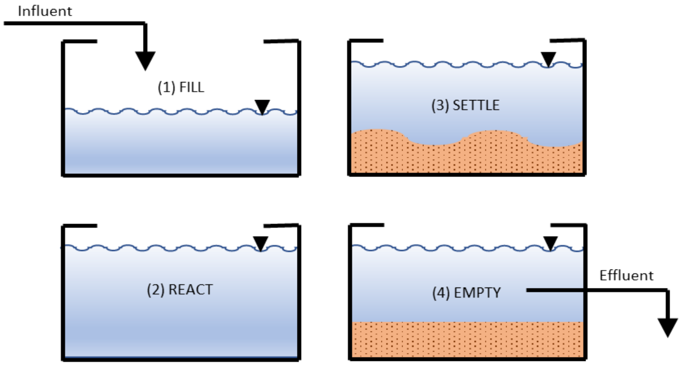
Figure 14.7 Complete Mix Activated Sludge Process



14.2.6 Sequencing Batch Reactor

In a sequencing batch reactor (Figure 14.8), the wastewater is continually diverted into a series of basins in which the treatment is done in batches. Once a basin is filled, it is aerated to accomplish the biodegradation of the organic waste and then the sludge is allowed to settle before the residual water is then decanted from the top of the basin. Once this process is completed, the basin is refilled, and the process is repeated. Note: This configuration of treatment units works well with smaller, intermittent flows of wastewater.

Figure 14.8 Sequencing Batch Reactor Activated Sludge Process



14.3 Microorganisms in Activated Sludge

In general, there are three types of microorganisms in activated sludge: bacteria, protozoa, and metazoa. In addition, you may also find algae and fungi in sludge as well, although algae are more common in lagoon systems. The presence of large amounts of fungi in activated sludge usually means that system has a lower-than-normal pH and/or the sludge is old.

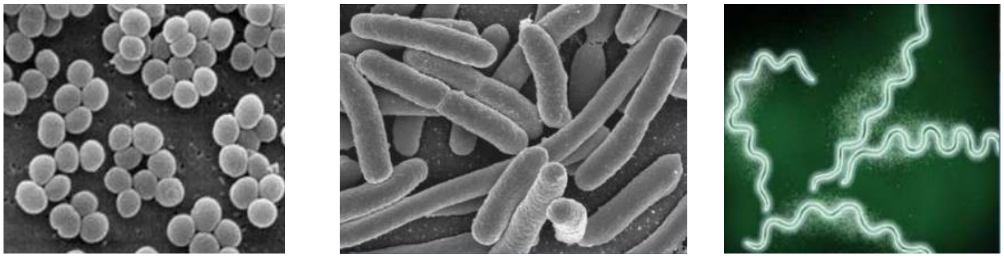
14.3.1 Bacteria

Bacteria are small, simple, one-celled organisms that make up approximately 95% of activated sludge microorganisms. Unlike plants and animals that can be classified and named based on anatomical differences, bacteria are classified by other criteria as listed below.

- Shape
    - *Coccus* – spherical (Figure 14.9 (a)).
    - *Bacillus* – rod-shaped species are important for floc formation (Figure 14.9 (b)).
    - *Spirillum* – spiral or corkscrew shaped (Figure 14.9 (c)).
- Carbon and Energy Source
    - *Heterotrophs* – derive cellular carbon from organic carbon.
    - *Autotrophs* – derive cell carbon from carbon dioxide.
- Oxygen Dependency
    - *Aerobic bacteria* – require oxygen to survive.
    - ***Anaerobic bacteria*** – do not require oxygen to survive (oxygen is toxic).
    - ***Facultative bacteria*** – prefer oxygen but can survive without it.
- Temperature Dependency (Metcalf and Eddy, 2003)

- *Psychrophilic* – cold loving, active range: 10°-30°C, optimum 12°-18°C.
- *Mesophilic* – moderate loving, active range: 20°-50°C; optimum 25°-40°C.
- *Thermophilic* – heat loving, active range: 35°-75°C; optimum 55°-65°C.

Figure 14.9 Different Bacteria Types Classified by Shape



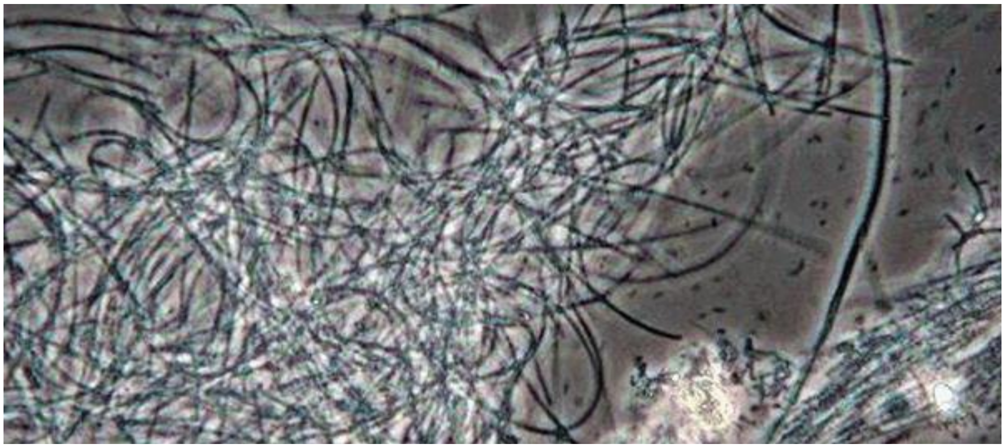
(a) coccus bacteria (b) bacillus bacteria (c) spirillum bacteria

As an operator, you will need to be on the look-out for the emergence of an over-growth of filamentous bacteria (Figure 14.10). Filamentation involves the abnormal growth of some bacteria in which the cells do not separate after division but elongate and grow into long thread-like strands. While some filamentous bacteria in the sludge can help with floc formation, excessive amounts can cause problems with optimal sludge settling due to bulking and foaming.

Filamentation can normally occur when:

- The aeration tank has a low dissolved oxygen concentration.
- The ratio of the food (i.e., BOD in wastewater) to the microorganisms is low.
- The pH is too low.
- The wastewater contains toxic chemicals.
- The wastewater has become septic. Septic wastewater is usually defined as anaerobic wastewater.
- The wastewater has excessive amounts of grease and oil.
- The wastewater is colder than normal.

Figure 14.10 Picture of Filamentous Bacteria



14.3.2 Protozoa

Protozoa are larger than bacteria and make up about 4% of the microorganisms in activated sludge. They can be divided into three main groups (Figure 14.11):

- Amoebae- single-celled animal that moves by extending fingerlike projections.
    - Normally present only in very young sludge.
- Flagellates- organism that uses long, tapering, hair like appendages to move.
    - Possess a whip like structure that helps them move through the water.
    - Feed primarily on soluble organic nutrients.
- Ciliates- protozoans characterized by the presence of hair-like cilia.
    - Feed mostly on bacteria, algae, and yeast.
    - Free-swimming ciliates.
    - Crawling ciliates.
    - Stalked ciliates.

Figure 14.11 Different types of protozoa

(a) Amoebae (b) Flagellates (c) Ciliates

14.3.3 Metazoa

Metazoa are multi-cellular organisms that make up about 1% of microorganisms in sludge. They are classified as animals. The three most common metazoa found in an activated sludge treatment system are:

- Rotifers (Figure 14.12(a)).
    - Remove leftover bacteria, algae, or smaller protozoa.
    - Dead rotifers indicate toxic conditions in the activated sludge.
- Nematodes (“worms”) (Figure 14.12(b)).
    - Feed on bacteria, fungi, and small protozoa.
- Tardigrades (“water bears”) (Figure 14.12(c)).
    - Can survive environmental extremes and toxic sensitivity.

Figure 14.12 Different types of metazoa

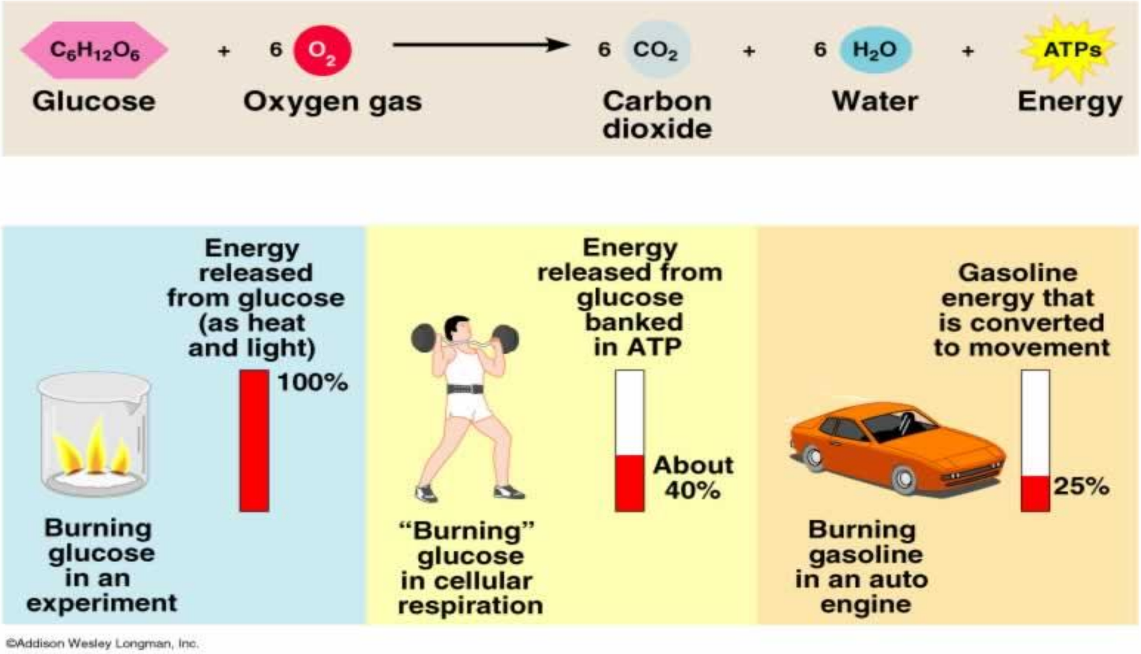
(a) Rotifers (b) Nematodes (c) Tardigrades

14.4 Role of Bacteria in the Activated Sludge Process

Wastewater treatment can be described as a biological treatment in that it uses activated sludge. Activated sludge occurs when a mixture of microorganisms, primarily bacteria, held in open concrete tanks or reactors are brought in contact with the organic material in the influent (which is food for the microorganisms). The bacteria are "activated" by providing an ideal growth environment and oxygen, which is pumped into the tanks through an aeration system. Microorganisms use the organic matter (which is quantified by BOD_5 in wastewater) for raw materials and as a source of energy needed to produce new cells, just like we use food to grow and survive.

Aerobic bacteria, as do nearly all living organisms that require oxygen, use glucose (a sugar) to make energy (as stored in a molecule called adenosine triphosphate ATP) and produce carbon dioxide and water as seen in Figure 14.13.

Figure 14.13 How Aerobic Bacteria Make Energy



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14.5 Factors That Affect the Growth of Bacteria

New bacterial cells are produced by cell division. Bacteria absorb and break down organic matter for use in making new cells and cellular structures and for use in converting and storing energy through a process called cellular metabolism. Metabolism involves a set of chemical reactions that occur inside the cell to maintain life. For the bacteria to be able to grow properly in the aeration basin, several different conditions or factors must be monitored and controlled. Some of these include:

- The amount of food coming into the basin.

- The amount of flow coming into the basin.
- The amount of oxygen diffused or mixed into the aeration basin.
- The temperature of the activated sludge.
- The pH of the wastewater and activated sludge.
- The balance of nutrients within the wastewater.
- The presence or absence of toxins in the wastewater.

14.5.1 Food

Food for the bacteria in the aeration tank is provided by organic material in wastewater flowing into the basin. The amount of food available for bacteria is normally measured indirectly as BOD_5. This is the amount of oxygen needed to break down the food over five days. By measuring the amount of BOD_5 entering the aeration basin, the operator can track how much food is available for the bacteria. By measuring the amount of BOD_5 leaving the aeration basin, the operator can determine how much BOD_5 has been consumed.

14.5.2 Flow

The amount of flow that enters the aeration basin must be controlled so that the bacteria in the basin have enough time to consume the incoming food and for sludge to settle properly in the secondary clarifier. If the flow rate is too high the bacteria will not have enough time to properly treat the wastewater. If the flow rate is excessively high, due to an influx of inflow and infiltration into the collection system which can sometimes happen after storm events, some of the bacteria can be flushed out of the plant through the secondary clarifier. This reduces the bacterial population available to break down BOD into CO_2 and water. If the flow is too low, the detention time may become too long, and part of the basin may become anaerobic and turn septic. In addition, filamentous bacteria may start to increase in number and affect sludge settling later in the system.

14.5.3 Dissolved Oxygen

Dissolved oxygen (DO) is needed in an activated sludge plant to allow microorganisms, mainly bacteria, to degrade BOD_5. If too little oxygen is supplied, the bacteria on the outer edges of a floc particle will use the available oxygen and the bacteria in the center of the floc particle will die due to lack of oxygen. This can cause the particles of floc to fall apart. The breakdown of floc can lead to poor settling and can create a cloudy effluent due to the presence of elevated concentrations of TSS. For optimal growth, it is important that the operator makes sure there is sufficient oxygen in the aeration basin to support the maintenance and growth of bacteria. This will normally require the oxygen concentrations to remain between 2.0 to 5.0 mg/L. In most systems, oxygen probes in the aeration basin are used to provide a continuous oxygen reading, which is then relayed back to the control room. For systems without such technology, the operator will have to check the oxygen levels using a hand-held oxygen meter. When sufficient oxygen is provided, the process should not have an unpleasant odor.

14.5.4 Temperature

Temperature controls the rates of both biological and chemical reactions. Both types of reactions will increase as temperature increases. Cold temperatures affect microorganisms by slowing down their metabolism. In fact, cellular metabolism will drop by one half for a 10°C drop in temperature (Ref. 3). Low temperatures do not kill bacteria, they often survive temperatures below freezing, but their growth and reproduction will slow down significantly when temperatures drop below a certain point.

As with the other environmental variables pH, DO, etc., there is no single temperature at which all microorganisms thrive. Bacteria are usually grouped based on their tolerance for heat and cold. However, in practice, the range of water temperatures in activated sludge processes do not vary much beyond the mesophilic range.

Table 14.1 Temperature Classification of Microorganisms

Bacteria	Meaning	Normal Range, °C (°F)	Optimum Range, °C (°F)
Psychrophilic	“cold loving”	10 - 30 (50 - 86)	12 - 18 (54 - 64)
Mesophilic	“moderate loving”	20 - 50 (68 - 122)	25 - 40 (77 - 104)
Thermophilic	“hot loving”	35 - 75 (95 - 167)	55 - 65 (131 - 149)

Cold water holds more oxygen than warm water. As the temperature of the wastewater increases, the activity of the microorganisms increases, but the amount of oxygen available decreases. However, as noted previously, activated sludge process introduce additional oxygen into the treatment process through mechanical aeration to maintain a proper balance (i.e., between 2.0 to 5.0 mg/L).

During elevated temperatures in the summer, a lower concentration of microorganisms (MLVSS) is needed to degrade and stabilize the BOD_5. During colder temperatures in the winter, a higher concentration of microorganisms (MLVSS) is needed to degrade and stabilize the same amount of BOD_5. This is because the bacteria are either working more efficiently in warmer water or less efficiently in colder water.

14.5.5 pH

Biological and chemical reactions are also affected by pH. Most microorganisms can survive within a pH range of 6.0 to 9.0, although the optimal range for most bacteria is between 6.8 to 7.2. Acidic (low pH) or basic (high pH) conditions can affect both microorganism growth and survival in negative ways, which impacts the treatment of wastewater. For example, more acidic conditions in wastewater promote the growth of fungi which do not settle very well and thus can cause serious operational problems at the plant. As a result, operators should measure both influent pH and aeration basin pH to ensure the plant continues to run efficiently.

14.5.6 Nutrient Balance

In addition to needing a food that contains carbon, microorganisms need nutrients such as nitrogen and phosphorus to survive and remain active. These nutrients are naturally provided in the wastewater, but it is important to be aware of the amount of these entering the system to ensure that the microorganisms have enough to survive and grow. Thus, operators must keep a watch on the nutrient balance in the system.

The relative ratios of carbon/nitrogen/phosphorus for ideal biological stabilization of organic matter under aerobic conditions should typically be in the range of 100:10:1 to 100:5:1 (Ref. 4).

Another way of viewing this nutrient balance is to consider the BOD_5 as the carbon source, so that for every 100 ppm of BOD_5 to be removed, there would have to be 5 ppm of nitrogen and 1 ppm of phosphorus available for cell growth, reproduction, and energy production. As long of the units of measurement between the BOD_5, nitrogen and phosphorus are the same, the ratio will be consistent. If a nutrient deficiency exists, the biological process to remove BOD could be less efficient. If there is a nutrient imbalance (e.g., too much or too little nitrogen or phosphorus), the sludge will fail to settle properly in secondary clarifiers. A nutrient imbalance is normally caused either by the addition of industrial wastewater to domestic flows or excessive inflows and infiltration into the collection system.

14.5.7 Toxic Pollutants

Toxic chemicals are chemical or biological products that are harmful to organisms. Incoming wastewater to a treatment plant may occasionally contain materials and compounds that are toxic to the microorganisms in the aeration basin. The Environmental Protection Agency has identified 129 priority pollutants that have been grouped into 65 classes that are regulated by different discharge standards. Several of these compounds have been found to be toxic to microorganisms in wastewater treatment at relatively low concentrations (Ref. 5) . Some of the primary metal toxins of concern include:

- Cadmium (Cd)
- Chromium (Cr)
- Copper (Cu)
- Lead (Pb),
- Nickel (Ni)
- Zinc (Zn)

Other pollutants such as herbicides, pesticides, and synthetic chemicals also have the capability to inhibit or kill the bacteria needed to treat wastewater. In some cases, the presence of quaternary disinfectants, typically used in schools, hospitals, and meat plants can kill off microorganisms in the wastewater plant. Excessive antibiotics can also be an issue because they can kill bacteria or result in the rise of antibiotic resistance in organisms that may result in potential pathogens that could then be discharged into the environment. For systems which receive industrial discharges, it is important to have an efficient pretreatment program to try to keep as many of these potential pollutants out of a wastewater treatment plant influent as possible. As a result, it may be necessary to monitor the plant influent for such compounds to protect the microorganisms in the aeration basin.

14.6 Process Design

When engineers design an activated sludge facility, they will normally begin with the expected design flow, which is typically measured in units of millions of gallons per day or MGD and the expected pollutant load, which is typically measured in lbs of BOD_5 that the facility is expected to treat. The dimensions of the aeration basin (i.e., volume (MG) and surface area (ft^2)) are then selected based on the topography of the site and general design parameters that engineers and operators have determined to provide good treatment levels.

Two of the more common design parameters used by engineers are the hydraulic retention time (HRT) and the volume loading rate (VLR). Typical values of HRT and VLR for several different types of activated sludges processes are provided in Table 14.2. While an operator will not be expected to design a plant, the ability to calculate the values of these parameters and then compare them against the typical values observed in Table 14.2 is important to ensure that the plant is operating as designed. If the values associated with the plant do not fall within these values, that could indicate that the aeration basin is not operating within its design specifications. This could mean either the plant is under-designed or over-designed for the flows and BOD_5 loadings that it is currently experiencing.

Table 14.2 Typical Design Parameters for Activated Sludge Process (Ref. 2)

Process	HRT hours	VLR lbs. BOD/1000 ft^3
Conventional	4 - 8	20 - 40
Extended Aeration	20 - 30	5 - 15
Oxidation Ditch	15 - 30	5 - 15
Step Feed	3 - 5	40 - 60
Contact Stabilization	0.5 - 1.0 [a] 2 - 4 [b]	60 - 75
Complete Mix	3 - 5	20 - 100
Sequencing Batch Reactor	15 - 40	5 - 15

a = in contact basin, b = in stabilization basin

14.6.1 Hydraulic Retention Time for the Aeration Basin and Secondary Clarifier

As discussed previously in section 13.2.2, the hydraulic retention time (HRT) is the average time it takes for the water component of wastewater to move through a primary clarifier. The same equation can be used to determine the average retention time in the aeration basin or the secondary clarifier as well. The HRT is both a design parameter used by engineers in sizing the aeration basin and an operator parameter to ensure that the wastewater spends sufficient time in each basin (Table 14.2). As discussed previously, the HRT can be calculated using one of the following equations.

$$[10]\ (HRT, days) = \frac{(Tank\ Volume, MG\ )}{(Flow, MGD)}$$

$$[11]\ (HRT, hrs) = \frac{(Tank\ Volume, ft^3)\ x\ 7.48}{(Flow, gpd)}\ x\ 24$$

$$[11'] \ (HRT, hrs) = \frac{(Tank\ Volume, ft^3)\ x\ 7.48}{(Flow, MGD)\ x\ 1{,}000{,}000}\ x\ 24$$

Example 14.3

The aeration tank of a conventional activated sludge facility has a volume of 30,000 ft^3. The flow through the wastewater treatment plant is 0.75 MGD. Calculate the hydraulic retention time in the aeration basin.

Solution:

First, convert the flow rate from million gallons a day (MGD) to gallons per day (gpd) by multiplying by 1,000,000.

$$0.75\ MGD\ x\ 1{,}000{,}000 = 750{,}000\ gpd$$

Since everything is in the correct units, the HRT can be calculated using equation 11.

$$[11] \ (HRT, hours) = \frac{30000\ ft^3\ x\ 7.48}{750{,}000\ gpd}\ x\ 24 = \ 7.2\ hours$$

By looking at Table 14.2 it can be seen that an HRT of 7.2 hours falls within the typical range (4-8 hrs) for a conventional activated sludge facility.

14.6.2 Volumetric Loading Rate

The volumetric loading rate (VLR) is the total load of BOD$_5$ in pounds that is being applied to the aeration basin divided by the total volume of the basin. The VLR is both a design parameter used by engineers in sizing the aeration basin and an operator parameter to ensure that the basin is large enough to accommodate the pollutant load (Table 14.2). The VLR (per 1000 ft^3) can be calculated using the following equation:

$$[13] \ (VLR, \frac{lbs/day}{1000^3}) = \frac{(BOD_5, lbs/day)}{(Basin\ Volume, 1000\ ft^3)}$$

Example 14.4

The aeration tank of a conventional activated sludge facility has a total volume of 30,000 ft^3. The flow through the wastewater treatment plant is 0.75 MGD. If the BOD$_5$ concentration in the influent to the aeration basin is 150 mg/L, what is the volumetric loading rate (in lbs per 1000 ft^3) to the aeration basin?

Solution:

First, convert the BOD$_5$ concentration into a load in pounds.

$$(BOD_5, \frac{lbs}{day}) = 150\, BOD_5\, mg/L\ x\, 0.75\, MGD\ x\, 8.34\ =\ 938\, lbs/day$$

Next, convert 30,000 ft^3 into units of 1000 ft^3, by dividing by 1,000 to give 30, 1000 ft^3.

$$[13]\ (VLR, \frac{lbs/day}{1000^3}) = \frac{938\ lbs}{30, 1000\ ft^3} = 31.2\, lbs/1000\ ft^3$$

By looking at Table 14.2 we can see that 31.2 lbs/1000 ft^3/day falls within the typical range (20 – 40 lbs) for a conventional activated sludge facility.

Note: Units of 1000 ft^3 may seem odd, but the conversion is done to give a more useful and recognizable value of 31.2. If you divided 938 by 30,000 you would get 0.031. Which number is easier to visualize?

14.7 Process Monitoring of Activated Sludge Plants

To monitor and control the treatment of wastewater, the operator needs to collect water quality samples at various points in the activated sludge process. A summary of the main samples to be taken and sample locations is shown in Figure 14.14 and Table 14.3. Sample results can then be used to calculate several additional process parameters (see Tables 14.4 and 14.55). These operational parameters can then be checked against industry standards to assess the efficiency of the process (Table 14.6).

As illustrated in Figure 14.14, ultimately, these operational parameters can be controlled by controlling the:

- ❶ Return activated sludge flow (QRAS)
- ❷ Waste activated sludge flow (QWAS)
- ❸ Oxygen supply rate (OSR)

Figure 14.14 Activated Sludge Process Sampling Locations and Process Parameters

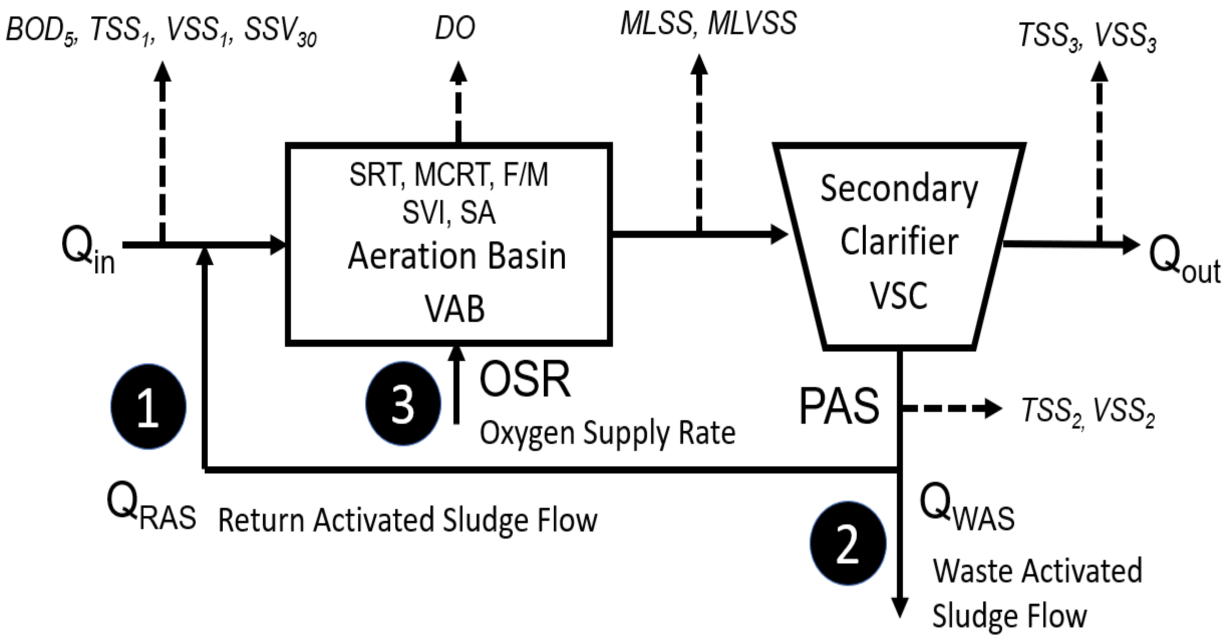


Table 14.3 Process Samples

Sample Type	Description
Q	Flowrate, MGD or gpm
BOD_5	Five Day Biochemical Oxygen Demand, mg/L
TSS (1,2,3)	Total Suspended solids, mg/L
VSS (1,2,3)	Volatile Suspended solids, mg/L
SSV_{30}	30 Minute Settable Solids Volume, mL/L
MLSS	Mixed Liquor Suspended Solids, mg/L
MLVSS	Mixed Liquor Volatile Suspended Solids, mg/L
DO	Dissolved Oxygen, mg/L

Table 14.4 Design Parameters

Design Parameter	Description	Used to Calculate Values in (Table 14.5)
Q	Flowrate, MGD or gpm	F/M, SA
V_{AB}	Volume of Aeration Basin, MG	SRT, MCRT, F/M, SA
V_{SC}	Volume of Secondary Clarifier, MG	SRT, MCRT

Note: V_{AB} and V_{SC} will depend on Q and HRT (see equations [10] and [11]).

Table 14.5 Process and Control Parameters

Process Parameter	Description	Depends On
SRT	Solids Retention Time	MLSS, TSS_3, Q_{WAS}
MCRT	Mean Cell Residence Time	MLVSS, VSS_3, Q_{WAS}
F/M	Food to Micro-Organism Ratio	BOD_5, MLVSS
SVI	Sludge Volume Index	SSV_{30}, MLSS
SA	Sludge Age	MLSS, TSS_3, Q_{WAS}

Table 14.6 Typical Design Parameters for Activated Sludge Process (Ref. 2)

Process	MLSS (mg/L)	MLVSS (mg/L)	SRT (days)	MCRT (days)	F/M (lbs/day/lbs)
Conventional	1000 - 3000	800 - 2400	3 - 15	3 - 15	0.2 – 0.4
Extended Aeration	2000 - 5000	1600 - 4000	20 - 40	20 - 40	0.04 - 0.10
Oxidation Ditch	3000 - 5000	2400 - 7000	15 - 30	15 - 30	0.04 - 0.10
Step Feed	1500 - 4000	1200 - 3200	3 - 15	3 - 15	0.2 - 0.4
Contact Stabilization	1000-3000[a] 6000-10000[b]	8000-2400[a] 4800-8000[b]	5-10	5-10	0.2 – 0.6
Complete Mix	1500-4000	1200-3200	3-15	3-15	0.2 – 0.6
Sequencing Batch Reactor	2000-5000	1600-4000	10-30	10-30	0.04 – 0.10

a = contact basin, b = stabilization basin

14.7.1 MLSS

The concentration of suspended solids in the aeration basin of an activated sludge process is defined as the mixed liquor suspended solids (MLSS) and is measured in milligrams per liter (or its equivalent – parts per million, ppm). MLSS consists mostly of microorganisms and non-biodegradable suspended matter. MLSS is calculated using the same method we used to calculate TSS (see Section 5.5.2). It is worth noting that although MLSS and TSS are essentially the same thing, the term MLSS is used for samples taken from an aeration basin (or activated sludge basin) while TSS is used for describing solids in the influent, effluent and wasted sludge. To measure the MLSS of the wastewater, a given volume of wastewater (measured in ml) is filtered through a pre-combusted, pre-weighted, glass filter. The filter and suspended solids and then dried in a drying oven at a temperature of 105°C. The filter is then weighed and the MLSS (mg/L) is then calculated using the following equation:

$$[14]\ \left(MLSS, \frac{mg}{L}\right) = \frac{(wt.of\ crucible, filter\ \&\ solids, g) - (wt\ crucible\ \&\ filter, g)}{(sample\ volume, mL)} x\ 1{,}000{,}000$$

Example 14.5

A 50 mL sample was collected for MLSS. The weight of the crucible and filter was 21.5308 g. The weight of the crucible, filter & dried solids was 21.5477 g.
What is the MLSS in mg/L?

Solution:

Because the sample and filter weight are in units of grams, and the sample size is in mL, we can use equation [14].

$$[14]\ MLSS = \frac{21.5477\ g - 21.5308\ g}{50\ mL}\ x\ 1{,}000{,}000 = 338\ mg/L$$

Knowing the concentration of MLSS is important because too high of a concentration can result in:

- Need for increased aeration, which increases electricity costs.
- Bulking of the solids causing the system to become overloaded because they do not settle.
- A drop in dissolved oxygen concentration due to increased bacterial activity.
- Foam near the surface of the water.
    - White foam is an indication of excess food.
    - Brown foam is an indication of too much MLSS.

Conversely, an MLSS concentration that is too low could result in:

- Not enough organic matter being removed from the waste.
- Lower nitrogen removal due to too young of a sludge age (i.e., less than 10 days).

14.7.2 MLVSS

The mixed liquor volatile suspended solids or MLVSS is the volatile portion of the MLSS and typically ranges from 75 to 85 percent of the MLSS, although each plant may have a different range in which the process of water treatment operates best. Technically, the concentration of MLVSS may more closely approximate the total active biological mass in the process (Ref. 6). MLVSS is calculated using the same method we used to calculate VSS (see Section 5.5.4), and similarly to MLSS and TSS, MLVSS is used for samples in the system as VSS is used for influent, effluent, and waste. To measure the MLVSS of the wastewater, you take the residue from the MLSS test and then combust it at a temperature of 550°C until it reads a constant weight. The weight lost on combustion is called MLVSS and is calculated using the following equation:

$$[15]\ \left(MLVSS, \frac{mg}{L}\right) = \frac{(wt.of\ crucible, filter\ \&\ solids, g) - (wt.of\ crucible, filter\ \&\ ash, g)}{(sample\ volume, mL)} x\ 1{,}000{,}000$$

Example 14.6

A 50 mL sample was collected for MLVSS. The weight of the crucible, filter and solids was 21.5447 g. The weight of the crucible, filter and ash was 21.5349 g. What is the MLVSS in mg/L?

Solution:

Because the sample and dish weight are in grams, and the sample size is in mL, use the formula.

$$[15]\ MLVSS = \frac{21.5447\ g - 21.5349\ g}{50\ mL}\ x\ 1{,}000{,}000 = 196\ mg/L$$

Note: the typical optimal ratio of MLVSS to MLSS is between 0.75 and 0.85 (Ref. 12).

14.7.3 Solids Retention Time and Mean Cell Residence Time

The **solids retention time** (SRT) and the mean cell residence time (MCRT) are two of the most important parameters of use in operating a wastewater treatment plant, since these will directly affect the levels of MLSS and MLVSS returned and wasted, and thus the food to microorganism (F/M) ratio (Ref. 7). Both the SRT and MCRT can be changed by controlling the influent flow rate (e.g., using flow equalization basins), the amount of return activated sludge (RAS) and amount of waste activated sludge (WAS). While SRT and MCRT are sometimes used interchangeably and sometimes even as a substitute for sludge age, each is technically calculated using different parameters.

14.7.3.1 SRT

The solids retention time is defined as the average time that the total suspended solids (TSS) remain in the system. If we assume that the solids in the secondary clarifier are negligible to the quantity of solids in the aeration basin, then we can calculate the SRT as follows (Ref. 2):

$$[16]\ SRT, days = \frac{(MLSS\ in\ aeration\ basin, lbs)}{(TSS\ wasted, \frac{lbs}{day}) + (TSS\ in\ secondary\ clarifier\ effluent, \frac{lbs}{day})}$$

Where:

$$(MLSS, lbs) = (Vol.\ Aeration\ Basin, MG)\ x\ 8.34\ x\ (MLSS, mg/L)$$

And:

$$\left(TSS\ wasted, \frac{lbs}{day}\right) = (Wasted\ Flow, MGD)\ x\ 8.34\ x\ (TSS_2, mg/L)$$

And:

$$(TSS\ in\ effluent, \frac{lbs}{day}) = (Effluent\ Flow, MGD)\ x\ 8.34\ x\ (TSS_3, mg/L)$$

Note: Many of the equations for calculating operational control parameters use conversion factors to convert numbers from one set of units (e.g., mg/L) to another set of units (e.g., lbs/gal). In the following problems, we will drop the notation associated with such to make the calculations less cluttered and potentially less confusing (e.g., instead of writing 8.34 lbs/gal we will just write 8.34). For example, technically:

$$lbs\ MLSS = Vol. Aeration\ Basin, MG\ x\ \left(1\frac{L}{M.mg}\right) x\ \ 8.34\frac{lbs}{gal}\ x\ MLSS\ \left(\frac{mg}{L}\right)$$

However, as in the example above, we will simplify this by writing (MLSS, lbs) as follows:

$$(MLSS, lbs) = (Vol. Aeration\ Basin, MG)\ x\ (8.34)\ x\ (MLSS, mg/L\ )$$

For those operators who might be interested in some of the other conversions that are occurring “behind the scenes”, these are listed below, however you will not need to know these for the operator examinations:

1 ft^3 = 28.32 liters or 28.32 liters/ft^3
1 ft^3 = 7.48 gallons or 7.48 gallons/ft^3
1 gallon = 8.34 lbs or 8.34 lbs/gallon
1 ft^3 of water = 62.4 lbs or 62.4 lbs/ft^3
1 g/mL = 1,000,000 mg/L
1 million (M) = L/mg or 1 L/M.mg

Thus, in the equations that follow, we will try to minimize including all these conversion factors in the equations to make things easier and to avoid any potential confusion. Although we are not writing them in the equations, they are nonetheless still there and will be reflected in the constants (e.g., 8.34, 7.48, etc.) that you still see appearing in the equations.

Example 14.7

Calculate the SRT for an activated sludge plant with the following conditions:

- Aeration basin: 110 feet *x* 40 feet *x* 13 feet deep.
- Inflow rate: 1.47 MGD.
- MLSS concentration: 1500 mg/L.
- Waste sludge flow rate: 0.01 MGD.
- Waste sludge concentration (i.e., TSS_2): 7750 mg/L.
- Secondary clarifier effluent (i.e., TSS_3): 17 mg/L

Solution:

$$Volume\ of\ aeration\ basin, ft^3 = 10\ ft\ x\ 40\ ft\ x\ 13\ ft = 57{,}200\ ft^3$$

$$Volume\ of\ aeration\ basin\ (MG) = 57{,}200\ \text{ft}^3\ x\ 7.48\ /\ 1{,}000{,}000 = 0.428\ MG$$

First covert the MLSS from mg/L to lbs.

$$MLSS, lbs = 0.428\ MG\ x\ \ 8.34\ x\ 1{,}500\ mg/L = 5{,}354.3\ lbs$$

Next, calculate TSS wasted and the TSS in the effluent in lbs/day.

$$(TSS\ wasted, \frac{lbs}{day}) = 0.01\ MGD\ x\ 8.34\ x\ 7{,}750\ (mg/L) = 646.35\ lbs/day$$

$$(TSS\ in\ effluent, \frac{lbs}{day}) = 1.47\ MGD\ x\ 8.34\ x\ 17\ (mg/L) = 208.40\ lbs/day$$

Thus, if the loadings are measured over the course of a day, then:

$$[16]\ SRT, days = \frac{5353\ lbs\ MLSS}{646.35\ lbs\ wasted + 208.42\ lbs\ effluent} = 6.26\ days$$

14.7.3.2 MCRT

The mean cell residence time (MCRT) is defined as the average time that the microorganisms or biomass remain in the system. If we assume that the biomass (as approximated by VSS) in the secondary clarifier is negligible to the amount in the aeration basin, then we can calculate the MCRT as follows (Ref. 2):

$$[17](MRCT, days) = \frac{(MLVSS\ in\ aeration\ basin, lbs)}{(VSS_2\ wasted, lbs/day) + \ (VSS_3\ in\ secondary\ clarifier\ effluent, lbs/day)}$$

Where:

$$(MLVSS, lbs) = (Vol. Aeration\ Basin, MG)\ x\ \ 8.34\ x\ (MLVSS\ , mg/L\ )$$

And:

$$(VSS\ wasted, lbs/day)\ \ = (Wasted\ Flow, MGD)\ x\ 8.34\ x\ (VSS_2\ \ mg/L\ )$$

And:

$$(VSS\ in\ effluent, lbs/day)\ \ = (Second. Clarifier\ Effluent, MGD)\ x\ 8.34\ x\ (VSS, mg/L\ )$$

Note: VSS is calculated in the same way that the MLVSS is calculated.

Notice the only difference between equations [16] and [17] is that SRT is expressed as a function of MLSS and TSS, while MCRT is expressed in terms of MLVSS and VSS. Specifically, SRT is measuring the residence time of the total solids in the basin, while MCRT is measuring the residence time of the bacteria in the basin. MCRT assumes that the volatile solids used to calculate MCRT (i.e., MLVSS and VSS) are made up mostly of bacteria and not non-living organic material or inorganic solids. Therefore, the SRT and the MCRT should give similar, if not equivalent, values.

Example 14.8

Calculate the MCRT for an activated sludge plant for the following conditions:

- Aeration basin size: 110 feet *x* 40 feet *x* 13 feet deep
- Inflow flow rate: 1.47 MGD
- MLVSS concentration: 1,200 mg/L
- Waste sludge flow rate: 0.01 MGD
- Waste sludge concentration (i.e., VSS_2): 6,200 mg/L
- Secondary clarifier effluent (i.e., VSS_3): 13.6 mg/L

Solution:

$$Volume\ of\ aeration\ basin, ft^3 = 110\ ft\ x\ 40\ ft\ x\ 13\ ft = 57{,}200\ ft^3$$

$$Volume\ of\ aeration\ basin,\ MG = 57{,}200\ ft^3\ x\ 7.48\ /\ 1{,}000{,}000 = 0.428\ MG$$

First covert the MLVSS from mg/L to lbs.

$$lbs\ MLVSS = 0.428, MG\ x\ \ 8.34\ x\ 1{,}200, mg/L = 4{,}283.4\ lbs$$

Next, calculate VSS wasted and the VSS in effluent.

$$VSS\ wasted, lbs/day = 0.01\ MGD\ x\ 8.34\ x\ 6{,}200, mg/L = 517.08, lbs$$

$$VSS\ in\ effluent, lbs/day = 1.47\ MGD\ x\ 8.34\ x\ 13.6, mg/L = 166.73, lbs$$

Finally, use equation [17] to determine the MCRT.

$$[17]\ MCRT, days = \frac{4{,}283.4\ lbs\ MLVSS}{517.08\ lbs + 166.73\ lbs} = 6.26\ days$$

14.7.4 Sludge Age

Similar to SRT and MCRT, sludge age (SA) provides useful information that helps the operator maintain the proper concentration of solids in the system. Young sludge tends to produce light and fluffy floc particles that settle slowly. Old sludge settles too fast, is very dark and granular, and can create a very turbid water. In the engineering and scientific literature, sludge age is technically calculated using either Eq. [16] or [17], however, in practice it is frequently approximated with the following simpler equation:

$$[18]\ (SA, days) = \frac{(MLSS\ in\ aeration\ basin, lbs)}{(\ TSS_1\ in\ influent, lbs/day)}$$

Example 14.9

Calculate the Sludge Age (SA) for an activated sludge plant for the following conditions:

- Aeration basin size: 110 feet x 40 feet x 13 feet deep
- MLSS concentration: 1,500 mg/L
- Influent TSS1 concentration: 100 mg/L
- Influent flowrate (i.e., Qin): 1 MGD

Solution:

$$Volume\ of\ aeration\ basin, ft^3 = 110\ ft\ x\ 40\ ft\ x\ 13\ ft = 57{,}200\ ft^3$$

$$Volume\ of\ aeration\ basin\ (MG) = (57{,}200\ ft^3\ x\ 7.48)/\ 1{,}000{,}000 = 0.43\ MG$$

First covert the MLSS from mg/L to lbs.

$$MLSS, lbs = 0.43, MG\ x\ 8.34\ x\ 1,500, mg/L = 5{,}379.30\ lbs$$

Next, calculate TSS in lbs/day in the influent.

$$TSS\ lbs, day = 1\ MGD\ x\ 8.34\ x\ 100\ mg/L = 834.00 \frac{lbs}{day}$$

Finally, use equation [18] to determine the Sludge Age (SA).

$$[18]\ SA, days = \frac{5{,}379.30\ lbs\ MLSS}{834.00 \frac{lbs}{day}} = 6.45\ days$$

14.7.5 Food to Microorganism (F/M) Ratio

In addition to sludge age, solids retention time and MCRT, there is another value that can be calculated to indicate how well a plant is treating the wastewater. The F/M ratio uses the amount (lbs) of BOD consumed in the aeration tank. We can think of this as food (F) for the microorganisms. The other value is the mass of microorganisms or “bugs” (M) in the basin. The relative ratio of food (F) to microorganisms or bacteria (M) is another measure of how well the treatment process is working.

Food (F) can be calculated as follows:

$$\boxed{Food = (Flow, MGD)\ x\ 8.34\ x\ (BOD_5, mg/L\ )}$$

The microorganisms (M) in the aeration basin can be approximated as follows:

$$\boxed{Microorganisms, lbs = Volume\ of\ the\ aeration\ basin, x\ MLVSS, mg/L\ \ x\ 8.34}$$

Thus, the Food to Microorganism ratio is calculated as follows:

$$[19]\ F/_M = \frac{(Food, lbs/day\ )}{(Microorganisms, lbs\ )}$$

According to the 2014 edition of the Ten State Standards, the optimal design standard for the organic loading for a conventional aeration tank is 30 lb BOD_5/day/1000ft^3. The associated F/M ratio should vary between 0.2 to 0.4. This assumes the MLSS ranges from between 1,000 mg/L and 3,000 mg/L (Ref. 8).

At the beginning of the treatment process, the food to microorganism ratio (F/M) is high and the bacteria are reproducing as quickly as the environmental conditions will allow. The bacteria are mobile and dispersed enough so that they will not bind to each other and settle out of the water. A low F/M means that there is a limited amount of food available, which may contribute to the bacteria becoming less mobile, developing a slime layer, and starting to make floc and settle out. However, the bacteria will tend to bind together better and settle well in the clarifier (Ref. 9).

Example 14.10

The flow to a 1 MG complete mix activated sludge aeration basin is 6.0 MGD with an influent BOD concentration of 150 mg/L. The MLVSS is 2,400 mg/L. What is the food to microorganism (F/M) ratio?

Solution:

First calculate the food. See equation [2].

$$Food = 6.0\ MGD\ x\ 8.34\ x\ 150\ \ mg/L = 7{,}506\, lbs/day$$

Next calculate the mass of the microorganisms. See equation [1].

$$Microorganisms, lbs = 1\ MG\ x\ 2{,}400\, mg/L\ \ x\ 8.34 = 20{,}216\ lbs$$

Finally, calculate the F/M Ratio:

$$[19]\ F/_M = \frac{7506\, lbs/day}{20{,}216\ lbs} = 0.37 \frac{lbs/day}{lbs}$$

Note: this is within the range for a complete mix basin (Table 14.5).

Note: The idea of lbs per day and lbs was introduced in equation [1] and [2]. In this example both were used.

Example 14.11

The flow into an oxidation ditch is 3.2 MGD with a net BOD_5 removal of 188 mg/L. The MLSS of the oxidation ditch is 3,400 mg/L (65% of which is volatile). The oxidation ditch can hold 4.5 MG. What is the F/M of this system?

Solution:

First, we calculate the food.

$Food\ (lbs) = 3.2\ MGD\ x\ 8.34\ x\ 188\ mg/L = 5{,}017.34\ lbs/day$

Next, we calculate the mass of the microorganisms. We must convert MLSS to MLVSS, so multiply 3,400 x 65% or (0.65).

$MLVSS = 0.65\ x\ MLSS = 0.65\ x\ 3{,}400\ mg/L = 2{,}210\ mg/L$

$Microorganisms\ (lbs) = 4.5\ MG\ x\ 8.34\ x\ 2{,}210\ mg/L = 82{,}941.3\ lbs$

Finally, calculate the F/M Ratio:

$$[19]\ {}^{F}/_{M} = \frac{5{,}017.3\ lbs/day}{82{,}941.3\ lbs} = 0.060$$

Again, this is within the range for an oxidation ditch (Table 14.5).

14.7.6 Sludge Volume Index

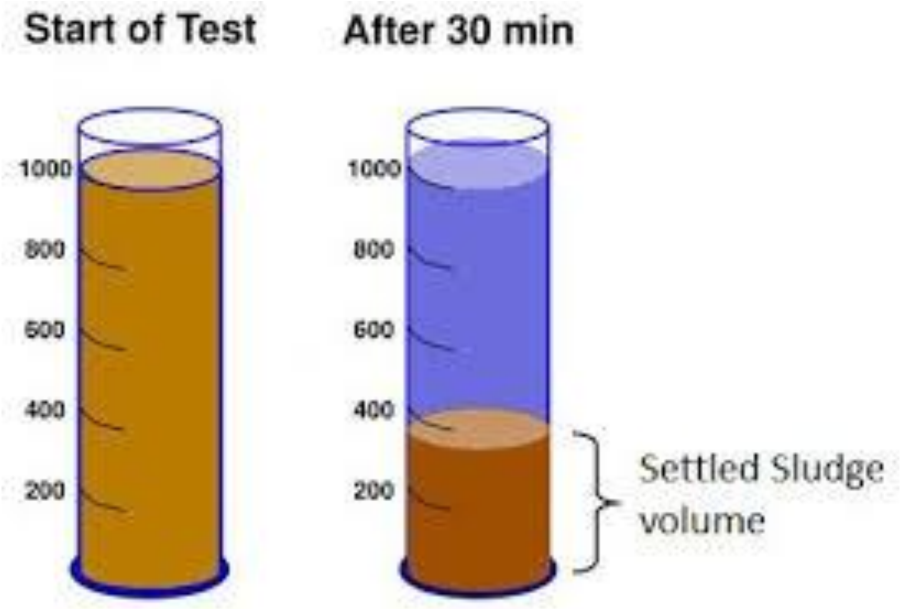
The **sludge volume index (SVI)** measures the settling characteristics of the sludge and is used to determine the amount of return activated sludge (RAS) to pump. A change in SVI can indicate problems in the operation of the plant, such as the emergence of filamentous organisms or a change in the sludge age, as well as SRT, MCRT and F/M. A low SVI can also indicate the possible washout of the clarifier due to high flows. Alternatively, it could also indicate the presence of too many solids in the system. In most cases, the problem may be corrected by adjusting the RAS or WAS (Ref. 10).

The standard test for SVI involves collecting a fresh sample, between the aeration basin and the secondary clarifier, as would be collected for MLSS determination. This sample is typically 1 to 2 liters depending upon the type of settling cylinder or settleometer being used. Part of the sample is used to determine the concentration of the MLSS as discussed previously. The remaining volume of the sample (at least 1 liter) is then placed in a graduated cylinder (Figure 14.15) and allowed to settle over 30 minutes. The volume of the sludge that has settled over the 30-minute period is then read off the cylinder and recorded as SSV_{30}. Knowing these two values, MLSS and SSV_{30}, the SVI can be determined using the following equation (Ref. 4):

$$[20]\ (SVI, mL/g) = \frac{Settled\ Sludge\ Volume\ (SSV_{30}) \times 1000}{(MLSS, mg/L\ )}$$

Note: 1 mL of settled sludge is equal to 1 gram.

Figure 14.15 Standard SVI Test



Example 14.12

The 30-minute settled sludge volume is 450 mL, collected in a 1 L sample that had a MLSS of 4,000 mg/L. What is the SVI?

Solution:

Since everything is in the correct units, SVI can be calculated using equation [20].

$$[20]\ (SVI, \frac{mL}{g}) = \frac{450\ mL\ x\ 1000}{4{,}000, mg/L} = 112.5\, mL/g$$

Some general guidelines for SVI are shown in Table 14.6. While these values represent general guidelines, every plant operates differently, so the best SVI for each plant will be unique. Ideally, an operator should determine the SVI value when the facility is running at an optimal level and then use that value as a benchmark for future operational decisions.

Table 14.7 Possible Ranges of SVI for a Typical Activated Sludge Plant

Range of SVI values	Interpretation
80 mL/g or less	Typically associated with an older, over-oxygenated sludge. Effluent BOD results may be satisfactory, but TSS values may be high.
100 to 200 mL/g	Normally associated with a clear, good-quality effluent.
250 mL/g or higher	Typically associated with younger sludge or filamentous sludge bulking.

14.8 Process Control

To manage the operation of an activated sludge facility effectively, the operator must collect various water quality samples, which can then be used to calculate several important operational parameters. Once calculated, status of the operations can be determined by comparing the operational parameters against standard industry values presented in Tables 14.6 and Table 14.7, or against historical values for the plant that correspond to good performance and effluent values. Examples of important water quality samples and operational parameters are given below (Ref 16).

Important measured sample results:

- TSS/MLSS
- VSS/MLVSS
- SSV_{30}
- BOD

Important calculated operational parameters:

- Solids residence time (SRT).
- Mean cell residence time (MCRT).
- Food to microorganism ratio (F/M).
- Sludge volume index (SVI).
- Sludge age (SA).

All the operational parameters such as SRT, MCRT, SA, F/M ratio, and SVI, as well as the values of MLSS, MLVSS, and ultimately the effluent BOD_5, are determined by a few parameters under the control of the operator. These include:

- Q_{RAS} (Return Activated Sludge Flow Rate)
  - Return activated sludge flow rate from secondary clarifier to aeration basin.

The return activated sludge flowrate (Q_{RAS}) directly affects the values of the MLSS, the MLVSS, the Food to Microorganism ratio (F/M), and the sludge volume index (SVI). Without changing anything else, if you want to increase MLSS, MLVSS, SVI or decrease the F/M then you could increase the Q_{RAS}.

- Q_{WAS} (Waste Activated Sludge Flow Rate)
  - Waste activated sludge flow rate from secondary clarifier.

The rate of wasted activated sludge directly impacts the SRT, the MCRT, and the sludge age (SA). Without changing anything else, if you want to increase the SRT, MCRT and SA, then you need to decrease the Q_{WAS}.

- OSR (Oxygen Supply Rate)
  - The rate or amount of oxygen or air supplied to the aeration basin.

The Oxygen Supply Rate (OSR) is important to maintain proper dissolved oxygen levels in the aeration basin (typically 1.0 - 2 mg/L). Higher DO concentrations above 2 mg/L may improve nitrification rates in basins with high BOD loads. Values above 4 mg/L do not improve operations significantly but increase the aeration costs considerably (Ref. 2).

14.8.1 Return Activated Sludge Flowrate (Q_{RAS})

The return activated sludge (RAS) flowrate (Q_{RAS}) is the flowrate of sludge that is pumped out of the secondary clarifier and returned to the influent of the aeration basin. This return of activated sludge is done to maintain a healthy population of microorganisms in the aeration basin. It is important that this flowrate be controlled to maximize the efficiency of the treatment process. The rate is typically set as a function of the influent rate to the aeration basin based on operator or plant experience. Examples of typical ranges of Q_{RAS} as a percentage of the influent flowrate to the aeration basin, for different types of activated sludge processes are given in Table 14.8 (Ref. 2).

Table 14.8 Typical Design Parameters for Activated Sludge Process

Process	Q_{RAS} as a % of Influent
Conventional	25 - 75
Extended Aeration	50 - 150
Oxidation Ditch	75 - 150
Step Feed	25 - 75
Contact Stabilization	50 - 150
Complete Mix	25 - 100
Sequencing Batch Reactor	N/A

Although the Q_{RAS} will affect the values of the MLSS, MLVSS, and F/M, the return activated sludge flowrate is typically <u>not</u> used to control either system or operational control parameters. Instead, the waste activated sludge flowrate (Q_{WAS}) is typically used to control the operational parameters and the efficiency of the plant. There are times, however, when the RAS needs to be changed. For example, the rate may need to be decreased to help control a rising sludge blanket in the secondary clarifier and to buffer acids. Under such circumstances, the required Q_{RAS} needed to maintain a MLVSS concentration for a given waste volatile suspended solids concentration VSS_2 can be determined using the following equation (Ref. 11):

$$[21]\ (Q_{RAS}, MGD) = \frac{(Q\ influent, MGD)\ x\ (MLVSS, \frac{mg}{L})}{(VSS_2, \frac{mg}{L}) \quad - \ (MLVSS, mg/L\ )}$$

Example 14.13

Given the following data, determine the Q_{RAS} needed to sustain a MVLSS concentration of 2,000 mg/L in the aeration basin if the VSS2 in the waste line is 6,000 mg/L.

- Q influent (MGD) = 4.0 MGD
- SVI = 100

Solution:

Calculate the Q_{RAS}:

$$[21]\ (Q_{RAS}, MGD) = \frac{(4\ MGD)\ x\ (2{,}000\ \frac{mg}{L})}{(6{,}000\ \frac{mg}{L})\ -\ (2{,}000\ \frac{mg}{L})} =\ 2.0\ MGD$$

In addition to expressing the return flow rate in terms of the MLVSS, QRAS can also be approximated in terms of the settle sludge volume, SV_{30} described previously. Although this method is slightly simpler than equation [21] it is typically not quite as accurate since the sludge volume obtained from the settleability test might not exactly model what is actually happening in the actual clarifier. Nonetheless, the Q_{RAS} can also be approximated using equation [22].

$$[22]\ (Q_{RAS}, MGD) = \frac{(Q\ influent, MGD)\ x\ (SV_{30}, mL\ )}{1000 - (SV_{30}, mL)}$$

Example 14.14

If the influent into the aeration basin is 4 MGD, estimate the Q_{RAS} needed to sustain a SV_{30} of 450 mL.

Solution:

Calculate the Q_{RAS}:

$$[22]\ (Q_{RAS}, MGD) = \frac{(4\ MGD)\ x\ (450\ mL\ )}{1000 - (450\ mL\ )} =\ 3.27\ MGD$$

14.8.2 Waste Activated Sludge Flowrate (Q_{WAS})

The efficiency of the treatment process can be monitored by measuring such parameters as MLSS, MLVSS, SRT, MCRT, F/M ratio and sludge age. Each of these parameters is typically controlled by the amount of sludge that is wasted from the secondary clarifier and the rate at which the sludge is wasted (Q_{WAS}). As has been previously discussed, the continual addition of organic food or BOD to the aeration basin will result in the increase growth of biomass. To maintain a balanced and stable system, this increase of biomass must be removed through the wasting of the excess biomass or sludge. If the excess solids are not removed, the SRT, MCRT and sludge age will increase, and the process efficiency will decrease. The decrease in efficiency will then affect the sludge settling rates. Eventually, if these excess solids are not removed, they can overflow the weirs of the clarifiers and end up in the receiving waters.

In general, the secondary clarifiers in an activated sludge facility will thicken the activated sludge to three to four times the concentration in the aeration basin. This can result in waste activated sludge MLSS concentrations or $C_{WAS,}$ where C stands for concentration, and return activated sludge MLSS concentrations, or C_{RAS} from 2,000 to 10,000 mg/L (Ref. 12).

In general, it is important not to make sudden or drastic changes to the Q_{WAS} since the system responds better to more gradual changes. Ideally, the sludge should be wasted on a continuous basis, with the Q_{WAS} not being changed more than 10 to 15 percent from one day to the next (Ref. 12).

The sludge from the secondary clarifier is either removed and recycled or wasted using positive displacement (piston) or air-lift pumps. Unfortunately, such pumps can be prone to plugging, especially at low return flow rates. As a result, operators should closely monitor these pumps to ensure their proper operation.

The following methods can help estimate the $Q_{WAS.}$

- Manually, by measuring the depth of sludge in the secondary clarifier.
- Microscopically, by estimating the types of species and population numbers of protozoa and metazoans.

14.8.3 Manual Determination of Q_{WAS}

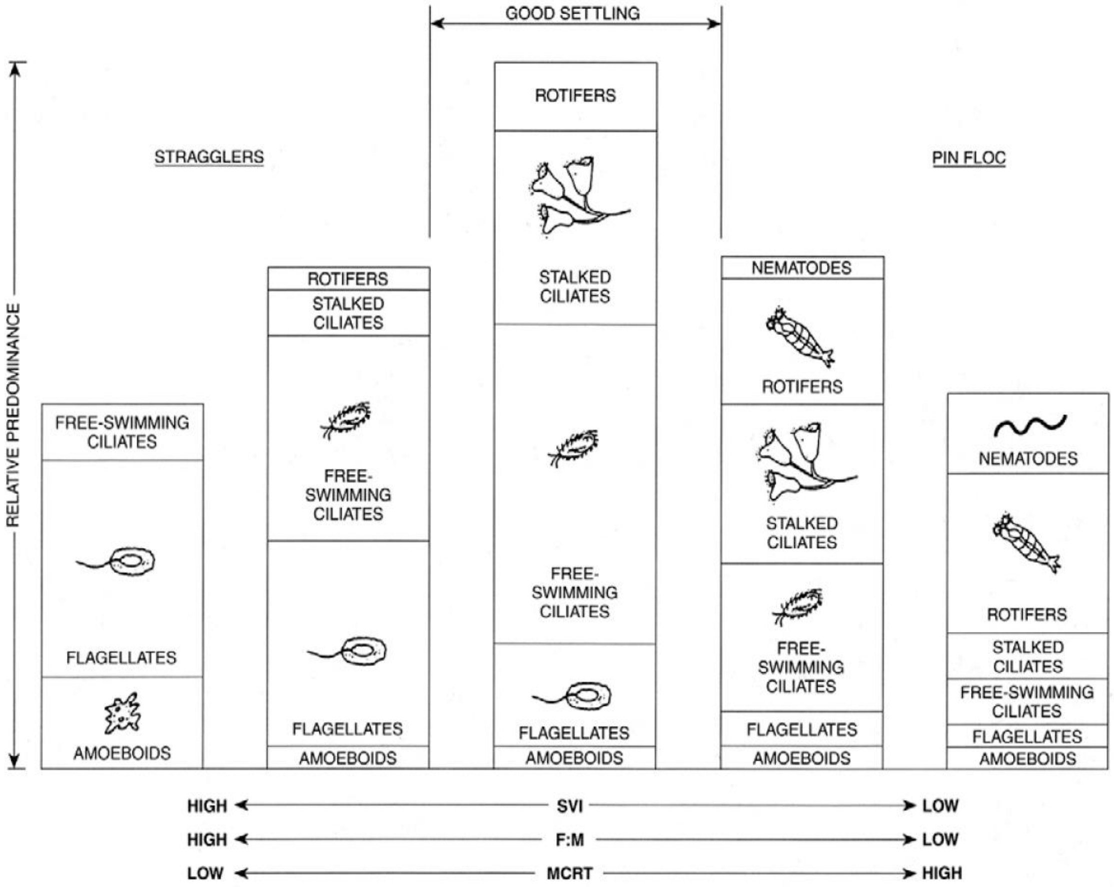
As the solids from the aeration basin flow into the secondary clarifier, they will begin to settle out and form a blanket of sludge at the bottom of the clarifier. Left unchecked, the sludge would eventually fill the clarifier and overflow the weirs, causing it to be discharged into the plant effluent. Discharge of sludge can be avoided by pumping some solids out of the tank, thereby wasting them. Ideally the flowrate of wasting, $Q_{WAS,}$ should be selected to keep the sludge blanket at a fairly constant depth. Ultimately this depth needs to be determined by experience and when the plant is working well. Most secondary clarifiers are designed to allow the following: 2 to 3 feet of depth for sludge thickening, 3 feet of buffer between the top of the sludge blanket and the top of the clarification zone, and 8 feet for clarification (Ref. 12). The depth of the sludge blanket in a secondary clarifier is typically measured manually using a clear plastic tube (e.g., Sludge Judge®) or using some type of ultrasonic automatic monitor. If the depth of sludge increases higher than a desired level, then the Q_{was} can be increased.

14.8.4 Microscopic Determination of Q_{WAS}

One way to judge the health of the activated sludge process is to calculate the values of different operational control parameters (e.g., SRT, MCRT, F/M) and compare the values against typical industry values associated with healthy processes. Perhaps a better indication of the overall health of the biological processes of the activated sludge process can be obtained by examining the actual solids from your own plant under a microscope for the number and diversity of protozoa and metazoans. (Figure 14.16).

A general indication of the relative values (i.e., high, medium, low) of several important operational parameters, such as the SVI, F/M, SRT, MCRT, and SA, can be inferred by looking at the relative proportion or predominance of different types of protozoa and metazoans present in sludge. The number and variety of species can provide some direction for increasing or decreasing the Q_{RAS}, in the case of the SVI, or increasing or decreasing the Q_{WAS} in the case of F/M and SA. For example, if most of the population is made up of flagellates and amoeboids, the options available may be to increase Q_{RAS} or decrease Q_{WAS}.

Figure 14.16 Range of Activated Sludge Operational Parameters as a Function of the Relative Predominance of Different Microorganism (Ref. 2)



14.8.5 Summary

Both Q_{RAS} and Q_{WAS} can be used to modify the MLSS and MLVSS concentrations as well as several operational parameters. However, instead of trying to keep track of all these factors (and given the fact that many of the parameters depend on the others), an operator will usually pick one or two of the control parameters to use in adjusting the operation of the activated sludge process. These will typically include:

- Q_{RAS} (normally used to adjust SVI).
- Q_{WAS} (normally used to adjust either the SRT, MCRT, F/M ratio or the sludge age).

A general summary of the impacts of Q_{WAS} on these associated operational parameters is provided in Table 14.9.

Table 14.9 Relationship Between Q_{WAS} and Various Operational Parameters

If you want to increase SRT:	Then decrease Q_{WAS}
If you want to decrease SRT:	Then increase Q_{WAS}
If you want to increase MCRT:	Then decrease Q_{WAS}
If you want to decrease MCRT:	Then increase Q_{WAS}
If you want to increase F/M:	Then increase Q_{WAS}
If you want to decrease F/M:	Then decrease Q_{WAS}
If you want to increase SA:	Then decrease Q_{WAS}
If you want to decrease SA:	Then increase Q_{WAS}

14.8.6 Oxygen Supply Rate

The health of the biomass in the aeration basin depends to a large extent on having enough oxygen to support the cellular respiration and growth of microorganisms. Oxygen can be provided to the aeration basin using one of two different approaches:

- Using a diffused aeration system.
- Using a mechanical aeration system.

In a diffused aeration system, air is pumped into the bottom of the basin through diffusers that release bubbles, which rise through the biomass up to the surface of the water. This allows maximum contact between the oxygen in the pumped air and the microorganisms in the biomass.

The most common types of diffusers generate either fine or coarse bubbles. Such diffusers can be placed throughout the floor of the aeration tank, along the basin sides, or in the center of the basin. In general, the most efficient combination is the use of fine bubble diffusers, full floor coverage placement, and annual cleaning of the diffusers. Another reason why the decision on what type of aeration system to use is important is because a diffused aeration system will typically consume more than ½ of all the power in the wastewater treatment plant (Ref. 10).

Diffused aeration systems are driven by either centrifugal blowers or positive displacement blowers. A centrifugal blower output will vary depending upon the discharge pressure. Positive displacement blowers will produce the same output at a given speed no matter the discharge pressure. The primary disadvantage of a centrifugal blower is that they cannot achieve the high compression ratio of positive displacement blowers without the use of multiple stages. The primary disadvantage of a positive displacement blower is that it will continue to force air into the discharge line even if a blockage occurs which could result in damage to the pump or a bursting of the discharge line. As a result, some type of pressure relief valve is normally required on the discharge side of the blower.

In a mechanical aeration system, some type of mechanical device is used to force air and surface water down into the biomass. The most common types of mechanical devices use paddles, discs, spray, or turbine mechanisms.

As we have already discussed, the optimal oxygen levels in an activated sludge reactor should typically be between 2.0 to 4.0 mg/L. In general, the higher the oxygen levels the more biomass will be produced. As also discussed previously, the operator should keep track of the oxygen levels in the aeration basin either through continuous telemetry or by taking regular instantaneous reading using a hand-held meter. If the oxygen readings are not within the desired levels, the operator will have to adjust the amount of air being fed into the aeration tank.

The level of required dissolved oxygen in a diffused aeration system can be controlled in several ways including:

- Controlling air valves.
- Controlling the blower output using variable frequency drives on the motor.
- Increasing or decreasing the number of blowers in operation.
- Cleaning or replacing diffusers.
- Changing the number of diffusers.
- Adjusting the MLSS levels (by controlling the Q_{RAS}).

The level of dissolved oxygen in a mechanical aeration system can also be controlled in several ways, including:

- Increasing or decreasing the aerator speed by using variable frequency drives on the motors.
- Increasing or decreasing the aerator submergence by adjusting the basin water level.
- Increasing or decreasing the number of aerators in operation.
- Adjusting the MLSS levels (by controlling the Q_{RAS}).

Note: Throttling air valves when using a positive displacement blower will not reduce air flow output but will simply raise the operating pressure of the blower and result in a higher electric cost as a result. However, throttling an inlet air valve on a centrifugal blower will reduce air discharge flow.

14.8.7 Specific Oxygen Uptake Rate

The **specific oxygen uptake rate** (SOUR) represents the amount of oxygen that is used by microorganism to break down and remove the organic material in the wastewater. As a result, this rate can be used to measure the biological activity in the activated sludge process. The SOUR is measured in the laboratory by taking a sample of mixed liquor, typically from the effluent of the aeration basin, saturating the sample with oxygen, and then measuring the decrease in oxygen over time using a DO probe. The difference between the original and final oxygen concentrations (mg O_2/L/min) is then divided by the concentration of the MLVSS (mg/L) to calculate the SOUR (O_2/g of MLVSS/hr). Under normal conditions, the SOUR should be proportional to the strength of the influent waste as measured by the chemical oxygen demand (COD) or BOD_5. However, if the SOUR starts to decrease while the influent COD remains high, this might be an indication that something toxic is killing the microorganisms in the aeration basin (Ref. 12). SOUR can be calculated in the lab using the following equations:

$$[23]\ Oygen\ Uptake\ Rate: OUR\left(\frac{\frac{mg}{L}}{hr}\right) = \frac{(DO_1 - DO_2)}{(Time\ 2 - Time\ 1)}\ x\ 60\ (\frac{min}{hr})$$

$$[24]\ Specific\ Oxygen\ Uptake\ Rate: SOUR\ (\frac{mg}{g})/hr = \frac{(OUR, \frac{mg}{L}/\mathrm{hr})}{(MLVSS, mg/L)}\ x\ 1000$$

Example 14.15

Several samples of MVLSS are taken from the aeration basin and placed in bottles which have dissolved oxygen probes inserted. The average of the initial DO values was 7.8 mg/L. After 10 minutes, the average of the DO values was 5.1 mg/L. If the initial MVLSS concentration in the aeration basin was 2,750 mg/L, determine the final SOUR value.

Solution:

First, determine the OUR.

$$[23]\ Oygen\ Uptake\ Rate: OUR\left(\frac{\frac{mg}{L}}{hr}\right) = \frac{\left(7.8\frac{mg}{L} - 5.1\ mg/L\right)}{(10\ min - 0\ min)} \times 60\ (\frac{min}{hr})$$

OUR = 16.2 mg/L/hr

Next, determine the SOUR.

$$[24]\ Specific\ Oxygen\ Uptake\ Rate\ (SOUR)(\frac{mg}{g})/hr = \frac{(16.2\ \frac{mg}{L}/hr\ )}{(2{,}750\ mg/L)}\ x\ 1000$$

SOUR = 5.9 mg/g/hr

14.9 Operational Issues

As with any complex biological and chemical process, the activated sludge treatment may occasionally develop operational problems or issues that need to be corrected. Some of the common issues are listed below.

14.9.1 Low Oxygen Levels in the Aeration Basin

Low oxygen levels in the aeration basin can be caused by:

- Faulty meters or probes (check, clean and calibrate probes on a regular basis).
- Inadequate air supply (increase the air supply – see Section 14.7).

- Excessive organic loading (reduce influent loading by decreasing sewer inflow and infiltration, or by using equalization basins to maintain a constant load).

14.9.2 Lack of Proper Settling of Solids in the Secondary Clarifier

The lack of proper settling can be caused by:

- Excessive filamentous organisms (Section 14.9.6).
- Sludge age that is too young (increase sludge age, by decreasing Q_{WAS}).
- Sludge age that is too old (decrease sludge age, by increasing Q_{WAS}).
- Clarifier washouts due to high flows (reduce sewer inflow and infiltration).
- Too many solids in the system (maintain proper levels of MLSS).

14.9.3 Irregular Floc

Occasionally, the floc in the settling basin may develop characteristics which inhibit the settling of solids. The two most common problems are pin floc and straggler floc. Both have poor settling characteristics. Pin floc (Figure 14.17) is normally associated with older sludges (i.e., high MLSS levels), while straggler floc (Figure 14.18) is normally associated with younger sludges (i.e., low MLSS levels). Pin and straggler floc can also indicate the potential onset of **denitrification** in the basin or the presence of excessive amounts of fats, oils, or grease (FOG). An effective industrial pretreatment program can control FOG if these are coming from an industrial source such as animal processing facilities. The main way to prevent pin and straggler floc is to maintain optimal MLSS levels in the basin (Table 14.6) which is ultimately controlled by SRT.

Figure 14.17 Example of Pin Floc

Figure 14.18 Example of Straggler Floc

14.9.4 Sludge Bulking

Sludge bulking occurs when the sludge will not settle properly and exhibits an expanded or inflated texture. Sludge bulking is normally caused either by excessive amounts of filamentous bacteria (filamentous bulking) or by excessive amounts of extracellular biopolymer (viscous or slime bulking). Filamentous bulking can be controlled by limiting the growth of filamentous bacteria (Section 14.9.6), while viscous or slime bulking can be controlled by maintaining a proper nutrient balance (Ref. 2).

Additional potential factors that can contribute to sludge bulking can include (Ref. 2):

- Wastewater characteristics such as variations in flowrate, pH, temperature, septicity, and nutrient content.
- Design, including limited air supply, poor mixing, short-circuiting, poor clarifier design and limited return sludge pumping capacity.
- Operational issues (e.g., low dissolved oxygen, insufficient nutrients, low F/M, insufficient soluble BOD).

14.9.5 Foaming in the Aeration Basin

Foam is a mass of small gas bubbles that form on the surface of a liquid. In the case of activated sludge, foaming is a common problem which can be caused by several factors:

- Normal sludge has a light tan color and covers 10 to 25% of the tank surface. The bubbles dissipate quickly.
- Young sludge is indicated by stiff white, billowing foam. It is usually found in an overloaded plant. Sludge age and MCRT can be increased by increasing RAS or decreasing WAS.

- Filamentous foaming organisms (e.g., Norcardia, Microthrix) will produce excessive brown foam.
    - Norcardia will have a strong greasy dark tan foam that will carry over onto the clarifier. This scum should be wasted rather than returned to the aeration tank.
    - A stable dark tan or brown greasy foam that can get thick enough to have a crust is an indication of a plant with Microthrix problems. This may be due to grease in the lift station or collection systems entering the plant.
- Think scummy dark brown foam indicates an old sludge due to high MCRT.
- Industrial/chemical discharges (e.g., detergents, phosphates) can overload the facility.

Filamentous foaming organisms can be controlled by adjusting the environmental conditions in the aeration basin by adjusting either the F/M ratio, the sludge age, and/or the levels of dissolved oxygen. Industrial/chemical discharges can be reduced by implementing and enforcing an effective pretreatment program and by monitoring the influent for compounds that might have a negative impact on the operation of wastewater treatment.

14.9.6 Filamentous Bacteria

The overgrowth of filamentous bacteria (filamentation) can occur when the:

- Aeration tank has a low dissolved oxygen concentration.
- F/M ratio is low.
- pH is low.
- Wastewater has a nutrient deficiency.
- Wastewater has become septic.
- Wastewater has excessive concentrations of grease and oil.

As a result, the problem can be reduced or eliminated by correcting each of the conditions listed above and ensuring that the system is operated at optimal conditions (see Section 14.6).

14.9.7 Energy Consumption

The traditional activated sludge process can consume a fair amount of electricity. By far, the greatest amount of electricity is consumed by the aeration system (i.e., approximately 60%), followed by wastewater pumping (12%), anaerobic digestion (11%), and lighting and buildings (6%). Energy usage, and associated costs, can be reduced by having energy efficient aeration systems, blowers, motors, pumps, and lighting.

14.10 Ponds and Lagoons

In addition to the use of concrete reactors and basins (as was introduced in the previous sections on activated sludge processes), solids and BOD removal can also be accomplished using ponds and lagoons. It should be stressed that for the purpose of this manual, the terms ponds and lagoons will be used interchangeably (which means they are the same thing). However, ponds tend to be small and shallow, and lagoons tend to be larger in size and deeper. In general, ponds and lagoons can be classified in multiple ways, depending upon:

- Their primary function.
- Aeration, whether aerobic, facultative, or anaerobic.

- Their number and configuration.

14.10.1 Classification Based on Function

Ponds and lagoons can be classified by how they are used in the overall treatment process. Three examples are described below.

14.10.1.1 Stabilization Ponds

Stabilization Ponds are primarily used at the beginning of the wastewater treatment process to stabilize the wastewater before subsequent treatment. Stabilization ponds can be used as a part of a pretreatment process of industrial wastewater or part of the overall treatment process for domestic wastewater. They can also be used as part of an equalization treatment of influent.

14.10.1.2 Treatment Ponds

Treatment Ponds are typically used as part of secondary treatment of wastewater. When coupled with mechanical aeration and sludge recycling, treatment ponds effectively operate like a modified activated-sludge process.

14.10.1.3 Polishing Ponds

Polishing Ponds are typically used at the end of the treatment process, either as a third stage treatment for effluent from activated sludge or trickling filter secondary clarifier effluent. They are also used as a third stage in a multi-stage flow-through lagoon system where they typically follow **facultative ponds** and are generally aerobic throughout their depth.

14.10.2 Classification Based on Aeration

14.10.2.1 Aerobic Ponds/Lagoons

Aerobic ponds support aerobic bacteria in the decomposition of organic wastes in wastewater. When the aerobic bacteria use oxygen to break down the organic matter, they produce ammonia and carbon dioxide. Aerobic ponds can be classified into naturally aerated ponds or mechanically aerated ponds depending upon the amount and source of oxygen being supplied to the pond. These types of ponds also encourage the growth of algae.

Naturally aerated ponds are typically relatively shallow, with depths varying from 1 to 2 feet, to allow sunlight to penetrate the full depth of the pond. Due to the shallow nature of the pond, dissolved oxygen is maintained throughout the entire depth of the pond to prevent the development of anaerobic conditions. The dissolved oxygen is typically supplied by algal photosynthesis and natural surface aeration. In some cases, minimal mixing may be required to expose all the algae to sunlight and to minimize solids deposition. When multiple ponds are used in series, the algae in such ponds can be effective in removing most of the nitrogen and phosphorus from the effluent. Such ponds can also remove a significant amount of the residual pathogens through die-off and settling. The typical detention or hydraulic residence time (HRT) for aerobic ponds is typically 5-40 days (Ref. 6).

Mechanically aerated lagoons typically have depths ranging from 6.5 to 16.5 feet. Solids in the lagoon are always kept in suspension by the injection of **diffused air** or by mechanical aerators.

Depending upon the hydraulic retention time, the effluent from the pond will typically contain between one-third and one-half the original influent BOD_5 load in the form of living and dead microorganisms (Ref. 2). As a result, some type of settling must be employed following the aeration, either in another lagoon or in an actual sedimentation basin.

Most aerated lagoons operate without any recycling of the solids. If the solids are recycled, the lagoon effectively behaves as a modified activated-sludge process. A summary of the general operating characteristics of both types of mechanically aerated lagoons are provided below in Table 14.10 (Ref. 2).

Table 14.10 Operational Characteristics of Mechanically Aerated Lagoons

Parameter	Without Recycling	With Recycling
TSS, mg/L	100 - 400	1500 - 3000
VSS/TSS ratio	70-80 % VSS/TSS	50-80 % VSS/TSS
SRT, days	3 - 10	10 - 30
HRT, days	3 - 10	0.25 - 2.0
Sludge	Accumulates in external facility or pond	Recycled to process from sedimentation basin or discharged to sludge drying fields
Nitrification	Not typically	Likely, especially in warmer climates

14.10.2.2 Facultative Ponds/Lagoons

Facultative ponds are the most common type of ponds used in wastewater treatment. They are usually 4 to 8 feet deep and consist of an aerobic layer overlaying an anaerobic layer of sludge at the bottom of the pond. Such ponds are frequently constructed as a single large pond with an inlet located near the center of the pond. However, such a design can result in short-circuiting and an ineffective use of the pond volume. USEPA strongly recommends the use of at least three cells, in series, with a well-designed inlet and outlet structures (Ref. 13). To be effective, hydraulic retention times for facultative ponds can range from 20 to 180 days.

Facultative ponds can be used as one part of a system of ponds. Typically, they would follow an anaerobic stabilization pond and be followed by an aerobic polishing pond (Figure 14.19). They can also be used as part of a more conventional treatment process (e.g., following a trickling filter or suspended growth process).

The oxygen in the aerobic zone can be provided by algae and surface re-aeration, while the anaerobic bacteria in the bottom zone will produce carbon dioxide, methane, and hydrogen sulfide. Carbon dioxide can also be released by cellular respiration in bacteria and algae.

Facultative ponds are normally designed to reduce effluent concentrations of BOD_5 to around 30 mg/L, but actual values may be greater due to presence of algae in the effluent. Organic removal can vary between 77-96%, nitrogen removal can vary between 40-95% and phosphorus removal rates are typically below 40%. TSS levels in the effluent can vary between 40 to 100 mg/L. The ponds are generally effective in removing fecal coliform due to the longer detention times and associated die off (Ref. 6).

An estimate of the organic loading applied to a facultative pond (typically 13 to 71 lbs/acre/day) can be obtained by dividing the daily BOD loading by the surface area of the lagoon using following equation [25] (Ref. 13):

$$[25]\ (Organic\ Loading, lbs\ BOD/acre/day) = \frac{(Flow, MGD)\ x\ 8.34\ x\ (BOD, \frac{mg}{L})}{(Area, acres)}$$

Example 14.16

The design flow to two 740 feet wide by 550 feet long lagoons is 0.7 MGD with an influent BOD concentration of 168 mg/L. What is the organic loading in lbs of BOD per acre per day?

Solution:

First, calculate the required surface area.

$$Surface\ Area\ (acres) = \frac{740\ ft\ x\ 550\ ft}{43{,}560\ ft^2/ac} = 18.69\ acres$$

Next, calculate the organic loading.

$$Organic\ Loading\ \left(\frac{lbs\,\frac{BOD}{acre}}{day}\right) = \frac{0.7\ MGD\ x\ 8.34\ x\ 168\ mg/L}{43{,}560\ ft^2/ac} = 52.48\ acres$$

Alternatively, one can calculate the required surface area of a pond for a given organic loading using equation [26].

$$[26]\ (Required\ Suface\ Area\ (acres) = \frac{(Flow, MGD)\ x\ BOD\ _5\ x\ 8.34\ \ (\frac{lb}{MG})(\frac{L}{mg})}{(Loading\ Rate, \frac{lb}{acre}\ x\ day)}$$

Example 14.17

The design flow to a lagoon is 0.7 MGD with an influent BOD concentration of 168 mg/L. If the desired organic loading in lbs of BOD per acre per day is 52.48, what is the required surface area?

Solution:

Using equation [26], the required surface area is:

$$[26] Required\ Surface\ Area\ (acre) = \frac{0.7\ MGD\ x\ 168 \frac{mg}{L} x\ 8.34}{54.28\ lbs \frac{BOD}{acre}\ x\ day} = 18.69\ acres$$

While facultative ponds are commonly used in wastewater treatment, they do have some disadvantages (Ref. 14):

- Significant amounts of nitrogen and phosphorus can be found in the effluent.
- Facultative ponds can require a large amount of area. For example, a pond with an influent of 1 MGD and a loading of 50 lb BOD_5/acre-day could require ponds with a total surface area of 30-acres.
- Inversions can occur in the spring and fall when the surface water layer may have a higher density than the lower lays due to fluctuations in temperature. The higher density water sinks during these unstable periods, creating turbidity, and produces objectionable odors.

14.10.2.3 Anaerobic Ponds

Anaerobic ponds are deep wastewater ponds, between 8 to 16 ft deep that have very low levels of dissolved oxygen to anaerobic conditions in much of the lagoon. The typical retention times for such lagoons range from 5-50 days (Ref. 14). The anaerobic bacteria that live in the bottom sludge of the pond decompose the organic material in the waste and produce carbon dioxide and methane like an anaerobic digester. Most anaerobic ponds are covered to collect these gases, or they are released to the atmosphere. In addition, gases such as hydrogen sulfide can be produced, leading to potential odor problems (Ref. 6).

Anaerobic ponds are usually used to treat strong industrial or livestock wastes. They are also used as the first stage in a multi-stage flow-through pond/lagoon system, typically preceding facultative ponds.

Unlike aerobic ponds, anaerobic ponds do not require oxygen and they produce less sludge. However, as noted above, they can also produce noxious odors due to release of hydrogen sulfide. The water in the ponds needs to be kept at a relatively high temperature to support the anaerobic digestion of wastes. As a result, they may require longer detention times in colder climates or winter, since most anaerobic ponds are designed to operate in the mesophilic temperature range and thus are inactive at temperatures below 15°C. Finally, because the anaerobic process does not completely degrade all the waste, some type of second stage aerobic process is typically employed (Ref. 6). Optimal operating conditions for anaerobic ponds are provided below.

14.10.3 Classification Based on Number and Configuration

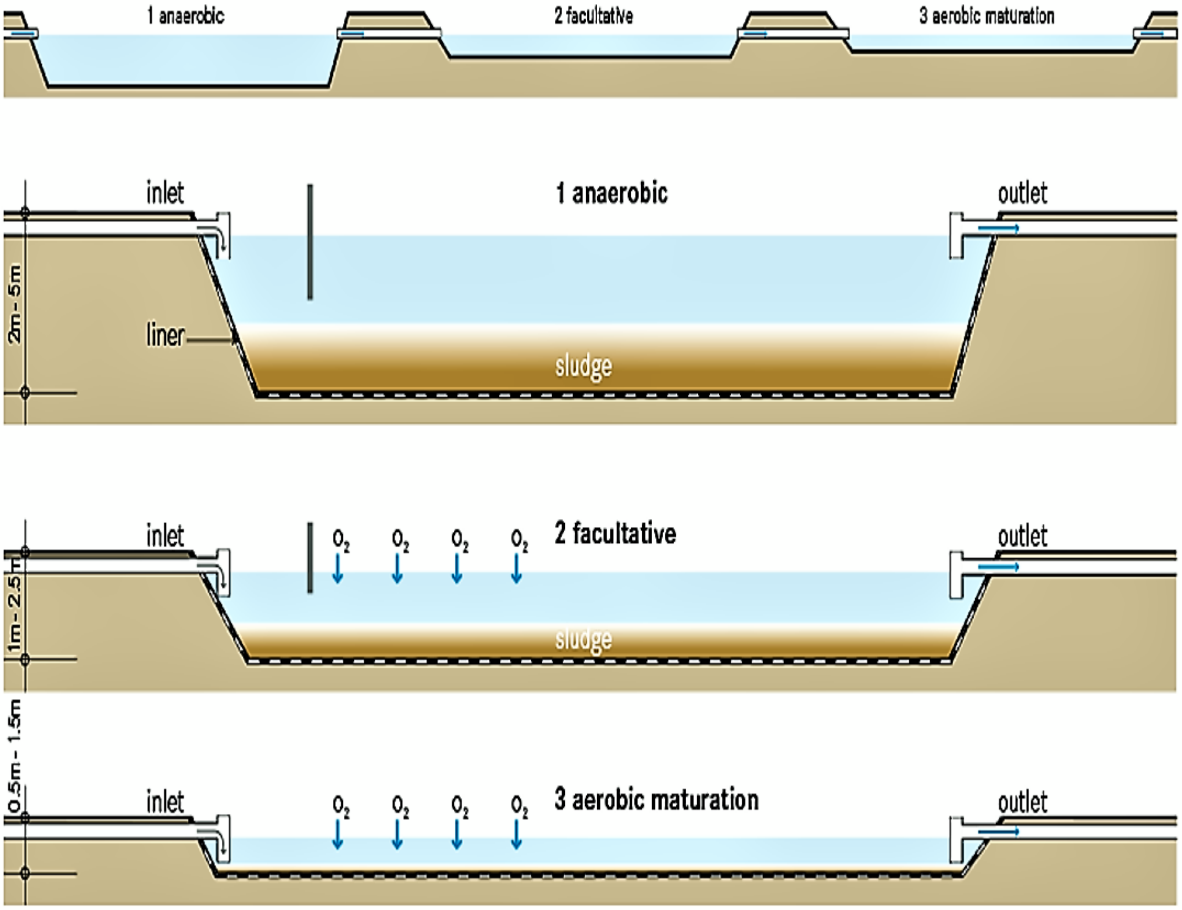
14.10.3.1 Single Ponds/Lagoons

Sometimes a wastewater pond will be constructed as a single unit. This may be the case with either a small wastewater facility or where a specific type of pond (e.g., anaerobic, facultative, or aerobic) is part of a tertiary treatment process. A single pond may also be used as a mechanically aerated ponds with return sludge, where the pond is effectively operating as an activated sludge system.

14.10.3.2 Ponds/Lagoons in Series

More often than not, individual wastewater ponds are part of a larger series of ponds that make up a cumulative treatment process (Figure 14.19).

Figure 14.19 Schematic of a Typical Pond Waste Stabilization System



In the above example, the wastewater first enters an anaerobic pond which serves as the primary treatment stage. The solids settle out as sludge and the organic load in the wastewater is typically reduced by up to 60%. The wastewater then passes on to the facultative pond where the total cumulative BOD removal can reach up to 75%. This pond also receives additional solids and biomass from the anaerobic pond which continue to settle out as sludge. The last pond in the series, the aerobic pond, serves as a finishing pond. Algae, when carrying out photosynthesis, help to add oxygen back into the waste-stream and consume carbon dioxide produced by the bacteria. This pond can also help to reduce the numbers of bacteria and pathogens in the effluent.

14.10.3.3 Ponds/Lagoons in Parallel

As the total design influent to a wastewater plant increases, one common solution to increased influent load is to construct a number of parallel ponds prior to primary treatment to provide treatment redundancies, as well as the ability to take a particular treatment process off-line for maintenance, sludge removal, or repair.

14.10.4 Operation and Maintenance of Ponds/Lagoons

14.10.4.1 General Operational Parameters

General operational parameters for the four different types of ponds discussed previously are provided in Table 14.11.

Table 14.11 General Operational Parameters for Ponds and Lagoons

Parameter	Aerated[1]	Aerobic[2]	Facultative[3]	Anaerobic[4]
Detention Time (d)	3-10	5-40	5-30	20-50
Pond size (ac)	2-10	2-10	2-10	0.5-2
Depth (ft)	6-20	3-5	4-8	8-16
pH	6.5-8.0	6.5-10.5	6.5-9.5	6.5-7.2
Temperature Range °C	0-30	0-30	0-50	15-50
Optimum Range °C	20	20	20	30
BOD Loading (lb/ac/day)	80-95	60-120	50-180	200-500

[1] Pond includes supplemental aeration (i.e., mechanical or diffused aeration)

[2] Pond does not include any supplemental aeration.

[3] Pond includes supplemental aeration. For ponds without supplemental aeration, typical BOD loadings are about one-third of those listed.

[4] Anaerobic ponds utilized for pretreatment of high strength wastes must be followed by an aerated, aerobic, or a facultative pond.

14.10.4.2 Stabilization Ponds/Lagoons

Pond scum on stabilization ponds should be removed regularly to ensure proper aeration and allow sunlight to penetrate the water to allow algae to photosynthesize. Excessive aquatic plants such as weeds, grasses, and trees should also be periodically removed to ensure that enough sunlight penetrates through the surface layer of the pond. In general, the sludge at the bottom of an anaerobic pond should be removed approximately once every 2 to 5 years or when the accumulated solids reach 1/3 of the pond volume. Sludge can be removed using a raft mounted sludge pump or by dewatering the pond and removing the sludge manually using a backhoe or front-end loader (Ref. 15).

Additional operational guidance for stabilization ponds/lagoons are summarized below:

- In order to decrease the potential for odor problems, operations should be started with at least one foot of water in the pond.
- The pH in an anaerobic pond should be generally kept between 6.5 and 7.2 to help optimize the growth of acid-producing anaerobic bacteria. If the pH falls below 6.5, soda ash can be added to the pond to regulate the pH.
- Short-circuiting problems can be reduced through the effective use of entrance and exit locations and baffle curtains.
- Pond depths of at least 3 feet are necessary to control weed growth.
- Plants (weeds) along the water's edge should be removed as they can impact the integrity of the bank.
- Pond banks can be lined with riprap to control weed growth and deter erosion caused by wind/wave action.
- In general herbicides should not be used to control vegetation, since the chemicals may wash into the basin and affect the biological processes.
- With enough wind action, suspended and floating plants (e.g., Duckweed) should not become a problem.

14.10.4.3 Aerated Ponds/Lagoons

Additional operational guidance for aerated lagoons is summarized below.

- Aerated lagoons require daily inspections to ensure that the aeration system is working properly.
- When performing daily inspections, check for "dead spots" where there appears to be no turbulence or mixing.
- In general, a minimum DO concentration of 2.0 mg/L and a pH above 7.5 should be maintained throughout the cells.
- Mechanical surface aerators should provide good turbulence and a little froth.
- The following parameters should be monitored and recorded on a regular (daily) basis: basin inflow, DO, pH, BOD_5, TSS, alkalinity, and sludge depth. Volatile acids should be checked in facultative ponds.

14.11 Fixed Media Treatment Technologies

As we have already seen, wastewater can be treated using two different types of suspended media treatment systems: activated sludge or ponds/lagoons. Instead of using suspended systems in which the wastewater is suspended or detained in a large tank or pond, wastewater can also be treated using systems where the treatment media (e.g., natural or manufactured surfaces) are fixed and the wastewater flows over the media. The two most common fixed media secondary treatment processes are trickling filters and rotating biological contactors. In general, such systems can provide the removal of up to 90% or more of the total BOD loading (Ref. 17).

14.11.1 Trickling Filters

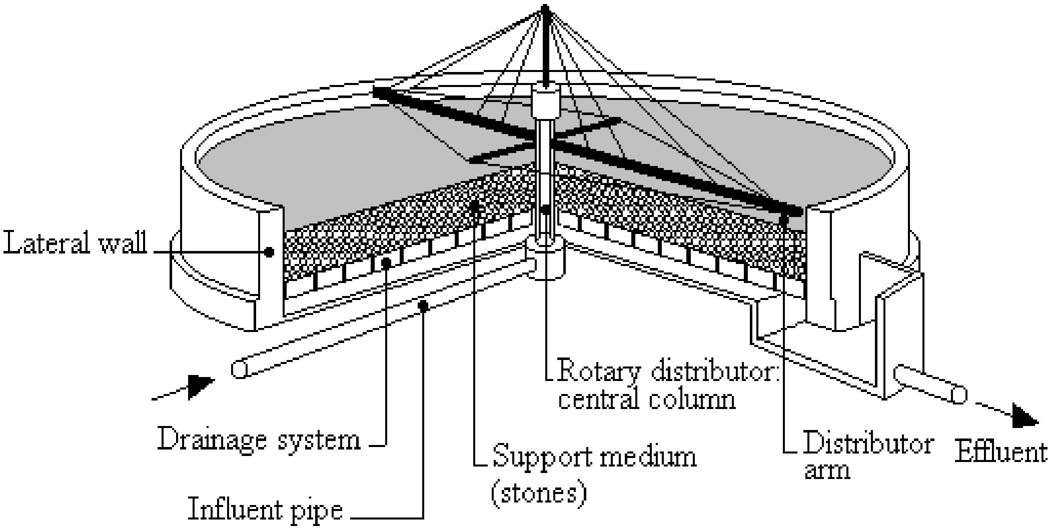
A schematic of a typical trickling filter is provided in Figure 14.20. Wastewater trickles out of a rotating arm and falls onto a filter bed made up of various type of filter media such as rock, plastic, or slag. Bacteria growing on the filter media then interact with the wastewater to reduce the organic content.

Trickling filters have many advantages:

- They are simple and reliable.
- Their smaller surface area requires less land.
- The bacteria living on the media rapidly reduces BOD in wastewater.
- They require very little power.
- They tend to be very durable.

As with any wastewater technology, it is still important that the operator continue to make periodic observations to ensure that the filter is operating effectively. Filters may occasionally need to be cleaned of snails and crane fly larva, which can be achieved by increasing the flushing intensity.

Figure 14.20 Schematic of a Trickling Filter Biological Treatment System



Trickling filters typically consist of three basic parts: the media (and retaining structure), the underdrain system, and the distribution system (Ref. 17).

The media provide a large surface area upon which a biological slime grown develops. The slime growth, sometimes called a zoogleal film, contains the living organisms that break down the organic material. The media may be rock, slag, coal, bricks, redwood blocks, molded plastic, or any other durable material. The media should be of such sizes and stacked to provide empty spaces or voids to allow air to ventilate the filter and keep the conditions aerobic. For rock, the size will usually be from about two inches to four inches. The actual size is not extremely critical, but it is important that the media be uniform in size to allow for adequate ventilation.

The media depth ranges from about three to eight feet for rock media trickling filters and 15 to 30 feet for synthetic media.

The underdrain system supports the media and permits air flow. Common materials for construction underdrain systems include spaced redwood stringers and prefabricated blocks constructed of concrete, vitrified clay, or other suitable material.

The distribution system is usually a rotary-type distributor consisting of two or more horizontal pipes supported a few inches above the filter media by a central column. The wastewater is fed from the column through the horizontal pipes and is distributed over the media through orifices located along one side of each of these pipes or arms. Rotation of the arms is due either to the rotating water-sprinkler reaction form wastewater flowing out the orifices or by some mechanical means. The distributors are equipped with mechanical-type seals at the center column to prevent leakage and protect the bearings, stay rods for seasonal adjustment of the distributor arms to maintain an even distribution of wastewater, and arm dump gates at the end of each arm to permit easy flushing.

The fixed-nozzle distribution system is not as common as the rotary type but is commonly found only in small wastewater treatment plants. Disadvantages of fixed nozzles include difficult access for nozzle cleaning and high pumping requirements to maintain good hydraulic distribution.

Depending upon the hydraulic loading rate, trickling filters can be sub-classified based on either rate (i.e., low-rate, intermediate rate, high rate, or super high-rate), configuration, or function. Two-stage configurations involve two trickling filters in series, separated by an intermediate clarifier. Roughing filters are typically much deeper than regular filters and are used to “knock down” an initial BOD loading before some other type of treatment. Examples of the typically operational characteristics of these different types of filters are summarized in Table 14.12. Underdrains are vital to the operation of trickling filters to allow air to circulate up through the media to keep the bacteria oxygenated.

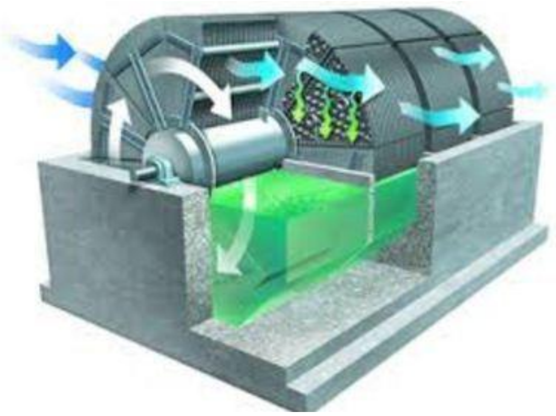
Table 14.12 Operational Characteristics of Different Types of Trickling Filters

Item	Low-Rate	Intermediate Rate	High-Rate	Super High-Rate	Two-Stage	Roughing
Filter Medium	Rock, Slag	Rock, Slag	Rock	Plastic	Rock, Plastic	Plastic, Redwood
Hydraulic Loading, gpm/ft^2	0.02 - 0.06	0.06 - 0.16	0.16 - 0.64	0.2 - 1.2	0.16 - 0.64	0.8 - 3.2
BOD_5 loading, lbs/1000 ft^3/day	5 - 25	15 - 30	30 - 60	30 - 100	60 - 120	100 - 500
Depth, feet	6 - 8	6 - 8	3 - 6	10 - 40	6 - 8	15 - 40
Recirculation Ratio	0	0 - 1	1 - 2	1 - 2	0.5 - 2	1 - 4
Filter Flies	Many	Varies	Few	Few or None	Few or None	Few or None
Sloughing	Intermittent	Intermittent	Continuous	Continuous	Continuous	Continuous
BOD_5 Removal Efficiency, %	80 - 90	50 - 80	60 - 90	60 - 90	85 - 95	40 - 70
Effluent	Well nitrified	Some nitrification	No nitrification	No nitrification	Well nitrified	No nitrification

14.11.2 Rotating Biological Contactor

Rotating biological contactors (RBC) treat wastewater by allowing water to come into contact with biological medium so that the attached bacteria can break down the organic solids. RBCs operate by rotating plastic discs that contain a growth of microorganisms and a slime layer (Figure 14.21). This rotating system allows the organisms on the contactor to obtain the oxygen necessary for growth from the air, while also getting the nutrients from the wastewater.

Figure 14.21 Rotating Biological Contactor (Indiamart)



14.12 Secondary Clarifiers

After the wastewater is treated biologically, the effluent is passed on to a secondary clarifier where the biological sludge is separated from the liquid waste. These clarifiers function very similarly to primary clarifiers as discussed in Chapter 13. As with primary clarifiers, they can come in both circular and rectangular designs. Some typical design guidelines for secondary clarifiers for an activated sludge process are provided below:

Table 14.13 Typical Design Guidelines for Secondary Clarifiers for Activated Sludge

Type of Treatment	Overflow Rate, gal/ft^2/day		Solids Loading, lb/ft^2/hr	
	Average	**Peak**	**Average**	**Peak**
Air-activated sludge	400 - 700	1000 - 1600	0.8 – 1.2	1.6
Oxygen activated sludge	400 - 700	1000 - 1600	1.0 - 1.4	1.8
Extended aeration	200 - 400	600 - 800	0.2 - 1.0	1.4

14.12.1 Operation Considerations for Secondary Clarifiers

In general, it is a good idea to have multiple clarifiers if the average design flow of the facility exceeds 100,000 gallons/day (Ref. 8). Process control adjustments for facilities with multiple clarifiers that may help to eliminate or prevent long term solids washouts include:

- Even distribution of flow to all clarifiers.
- Reducing excessive return activated sludge (RAS) flowrates by increasing the waste activated sludge (WAS).
- Maintaining sludge blanket depths in all units at 1-3 feet.

If abnormal conditions are observed in the clarifiers (e.g., solids flowing over the weirs, sludge bulking), the operator should investigate the following:

- Are sludge return pumps working properly?
- Is the sludge collection equipment such as flights, scrapers, and suction orifices working properly?
- Are the sludge blanket depths adequate (i.e., 1-3 ft)?

14.13 Finding Help

If you find yourself dealing with an operational problem that you cannot solve, there are several resources that you can consult to try to come up with an effective solution. A few of those are listed here:

- Other operators: you may be able to check with an operator at another utility. One way to develop relationships with other operators is through the **Kentucky Water and Wastewater Operators Association** (KWWOA). KWWOA provides annual conferences and training courses.

- Kentucky Certification and Licensing Branch (CLB)**:** As their name implies, **CLB** has staff that can assist utilities that may be struggling with an operational issue.
- Kentucky Division of Water (DOW)**:** **DOW**'s Field Operations Branch consists of ten regional offices located throughout the state. Regional office staff provide technical assistance to the public, respond to emergencies, and provide support to other DOW programs.
- Kentucky Infrastructure Authority: **KIA**, under the Office of the Governor and administratively attached to the Department for Local Government (DLG), provides financial help in the way of grant and loan assistance to communities for water and wastewater needs.
- Kentucky Rural Community Assistance Program (KY-RCAP): **KY-RCAP** provides consulting services to help rural communities address their drinking water and wastewater treatment needs. RCAP provides training and technical assistance to water and wastewater systems under 10,000 in population.
- Kentucky Rural Water Association (KRWA): **KRWA** provides training and technical assistance to water and wastewater systems.
- Kentucky Water Resources Research Institute (KWRRI): For more complicated problems, or problems needing additional research, **KWRRI** at the University of Kentucky can help connect you with water researchers across the commonwealth who might be able to help address a specific problem. They also work closely with DOW, KIA, KY-RCAP and others in support of water and wastewater utilities. KWRRI administers a small federal grant program that may be able to support research dealing with operational issues.

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14.15 Other Resources

Treatment Plant Operator.
The Wastewater Blog.
Khan Academy. **Biology**.
Kentucky Rural Water Association.
Kentucky Water Resource Research Institute.
Kentucky Water and Wastewater Operators Association.
Clean Water Professionals of Kentucky/Tennessee.
Kentucky Operator Certification Program.
Water Technology.

Chapter 15

Tertiary [Third Level] Treatment

15.1 Types of Advanced Tertiary Treatment

The third level of wastewater treatment provides a series of steps to further clean the water before returning it to the environment or reuse. Tertiary treatments may be needed to address the following scenarios of residual pollutants or contaminants after secondary treatment:

- The need to remove organic matter and total suspended solids beyond what can be accomplished by conventional or secondary treatment.
- The need to remove residual total suspended solids so that the treated wastewater can be more effectively disinfected.
- The need to remove nitrogen and phosphorus beyond what can be accomplished by conventional secondary treatment.
- The need to remove specific inorganic substances such as heavy metals and organic compounds (e.g., MBTE, NDMA, PFAS) to meet more stringent discharge requirements.

Several different advanced treatment technologies have been developed to address such pollutants. These are summarized in Table 15.1.

Table 15.1 Advanced Treatment Methods for Associated Types of Pollution

Treatment Method	Suspended Solids	Particulate Organic Matter	Dissolved Organic Carbon	Total Organic Carbon	Volatile Organics	Dissolved Inorganic Matter	Ammonia	Phosphorus
Depth Filtration	X	X						X
Surface Filtration	X							
Micro & Ultra Filtration	X							
Reverse Osmosis	X	X	X	X		X	X	X
Adsorption	X	X	X	X				
Air Stripping					X		X	
Ion Exchange	X			X		X	X	
Chemical Oxidation		X		X				
Chemical Precipitation	X			X				X
Advanced Oxidation [a]			X	X				
Distillation	X	X	X	X	X	X	X	X
Biological treatment [b]							X	X

a. Permanganate, hydrogen peroxide, ozone.

b. Usually this can be achieved in secondary treatment.

A detailed description of each of these methods is beyond the scope of this manual. To learn more about a particular process, refer to *Wastewater Engineering* by Metcalf and Eddy, 2003 (Ref. 1). For most operators, advanced treatment methods will normally be limited to one of the following four advanced treatment techniques:

1) Chemical precipitation for suspended solids, total organic carbon, and phosphorus removal.
2) Depth filtration for suspended solids and phosphorus removal.
3) Air stripping for ammonia and volatile contaminants.
4) Adsorption for suspended solids and hard to treat organics (e.g., PFAS).

Each of these is briefly discussed in the following sections.

15.2 Chemical Precipitation

Suspended solids, total organic carbon, and phosphorus can all be removed by adding chemicals to the wastewater. This will then cause the pollutants to clump together with the chemical or coagulate and then settle out of the wastewater as a precipitate. The most common use of coagulation is to reduce the level of phosphorus in the wastewater effluent. The most common chemicals added to wastewater to achieve this objective are lime, alum, and iron salts.

15.2.1 Calcium

Calcium is usually added in the form of lime, $Ca\ (OH)_2$. Lime reacts with the natural alkalinity in the wastewater to produce calcium carbonate, which is primarily responsible for enhancing the removal of suspended solids and coagulated phosphorus. As the pH value of the wastewater increases beyond about 10, excess calcium ions will react with the phosphorus in the water and form a solid that can be removed. Dosing therefore will be based on the existing alkalinity of the wastewater, not the amount of phosphorus in the water. Because addition of lime increases the pH of the water, there will need to be a way to lower the pH before further treatment or disposal. This lowering of pH is commonly achieved using carbon dioxide or hydrochloric acid.

15.2.2 Aluminum

Alum or aluminium sulphate is widely used to treat phosphorus in wastewater. The dosage rate required is dependent on the level of phosphorus in the water as alum treatment is most effective at higher phosphorus concentrations. However, aluminium concentrations in the resulting sludge (i.e., greater than 2,000 mg/L) can adversely affect the microbial populations potentially creating problems with sludge treatment. This means that dosage rates of aluminium should be monitored.

15.2.3 Iron Salts

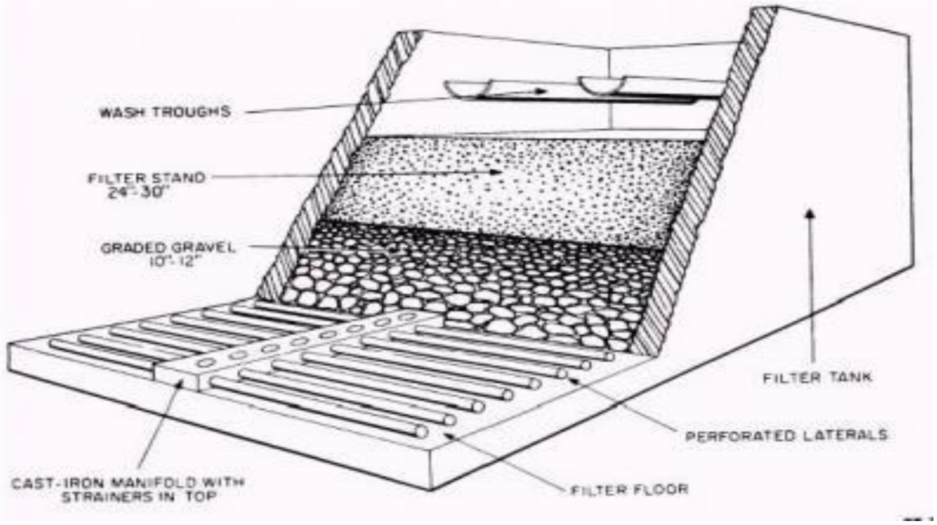
Ferric chloride, ferric sulphate, and ferrous sulphate are all widely used for phosphorous removal, although the actual reactions are not fully understood.

15.3 Sand Filtration

Filtration removes small particles from the water to reduce both solids and precipitated nutrients that remain in the water. Following secondary treatment, most of the larger solids have been removed, so this process is used for final cleaning and removal of small, suspended particles.

Sand filtration involves the removal of particles by passing the wastewater vertically through a bed of granular or compressible filter media. One of the more common types of rapid filtration involves the use of sand, supported by a bed of graded gravel. A cross section of a typical rapid sand filter is shown in Figure 15.1.

Figure 15.1 Cross Section of a Typical Rapid Sand Filter



Sand filters work by giving the remaining solids in the wastewater many chances to be captured or trapped between the sand particles in the filter. This occurs because sand is placed over a drainage system and water is loaded onto the top of the sand. The loading of wastewater should occur slowly enough that the surface of the sand remains undisturbed. The water will slowly drain through the sand bed, giving the remaining solids in the water time to be removed.

Table 15.2 Characteristics of Rapid and Slow Sand Filters

Characteristics	Rapid Sand Filter	Slow Sand Filter
Filtration Rate, m/h*	5 – 15	0.08 – 0.25
Media Effective Size, mm*	0.5 – 1.2	0.15 – 0.3
Bed Depth, m*	0.6 – 1.9	0.9 – 1.5
Run Length	1 – 4 days	1 – 6 months
Ripening Period	15 min - 2 hours	Several days
Regeneration Method	Backwashing	Scraping surface
Maximum Raw Water Turbidity	Unlimited (with proper treatment)	10 NTU

* Note that the units for some characteristics are metric, meters, and millimeters.

Table 15.2 lists some characteristics of rapid sand filters compared to slow sand filters. From these differences, it should be clear why slow sand filters are not used to clean wastewater. Sand filtration often provides discharge water that has less than 5 mg/L of BOD_5 and suspended solids. In addition, sand filtration can remove up to 80% of the ammonia. Several factors affect the performance of the sand filter:

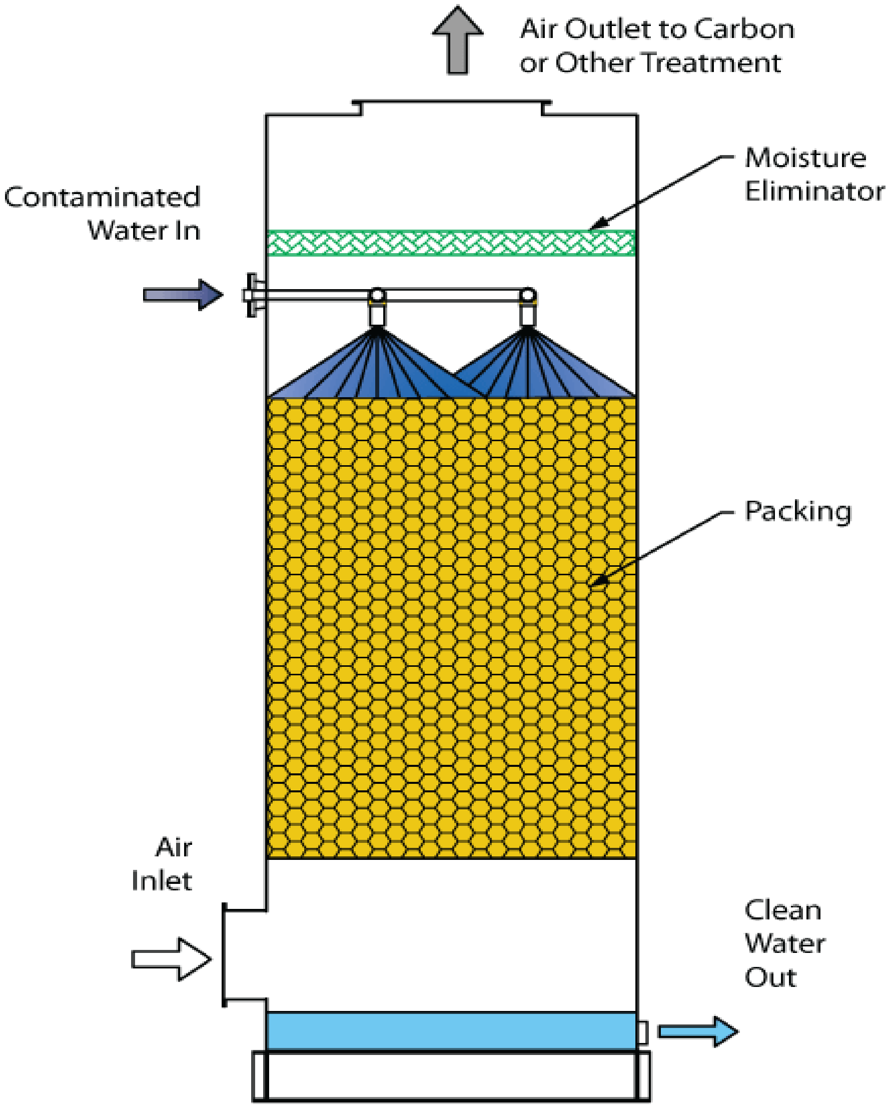
- Hydraulic loading rate.
- Organic loading rate.
- Sand depth.
- Maintenance of the system.

Maintenance of the sand filter must be performed to ensure that it is operating effectively. Rapid sand filters must be backwashed regularly to prevent clogging. The conventional rapid sand filter media has limited use in wastewater treatment because of its sensitivity to high suspended solids concentrations and wastewater is difficult to filter because the solids are sticky from biological activity. Dual-media and triple-media filters are more effective for wastewater filtration. The **mixed media gravity filter** is a coarse-to-fine filter because the pore space in the bed gradually tapers from coarse to fine in the direction of filtration. The number of media grains also increase at each successive layer which are deeper in the filter bed. Three different materials (coal, sand, and garnet) are used which enables storage of removed solids throughout the depth of the filter bed rather than only on the surface. The increased storage in mixed media filters extends the length of tilter fun between back-washing periods compared to the single-media filter beds. Even though, some single-media filters with coarse grains and shallow beds have been designed specifically for wastewater applications have proven to be successful (Ref. 2).

15.4 Air Stripping

Air stripping involves the removal of volatile compounds from wastewater by evaporation by passing the wastewater down through a vertical tower that contains some type of packing (typically plastic) while blowing air up from the bottom. The packing slows down the cascade of the wastewater so that more time is provided for the contaminants to volatilize which then move upward with the air. Depending upon the type of pollutant being removed from the wastewater, the air may then be treated by forcing the air through a secondary treatment unit which will normally involve some type of adsorption process. When removing ammonia/ nitrogen from the wastewater the air from the air stripping may be simply vented to the atmosphere. A schematic of a typical air stripping tower is provided in Figure 15.2.

Figure 15.2 Schematic of a Typical Air Stripping Tower



Ammonia stripping is a process that involves 3 steps:

1) The water pH must be raised to between 10.8-11.4. Typically, this is achieved by the addition of lime used for phosphorus removal.
2) The alkaline water is sprayed into the column and mixed with air, which allows the ammonia to be converted to other compounds.
3) The clean water is drained from the tower.

The advantages of air stripping are as follows:

- It is a relatively simple process that is not affected by changes in flow as long as the pH and temperature of the wastewater is maintained.
- There is no backwash needed to clean the column.
- Because this is a mechanical rather than biological process, toxic compounds in the wastewater will not affect performance.

The disadvantages of air stripping include:

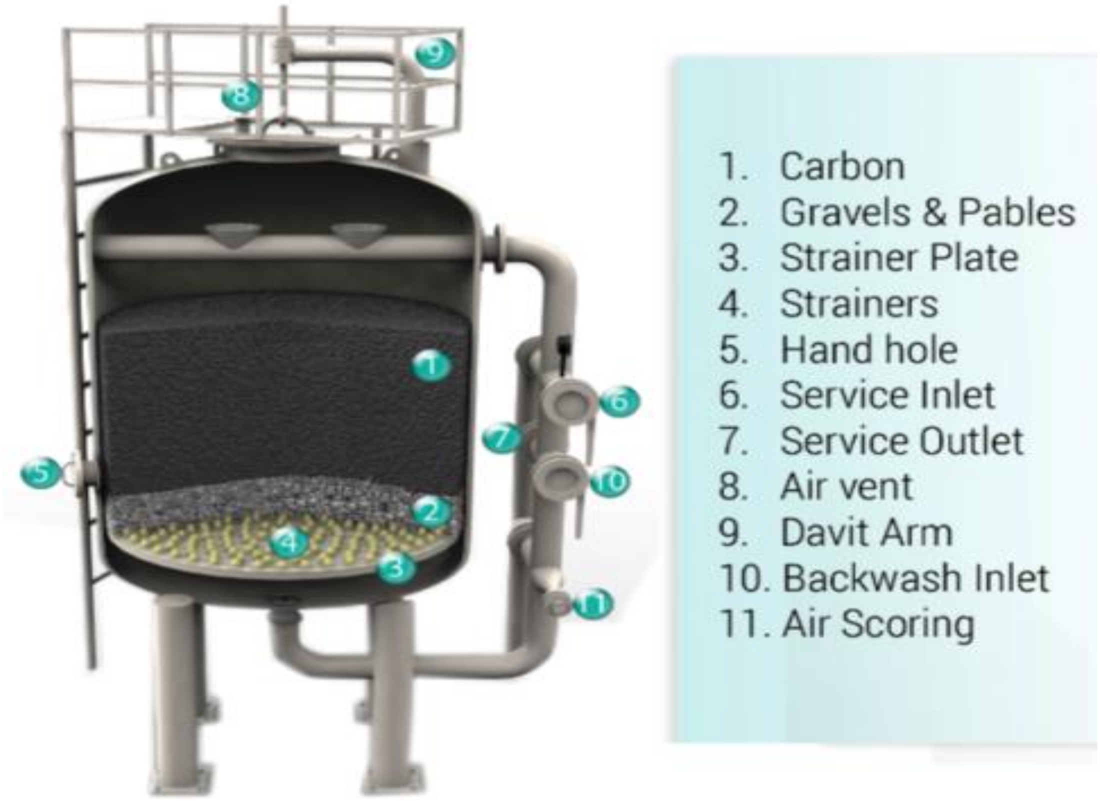
- Pumping of wastewater to the top of the column requires additional energy costs and maintenance.
- Scaling on column material at other parts of the column due to the lime added to the water to increase the pH.
- Ammonia stripping cannot be performed under freezing conditions.
- Ammonia is released to the air potentially creating air pollution concerns.

15.5 Adsorption

Adsorption treatment processes can be used to remove suspended solids and hard to remove organic compounds like MBTE, NDMA, and PFAS. In most cases, such systems work by passing the treated wastewater through a filtration chamber either using gravity or under pressure that contains some type of material that will adsorb the contaminants. The most common material used for this purpose is activated carbon.

Activated carbon systems work like other filtration systems. The water is loaded into the system, allowed to pass through the carbon, and then collected at the other end. As with sand filters, the activated carbon must be backwashed routinely to prevent clogging. A schematic of a typical activated carbon filter is provided in Figure 15.3.

Figure 15.3 Schematic of an Activated Carbon Filter



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Chapter 16

Disinfection

From the viewpoint of public health, as discussed in Chapter 10, page 86, disinfection is the most important stage of wastewater treatment. Wastewater disinfection takes place after all levels of wastewater treatment and just prior to the discharge of treated effluent. Disinfection is the primary cleaning process that kills, inactivates, or lowers the numbers of any pathogens found in wastewater. The removal of microorganisms from the wastewater is important to prevent the spread of infectious diseases by receiving waters used for public water supplies, recreation, irrigation, and aquatic life (Ref. 1). Table 16.1 lists some common microorganisms found in domestic wastewater and the diseases associated with them that could infect humans.

Table 16.1 Infectious Agents Potentially Present in Untreated Domestic Wastewater (Ref. 2)

Organism	Disease Caused
Bacteria	
Escherichia coli (enterotoxigenic)	Gastroenteritis
Leptospira (spp.)	Leptospirosis
Salmonella typhi	Typhoid fever
Salmonella (approx. 2,100 serotypes)	Salmonellosis
Shigella (4 spp.)	Shigellosis (dysentery)
Vibrio cholerae	Cholera
Protozoa	
Balantidium coli	Balantidiasis
Cryptosporidium parvum	Cryptosporidiosis
Entamoeba histolytica	Amebiasis (amoebic dysentery)
Giardia lamblia	Giardiasis
Helminths	
Ascaris lumbricoides	Ascariasis
T. solium	Taeniasis
Trichuris trichiura	Trichuriasis
Viruses	
Enteroviruses (72 types- e.g., polio, echoviruses, and coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis
Hepatitis A virus	Infectious hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis

Note: Adapted from Crites and Tchobanoglous, 1998.

Wastewater must be adequately treated to remove as much organic matter as possible prior to disinfection to reduce the generation of disinfection by products. A variety of physical and chemical methods are used to disinfect wastewater prior to it being discharged. Common treatment options include aqueous solutions of chlorine, chlorine dioxide, hypochlorite, ozone, peracetic acid and ultraviolet radiation. Table 16.2 summarizes the advantages and the disadvantages of the most common conventional disinfectants.

Table 16.2 Conventional Disinfection Technologies (Ref. 5)

Technology	Advantages	Disadvantages
Chlorine	Easy to handle. Economical. Technology well established. Does not require on-site generation.	Longer contact time than ozone. Disinfection by products formed. Wastewater must be dechlorinated prior to discharge. Very corrosive. Residual toxicity of the effluent.
Chlorine dioxide	More effective than chlorine with a shorter contact time.	Residual toxicity of the effluent. Disinfection by products formed. Must be generated on-site. More costly than chlorine. Increase the concentration of solids in the effluent.
Ozone	Short contact time.	No residual potential. Disinfection by products formed with bromine. Must be generated on-site. Higher electricity costs. High management costs.
Peracetic acid	Effective. Long shelf life. No disinfection by products formed.	Disinfection by products formed. Increase BOD and COD concentration in the effluent possible.
UV irradiation	Short contact time. No residual disinfection. No disinfection by products formed. Effective against viruses.	High cost and energy demand. Turbidity decreases effectiveness. No residuals.

Choosing the appropriate method of disinfection depends on several factors (Ref. 3):

- The characteristics of the wastewater and treatment processes prior to disinfection. This includes, but is not limited to, waste flow rates, pH, and disinfectant demand rates.
- The ability to kill or inactivate any infectious organism under normal operating conditions.
- How easy and safe the material is to handle, store, and ship.
- The presence or generation of any toxic residuals or disinfection by-products following disinfection.
- Economic considerations such as cost of the chemicals, equipment, utilities, and operations and maintenance.
- Any regulatory requirements such as disinfection by product violations.

16.1 Chlorination/De-chlorination

Chlorine and chlorine derivatives are the most common disinfectants used throughout the world because of their disinfecting properties and low cost. This is because chlorine in its various forms will either kill, inactivate, or significantly lower the numbers of most of the pathogens that cause illness in humans and animals (Ref. 4).

16.1.1 Chlorination

Chlorination is the process of adding chlorine or chlorine derivatives to water to kill bacteria and other microbes in water. Chlorine is available for disinfection in gas, liquid, and solid forms. The most common chlorine compounds used in wastewater treatment plants are chlorine gas (Cl_2), calcium hypochlorite [$Ca(OCl)_2$], sodium hypochlorite ($NaOCl$), and chlorine dioxide (ClO_2).

Chlorine will react with wastewater and combine with many of its contents such as metal ions, ammonia, and organic matter. These contents react and combine with chlorine prior to its reaction with pathogens. The interaction between chlorine and inorganic and organic material and what is used to kill microorganisms is called the **chlorine demand**. It is the difference between the amount of chlorine added to the wastewater (i.e., dosage) and the amount of residual chlorine that remains after a given contact time. The mechanism of chlorine disinfection and killing of microorganisms occurs by oxidizing cellular material and breaking down the cell wall of bacteria and protozoa.

The dosage of chlorine necessary to treat the wastewater can be found either through laboratory testing or actual measurements of the field samples. Keep in mind that the dosages established through these means will give a base feed rate but changing conditions during treatment will require that feed rates be corrected in real time.

Chlorine Dose = Chlorine Demand + Chlorine Residual (Ref. 4)

Several common inorganic materials found in wastewater react first with chlorine (Ref. 4):

- Hydrogen sulfide
- Ferrous iron
- Manganese ions
- Nitrite

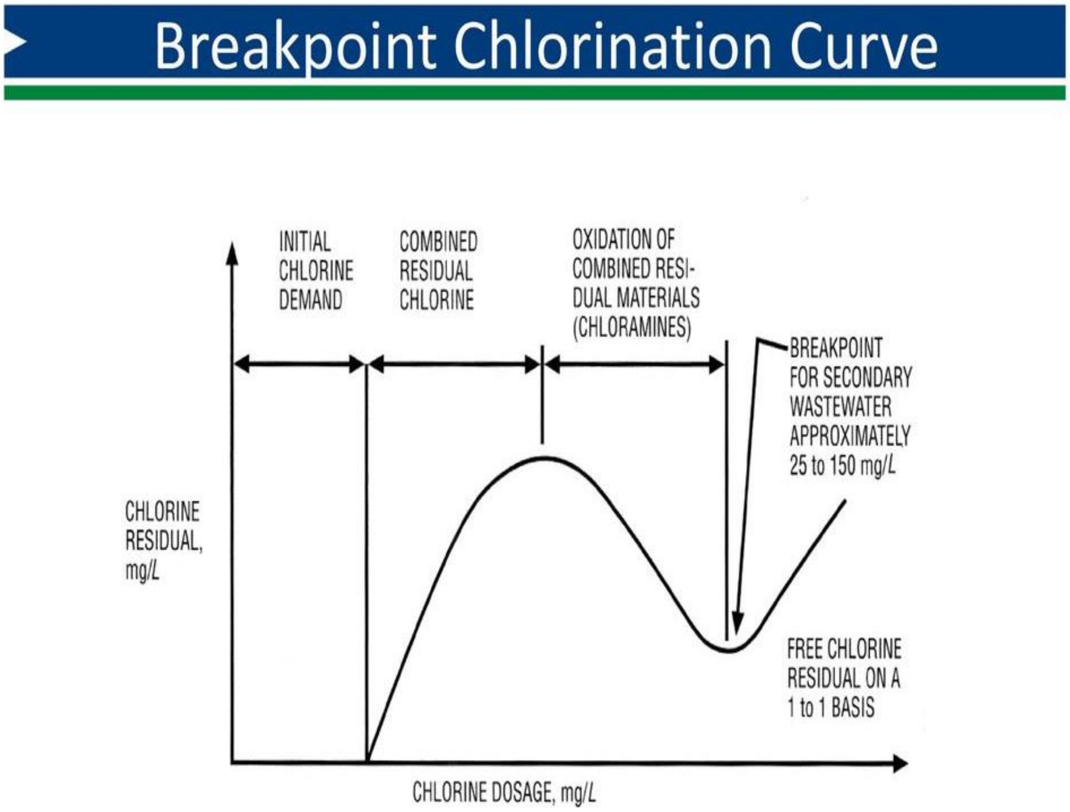
Following these interactions, chlorine will also react with Ammonia (NH3). Ammonia combines with chlorine to form one of three different forms of chloramine, which can also act as disinfectants.

Organic compounds are the last set of contents to react with available chlorine in the wastewater. These compounds generally originate from water containing dissolved organic matter from decayed animals, plants, bacteria, and algae.

16.1.1.1 Breakpoint Chlorination

Breakpoint chlorination is the process where chlorine is added to water or wastewater until the amount of chlorine needed to interact with any other compounds is satisfied. This initial amount of chlorine required is called the chlorine demand. At this point, further additions of chlorine will result in a free chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint as demonstrated in Figure 16.1. In wastewater treatment, breakpoint chlorination is a means of eliminating ammonia, which is converted to an oxidized volatile form (Ref. 5).

Figure 16.1 Breakpoint Chlorination Curve



16.1.1.2 Chlorine Exposure

According to the CDC, the extent of poisoning caused by chlorine depends on the amount of chlorine a person is exposed to, how the person was exposed, and the length of time of the exposure. When chlorine gas contacts moist tissues such as the eyes, throat, and lungs, an acid is produced that can damage these tissues.

After exposure to dangerous concentrations of chlorine, the following signs and symptoms may develop:

- Blurred vision.
- Burning pain, redness, and blisters on the skin if exposed to gas. Skin injuries like frostbite can occur if it is exposed to liquid chlorine.
- Burning sensation in the nose, throat, and eyes.
- Coughing.
- Chest tightness.

- Difficulty breathing or shortness of breath. These may appear immediately if high concentrations of chlorine gas are inhaled, or they may be delayed if low concentrations of chlorine gas are inhaled.
- Fluid in the lungs (pulmonary edema) that may be delayed for a few hours.
- Nausea and vomiting.
- Watery eyes.
- Wheezing.

Please note that showing these signs or symptoms does not necessarily mean that a person has been exposed to chlorine. Long-term health complications may occur after breathing in high concentrations of chlorine. These complications are more likely to be seen in people who develop severe health problems such as fluid in the lungs (pulmonary edema) following the initial exposure.

If there is a chlorine release or leak, leave the area and get to fresh air. Quickly moving to an area where fresh air is available is highly effective in reducing exposure to chlorine. If the chlorine release was outdoors, move away from the area where the chlorine was released. Go to the highest ground possible, because chlorine is heavier than air and will sink to low-lying areas. If the chlorine release was indoors, get out of the building. If you think you may have been exposed, quickly remove your clothing, rapidly wash your entire body with soap and water, and get medical care as quickly as possible. Washing with soap and water will help protect people from any chemicals on their bodies.

Clothing that must be pulled over the head should be cut off the body instead of being pulled over the head. If you are helping other people remove their clothing, try to avoid touching any contaminated areas. If possible, seal the clothing in a plastic bag and then seal the first plastic bag in a second plastic bag. Removing and sealing the clothing in this way will help protect you and other people from any chemicals that might be on the clothes. If you placed your clothes in plastic bags, inform either the local or state health department or emergency personnel upon their arrival. Do not handle the plastic bags.

If your eyes are burning or your vision is blurred, rinse your eyes with plain water for 10 to 15 minutes. If you wear contacts, remove them before rinsing your eyes, and place them in the bags with the contaminated clothing. Do not put the contacts back in your eyes. You should dispose of them even if you do not wear disposable contacts. If you wear eyeglasses, wash them with soap and water. You can put the eyeglasses back on after you wash them. If you have swallowed (ingested) chlorine, do not induce vomiting or drink fluids. Seek medical attention right away.

Dial 911 and explain what has happened. No antidote exists for chlorine exposure. Treatment consists of removing the chlorine from the body as soon as possible and providing supportive medical care such as inhaled breathing treatments for wheezing in a hospital setting.

16.1.1.3 Advantages of Chlorination

The following are advantages of chlorination (Ref. 2):

- Chlorination is a well-established method of disinfection.
- It is cost effective.

- It is reliable and effective across a wide spectrum of pathogenic organisms.
- Because it is a gas, it has a flexible dosing control.
- It can eliminate certain noxious odors during disinfection because it is a powerful oxidizing agent.

16.1.1.4 Disadvantages of Chlorination

The following are disadvantages of chlorination (Ref. 2):

- Chlorine residual is toxic to aquatic life and requires de-chlorination.
- It is corrosive and toxic. Storage, shipping, and handling pose a health risk which requires increased safety precautions and regulations.
- If certain types of organic matter are present in wastewater, disinfection by-products (DBP) can be created. These DBP have been implicated in causing cancer.

16.1.1.5 Routine Operation Checklist Troubleshooting Guide for Chlorination

The following is a list of items recommended to check on a routine basis with details about potential problems and suggested corrective actions (Ref. 6).

- Chlorine lines, valves, and units:
    - Erratic readings may indicate the weighing scale is either not properly calibrated or needs repair – recalibrate or repair as necessary.
    - Chlorine leaks can cause personal injury or death, and corrosion of equipment and electronics – notify emergency response teams if required, work with trained personnel and follow all appropriate safety procedures. Repair all leaks immediately if properly trained.
    - Icing up of container or cylinder feed lines indicates the chlorination rate is too high – reduce feed rate or manifold cylinders and containers together. If an evaporator is being used, check to see if liquid chlorine is being withdrawn from the container bottom valve.
- Record scale reading:
    - Usage potential problems include degrading effluent increases chlorine demand (nitrite demand increase use), low scale weight, or chlorine about to run out. The corrective action is to monitor dosage and demand, adjust process to improve effluent quality, or replace container or cylinder before scale weight reaches zero to prevent sediment from entering the system.
- System gauge problems may cause downtime of the chlorination system:
    - Main manifold pressure can break rupture disc – may need to evacuate network and replace disc. Check all network valves for correct positioning.
    - Evaporator pressure can cause PRV to fail to close – check evaporator safety shutdown features and reactivate PRV to normal operation.
    - Water bath temperature and level can cause malfunction of heat exchanger element, thermostat, recirculation pumps, level probe, or water fill solenoid valve – check all devices, repair, or replace as needed, and return evaporator to normal operation.

    - Chlorinator gas pressure – low gas pressure causes rotameter to balance – check chorine supply pressure, repair, or replace chlorinator inlet gas line filter.
- Automatic change over system:
    - Injector vacuum and water line – low vacuum causes chlorinator to stop, low water pressure causes low vacuum – check and restore normal water pressure. Check and, if necessary, clean injector throat (orifice) and adjust orifice for increased vacuum production.
- Chlorinator:
    - System pressures, control selector positions, chlorinator rotameter – container runs out without automatically changing supply – check proper operation of system switch, all system valves, and changeover system automatic controls.
    - Rotameter moving from setpoint, erratic operation – improper effluent chlorination resulting from low vacuum, low gas pressure, or dirty V-notch plug or rotameter – check and reactivate operating vacuum level by establishing water flow to injector, operating gas pressure, and clean V-notch plug or rotameter.
    - Water present in rotameter tube:
        - Bad O-ring or gas injector – check and possibly replace O-ring to prevent backflow of water into chlorinator.
        - Malfunction in-line gas heater – check and possibly repair in-line gas heater to prevent chlorine gas from liquefying in the chlorinator.
    - Will not increase to full gas flow on rotameter – malfunctioned injector – check for proper water flow to the injector and for gas line vacuum leaks.
    - Chlorine residual – low or high readings – be sure power switch in in the ON position for electric positioners. Check and, if necessary, adjust dosage potentiometer. Check 4 to 20 mA signal from flow meter or chlorine residual or chlorine residual analyzer.

16.1.2 Liquid-Gas Chlorine

Elemental chlorine is toxic to all living organisms. At a concentration above the Immediately Dangerous to Life or Health (IDLH) limit of 10 ppm, it is extremely dangerous (Ref. 4). Liquid-gas chlorine is the most common chlorine compound used in the treatment of wastewater. Steel containers from 150 lb. cylinders to 90-ton tank cars are used to store the gas.

16.1.3 Hypochlorite

The strength of hypochlorite compounds is expressed as a percentage and refers to ‘available chlorine’ (Ref. 6). Most common forms available are calcium or sodium hypochlorite. Hypochlorite compounds are most often used in very small facilities where simplicity and safety are of more concern than cost. To avoid the potential hazard of handling liquid-gas chlorine in pressurized containers, some utilities invest in on-site generation of sodium hypochlorite solutions by electrolysis of brine. Consideration should be given to the cost of equipment, experience needed, and training requirements if this option is chosen.

Calcium hypochlorite is commonly referred to as bleaching powder or calcium oxychloride. This compound is relatively stable and has greater available chlorine than sodium hypochlorite. It is a white solid, although commercial samples appear yellow. It strongly smells of chlorine, owing to its slow decomposition in moist air. It is available in two forms: dry granular white powder or in tablet form in strengths of about 65 percent chlorine by weight. Calcium hypochlorite is difficult to manage with excessive maintenance problems resulting from the deposits of calcium ions throughout the system. It should be considered as an emergency alternative (Ref. 8). Sodium hypochlorite or bleach is a strong oxidizing agent in liquid form and is greenish or yellowish in color. Sodium hypochlorite is available in concentrations of 5 to 15% by weight trade strength (available chlorine) (Ref. 6). Some large wastewater treatment plants use sodium hypochlorite to avoid the potential hazard of liquid-gas chlorine. It is delivered and stored in containers under vapor pressures of 80 - 110 psi. or is made by electrolysis of brine. Although safer to use than chlorine gas, sodium hypochlorite is still a hazardous and corrosive substance.

As a result, it still requires process safety procedures and containment. This is to avoid exposure to workers and the environment and to prevent the loss of potency through exposure to air, which causes it to deteriorate (Ref. 7).

16.1.4 De-chlorination

Regulatory agencies have placed chlorine residual permit limits on POTWs to reduce the toxic effects on aquatic organisms and long-term adverse effects caused by the reaction of chlorine with organic matter to form toxic disinfection byproducts. The permit limits are 0.019 ppm for the maximum daily and 0.011 ppm for the monthly average allowed to enter the receiving stream from wastewater treatment plants (Ref. 8).

De-chlorination of plant effluent flow may be accomplished by various processes, which can be achieved using (Ref. 4):

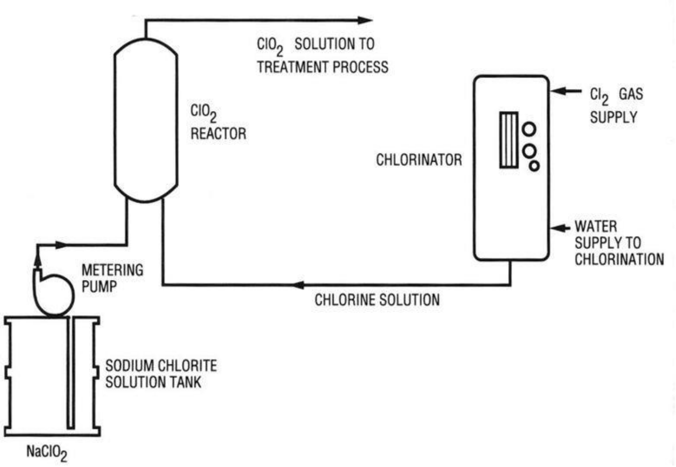
- Detention ponds that are designed to detain wastewater long enough for the chlorine to dissipate on its own.
- Aeration, bubbling air through the wastewater to force the chlorine out of the wastewater.
- Passing the chlorinated wastewater through an activated carbon filter resulting in the carbon adsorbing the chlorine.
- Dechlorinating with sulfur compounds, such as (Ref. 8):
    - Sulfur Dioxide (SO_2)
    - Sodium Sulfite (Na_2SO_3)
    - Sodium Bisulfite ($NaHSO_3$)
    - Sodium Metabisulfite ($Na_2S_2O_5$)
    - Sodium Thiosulfate ($Na_2S_2O_3$)

16.2 Chlorine Dioxide

Chlorine dioxide was discovered in 1814 by Sir Humphrey Davy (Ref. 6). He produced the gas by pouring sulfuric acid (H_2SO_4) on potassium chlorate ($KClO_3$). Chlorine dioxide is an oxidant that is more like ozone than chlorine. It is favored at some facilities because it does not react with ammonia to produce disinfection byproducts such as trihalomethanes (THM) and haloacetic acids (HAA). Chlorine dioxide exists as yellowish-green gas above 11°C, a reddish-brown liquid between minus 59°C and 11°C, and as bright orange crystals when colder. It does not break down by a chemical reaction when it enters water and is usually handled as a dissolved gas in solution in water.

Chlorine Dioxide is unstable as a compressed gas and must be generated at the point of use (Ref. 4). Potential hazards with chlorine dioxide include health concerns, explosiveness, and fire ignition. Chlorine Dioxide is significantly more expensive than chlorine.

Figure 16.2 Chlorine Dioxide Facility



16.3 Peracetic Acid (PAA)

The United States Environmental Protection Agency first registered peracetic acid as an antimicrobial in 1985 for indoor use on hard surfaces. Peracetic acid, also known as peroxyacetic acid or PAA, is an organic compound with the formula CH_3CO_3H. This organic peroxide is a colorless liquid with a characteristic acrid odor reminiscent of acetic acid. It can be highly corrosive, and it quickly decomposes in water forming compounds that will dissolve the cell wall killing the microorganisms found in the water. It also does not create toxic disinfection byproducts, even if too much peracetic acid is used. It breaks down into acetic acid and hydrogen peroxide, which subsequently decomposes to oxygen and water. Peracetic acid is stable in storage with a relatively long shelf life of between 12 to 18 months (Ref. 9)**.**

The first commercial use of PAA for wastewater disinfection in the United States was in Frankfort, Kentucky (Ref. 10). The Frankfort wastewater treatment plant evaluated PAA for use as a temporary disinfectant during an upgrade of their existing wastewater disinfection system (ozone). In 1980, the Frankfort wastewater treatment plant converted from chlorine gas to ozone for disinfection. The plant was then upgraded from a 6.6 MGD plant to a capacity of 9.9 MGD. In 2005, the decision was made to build a new higher capacity ozone generator in response to the higher capacity of the plant. Replacing the ozone generator necessitated a temporary disinfection technology during the six months between shutting down the old generator and the start-up of the new one. After evaluating several disinfection technologies, including sodium hypochlorite and sodium bisulfite, the city went out to bid for a disinfection technology and PAA was chosen.

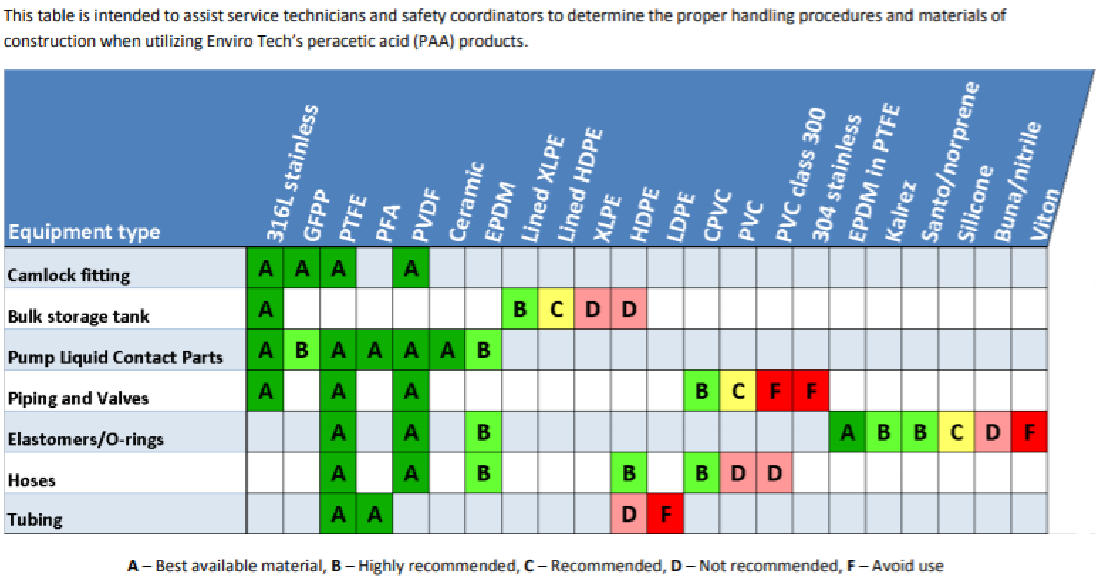
The case study process was closely monitored by Frankfort laboratory personnel. The wastewater traveled through a static mixer and a disinfection chamber with a 26-minute contact time at the permit flow. The target dose rate was automatically held constant based on the final effluent flow. Staff monitored PAA residuals at the discharge point using a Chemetrics K-7905 test kit. Staff performed daily bacterial analyses using the filtration method and analyzed BOD and pH samples daily.

The case study results determined that within design flow conditions, PAA 12% peracetic acid solution was effective at controlling fecal coliforms and *E. coli* at a target dose of 0.7 ppm. The effluent treated with PAA passed acute toxicity tests for Ceriodaphna dubia. Additionally, treatment costs with PAA were competitive to disinfection with sodium hypochlorite and sodium bisulfite. The residual PAA in the wastewater discharge was less than one ppm, which eliminated the need of a neutralization step.

Peracetic acid is applied to the wastewater process from a bulk or intermediate storage vessel directly into the wastewater. Typically, a pump is used to transfer the PAA from the storage vessel into the secondary effluent. Good dispersion/mixing can improve the effectiveness of the amount of PAA added. The injection rate is controlled by proportional flow control from a 4-20 mA signal sent from the wastewater utility effluent flow measurement. Most systems in the USA receive PAA in containers not larger than 300-gallon one-way disposable totes. The single most expensive item (for tote systems) is a flow paced pump skid that cost less than $50,000 for a 50 MGD facility at 4 ppm PAA.

Peracetic acid feed is best controlled with a flow-paced pump and residual monitoring. Peracetic acid can be fed using either diaphragm or peristaltic chemical pumps. It is important to ensure that all equipment is comprised of peracetic acid compatible material (Figure 16.3).

Figure 16.3 PAA Product Storage and Handling



This table is intended to assist service technicians and safety coordinators to determine the proper handling procedures and materials of construction when utilizing Enviro Tech's peracetic acid (PAA) products.

Equipment type	316L stainless	GFPP	PTFE	PFA	PVDF	Ceramic	EPDM	Lined XLPE	Lined HDPE	XLPE	HDPE	LDPE	CPVC	PVC	PVC class 300	304 stainless	EPDM in PTFE	Kalrez	Santo/norprene	Silicone	Buna/nitrile	Viton
Camlock fitting	A	A	A		A																	
Bulk storage tank	A							B	C	D	D											
Pump Liquid Contact Parts	A	B	A	A	A	A	B															
Piping and Valves	A		A		A								B	C	F	F						
Elastomers/O-rings			A		A		B										A	B	B	C	D	F
Hoses			A		A		B				B		B	D	D							
Tubing			A	A							D	F										

A – Best available material, **B** – Highly recommended, **C** – Recommended, **D** – Not recommended, **F** – Avoid use

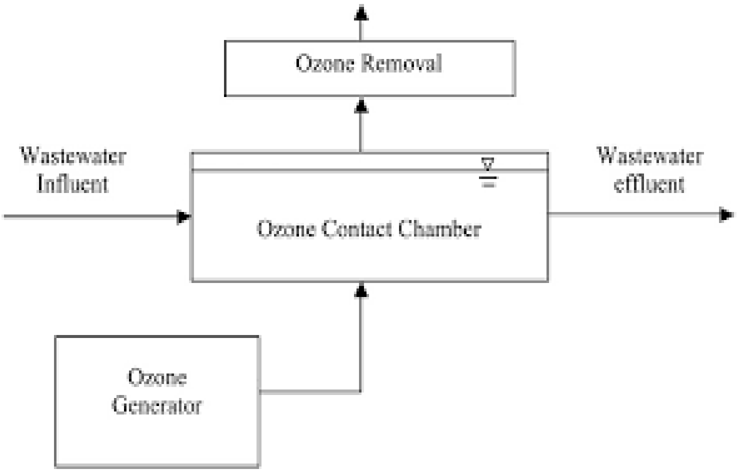
16.4 Ozone Disinfection

The use of ozone as a disinfection agent has the benefit of increasing the dissolved oxygen content of the treated wastewater and it does not produce a toxic residual as seen with chlorine. However, because the ozone must be generated on-site, ozonation can require prohibitive up-front capital expenditures compared to traditional chlorination.

Ozone is produced when oxygen (O_2) molecules are broken down by an energy source into oxygen atoms which then collide with an oxygen molecule to form an unstable gas, ozone (O_3), which is used to disinfect wastewater (Ref. 11).

The effectiveness of disinfection by ozone depends on the susceptibility of the target organisms, the contact time, and the concentration of the ozone. As shown below, the components of an ozone disinfection system include feed-gas preparation, ozone generation, ozone contacting, and ozone destruction (Fig 16.4) (Ref. 11). Ozone disinfection is generally used at medium to large sized plants after at least secondary treatment. In addition to disinfection, another common use for ozone in wastewater treatment is odor control.

Figure 16.4 Components of an Ozone Disinfection System



16.4.1 Advantages of Ozone Disinfection

The advantages of ozone disinfection include (Ref. 11):

- Ozone is more effective than chlorine in destroying viruses and bacteria.
- The ozonation process requires a short contact time to be effective. However approximately 10 to 30 minutes is required to degas the ozone from the water.
- There are no harmful residuals that need to be removed from the water after ozonation because ozone decomposes rapidly.
- After ozonation, there is no regrowth of microorganisms, except for those protected by particulates in the wastewater stream.
- Ozone is generated onsite so there are fewer safety problems associated with shipping and handling.

- Ozonation elevates the dissolved oxygen concentration of the effluent. The increase in dissolved oxygen can eliminate the need for re-aeration.

16.4.2 Disadvantages of Ozone Disinfection

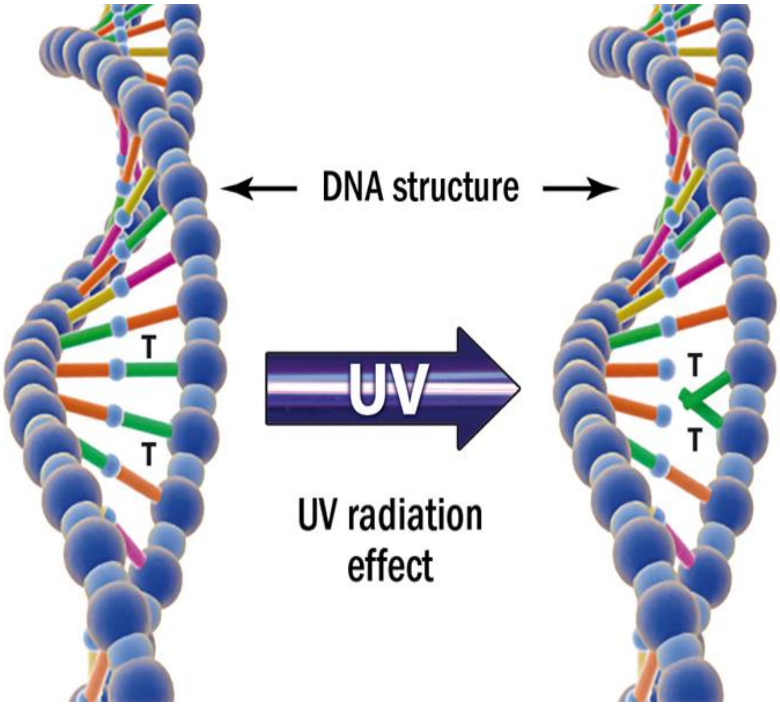
The disadvantages of ozone disinfection include (Ref. 11):

- Low dosages may not effectively inactivate some viruses, protozoal spores, and cysts.
- Ozonation is a more complex technology than chlorine or UV disinfection, requiring complicated equipment and efficient contacting systems.
- Ozone is very reactive and corrosive, requiring corrosion-resistant material such as stainless steel.
- Ozonation is not economical for wastewater with high levels of suspended solids, BOD, chemical oxygen demand, or total organic carbon.
- Ozone is extremely irritating and toxic, so off-gases from the contactor must be vented correctly to prevent worker exposure.
- The cost of treatment can be relatively high in capital and in power intensiveness.

16.5 Ultraviolet Radiation Disinfection

Ultraviolet radiation (UV) disinfection uses special lamps that emit light with a specific wavelength (usually around 254 nm) that is outside of the range of human vision. The light from these lamps penetrates the cell wall of microorganisms and virus particles and damages the cells or virus's ability to reproduce (Ref. 12). UV radiation alters the genetic material of the cell or virus and inactivates potential pathogens but does not remove them from the water.

Figure 16.5 UV Radiation Effect



Ultraviolet light poses a special problem because it is invisible. Intense UV exposure can result in damage to the eye. If an operator needs to perform work inside a UV unit, they should be sure it is turned off and remains off during the maintenance procedure. Follow OSHA's LockOut and TagOut practices and procedures which are in place to safeguard workers from hazardous energy releases (Ref. 13).

The effectiveness of the UV disinfection process is directly related to the (Ref. 12):

- Wastewater characteristics.
- Lamp intensity.
- Exposure time of the microorganisms to the radiation.
- Reactor configuration.

A UV disinfection system is made up of a reactor chamber, mercury arc-lamps, quartz sleeves, and ballast (Ref. 12).

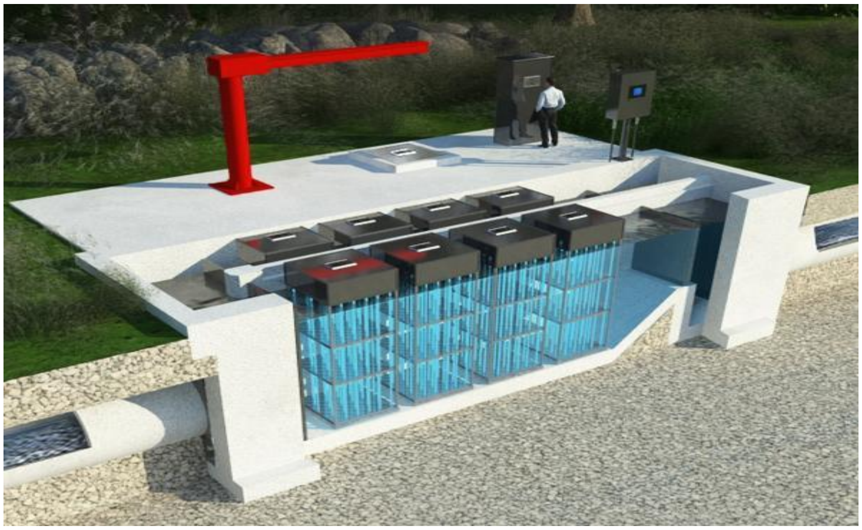
- The UV reactor chamber is where the wastewater is exposed to the UV light and physically contains the UV lamp and sleeve. Reactors control the flow of water through the system and are usually constructed with high quality stainless steel. Traditionally the UV reactors are installed in open channels with direct contact.
- The UV lamp is housed in a quartz sleeve.
    - The optimum wavelength to effectively inactivate microorganisms is in the range of 250 to 270 nm.
    - The intensity of the radiation emitted by the lamp dissipates as the distance from the lamp increases.
    - Low-pressure lamps emit monochromatic light at a wavelength of 253.7 nm. Standard lengths of the low-pressure lamps are 0.75 and 1.5 meters with diameters of 1.5 to 2.0 cm. The ideal lamp wall temperature is between 95 and 122°F.
    - Medium-pressure lamps are generally used for larger facilities. They have approximately 15 to 20 times the germicidal UV intensity of low-pressure lamps. The medium-pressure lamp disinfects faster and has greater penetration capability. However, these lamps operate at higher temperatures with a higher energy consumption.
- The quartz sleeve is a clear tube usually made of quartz since regular glass absorbs ultraviolet radiation with short wavelengths. The sleeve also provides a barrier between the UV lamp and the wastewater being treated.
- The ballast is the control unit for the reactor that provides the starting voltage for the lamps and maintains a continuous current. The current will heat up the metallic filament that creates a mercury vapor. The vapor will cause the lamp to heat up and increase pressure within the tube to emit UV radiation.

There are two types of reactor configurations (Ref. 12):

- Contact: Where UV lamps are submerged in the wastewater either parallel (Figure 16.6) or perpendicular (Figure 16.7) to the direction of wastewater flow.
- Noncontact: Where UV lamps are positioned above the channel that carries the wastewater.

Figure 16.6 Example of Parallel Ultraviolet Lamps

Figure 16.7 Vertical UV Reactor



The configuration of the UV lamps is important to allow the highest exposure of light to be in contact with microorganisms and to eliminate the ‘canyon wall effect’. The canyon wall effect describes how light is blocked by canyon walls or the prevented to shine on all surfaces of the canyon. Canyons are very deep, narrow valleys with steep slopes. Imagine being at the bottom of a 300-foot canyon on a cloudless day. During the morning, the surface floor of the canyon is shady because of the angle of the sun. As the sunlight shines directly overhead, the canyon floor is no longer shaded. As the sun moves behind the canyon ridge, the floor is again shaded. Now imagine the UV reactor with wastewater flowing through an open channel. The UV lights need to be positioned either parallel or perpendicular to the flow to eliminate this shadowing effect.

UV radiation is a form of electromagnetic radiation. The main source of UV rays is the sun, although it can come from man-made sources such as tanning beds and welding torches. There are three different types of UV radiation: UV-A, UV-B, and UV-C (Ref. 12).

- UV-A rays have the have the longest wavelengths and the least amount of energy among UV rays. These rays can cause skin cells to age and can cause some indirect damage to cells' DNA. UV-A rays are mainly linked to long-term skin damage such as wrinkles, but they are also thought to play a role in some skin cancers.
- UV-B rays have shorter wavelengths than UV-A but longer wavelengths than UV-C and have slightly more energy than UV-A rays. They can damage the DNA in skin cells directly and are the main rays that cause sunburns. They are also thought to cause most skin cancers.
- UV-C rays have the shortest wavelengths and more energy than the other types of UV rays. Fortunately, because of this, they react with ozone high in the atmosphere and don't reach the ground, so they are not normally a risk factor for skin cancer. But UV-C rays can also come from some man-made sources, such as arc welding torches, mercury lamps, and UV sanitizing bulbs used to kill bacteria and other germs (such as in water, air, food, or on surfaces).

16.5.1 Advantages of UV Disinfection

The advantages of UV disinfection include (Ref. 12):

- It is effective at inactivating most microorganisms and viruses.
- UV is a physical rather than chemical process which eliminates the need to generate, handle, store or transport toxic or hazardous materials.
- There is no residual effect in the effluent to harm the environment.
- UV is operator friendly and easy to use.
- Shorter contact timer than other disinfection processes (about 20 to 30 seconds with low-pressure lamps).
- Smaller footprint for equipment than other methods.

16.5.2 Disadvantages of UV Disinfection

The disadvantages of UV disinfection include (Ref. 12):

- Low dosage may not inactivate some organisms.
- Organisms can sometimes repair their genetic material if the damage is not too great and therefore survive disinfection.
- It is necessary to clean and maintain the UV tubes frequently.
- Elevated TSS and turbidity in the effluent can render UV disinfection ineffective. Pathogens that exist inside the TSS particle are protected from UV radiation and survive.
- UV disinfection is not as cost-effective as chlorination but is competitive when de-chlorination costs and fire and safety code costs are considered.

16.6 References

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Chapter 17

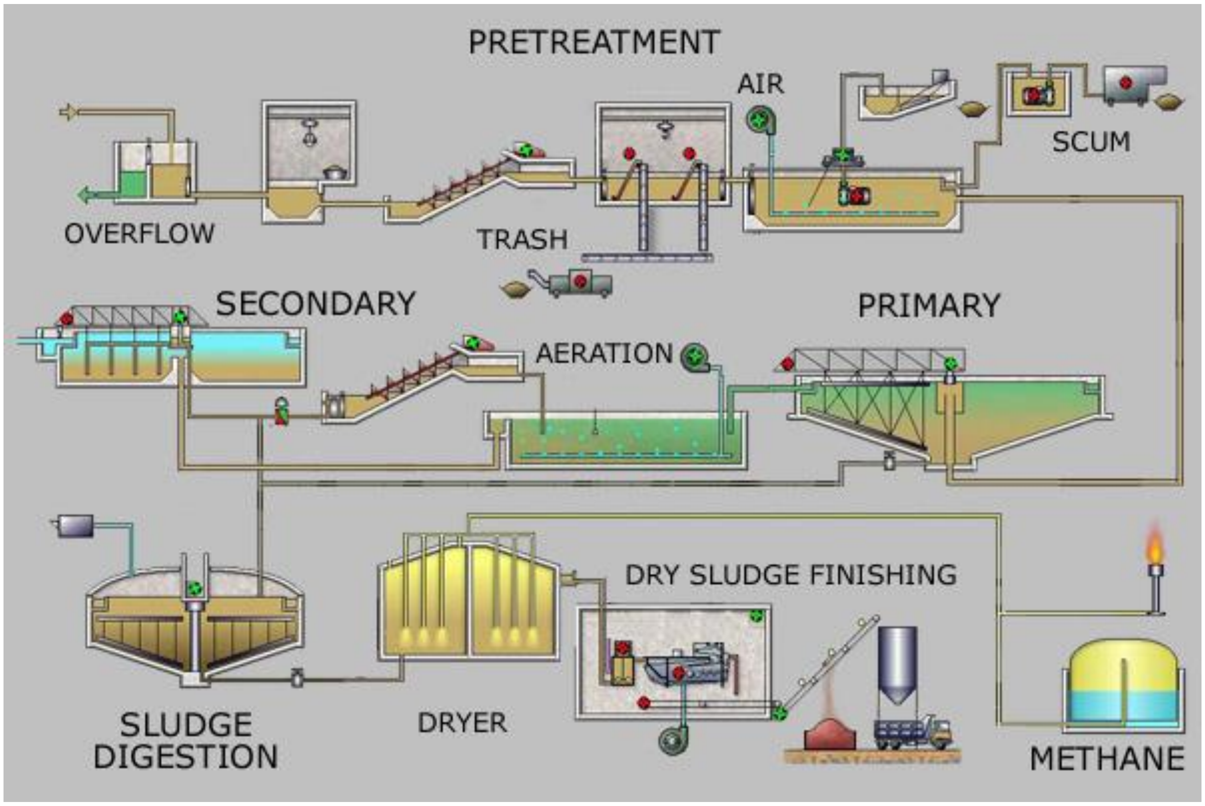
Digestion

Digestion is a means of stabilizing sludge to reduce the amount of organic matter in the solid materials. Digestion also reduces the odorous and foul-smelling characteristics of sludge. The goal of digestion is to reduce the sludge volume by nearly 50%. Digested sludge is dark brown to black, has a faint humus (earthy) odor, and contains very large amounts of gas. When thoroughly digested, the odor is relatively faint like that of hot tar, burnt rubber, or sealing wax.

Digesters are used to treat the sludge that is wasted from primary and secondary clarifiers (see Figure 17.1). Sludge digesting occurs in large enclosed heated tanks called digesters. **Sludge digestion** can occur using one of two different processes: aerobic digestion, which uses bacteria that need oxygen to live, and anaerobic digestion, which uses bacteria that do not need oxygen to live. Aerobic digesters generally produce lower BOD concentrations in the supernatant liquor, produce an odorless humus-like biologically stable end product, are easier to operate than anaerobic digestors, and have lower capital costs. However, aerobic digestors also require more energy for supplying the required oxygen, and do not recover any resulting methane.

Digesters are typically designed to operate over a specific range of temperatures depending upon the type of bacteria that are being grown in the digester. Temperature ranges between 86 to 100° F are used to support mesophilic microorganisms while temperature ranges between 122 to 140° F are used to support thermophilic (heat-loving) microorganisms (Ref. 1). Different populations of anaerobic microbes have been found to thrive in these temperature zones.

Figure 17.1 Location of the Sludge Digestion Process in the Wastewater Treatment Process



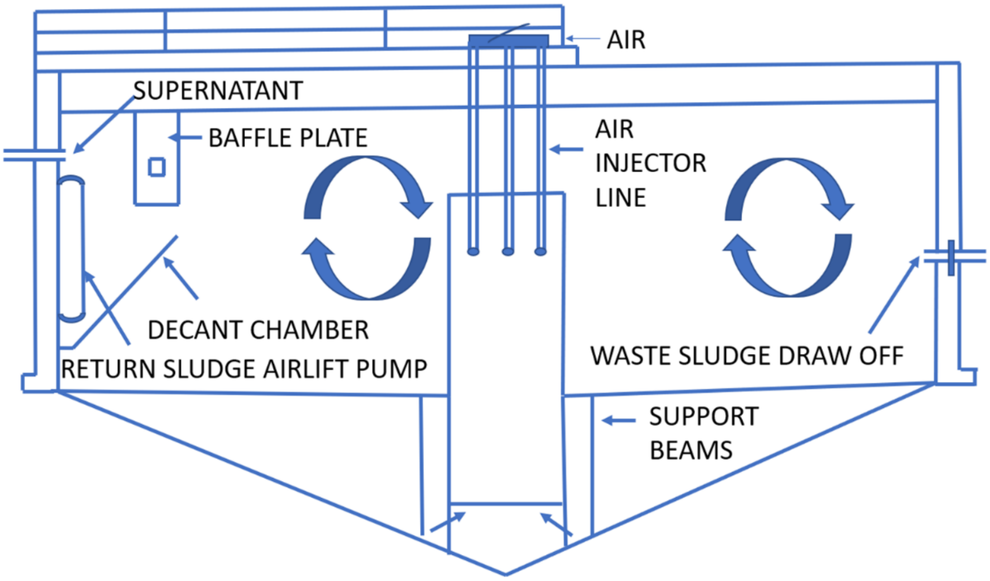
Flow diagram of traditional wastewater treatment plant processing (artwork by Leonard G.).

Generally, thermophilic anaerobic digestion would be used when greater pathogen kill is necessary. This temperature range can produce Class A Biosolids. Class A Biosolids is a designation for dewatered and heated sewage sludge that meets USEPA guidelines for land application with no restrictions. Class A Biosolids can be legally used as fertilizer on farms, vegetable gardens, and can be sold to home gardeners as compost or fertilizer. Thermophilic digesters require less time to process raw material but may have higher costs and be more difficult to operate. In general, mesophilic digesters are easier to operate and maintain, but will not result in enough pathogen kill to produce Class A Biosolids (Ref. 1).

17.1 Aerobic Digestion

Aerobic digestion involves the further digestion of organic material using aerobic bacteria 9i.e. bacteria that require oxygen to live). Aerobic digestion reduces BOD to a minimum and therefore stabilizes the sludge. Aerobic digestion is normally carried out in unheated tanks called digesters that are like those used in the activated sludge process. As the remaining BOD is consumed by microorganisms, the bacteria will start to eat their own cell material to get energy (Ref. 2). This process is called endogenous respiration and is the main biochemical reaction in the aerobic digestion process. Typically, 75% to 80% of cell tissues is aerobically oxidized into carbon dioxide, water, and ammonia, while 20-25% is inert components and organic compounds that are biodegradable. A schematic of a continuous operation aerobic digestor is provided in Figure 17.2.

Figure 17.2 Schematic of a Continous Operation Aerobic Digestor



Aerobic digestions may be used to treat waste-activated sludge, mixtures of waste-activated sludge or trickling-filter sludge and primary sludge, or waste sludge from extended aeration plants. Historically aerobic digesters have been used primarily in smaller plants (i.e., less than 5 MGD) but in recent years they have also been used in larger plants (Ref. 3).

Aerobic digesters are typically used in treatment systems that utilize an activated sludge process (Ref. 4). Aerobic digesters can either be open or covered and usually constructed from reinforced concrete and steel. Open tank aerobic digesters are more common and are usually found in package treatment plants (Ref. 5). Closed or covered tanks minimize heat loss and minimize freezing. If the aerobic digesters are below ground level, then they are well insulated by the soil. If the aerobic digester is above ground level, then the tank may need to be insulated in cold climates (Ref. 6).

The sludge from the secondary clarifier should typically be pumped to the digester in small quantities several times a day. Thus, aerobic digesters are designed to allow the liquid level to fluctuate, allowing digestion to proceed even if partially emptied or refilled. The contents in the digester are aerated by continual stirring to make sure that enough oxygen is available for use by the bacteria. The microorganisms that enable this digestion require similar conditions to aeration tanks in the secondary treatment. Factors that must be considered in the design and operation of aerobic digesters are as follows (Ref. 6):

- Temperature:
  - Biological processes function more efficiently when the temperature is higher.
  - Tanks should be covered or insulated to minimize heat loss.
- pH:
  - The digestion process performs well at between pH 6.0 to 7.6.
- Oxygen requirements:
  - The solids and bacteria are to be maintained in suspension with enough air or oxygen to maintain dissolved oxygen between 1 mg/L and 2 mg/L.
  - When oxygen concentrations drop too low, there will be incomplete digestion and the potential for foul odors due to anaerobic conditions.
- Sludge Retention Time (SLRT) in a digester is calculated using equation [27]:

$$\boxed{[27]\ SLRT\ (days) = \frac{Total\ Sludge\ Mass\ (lbs)}{Solids\ Removed\ per\ Day\ \left(\frac{lbs}{day}\right)}}$$

  - Typically, a higher SRT causes the degree of solids reduction to increase, however, a higher retention time can make the sludge more difficult to dewater.
- Sludge characteristics:
  - High solids concentrations can impact the effectiveness of removing the water as the solids settle.
- Mixing:
  - Aerobic digestion requires adequate contact time between the organisms and their food supply.
  - Adequate mixing is provided when the diffusers supplying air or oxygen are at a rate of 20 to 35 ft^3/min/1000 ft^3 of digester.
  - Supplemental air is required when the aeration rate needed to meet the SOUR is less than the rate needed to keep the organisms in suspension.

For aerobic digestion to work properly, the operator must ensure that the digester be operated to satisfy the standard operating conditions summarized in Table 17.1.

Table 17.1 Standard Operating Conditions for Aerobic Digesters

Monitoring Parameter	Frequency	Operating Range		
		Minimum	Optimal	Maximum
Temperature, ^{0}F	Daily	59	68	98.6
pH	Daily	6.0	7.0	7.6
Dissolved Oxygen, mg/L	Daily	0.1	1 - 2	2.0
Alkalinity, mg/L as calcium carbonate	Weekly	100	>500	--
Ammonia-Nitrogen, mg/L	Weekly	--	<20	40
Nitrate, mg/L	Weekly	--	<20	--
Nitrite, mg/L	As Required	--	<10	--
SOUR, mg oxygen/h/g total solids	As Required	--	<1.5	--
Phosphorus, mg/L	As Required	--	<5	--

As mentioned in Chapter 10, aerobic digesters must maintain sufficient dissolved oxygen in the system to operate effectively. To ensure that the digester is functioning well, the specific oxygen uptake rate (SOUR) can be measured (see Section 14.8.8). The SOUR is a process control test which measures the oxygen used by microorganisms in digesters and is used to determine the level of biological activity and the resulting solids destruction. A high SOUR indicates high microbial activity. A low SOUR indicates lower microbial activity because there is little food left (organic matter) for bacteria to use. The SOUR is expressed in terms of milligrams of oxygen per gram of total solids per hour during active aerobic digestion (Ref. 7).

The SOUR test is performed by taking a well-mixed sample of aerated sludge from the digester. The sample is then placed on a magnetic stirrer to maintain mixing conditions. Measurements of the initial DO are taken using a DO meter. Additional DO measurements are then taken every 30 seconds until the DO drop begins to taper off from previous readings, usually 6 or 7 minutes (Ref. 7). The Oxygen Uptake Rate (OUR) can be calculated using Equation [23] which can then be used with Equation [24] to calculate the final SOUR.

If the digester is operating outside the optimal parameters range (as shown in Table 17.1), the operator can use the trouble-shooting guide in Table 17.2 to diagnosis and then take corrective actions.

Table 17.2 Possible Causes and Corrective Actions for Aerobic Digester Operation

Indicators/Observations	Probable Cause	Check/Monitor	Solutions
Excessive Foaming	Organic overload	Organic load	Reduce feed rate
			Increase solids in digester by decanting
	Excessive aeration	Dissolved Oxygen	Reduce aeration rate
Low Dissolved Oxygen	Clogging	Decant digester, withdraw sludge, inspect diffusers	Clean diffuser or replace with coarse-bubble diffusers or sock-type devices
	Improper liquid level	Check equipment specifications	Establish proper liquid levels

	Blower malfunction	Air delivery rate, pipeline pressure, valving	Repair pipe leaks; set valves in proper position; repair blower
	Organic overload	Check organic load	Reduce feed rate
Sludge has objectionable odor	Inadequate solid retention time	Solids Retention time	Reduce feed rate
	Inadequate aeration	Dissolved oxygen should exceed 1 mg/L	Increase aeration, reduce feed rate
Ice formation on mechanical aerators	Extended freezing weather	Check digester surface for the ice block formation	Break and remove ice before it causes damage
pH in digester has dropped to undesirable level (less than 6.0-6.5)	Nitrification is occurring and wastewater alkalinity is low	pH of supernatant	Add sodium bicarbonate to feed sludge or lime or sodium hydroxide to digester
	In covered digester, carbon dioxide is accumulating in air and is dissolved into sludge		Vent and scrub carbon dioxide

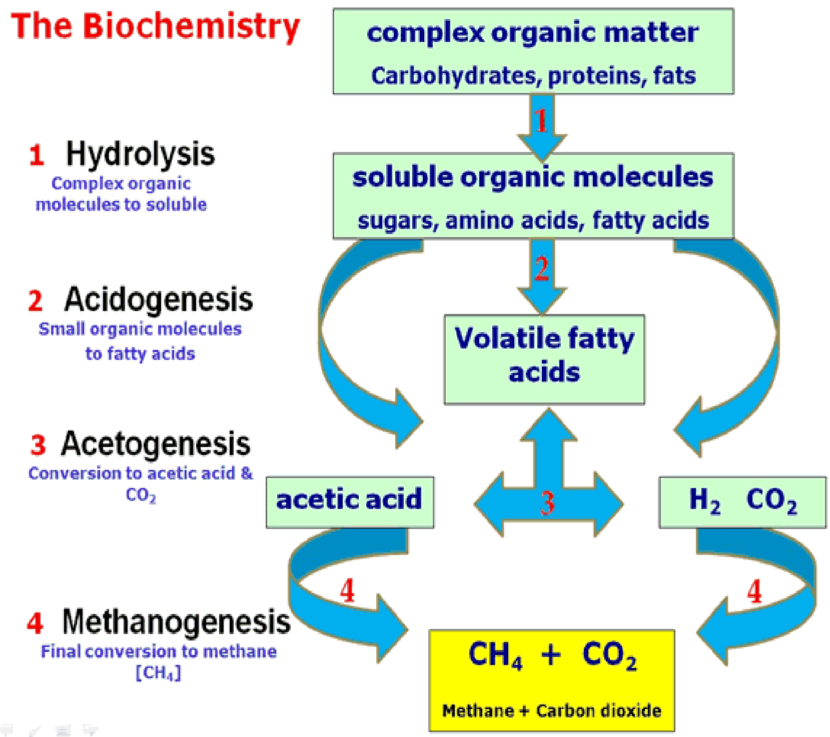
17.2 Anaerobic Digestion

Anaerobic digestion is a complex biological process involving several groups of anaerobic (do not need oxygen to survive) and facultative organisms (acid formers and methane fermenters) which simultaneously break down and assimilate organic matter in the absence of oxygen (Ref. 8). The acid former bacteria convert any organic compounds into volatile organic acids while the methane fermenters convert the acids into methane and carbon dioxide. The process involves a sequence of reactions where microorganisms break down organic matter in the absence of oxygen. This breakdown of organic matter will reduce the amount of solid material that will need to be landfilled or otherwise disposed. The overall process typically involves four different steps or stages (Ref. 9):

- First stage- Hydrolysis.
    - Complex organic materials are broken down into simpler compounds like simple sugars, fatty acids, and amino acids.
- Second stage- Acidogenesis.
    - Acid forming bacteria further break down the sugars and fatty acids into volatile fatty acids, carbon dioxide, ammonia, hydrogen sulfide, and other by products.
- Third stage- Acetogenesis.
    - Volatile fatty acids formed in the second stage are broken down into acetic acid, carbon dioxide and hydrogen.
- Fourth stage- Methanogenesis.

- Methane fermenting bacteria convert the simple acids such as acetic acid into methane and carbon dioxide.

Figure 17.3 The Process of Anaerobic Digestion (Ref. 10)



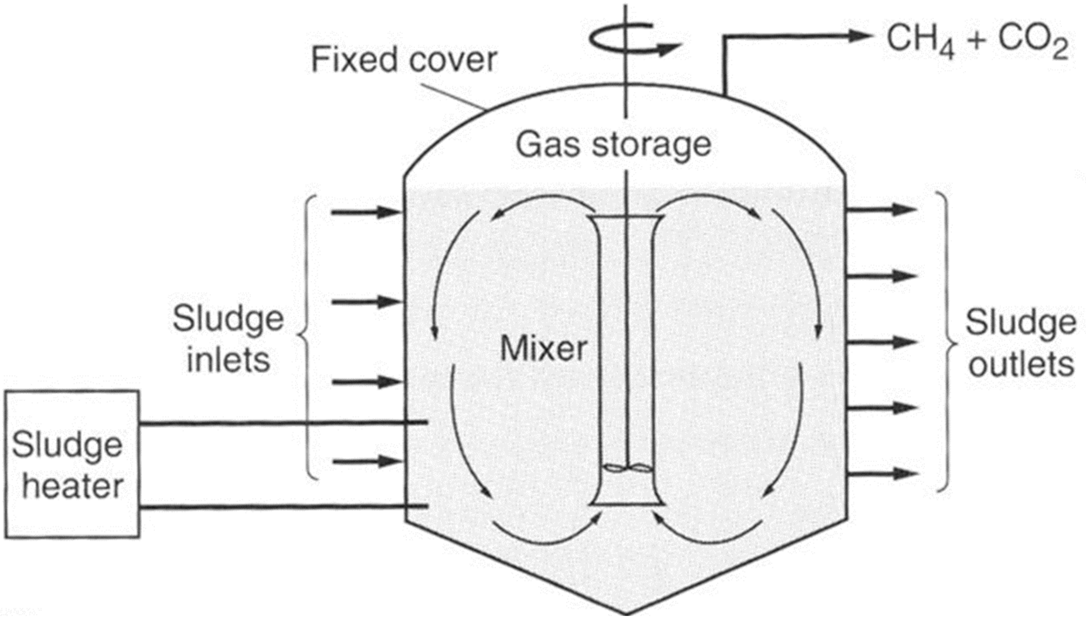
A stable anaerobic digestion process requires maintaining **anoxic** conditions in the digestor (i.e., lack of free oxygen) and a balance between several different populations of microorganisms. The acid formers, which drive steps 1 and 2 can thrive in the widest range of environmental conditions. Because they react quickly to an increase in food availability, fatty acid concentration can rise quickly causing the pH to fall to unacceptable levels. Thus, if too much raw sludge is added to an anaerobic digester, the pH will drop which will cause the digestor to go septic or sour and which may then take 30 to 60 days to recover. When this happens, methane production in step 4 stops and the system fails (Ref. 9). Care must be taken to operate an anaerobic digester so that the rate of acid formation and methane formation are approximately equal. Otherwise, the reactions can get out of balance. As a result, the pH of the reactors needs to be monitored. Methane fermenters function best at a pH range of 6.6 to 7.6.

Anaerobic digesters produce methane gas, which can be collected and burned either to release its energy as heat or used to produce electricity (Ref. 11). Many sustainable wastewater treatment plants use the methane to provide heat for the digester so that the entire process can continue as an example of a sustainable loop. However, it should be remembered that methane gas can be explosive, thus care must be taken in its management.

17.2.1 Types of Anaerobic Digesters

Today, most anaerobic digestors are designed using a single-stage high-rate digester (see Figure 17.4) where the sludge is mixed by gas recirculation, pumping, or draft-tube mixers and the sludge is heated to achieve optimum digestion rates. High-rate digestion processes are heated and completely mixed with detention times of typically 10-20 days.

Figure 17.4 Single-Stage High Rate Anaerobic Digester (Ref. 3)

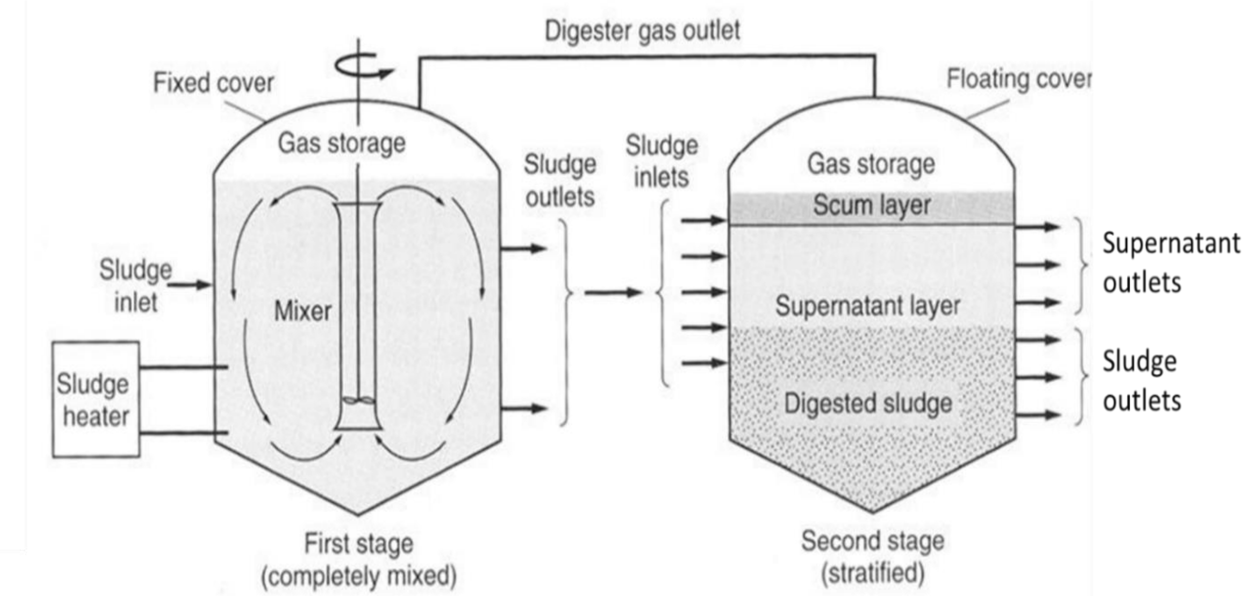


Note: Uniform feeding is important. Total solids are reduced by 50%. May have fixed or floating covers (methane + oxygen = trouble).

Historically, anaerobic digestors were operated using a two-stage digestion process in which a high-rate digester is coupled in series with a second conventional standard rate digester (see Figure 17.4). The first tank is used for digestion and is heated and equipped with mixing facilities and usually has detention times ranging from 10-20 days. The second tank is usually unheated and used primarily for storage with detention times ranging from 30 to 60 days.

In a two-stage system (Figure 17.5), the primary anaerobic digester is heated for optimal stabilization and requires complete mixing. Almost all the stabilization of the sludge and gas production occurs in the primary anaerobic digester. Therefore, only the capacity of the primary anaerobic digester is used when calculating loading rates. The high-rate digesters have a much higher solids loading rate than conventional anaerobic digesters. The sludge is completely mixed by gas recirculation, pumping, or draft-tube mixers (separation of supernatant does not occur) and the sludge is heated to get the optimum digestion rate (Ref. 1).

Figure 17.5 Two-Stage Anaerobic Digester (Ref. 3)



Note: Not common in current practice. First tank is for digestion. Second tank is primarily for storage.

The secondary digester is not heated and has four main purposes: to store digested sludge, to be used as a standby primary tank, to be used as a source for seed sludge, and to be used as a settling basin for supernatant withdrawal (Ref. 1). The operation and maintenance of an anaerobic digester must focus on maintaining conditions that will ensure the success of the digestion process. The primary factors affecting digester performance include (Ref. 12):

- Temperature
    - The methane fermenters are temperature sensitive, making it necessary to keep the temperature steady and higher than ambient temperatures.
    - Digesters are usually heated.
- pH
    - Lower pH, due to volatile acid production without subsequent conversion to methane and carbon dioxide, will cause the system to fail.
- Alkalinity
    - Sources of alkalinity are produced during digestion and aid in maintaining pH but should be supplemented if the pH gets too low.

While there are several different kinds of anaerobic digesters, the one most commonly used is a high-rate mesophilic digester (Ref. 11). The typical operating parameters of this type of digester are summarized in Table 17.3.

Table 17.3 High-Rate Anaerobic Digester Operating Parameters (Ref. 11)

Parameter	Value
VSS reduction	45 – 55%
pH	6.8 – 7.2
Alkalinity	2500 – 5000 $\mathrm{mg/L\ as\ CaCO_3}$
Methane content of biogas	60 - 65% (by volume)
Carbon Dioxide content of biogas	35 – 40% (by volume)
Volatile acids (VA)	50 – 300 $\mathrm{mg/L\ as\ VA}$
Volatile acid: alkalinity ratio	< 0.3 $\frac{\mathrm{mg\ VA}}{\mathrm{mg\ CaCO_3}}$
Ammonia	800 – 2000 $\mathrm{mg/L\ as\ N}$

Operation and maintenance of a typical mesophilic digester include (Ref. 11):

- Maintaining pH in the optimal range.
- Maintaining temperature in the optimal range.
- Maintaining sufficient alkalinity.
- Minimizing tank foaming.
- Minimizing odor.
- Routine cleaning of the tank.
- Maintaining safe work areas (remember that methane can be explosive).

Most digesters are designed to operate with a loading rate of 0.12 to 0.16 lbs VSS/day/ft^3. Equation [28] is used to calculate the volatile solids loading on an anaerobic digester as follows (Ref. 12):

$$\boxed{[28]\ Digester\ Loading = \frac{Volatile\ Solids, lbs/day}{Digester\ Volume, ft^3}}$$

Monitoring the levels of volatile acids and alkalinity is the key to successful anaerobic digester performance (Ref. 13). As long as the levels of volatile acids remain low and the alkalinity levels stay high (e.g., 120 mg/L volatile acids and 2,400 mg/L alkalinity), anaerobic digestion will occur. When the ratio starts to increase, corrective action must be taken immediately to prevent the increase in CO_2 production, which will result in a drop in pH and eventually a soured digester (Ref. 12).

Example 17.1

Calculate the digester loading in an anaerobic digester if the waste sludge flow is 8,500 GPD, the TSS is 3.5%, the VSS is 65% of the TSS and the digester volume is 50,000 gallons.

Solution:

First calculate the weight of volatile solids that are being loaded to the digester per day. Start with the information we have, which is the sludge flow into the digester at a rate of 8,500 gallons per day. First, we need to convert gallons to lbs by using the conversion factor that:

$$1\ gallon\ of\ water = 8.34\ pounds\ of\ water$$

Because sludge is mostly water, we can assume that this conversion applies to the sludge volume as well. This means that:

$$5{,}000\ \frac{gallons\ of\ sludge}{day}\ x\ \frac{8.34\ lbs\ sludge}{1\ gallon\ sludge} = 41{,}700\ \frac{lbs\ sludge}{day}$$

Since we know that 3.5% of sludge is TSS, we can find the amount of TSS by using our knowledge of percentages.

$$41{,}700\ \frac{lbs\ of\ sludge}{day}\ x\ \frac{3.5\ lbs\ of\ TSS}{100\ lbs\ of\ sludge} = 1460\ \frac{lbs\ of\ TSS}{day}$$

Since we know that 65% of the TSS is VSS, we can now find the weight of the VSS loaded into the digester per day.

$$1{,}460\ \frac{lbs\ of\ TSS}{day}\ x\ \frac{65\ lbs\ of\ VSS}{100\ lbs\ of\ TSS} = 949\ \frac{lbs\ VSS}{day}$$

Now that we have the VSS loading, we need to convert the digester volume from gallons to ft^3. This is done using our conversion factor:

$$7.48\ gallons = 1\ ft^3$$

Since the digester is 50,000 gallons in volume, we find that:

$$50{,}000\ gallons\ x\ \frac{1ft^3}{7.48\ gallons} = 6{,}685ft^3$$

Now that we have the VSS loading and the volume of the digester in the correct units we can use our equation to calculate the digester loading rate.

$$Digester\ Loading\ Rate = \frac{949\ \frac{lbs\ VSS}{day}}{6{,}685\ ft^3} = 0.14\frac{lbs\ VSS}{ft^3 - day}$$

Water Environment Federation (WEF) has a brief document that outlines operations and maintenance information for anaerobic digesters (Ref. 12).

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17.4 Other Resources

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Chapter 18

Dewatering of Sludge

The primary purpose of dewatering sludge is to reduce the water content and thus the volume and weight of the sludge, which reduces the cost of disposal (Ref. 1). There are several different methods for dewatering sludge, including mechanical systems, such as presses or centrifuges, and air-drying processes, such as sand beds.

Any dewatering process which involves free flowing sludge will produce turbulence in the sludge and will release odorous gases, such as hydrogen sulfide, generated by sludges allowed to become septic. To keep sludges from becoming septic, the amount of hydrogen sulfide gas in the sludge must be minimized. This can be accomplished through the addition of chemicals such as potassium permanganate, or by ensuring that the pH is kept above 7.5. Chemicals used to control the levels of hydrogen sulfide may also give off residual odors. For example, polymers often release a 'fishy smell' during dewatering. As a result, the odor control and cost-effectiveness should be considered when picking a polymer for use in coagulating the sludge.

18.1 Mechanical Dewatering Equipment

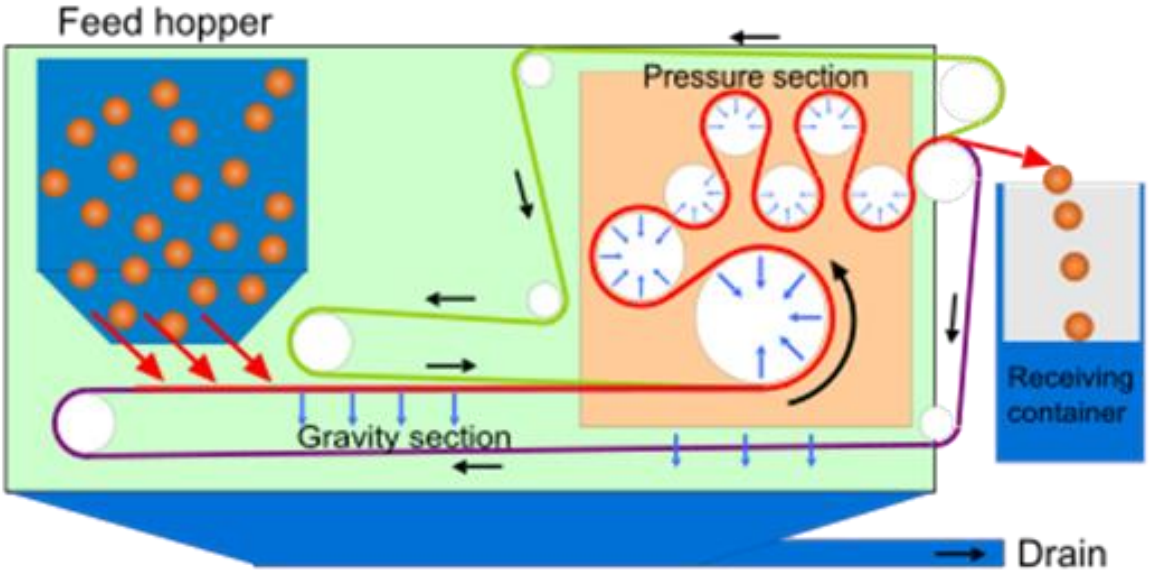
When land is at a premium or climate can inhibit air-drying systems, mechanical systems like presses are usually used to dry sludge (Ref. 1). While there are a couple of different methods to do this, the basic idea is that pressure or centrifugal force is applied to sludge to remove excess water from the sludge.

18.1.1 Belt Filter Press

Belt filter presses, when used with polymers, can achieve a cake of between 15 to 25% solids. These presses remove excess water using pressure filtration and operate in a continuous manner and consist of two belts that travel over a series of rollers. As shown in Figure 18.1, belt presses have 4 main zones: a preconditioning zone, a free drainage zone, a linear compression (low-pressure) zone and a roller compression (high-pressure) zone (Ref. 2).

As Figure 18.1 demonstrates, sludge is delivered to the belt, by gravity, from a feed hopper onto one belt in the gravity section (shown in purple). Fluid is extracted initially by simple drainage due to gravity (Ref. 3). The sludge is sandwiched by another belt (shown in green) as it moves into the pressure section. A series of perforated and unperforated rollers squeeze the two belts together applying pressure to continue dewatering the sludge. The water is collected in filtrate trays at the bottom of the press and discharged through a drain. The solids stay between the belts until they are scraped off into a receiving chamber, at the discharge end of the press as the belts separate. The two belts then travel through respective washing chambers for the removal of fine solids to decrease the possibility of plugging.

Figure 18.1 Diagram of a Belt Filter



The belt is a key element of the filtration system as it determines the actual output and quality of the dewatered sludge. The belts are either a porous filter cloth belt or woven wire mesh belt that are designed for durability while allowing water to be removed from the sludge. Figures 18.2 and 18.3 are examples of mesh filter belts.

Figure 18.2 Woven Wire Mesh Belt Example

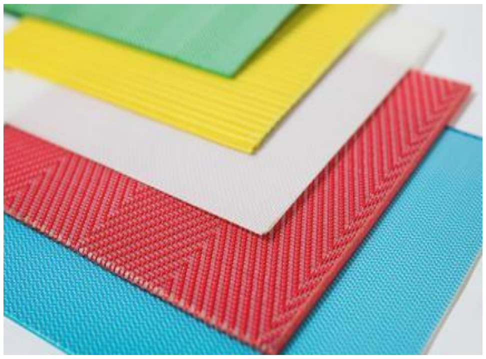
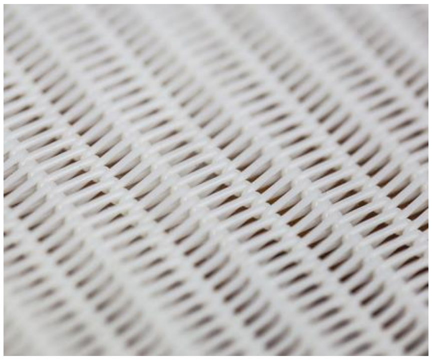


Figure 18.3 Spiral Mesh Belt Example



Factors affecting belt pressure filtration include (Ref. 4):

- Sludge type and characteristics.
- Sludge conditioning.
    - Polymers produce large, strong floc particles (super-flocculation) that allow water to freely drain from the sludge in the gravity drainage zone.
    - Polymers can produce sludge cakes in the range of 24 to 26%.
- Belt tension or pressure.
    - Too much tension does not increase cake dryness. Too much pressure can push sludge deep into the belt pores, causing extrusion and the belts to blind.

- Belt speed.
    - Typical belt speeds 2 to 10 feet/minute (affects thickness of the cake).
- Hydraulic loading.
- Type of belt and mesh.
    - Affect the dryness of the cake and the solids output.

The following are causes of and prevention measures for various belt filter press operational problems:

- Improperly conditioned sludge due to:
    - Varying characteristics of sludge feed – make sure sludge is blended prior to dewatering.
    - Improper polymer selection or dosage rate – selection of polymer and dosage rate should be checked often, especially when changes in sludge characteristics are expected.
    - Improper point of application – evaluate application point and change as necessary.
- Not enough gravity drainage of sludge – evaluate belt speed and drainage time, polymer selection and sludge conditioning system, belt weave and material, position of plows for lateral sludge movement if applicable.
- Loss of sludge between belts – reduce belt tension, adjust belt speed to run faster, reduce sludge feed rate.
- Proper housekeeping – properly train operators, provide steam cleaning equipment to assist cleanup.
- Poor safety practices – provide safety training and ensure safety rules are followed.
    - Do not remove spray and other equipment guards during operation. However, guards should be designed for easy removal for repair or replacement.
    - Do not inactivate tripwire and limit switches to make unit access easier – design safety equipment to reduce or prevent interference with operation.
    - Ensure that Lock-out Tag-out procedures are followed.

Foul-smelling odors may occur during operation of the belt filter press. Having a good ventilation system, keeping the sludge fresh, and using odor-neutralizing chemicals such as potassium permanganate can help control odors (Ref. 2).

18.1.2 Plate and Frame Presses

An alternative to the belt filter presses are plate and frame pressure filters (Figure 18.4). They also rely on pressure filtration. The most common types of pressure filters are the fixed-volume recessed plate filter or the diaphragm filter press. The plate filter press operates in a batch manner and consists of vertical plates which are held rigidly in a frame and pressed together. Sludge is fed into the press between the plates along the length of the press. As the sludge is pressed between the plates, water passes through the fibers of the filter cloth mounted on the face of each plate and is discharged from the bottom of the press (Ref. 4).

As the cake builds up between the plates, the volume of water being discharged will decrease. When the discharge flow is near zero, the sludge feed is shut off and the plates are released. This allows the dried sludge to fall by gravity into a hopper or conveyor.

Figure 18.4 M.W. Watermark Plate and Frame Filter Press

Plate and frame presses can achieve a cake solids concentration of 30 to 60%. The solids removal efficiency is affected by:

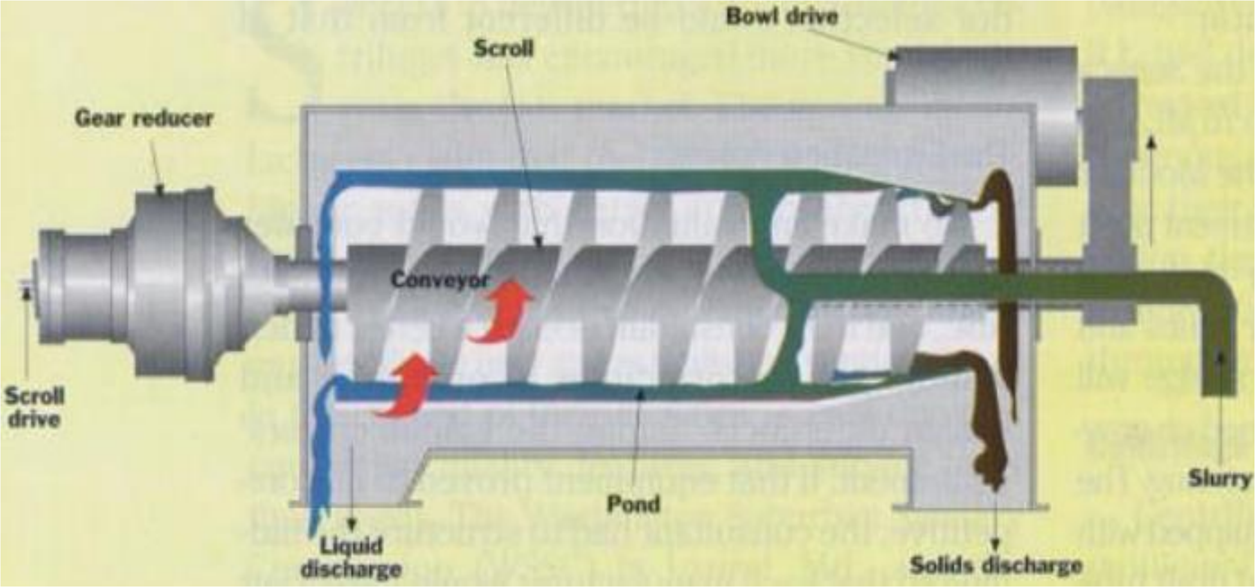
- Sludge type.
- Age or freshness of the sludge.
- Chemical conditioning before dewatering.
- Filter pressure.
  - Initial pressure is maintained at approximately 25 psi for 5 to 10 minutes then increased at approximately 5 psi/min intervals until the final operating pressure is reached, which can vary from 100 to 225 psi (Ref. 4).
- Filtration time.
- Solids loading.
- Filter cloth type.
  - If the cloth is not broken and cake is discharge cleanly, the suspended solids recovery will be about 99%.

18.1.3 Centrifuge

Another technology used to dewater sludge is a centrifuge. Sludge is fed to a rotating "screw" where the rotational forces hold the dry material to the conveyor while the water is discharged to the sides and bottom (Figure 18.5). The centrifuge most often used at wastewater treatment plants is the solid bowl unit also called the decanter, conveyor, or scroll centrifuge.

Centrifuges are fully automated but need to be monitored by the operator regularly. Conditioning the sludge with a polymer prior to entering the centrifuge will increase the dewatering of the sludge (Ref. 5).

Figure 18.5 Centrifuge Thickening and Dewatering System Schematic



The solid-bowl centrifuge operates in one of two modes: countercurrent or continuous concurrent. The major difference in design relates to the location of the sludge feed ports, the removal of the centrate (liquid being removed), and the internal flow patterns of the liquid and solid phases.

Several factors can influence the operation of the centrifuge, including:

- Feed Rate.
- Sludge Characteristics.
- Chemical Conditioning.
- Sludge Temperature.

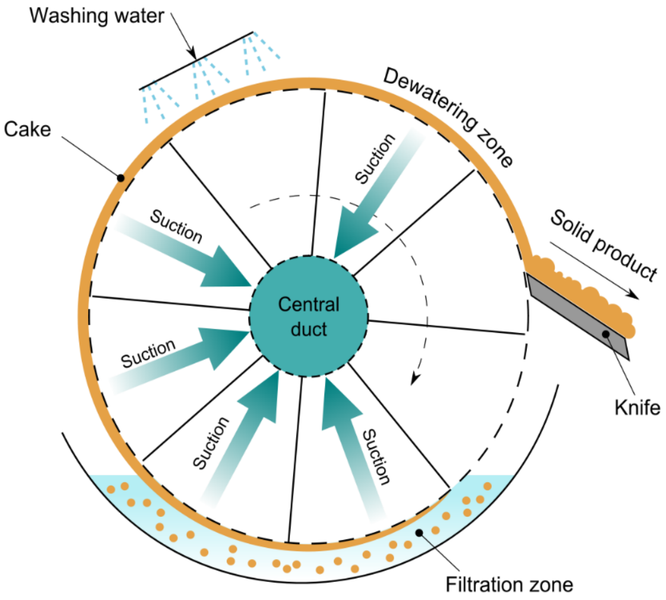
Most wastewater treatment plants with solid-bowl centrifuges use polymers such as organic polyelectrolytes for flocculating purposes. Polymer use improves centrate clarity, increases capacity, often increases cake dryness, and reduces odors. Anionic polymers may yield a better product if aluminum or ferric salts are present (Ref. 5).

18.1.4 Vacuum Filters

Another technology used to dewater sludge is a vacuum filter. A vacuum filter consists of a horizontal cylindrical drum that rotates while partially submerged in a vat of sludge. The filter drum is divided into several sections. A pipe connects each compartment to a rotary valve. Bridge Blocks in the valve divide the drum sections into three zones: the cake formation zone, the cake drying zone, and the cake discharge zone. The filter drum is submerged to about 20 to 35% of its depth in a vat of conditioned sludge (Ref. 4).

The following are the five basic types of designs used for the rotary vacuum drum filter: the belt, the scraper, the roll, the string, and the pre-coat discharge. The standard is usually the scraper discharge design as shown in Figure 18.6.

Figure 18.6 Oliver-Type Rotary Vacuum-Drum Filter



The drum is pre-coated with a filter aid, typically of diatomaceous earth or perlite. After the pre-coat has been applied, the liquid to be filtered is sent to the tub below the drum. The drum rotates through the liquid and the vacuum sucks liquid and solids onto the drum pre-coat surface. The liquid portion is "sucked" by the vacuum through the filter media to the internal portion of the drum, and the filtrate is pumped away. The solids adhere to the outside of the drum, which then passes a knife, cutting off the solids and a small portion of the filter media to reveal a fresh media surface that will enter the liquid as the drum rotates. The knife advances automatically as the surface is removed.

The filter cloth is one of the most important components on the filter and is typically made of weaving polymer yarns but can be made of natural or synthetic fibers, coil springs, or a wire mesh fabric (Ref. 6). The best selection of cloth can increase the performance of filtration when considering the cloth’s durability and solids binding characteristics.

The advantages and limitations of a rotary vacuum drum filter compared to other separation methods are as follows:

- The rotary vacuum drum filter is a continuous and automatic operation, so the operating cost is low.
- The variation of the drum speed rotating can be used to control the cake thickness.
- The process can be easily modified (pre-coating filter process).
- Can produce relatively clean product by adding a showering device.

The limitations of rotary vacuum drum filter compared to other separation methods are as follows:

- Due to the structure, the pressure difference is theoretically limited to atmospheric pressure (1 bar), and in practice somewhat lower.

- Besides the drum, other accessories (e.g., agitators and vacuum pump) are required.
- The discharge cake contains residual moisture.
- High energy consumption by the vacuum pump.

Several variables can impact the operation of the vacuum filter, including (Ref. 4):

- Sludge quality – depends on composition of the sludge, holding time before dewatering, and solids concentration. Sludge holding time decreases the ability of the sludge to dewater (older sludge is harder to dewater).
- Chemical conditioning – changes in the sludge's physical and chemical makeup to produce sludge that releases water more freely to produce a dryer cake. Chemicals that are commonly used are lime, ferric chloride, and polyelectrolytes.
- Filter media type and condition – should be chemically resistant to the material being handled on the vacuum filter.
- Drum submergence.
    - Increasing the time of the filter drum being submerged in the sludge vat increases the filter cycle time for the cake to form but reduces the cake drying ratio. This produces a thicker but wetter cake.
    - Decreasing the time being submerged decreases the sludge cycle time and increases the sludge drying ratio. This produces a thinner but drier cake.
- Drum speed.
    - Increasing will shorten both the filter cycle time and the time for the cake to form. This produces a wetter cake but increase filter yield.
    - Slowing usually produces a drier cake but a lower filter yield.
    - Higher speeds decrease the time that cloths are washed.
- Vacuum level – for a dry cake, the vacuum generally ranges from 15 to 20 in Hg. The lower the vacuum, the wetter the cake.

18.2 Air Drying Systems

The main alternative to mechanical drying systems is to use air drying systems. Air drying refers to dewatering methods that remove moisture by natural evaporation, gravity, or induced drainage. These methods are simpler, easier to operate, and require less energy than mechanical systems. Because of the land area required, labor to remove the sludge cakes, and time needed to allow for the dewatering, air drying is typically used at small to medium-sized plants. Design flows are typically less than two MGD. In cold or wet climates, air drying systems should be covered (Ref. 4). There are four categories of drying beds:

- Conventional drying beds.
- Paved rectangular drying beds.
- Rectangular vacuum-assisted drying beds.
- Wedge-wire drying beds.

18.2.1 Conventional Rectangular Drying Beds

Conventional rectangular drying beds are primarily sand beds (Figure 18.7). They have been used for a long time in the treatment of sludge because they are simple systems that use gravity and evaporation to dewater the sludge (Ref. 4).

Figure 18.7 Sand Drying Bed Examples

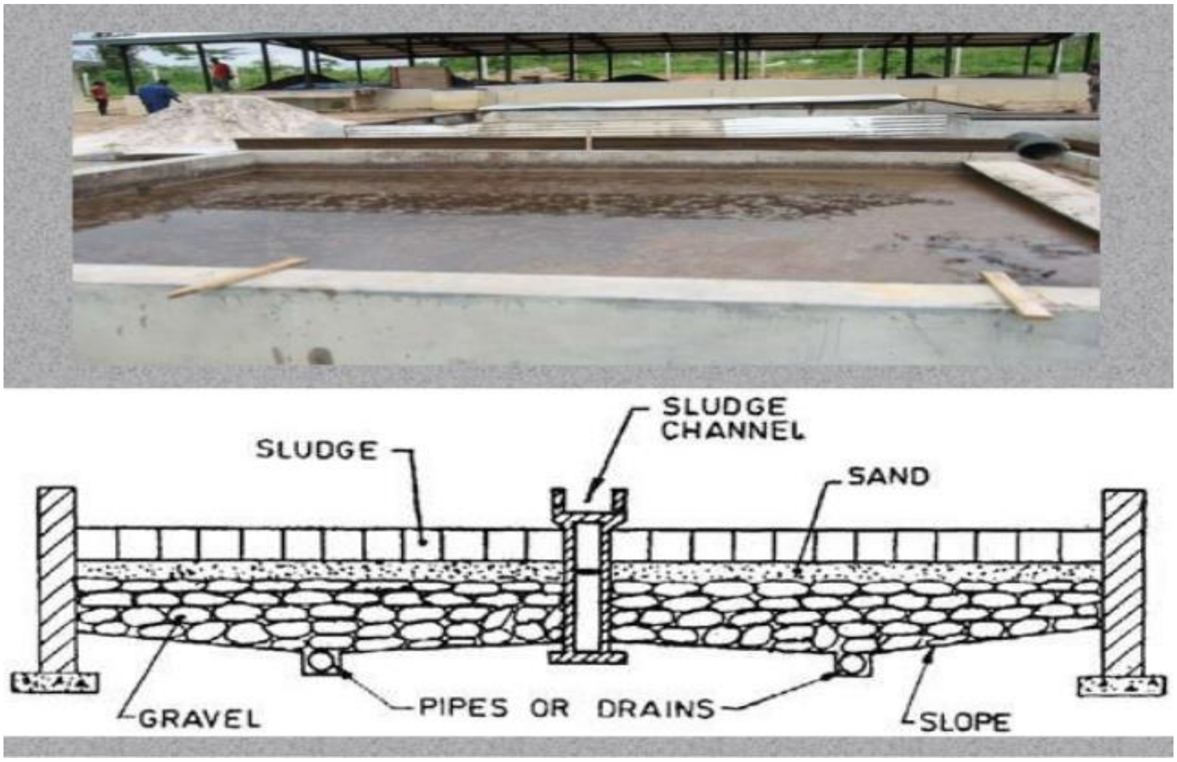
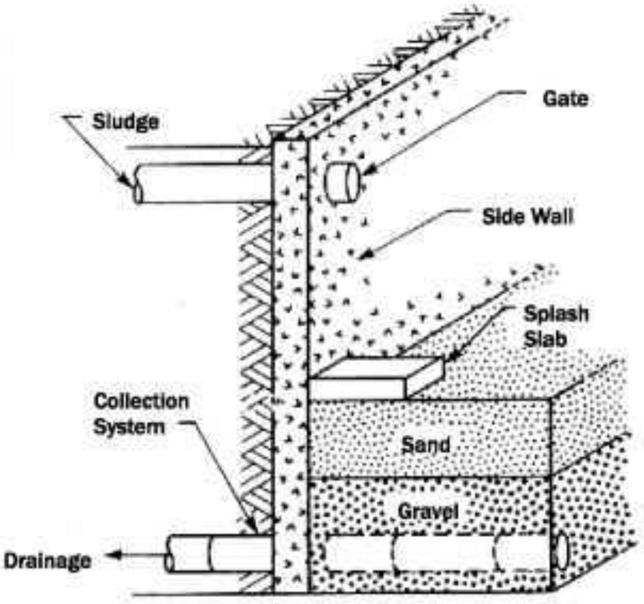


Figure 18.8 Sand Drying Bed Diagram



As shown in Figure 18.8, sand drying beds contain 12 to 20 inches of gravel covering drainage pipes, with 6 to 9 inches of sand on top of the gravel. Sludge is added onto the beds to a depth of 8 to 12 inches, which will result in dewatered sludge ready for removal in three to four weeks during the warm weather months. This process can be sped up with the addition of polymers (Ref. 7). Sludge on sand beds is dewatered just by drainage and evaporation. Water drains through the sludge and into the sand where it is removed by the underdrain system. After a few days the sand layer will clog with fine particles. After the sludge supernatant (liquid laying on top of the solid layer) forms, the surface water is decanted as necessary. Evaporation removes any remaining water.

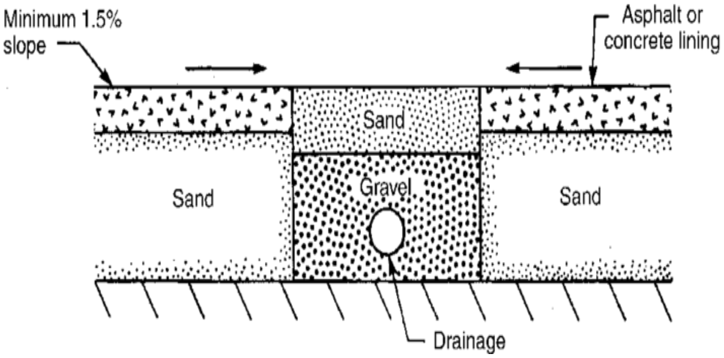
Sand beds will typically dewater sludge to a solids content of 70 to 80%, however they can be as effective as 95% if conditions are optimal (Ref. 7). Several factors affect drying bed performance including:

- Sludge type.
  - The nature of the sludge can impact dewatering.
- Chemical conditioning.
  - Polymers can cut the drying time.
- Climatic conditions.
  - Low temperatures, rain events and freezing can have a significant impact on drying time. As a result, some treatment plants use aerobic digesters to serve as holding tanks during more extreme temperatures.
- Sludge application rates and depths.
  - A depth of greater than 12-inches can increase the drying time.
- Removal of previously dried sludge.
  - Pouring wet sludge on previously dried sludge can create a layer of sludge that will not dry.

18.2.2 Paved Rectangular Drying Beds

Figure 18.9 shows the typical design for a paved drying bed. The main advantages of paved drying beds are that front-end loaders can be used for easy removal of sludge cake, augur-mixing vehicles can speed up drying, and bed maintenance is reduced (Ref. 4). However, for a given amount of sludge, paved drying beds tend to inhibit draining which will then require more surface area than needed for conventional sand drying beds.

Figure 18.9 Typical Paved Drying Bed

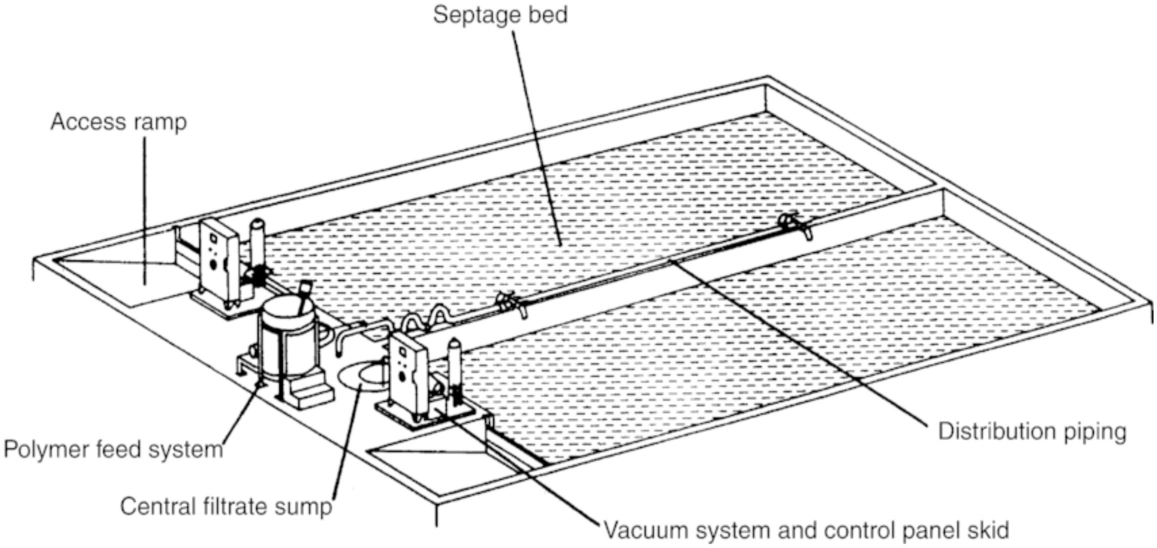


Cake solids concentrations of up to 50% can be obtained in dry climates, but the concentration depends on the number of days the sludge remains on the bed and the number of times it is mixed.

18.2.3 Vacuum-Assisted Beds

Vacuum-assisted beds have a vacuum on the underside of rigid, porous media plates on which conditioned sludge is placed (Ref. 4). An example of a vacuum-assisted bed is shown in Figure 18.10.

Figure 18.10 Vacuum-Assisted Drying Bed Example



The typical schedule for a vacuum drying system is listed in Table 18.1.

Table 18.1 Typical Vacuum Drying Bed Schedule

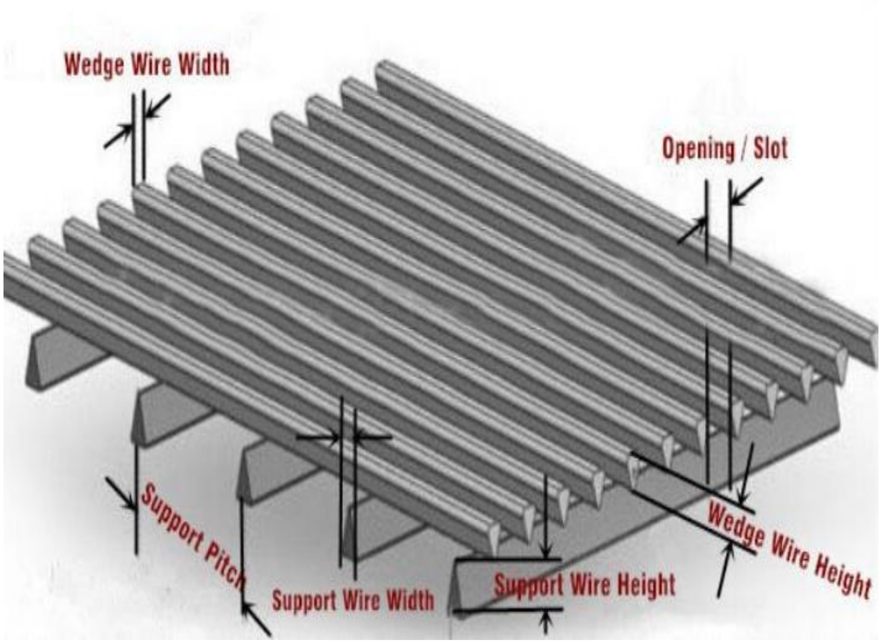
Stage	Vacuum, in. Hg	Duration, hours
1. Gravity dewatering	0	1 to 5
2. Low vacuum	1 to 4	1 to 2
3. Intermediate vacuum	5 to 8	1 to 2
4. High vacuum	10 to 15	1 to 2
5. Air drying	0	variable

The sludge cake is air dried after the completion of the vacuum cycle until the cake can be removed or lifted from the bed with minor solid residuals left behind (Ref. 4). The cake is removed usually with a small tractor. A cake solids concentration of 9 to 35% is typically produced. These beds may be extremely labor intensive and expensive to operate.

18.2.4 Wedge-Wire Beds

The wedge-wire, or wedge-water, process is physically like the vacuum-assisted drying beds. The media consists of a septum with wedge-shaped slots about 0.1 in wide. The septum supports the sludge cake and allows drainage through the slots (Ref. 4). The typical features of a wedge-wire screen plate are shown below in Figure 18.11.

Figure 18.11 Wedge-wire Screen Features



The slurry is typically applied through a pipe to the bed as shown in Figure 18.12.

Figure 18.12 Loading Slurry onto Wedge-wire Bed

After a few days, the dried sludge can be removed, as shown in Figure 18.13, and the bed cleaned. The system functions by the force of gravity. The only energy costs are the minor requirements of the auxiliary pumping and polymer equipment.

Figure 18.13 Removal of Sludge Cake

18.3 Incineration

A third way to deal with sludge is through incineration. Incineration removes all moisture from the sludge thereby reducing volume. Multiple-hearth furnaces and fluidized bed incinerators are the most common types used for sludge combustion in the United States (Ref 10).

The major advantages of incineration include (Ref. 8):

- Maximum reduction of solids, thereby lessening disposal requirements.
- Destruction of any residual pathogens or toxic compounds.
- The potential for energy recovery.

The major disadvantages of incineration include (Ref. 8):

- High capital and operating costs.
- The need for highly trained staff.
- The resulting residuals of air emissions and ash may have negative environmental impacts.
- Depending on the final constituents of the ash, the resulting residuals may be classified as hazardous wastes.

Because of these potential disadvantages, incineration is typically only used by medium to large sized wastewater treatment plants with limited disposal options (Ref. 8).

18.4 Disposal of Sewage Sludge

Sludge that is either applied to land, fired in a sewage sludge incinerator and/or placed on a surface disposal site must comply with Federal Regulation 40 CFR Part 503 (Ref. 9), the standards for use or disposal of sewage sludge. This regulation includes pollutant limits, requirements for pathogen and vector attraction reduction, management practices, monitoring, recordkeeping, and reporting among other requirements. Sludge that is land-farmed or sent to a landfill must pass a paint filter test, a toxicity characteristic leaching procedure (TCLP test), and have the appropriate level of pathogen reduction. The regulation applies to any person or treatment works that prepares sewage sludge, applies sewage sludge to the land, fires sewage sludge in an incinerator, and the owners and operators of surface disposal sites.

Regulation 40 CFR Part 503 is a self-implementing rule. This means that the requirements of Part 503 must be met even if a permit has not been issued. An enforcement action can be taken against a person or wastewater treatment plant that does not meet the requirements of Federal regulation even when that person or wastewater treatment plant does not have a permit for the use or disposal of sewage sludge.

18.5 References

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6. Metcalf & Eddy. (1972). *Wastewater Engineering: Collection, Treatment, Disposal*. New York, New York: McGraw Hill.
7. Wastewater 101. (2018). ***Study Time Treatment Plant (Discussion) - Solids Handling.***
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9. *Standards for the Use or Disposal of Sewage Sludge*. (2018). **40 CFR Part 503**.
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Chapter 19

Hazards

There are many hazards that exist at a wastewater treatment plant. There is always the potential for an accident, but there are also biological and chemical hazards that exist due to the nature of the plant operation. This chapter will provide some information about common hazards and what to be aware of, but this does NOT replace any safety manual or standard operating procedures in place at your wastewater treatment plant.

19.1 Potable Water Supply

According to the 2014 edition of the Ten State Standards, there shall be no cross-connections or direct physical connections between a potable water supply system and a sewer or sewer components which would permit the passage of any wastewater or polluted water into the potable supply. Direct connections are allowed from the potable water supply at points above grade for the following:

- Lavatory.
- Water closet.
- Laboratory sink (with vacuum breaker).
- Drinking water fountain.
- Eye wash fountain.
- Safety shower.

Hot water for any of the units above shall not be taken directly from a boiler used for supplying hot water to a sludge heat exchanger or digester heating unit.

Where a potable water supply is to be used for any other purpose in the wastewater treatment plant, a break tank, pressure pump, and pressure tank are to be provided. Water shall be discharged to the tank through an air gap at least 6 inches above the maximum flood line or the spill line of the tank, whichever is higher.

A sign shall be permanently posted at every hose bib, faucet, hydrant, or sill cock located on the water system beyond the break tank to indicate that the water is not safe for drinking (Ref. 1).

19.2 Physical Hazards

There are many opportunities for physical injuries at a wastewater treatment plant. Wet floors and walkways are slipping hazards. Broken or removed guard rails can increase the risk of falling into a pond, pit, clarifier, or tank. There is mechanical equipment which can cause electrical shock, burns, cuts, bruising, as well as more serious injuries (Ref. 2). It is important for all operators to follow safety guidelines, use proper protective equipment and use common sense to stay safe.

Operators should follow LockOut/TagOut (LOTO) safety protocols any time a machine is being worked on. Lockout/Tagout (LOTO) refers to the OSHA standard for control of hazardous energy sources (Ref. 3). Energy sources including electrical, mechanical, hydraulic, pneumatic, chemical, thermal, or other sources in machines and equipment can be hazardous to workers.

LOTO is a safety procedure used in industry and research settings to ensure that dangerous machines are properly shut off and not able to be started up again prior to the completion of maintenance or repair work. It requires that hazardous energy sources be "isolated and rendered inoperative" before work is started on the equipment in question. The isolated power sources are then locked, and a tag is placed on the lock identifying the worker who placed it. The worker then holds the key for the lock, ensuring that only he or she can remove the lock and start the machine. This prevents accidental startup of a machine while it is in a hazardous state or while a worker is in direct contact with it. Worker's servicing or maintaining machines or equipment may be seriously injured or killed if hazardous energy is not properly controlled. Injuries resulting from the failure to control hazardous energy during maintenance activities can be serious or fatal. Injuries may include electrocution, burns, crushing, cutting, lacerating, amputating, or fracturing body parts, and others. The following are examples of possible injuries to workers:

- A steam valve is automatically turned-on burning workers who are repairing a downstream connection in the piping.
- A jammed conveyor system suddenly releases, crushing a worker who is trying to clear the jam.
- Internal wiring on a piece of factory equipment electrically shorts shocking worker who is repairing the equipment.

19.3 Biological Hazards

Biological hazards include viruses, bacteria, fungi, protozoa, and nematodes. The potential for disease transmission through contact with pathogen contaminated wastewater, aerosols, compost, foam, sludge, and work surfaces are all considered to be risks for wastewater personnel (Ref. 2). Pathogens enter wastewater treatment facilities from the bodily wastes of infected animals from the following sources:

- Human waste including blood, feces, and urine.
- Domestic pets, farm animal and wild animal waste.
- Slaughterhouse waste.
- Fecal waste and urine from rodents in the sewers.
- Any pathogens that may enter the sewer due to decomposition of animals.

For a wastewater worker to become infected, three steps in disease transmission must occur (Ref. 4):

1) The pathogen must leave an infected individual or animal.
2) The pathogen must come in contact with an operator.
3) The pathogen must enter the body of the operator.

The common routes by which pathogens can enter an individual are:

- Ingestion (fecal-oral) - typically from failing to wash hands before eating, rubbing eyes or nose.
- Inhalation - by breathing air that is carrying airborne pathogens.
- Invasion - through contact with an open wound or skin that is pierced or broken.

The risk of disease transmission can be significantly decreased or eliminated using proper hygiene measures, protective equipment, and common sense. Measures available to reduce or prevent **infection** include:

- Automation of machines and sampling equipment.
- Cleanliness, especially thorough and frequent handwashing.
- Restrictions and precautions about eating food, drinking and tobacco use.
- Available and trained first aid personnel.
- Observance of correct sampling practices.
- Protective clothing and other protective personal equipment (PPE).
- Accurate recording of accidents and incidents. This may also include immunization records.
- Training, both initial and ongoing.
- Adequate ventilation of confined area and procedures for confined space entry (i.e., use of gas multi-meters).

19.4 Chemical Hazards

There are many examples of chemical hazards that could exist at a treatment plant. These hazards include chlorine, all acids and bases, chemicals used in coagulation and flocculation, chemicals used in sludge conditioning, etc.

19.4.1 Chlorine

It is important to remember that chlorine is extremely toxic. It was used as a chemical warfare agent in World War I. Many publications and websites contain a long list of concentrations of chlorine and their effect on the body, for example, minor irritation when 1-3 parts per million (ppm) is present up to immediate death at 1000 ppm. When dealing with any chemical that is toxic, the safest response is to eliminate any exposure to the chemical. Perhaps the most important number to remember is the Immediate Danger to Life and Health (ILDH). According to CDC/NIOSH, the current IDLH for chlorine is 10 ppm.

19.4.2 Other Hazardous Gases

The breakdown of waste in the wastewater can also create other toxic gases that cause irritation, major injuries, suffocation, and death. Some of these include:

- Hydrogen Sulfide, H_2S
- Methane, CH_4
- Ammonia, NH_3
- Carbon Dioxide, CO_2
- Carbon Monoxide, CO

Hydrogen sulfide is produced by the anaerobic biological reduction of sulfur containing materials in the wastewater. It is heavier than air and will collect in low-lying areas. It has a “rotten eggs” odor at low concentrations. It cannot be overemphasized that at higher concentrations, the ability to smell the gas is switched off in the brain, it is not the usual reaction of getting used to the smell. It is an irritant at low concentrations, will cause breathing problems at higher concentrations and will cause death with prolonged exposure at high concentrations. For concentrations of less than 100 ppm, an air purifying respirator may be used. Concentrations greater than 100 ppm are Immediately Dangerous to Life and Health (IDLH). Use of a hydrogen sulfide detector should be used before entering any confined space (Ref. 6).

Methane gas is produced by the digestion of volatile organic material by anaerobic bacteria. Methane is typically considered non-toxic; however, it is explosive at low concentrations. The lower explosive limit is 5% and the upper explosive limit is 15%. Because methane is lighter than air, it will rise in confined spaces. Other than its explosive nature, the main safety concern is that it displaces oxygen in the atmosphere, making it difficult to breathe. It does not have an IDLH. As with hydrogen sulfide, before entry into a confined space, the quality of the air should be checked with a gas multi-meter (Ref. 7).

Table 19.1 includes the IDLH for gases that might be encountered in a wastewater plant.

Table 19.1 IDLH for Gases Often Encountered in a Wastewater Plant

Gas	IDLH, ppm
Chlorine	10
Hydrogen sulfide	100
Carbon monoxide	1,200
Carbon dioxide	40,000
Ammonia	300
Ozone	5

19.4.3 Depleted Oxygen Atmosphere

The required oxygen content for a breathable atmosphere is 19.5% oxygen. Normal air is about 21% oxygen with 78% being made up of nitrogen and the rest trace gases.

As a final reminder, a multi-meter should be used before entry into any confined space (Figure 19.1). Readings should be available for oxygen levels, carbon monoxide, hydrogen sulfide and the upper and lower explosion limits for methane. Use a meter through the inspection port or by partially lifting the cover on any confined space before entry.

Figure 19.1 Multimeter Use in Confined Space

19.4.4 Safety Data Sheets

All chemical compounds and mixtures are shipped with a safety data sheet (SDS) which outlines the instructions for safe use and potential hazards associated with the product. These sheets also identify what to do in the event of a spill. These sheets should be collected and maintained in a location that is easily accessible in case of an emergency.

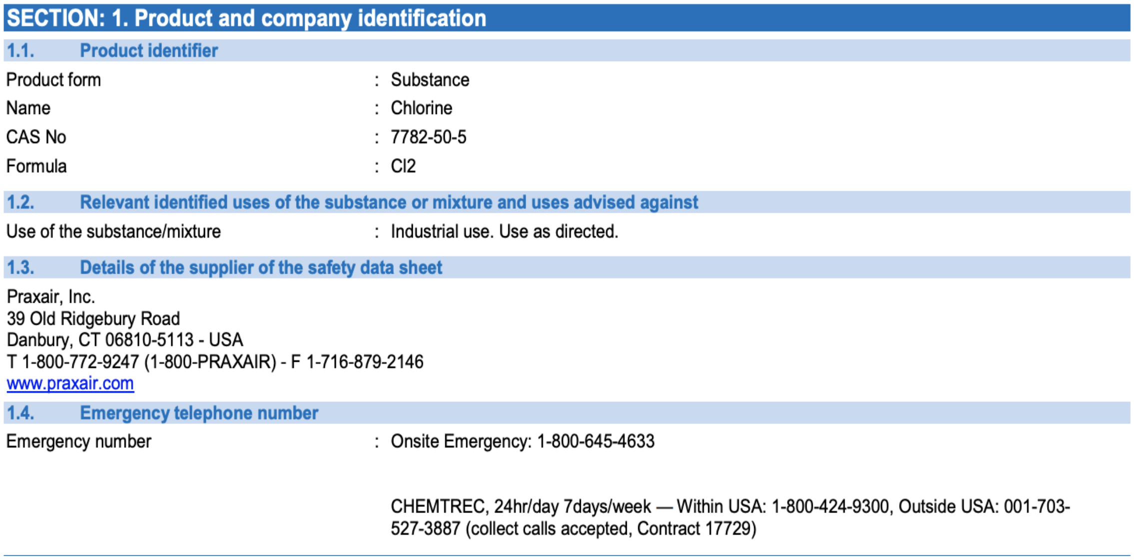
These safety data sheets include (Ref. 5):

1) Identification of the substance and manufacturer
2) Hazards identification.
3) Ingredients.
4) First Aid Measures.
5) Firefighting Measures.
6) Accidental Release Measures.
7) Handling and Storage.
8) Exposure Controls/Personal Protection.
9) Physical and Chemical Properties.
10) Stability and Reactivity.
11) Toxicological Information.
12) Ecological Information.
13) Disposal Considerations.
14) Transport Information.
15) Regulatory Information.
16) Other Information.

19.4.4.1 Product and Company Identification

The first section of the safety data sheet (SDS) identifies the product form, name, chemical identification number, chemical formula, the relevant uses, supplier information, and an emergency contact number (Figure 19.2).

Figure 19.2 First Section of the Safety Data Sheet: Product and Company Identification



SECTION: 1. Product and company identification

1.1. Product identifier

Product form : Substance
Name : Chlorine
CAS No : 7782-50-5
Formula : Cl2

1.2. Relevant identified uses of the substance or mixture and uses advised against

Use of the substance/mixture : Industrial use. Use as directed.

1.3. Details of the supplier of the safety data sheet

Praxair, Inc.
39 Old Ridgebury Road
Danbury, CT 06810-5113 - USA
T 1-800-772-9247 (1-800-PRAXAIR) - F 1-716-879-2146
www.praxair.com

1.4. Emergency telephone number

Emergency number : Onsite Emergency: 1-800-645-4633

CHEMTREC, 24hr/day 7days/week — Within USA: 1-800-424-9300, Outside USA: 001-703-527-3887 (collect calls accepted, Contract 17729)

19.4.4.2 Hazards Identification

The second section of the SDS identifies the classification of the mixture as well as the hazards that must be identified with labels on the chemical storage containers (Figure 19.3). This section identifies basic hazard statements like, “May cause or intensify fire,” or “Fatal if inhaled.” These statements are important and should be understood by the operator for each chemical stored in the facility.

The hazards section also identifies precautionary statements about safe handling like, “Wear protective gloves, protective clothing, eye protection, respiratory protection and/or face protection.” These statements should also be read and understood by the operator.

Figure 19.3 Second Section of the Safety Data Sheet: Hazard Identifcation

2.2. Label elements

GHS-US labeling

Hazard pictograms (GHS-US) :

GHS03 GHS04 GHS05 GHS06 GHS09

Signal word (GHS-US) : DANGER

Hazard statements (GHS-US) : H270 - MAY CAUSE OR INTENSIFY FIRE; OXIDIZER
H280 - CONTAINS GAS UNDER PRESSURE; MAY EXPLODE IF HEATED
H314 - CAUSES SEVERE SKIN BURNS AND EYE DAMAGE
H330 - FATAL IF INHALED
H400 - VERY TOXIC TO AQUATIC LIFE
CGA-HG22 - CORROSIVE TO THE RESPIRATORY TRACT

Precautionary statements (GHS-US) : P202 - Do not handle until all safety precautions have been read and understood
P244 - Keep reduction valves/valves and fittings free from oil and grease
P260 - Do not breathe gas
P264 - Wash hands thoroughly after handling
P271+P403 - Use and store only outdoors or in a well-ventilated place.
P273 - Avoid release to the environment.
P280+P284 - Wear protective gloves, protective clothing, eye protection, respiratory protection, and/or face protection.
P370+P376 - In case of fire: Stop leak if safe to do so
P405 - Store locked up
P501 - Dispose of contents/container Dispose in a safe manner in accordance with local/national regulations
CGA-PG05 - Use a back flow preventive device in the piping.
CGA-PG20+CGA-PG10 - Use only with equipment of compatible materials of construction and rated for cylinder pressure.
CGA-PG12 - Do not open valve until connected to equipment prepared for use.
CGA-PG18 - When returning cylinder, install leak tight valve outlet cap or plug.
CGA-PG06 - Close valve after each use and when empty.
CGA-PG02 - Protect from sunlight when ambient temperature exceeds 52°C (125°F).

2.3. Other hazards

Other hazards not contributing to the classification : None.

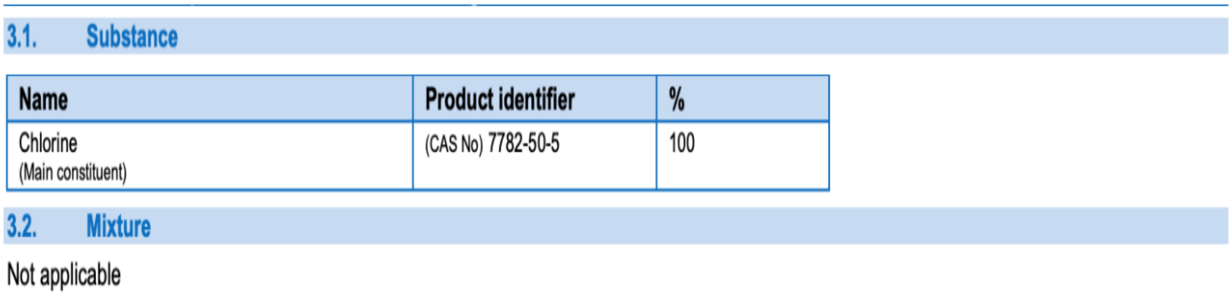
2.4. Unknown acute toxicity (GHS US)

No data available

19.4.4.3 Composition/Ingredient Information

Section 3 of the SDS identifies the chemical components of the product. In this example, it is just chlorine (Figure 19.4). There is nothing else included.

Figure 19.4 Section 3 of the Safety Data Sheet: Substance



3.1. Substance

Name	Product identifier	%
Chlorine (Main constituent)	(CAS No) 7782-50-5	100

3.2. Mixture

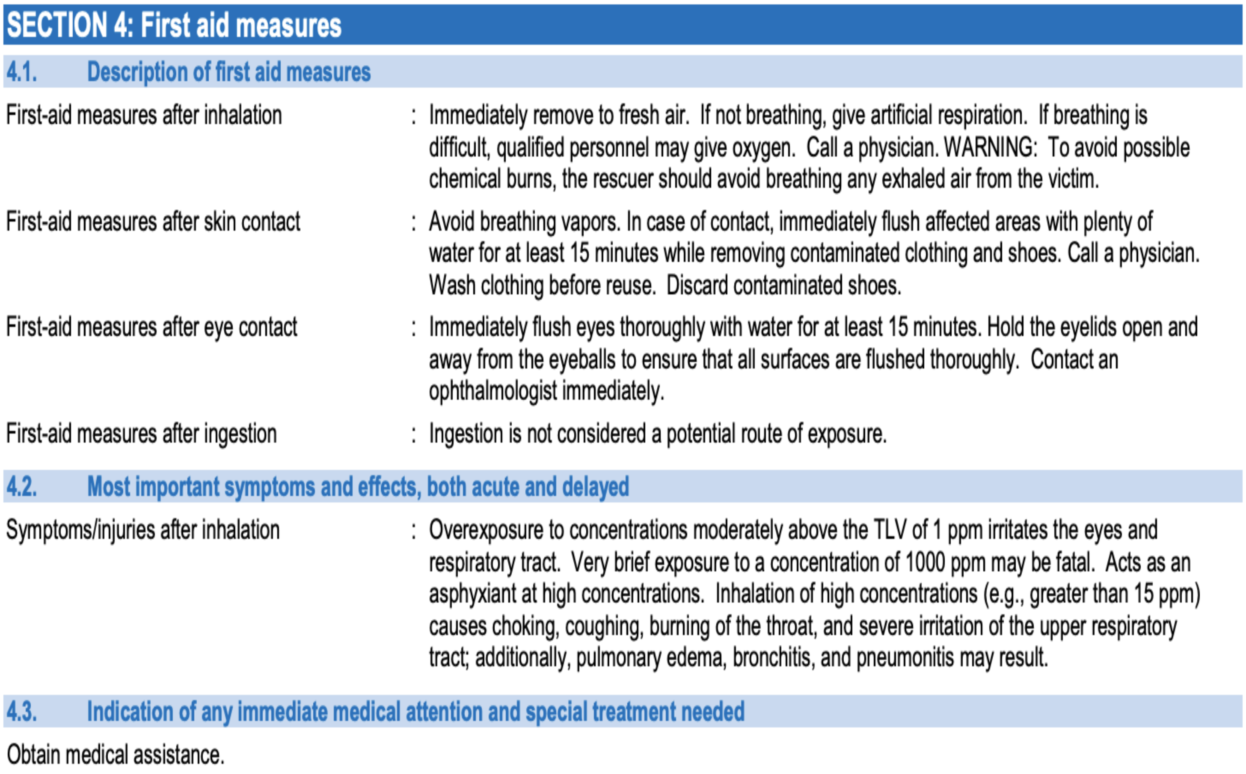
Not applicable

19.4.4.4 First Aid Measures

Section 4 of the SDS outlines what to do in the event of chemical exposure (Figure 19.5). For chlorine, this section particularly addresses what to do in the event of inhalation, skin contact, eye contact, or ingestion.

The information in this section can save a life, it is extremely important that the operator knows and understands how to properly handle exposure to any chlorine or any other chemical in the plant.

Figure 19.5 Section 4 of the Safety Data Sheet: First Aid Measures



SECTION 4: First aid measures

4.1. Description of first aid measures

First-aid measures after inhalation : Immediately remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, qualified personnel may give oxygen. Call a physician. WARNING: To avoid possible chemical burns, the rescuer should avoid breathing any exhaled air from the victim.

First-aid measures after skin contact : Avoid breathing vapors. In case of contact, immediately flush affected areas with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Call a physician. Wash clothing before reuse. Discard contaminated shoes.

First-aid measures after eye contact : Immediately flush eyes thoroughly with water for at least 15 minutes. Hold the eyelids open and away from the eyeballs to ensure that all surfaces are flushed thoroughly. Contact an ophthalmologist immediately.

First-aid measures after ingestion : Ingestion is not considered a potential route of exposure.

4.2. Most important symptoms and effects, both acute and delayed

Symptoms/injuries after inhalation : Overexposure to concentrations moderately above the TLV of 1 ppm irritates the eyes and respiratory tract. Very brief exposure to a concentration of 1000 ppm may be fatal. Acts as an asphyxiant at high concentrations. Inhalation of high concentrations (e.g., greater than 15 ppm) causes choking, coughing, burning of the throat, and severe irritation of the upper respiratory tract; additionally, pulmonary edema, bronchitis, and pneumonitis may result.

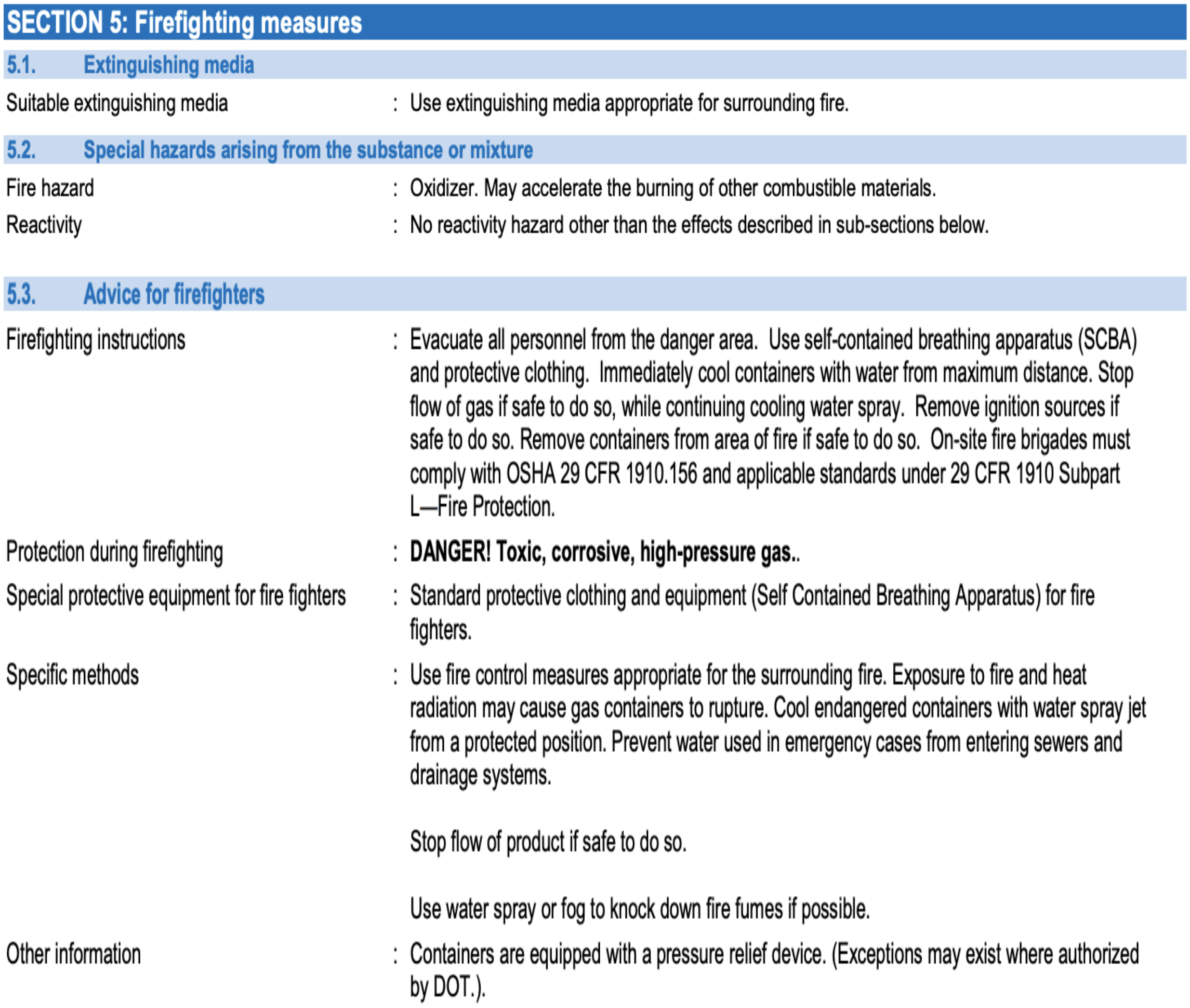
4.3. Indication of any immediate medical attention and special treatment needed

Obtain medical assistance.

19.4.4.5 Firefighting Measures

Section 5 of the SDS clearly identifies what to do in the event of a fire (Figure 19.6). It also identifies the chemical reactivity to fire. Because chlorine is an oxidizer, it has the potential to accelerate burning. In the event of a fire, the operator should tell fire personnel about the chemicals that are contained on site because some, like chlorine, are under pressure and are toxic, creating dangerous situation for firefighters. Any advice that should be given to the firefighters can also be found in section 5 of the SDS.

Figure 19.6: Section 5 of the Safety Data Sheet: Firefighting Measures

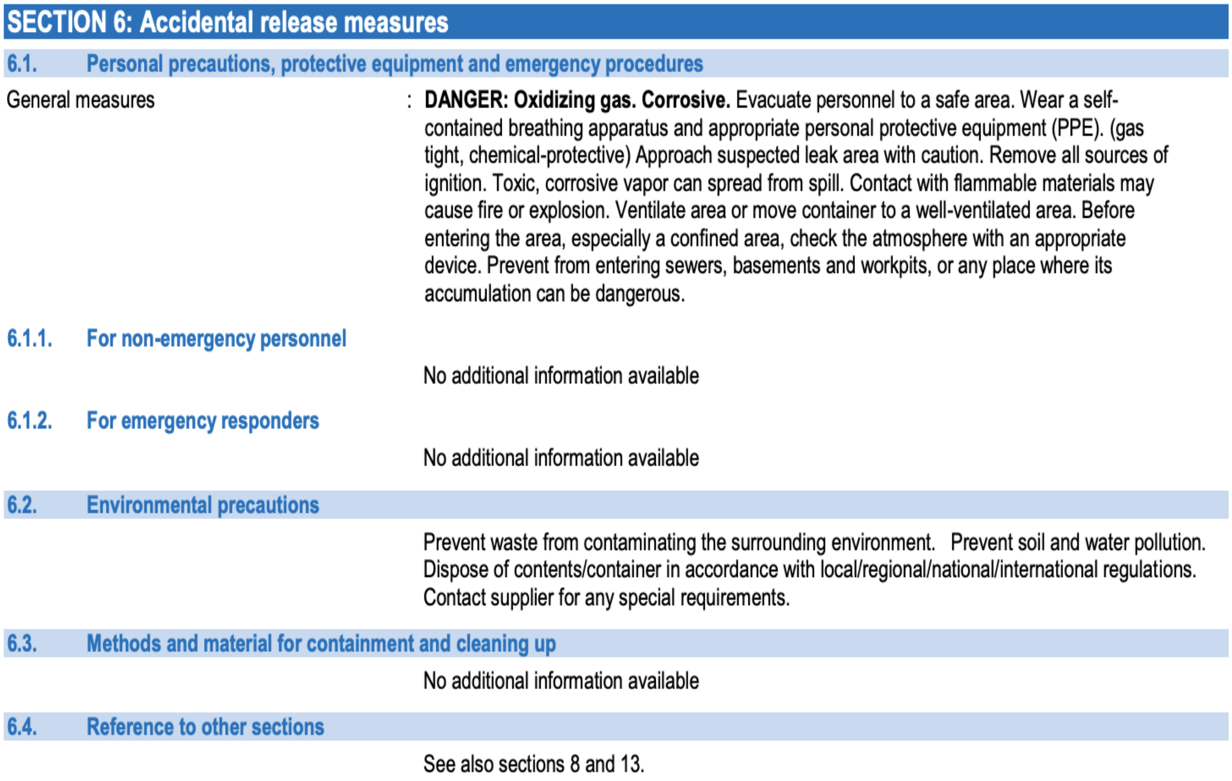


SECTION 5: Firefighting measures	
5.1. Extinguishing media	
Suitable extinguishing media	: Use extinguishing media appropriate for surrounding fire.
5.2. Special hazards arising from the substance or mixture	
Fire hazard	: Oxidizer. May accelerate the burning of other combustible materials.
Reactivity	: No reactivity hazard other than the effects described in sub-sections below.
5.3. Advice for firefighters	
Firefighting instructions	: Evacuate all personnel from the danger area. Use self-contained breathing apparatus (SCBA) and protective clothing. Immediately cool containers with water from maximum distance. Stop flow of gas if safe to do so, while continuing cooling water spray. Remove ignition sources if safe to do so. Remove containers from area of fire if safe to do so. On-site fire brigades must comply with OSHA 29 CFR 1910.156 and applicable standards under 29 CFR 1910 Subpart L—Fire Protection.
Protection during firefighting	: **DANGER! Toxic, corrosive, high-pressure gas.**.
Special protective equipment for fire fighters	: Standard protective clothing and equipment (Self Contained Breathing Apparatus) for fire fighters.
Specific methods	: Use fire control measures appropriate for the surrounding fire. Exposure to fire and heat radiation may cause gas containers to rupture. Cool endangered containers with water spray jet from a protected position. Prevent water used in emergency cases from entering sewers and drainage systems. Stop flow of product if safe to do so. Use water spray or fog to knock down fire fumes if possible.
Other information	: Containers are equipped with a pressure relief device. (Exceptions may exist where authorized by DOT.).

19.4.4.6 Accidental Release Measures

Section 6 of the SDS should be read and understood by the operator as it outlines exactly what to do in the event of a canister leak, incorrect use, or bad connection to equipment (Figure 19.7). In the event of a chlorine leak, everyone should be evacuated because the chemical is toxic to humans, and anything that could potentially start a fire should be removed.

Figure 19.7 Section 6 of the Safety Data Sheet: Accidental Release Measures



SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

General measures : **DANGER: Oxidizing gas. Corrosive.** Evacuate personnel to a safe area. Wear a self-contained breathing apparatus and appropriate personal protective equipment (PPE). (gas tight, chemical-protective) Approach suspected leak area with caution. Remove all sources of ignition. Toxic, corrosive vapor can spread from spill. Contact with flammable materials may cause fire or explosion. Ventilate area or move container to a well-ventilated area. Before entering the area, especially a confined area, check the atmosphere with an appropriate device. Prevent from entering sewers, basements and workpits, or any place where its accumulation can be dangerous.

6.1.1. For non-emergency personnel

No additional information available

6.1.2. For emergency responders

No additional information available

6.2. Environmental precautions

Prevent waste from contaminating the surrounding environment. Prevent soil and water pollution. Dispose of contents/container in accordance with local/regional/national/international regulations. Contact supplier for any special requirements.

6.3. Methods and material for containment and cleaning up

No additional information available

6.4. Reference to other sections

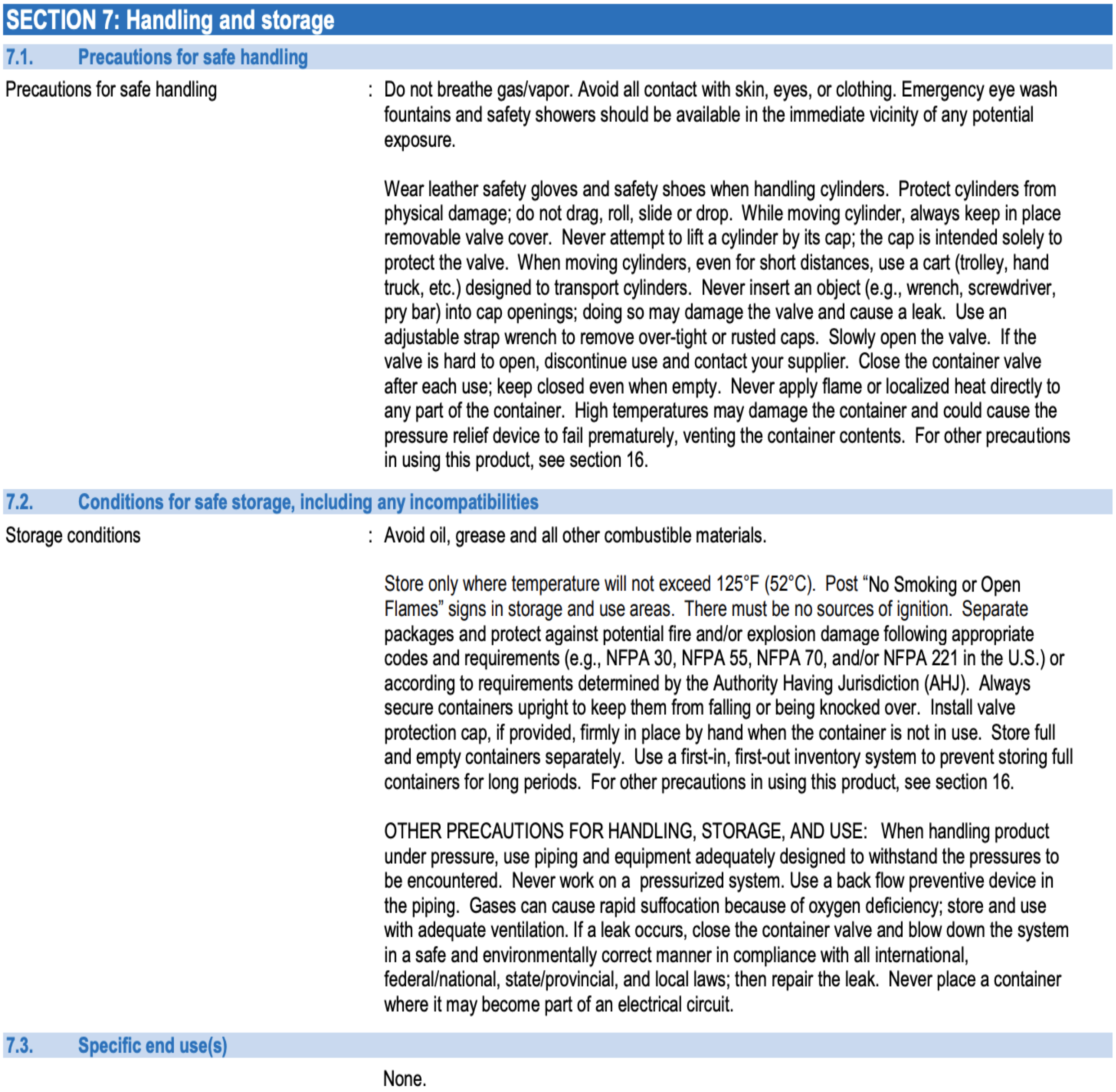
See also sections 8 and 13.

19.4.4.7 Handling and Storage

Section 7 of the SDS identifies all precautions for safe handling and safe storage (Figure 19.8). It is important for the operator of the plant to read and understand this section to ensure that the proper storage conditions are met.

The precautions will identify the proper protective clothing to wear, how to open the valve/container, whether the carton can be dragged or if it needs to be moved on a cart, etc. In the case of chlorine gas, the container is under high pressure and explosive so moving with a cart is required. It is also toxic and stored in high concentrations, so it should not come in contact with the skin, eyes, or clothing.

Figure 19.8: Section 7 of the Safety Data Sheet: Handling and Storage



SECTION 7: Handling and storage

7.1. Precautions for safe handling

Precautions for safe handling : Do not breathe gas/vapor. Avoid all contact with skin, eyes, or clothing. Emergency eye wash fountains and safety showers should be available in the immediate vicinity of any potential exposure.

Wear leather safety gloves and safety shoes when handling cylinders. Protect cylinders from physical damage; do not drag, roll, slide or drop. While moving cylinder, always keep in place removable valve cover. Never attempt to lift a cylinder by its cap; the cap is intended solely to protect the valve. When moving cylinders, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders. Never insert an object (e.g., wrench, screwdriver, pry bar) into cap openings; doing so may damage the valve and cause a leak. Use an adjustable strap wrench to remove over-tight or rusted caps. Slowly open the valve. If the valve is hard to open, discontinue use and contact your supplier. Close the container valve after each use; keep closed even when empty. Never apply flame or localized heat directly to any part of the container. High temperatures may damage the container and could cause the pressure relief device to fail prematurely, venting the container contents. For other precautions in using this product, see section 16.

7.2. Conditions for safe storage, including any incompatibilities

Storage conditions : Avoid oil, grease and all other combustible materials.

Store only where temperature will not exceed 125°F (52°C). Post "No Smoking or Open Flames" signs in storage and use areas. There must be no sources of ignition. Separate packages and protect against potential fire and/or explosion damage following appropriate codes and requirements (e.g., NFPA 30, NFPA 55, NFPA 70, and/or NFPA 221 in the U.S.) or according to requirements determined by the Authority Having Jurisdiction (AHJ). Always secure containers upright to keep them from falling or being knocked over. Install valve protection cap, if provided, firmly in place by hand when the container is not in use. Store full and empty containers separately. Use a first-in, first-out inventory system to prevent storing full containers for long periods. For other precautions in using this product, see section 16.

OTHER PRECAUTIONS FOR HANDLING, STORAGE, AND USE: When handling product under pressure, use piping and equipment adequately designed to withstand the pressures to be encountered. Never work on a pressurized system. Use a back flow preventive device in the piping. Gases can cause rapid suffocation because of oxygen deficiency; store and use with adequate ventilation. If a leak occurs, close the container valve and blow down the system in a safe and environmentally correct manner in compliance with all international, federal/national, state/provincial, and local laws; then repair the leak. Never place a container where it may become part of an electrical circuit.

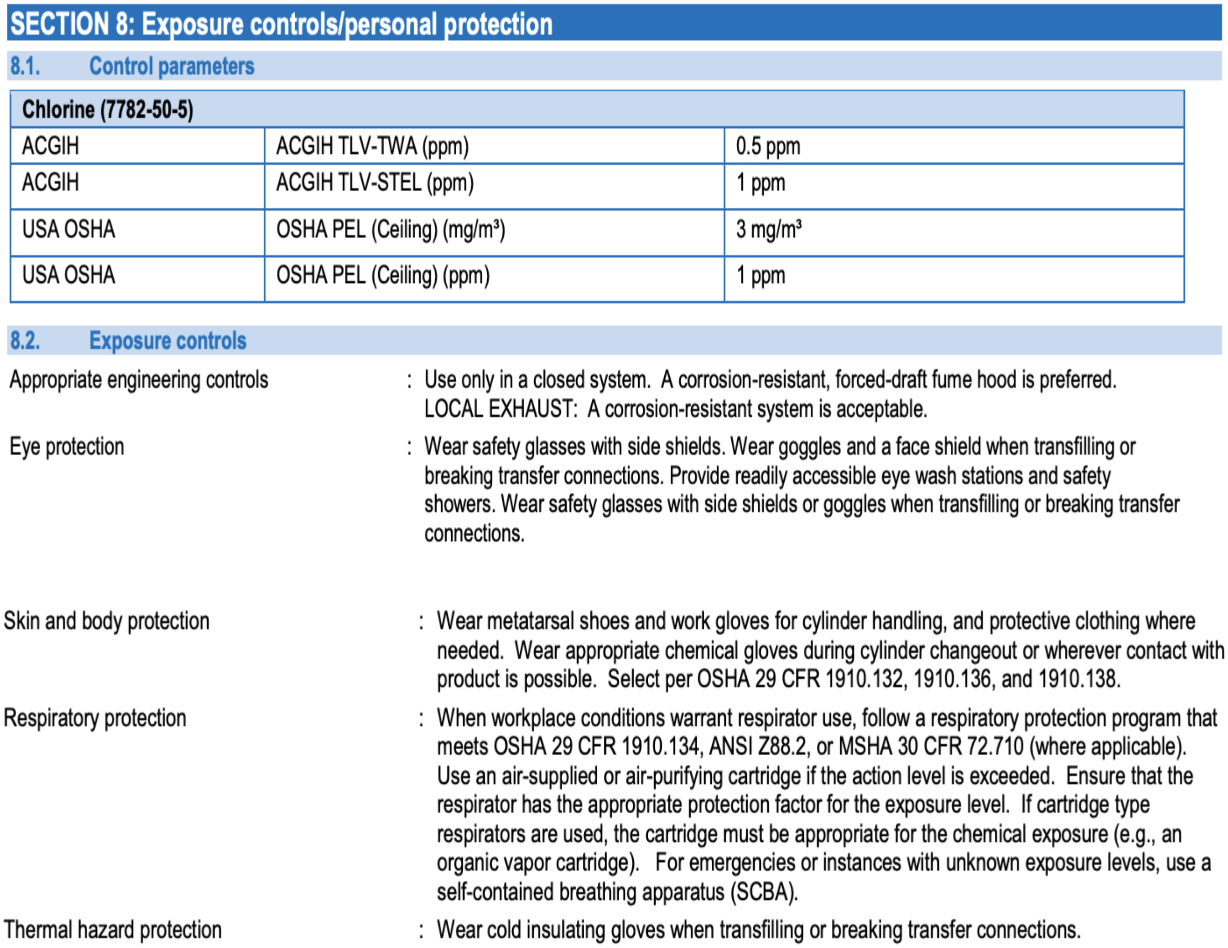
7.3. Specific end use(s)

None.

19.4.4.8 Exposure Controls/Personal Protection

Section 8 of the SDS identifies exposure control information (Figure 19.9). Section 8.1 identifies allowable exposure limits; these are set for worker safety. Section 8.2 identifies recommendations for measures to prevent illness and injury. The operator should read and understand these precautions and follow the requirements for personal protection.

Figure 19.9 Section 8 of the Safety Data Sheet: Exposure Controls/Personal Protection



SECTION 8: Exposure controls/personal protection

8.1. Control parameters

Chlorine (7782-50-5)		
ACGIH	ACGIH TLV-TWA (ppm)	0.5 ppm
ACGIH	ACGIH TLV-STEL (ppm)	1 ppm
USA OSHA	OSHA PEL (Ceiling) (mg/m³)	3 mg/m³
USA OSHA	OSHA PEL (Ceiling) (ppm)	1 ppm

8.2. Exposure controls

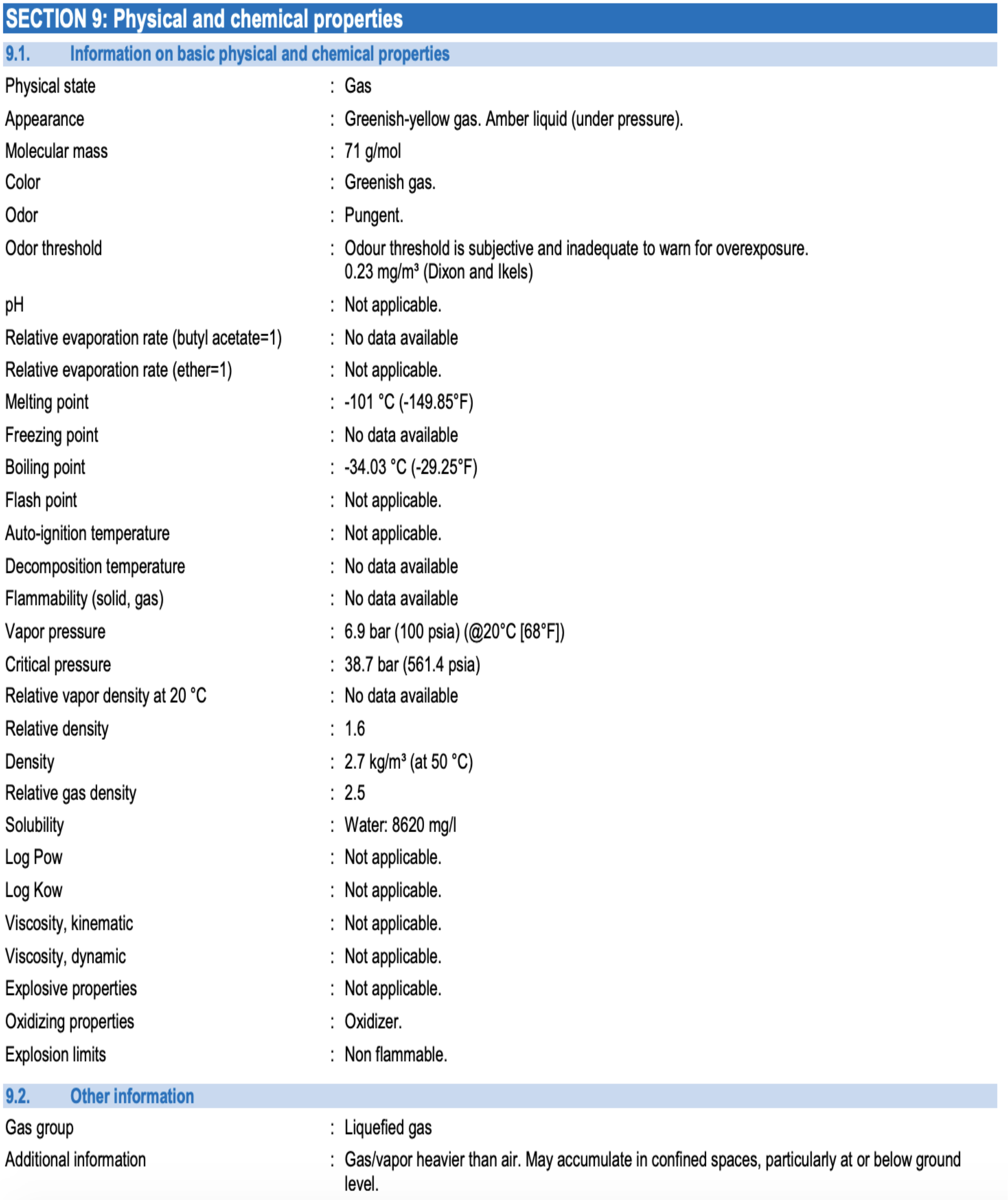
Appropriate engineering controls	: Use only in a closed system. A corrosion-resistant, forced-draft fume hood is preferred. LOCAL EXHAUST: A corrosion-resistant system is acceptable.
Eye protection	: Wear safety glasses with side shields. Wear goggles and a face shield when transfilling or breaking transfer connections. Provide readily accessible eye wash stations and safety showers. Wear safety glasses with side shields or goggles when transfilling or breaking transfer connections.
Skin and body protection	: Wear metatarsal shoes and work gloves for cylinder handling, and protective clothing where needed. Wear appropriate chemical gloves during cylinder changeout or wherever contact with product is possible. Select per OSHA 29 CFR 1910.132, 1910.136, and 1910.138.
Respiratory protection	: When workplace conditions warrant respirator use, follow a respiratory protection program that meets OSHA 29 CFR 1910.134, ANSI Z88.2, or MSHA 30 CFR 72.710 (where applicable). Use an air-supplied or air-purifying cartridge if the action level is exceeded. Ensure that the respirator has the appropriate protection factor for the exposure level. If cartridge type respirators are used, the cartridge must be appropriate for the chemical exposure (e.g., an organic vapor cartridge). For emergencies or instances with unknown exposure levels, use a self-contained breathing apparatus (SCBA).
Thermal hazard protection	: Wear cold insulating gloves when transfilling or breaking transfer connections.

19.4.4.9 Physical and Chemical Properties

Section 9 of the SDS identifies the physical and chemical properties of the chlorine/product (Figure 19.10). It will provide information regarding the appearance, odor, and density of the chemical.

Knowing this information can aid in knowing if there is a leak and how to handle it. For example, with chlorine gas, a leak can be detected by smell (i.e., strong swimming pool smell) and sight (i.e., greenish-yellow gas). We also know that chlorine gas will be near the ground because it is denser than air (chlorine has a density of 2.7 (kg/m^3), while air has a density of 1.225 (kg/m^3).

Figure 19.10: Section 9 of the Safety Data Sheet: Physical and Chemical Properties



SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Physical state : Gas
Appearance : Greenish-yellow gas. Amber liquid (under pressure).
Molecular mass : 71 g/mol
Color : Greenish gas.
Odor : Pungent.
Odor threshold : Odour threshold is subjective and inadequate to warn for overexposure. 0.23 mg/m³ (Dixon and Ikels)
pH : Not applicable.
Relative evaporation rate (butyl acetate=1) : No data available
Relative evaporation rate (ether=1) : Not applicable.
Melting point : -101 °C (-149.85°F)
Freezing point : No data available
Boiling point : -34.03 °C (-29.25°F)
Flash point : Not applicable.
Auto-ignition temperature : Not applicable.
Decomposition temperature : No data available
Flammability (solid, gas) : No data available
Vapor pressure : 6.9 bar (100 psia) (@20°C [68°F])
Critical pressure : 38.7 bar (561.4 psia)
Relative vapor density at 20 °C : No data available
Relative density : 1.6
Density : 2.7 kg/m³ (at 50 °C)
Relative gas density : 2.5
Solubility : Water: 8620 mg/l
Log Pow : Not applicable.
Log Kow : Not applicable.
Viscosity, kinematic : Not applicable.
Viscosity, dynamic : Not applicable.
Explosive properties : Not applicable.
Oxidizing properties : Oxidizer.
Explosion limits : Non flammable.

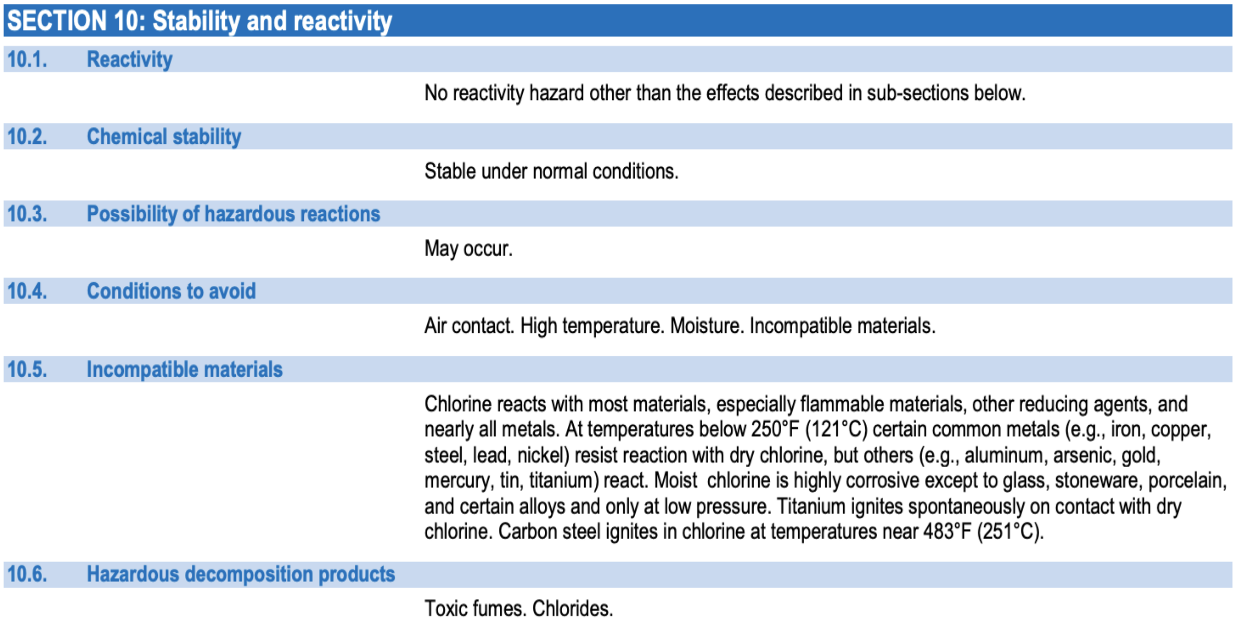
9.2. Other information

Gas group : Liquefied gas
Additional information : Gas/vapor heavier than air. May accumulate in confined spaces, particularly at or below ground level.

19.4.4.10 Stability and Reactivity

Section 10 of the SDS identifies if the chemical is stable and under what conditions it could break down into more hazardous components (Figure 19.11).

Figure 19.11 Section 10 of the Safety Data Sheet: Stability and Reactivity



SECTION 10: Stability and reactivity

10.1. Reactivity

No reactivity hazard other than the effects described in sub-sections below.

10.2. Chemical stability

Stable under normal conditions.

10.3. Possibility of hazardous reactions

May occur.

10.4. Conditions to avoid

Air contact. High temperature. Moisture. Incompatible materials.

10.5. Incompatible materials

Chlorine reacts with most materials, especially flammable materials, other reducing agents, and nearly all metals. At temperatures below 250°F (121°C) certain common metals (e.g., iron, copper, steel, lead, nickel) resist reaction with dry chlorine, but others (e.g., aluminum, arsenic, gold, mercury, tin, titanium) react. Moist chlorine is highly corrosive except to glass, stoneware, porcelain, and certain alloys and only at low pressure. Titanium ignites spontaneously on contact with dry chlorine. Carbon steel ignites in chlorine at temperatures near 483°F (251°C).

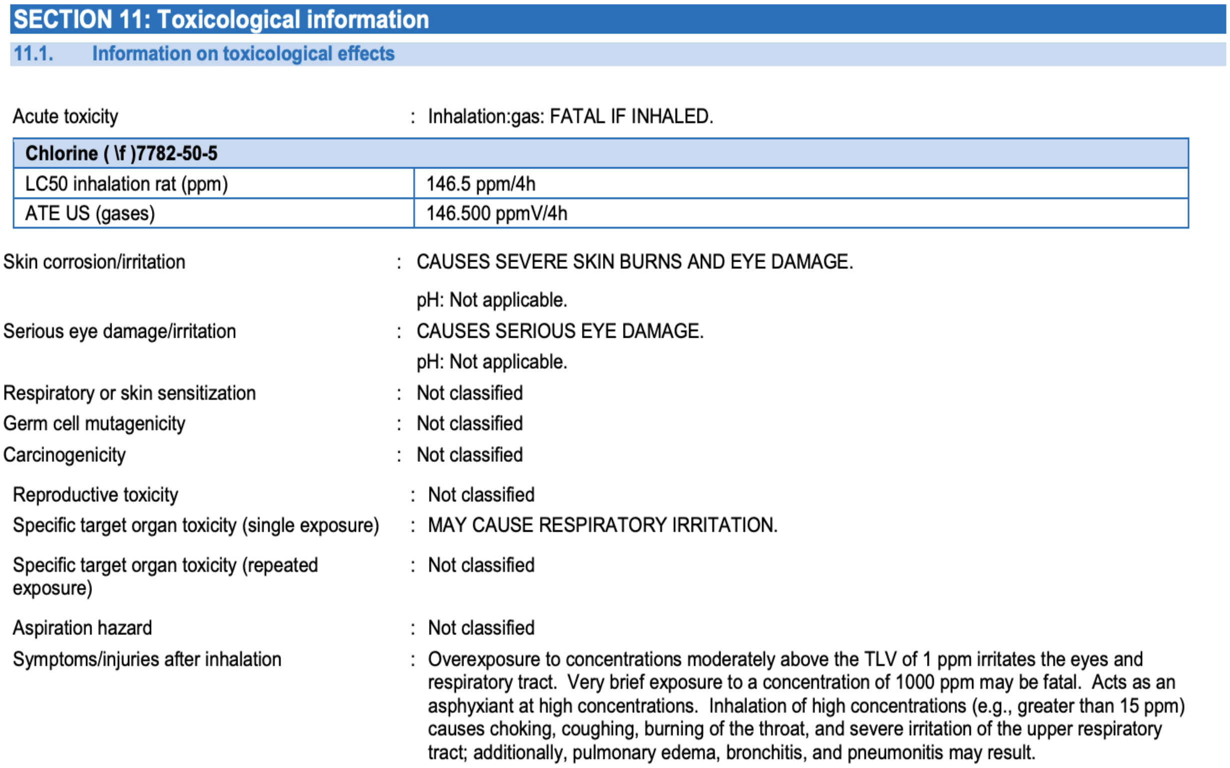
10.6. Hazardous decomposition products

Toxic fumes. Chlorides.

19.4.4.11 Toxicological Information

Section 11 of the SDS identifies the health effects of exposure and symptoms that might be observed (Figure 19.12). It also identifies the lethal dose (146.5 ppm/4-hour, inhalation for chlorine).

Figure 19.12 Section 11 of the Safety Data Sheet: Toxicological Information



SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity : Inhalation:gas: FATAL IF INHALED.

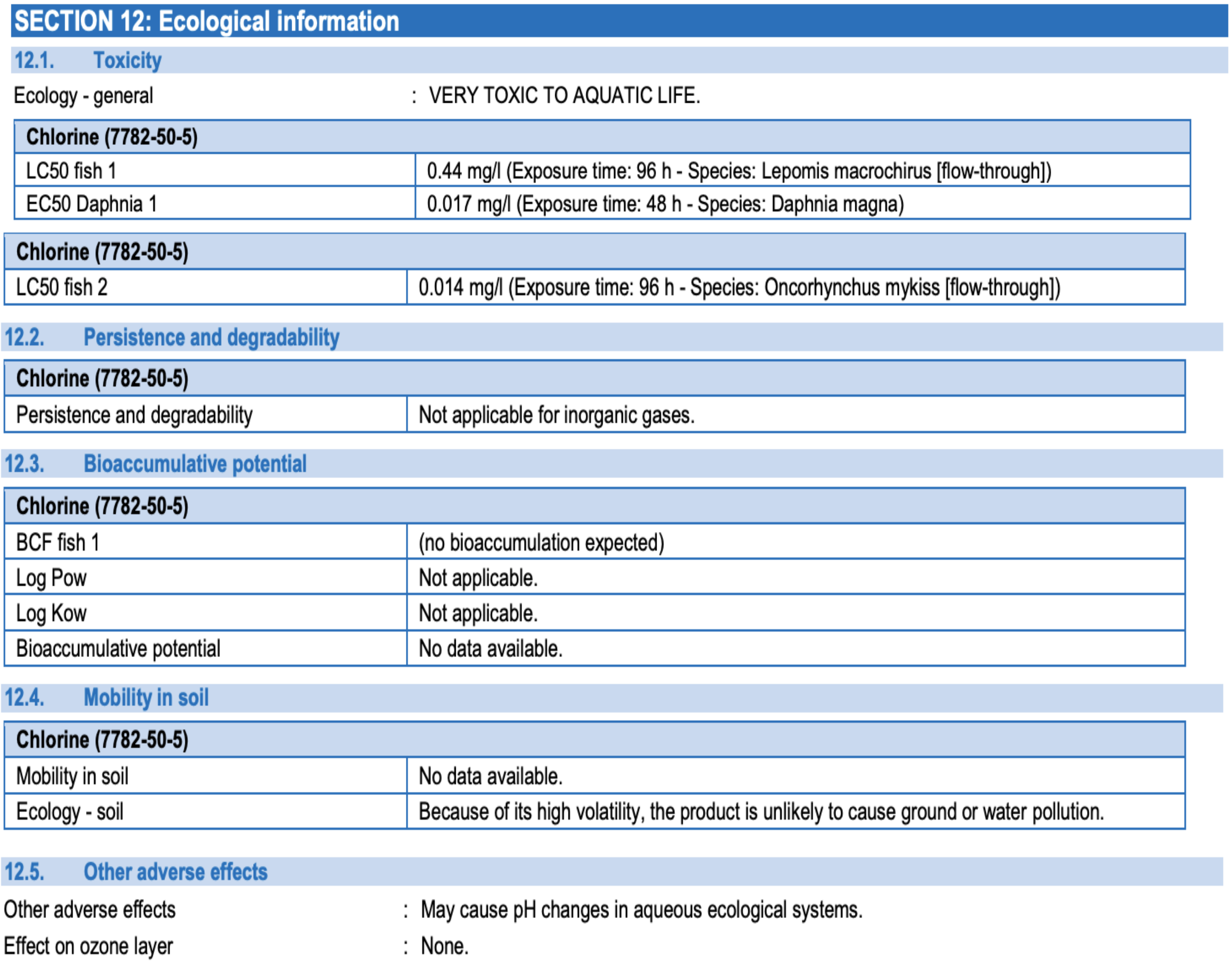
Chlorine (\f)7782-50-5	
LC50 inhalation rat (ppm)	146.5 ppm/4h
ATE US (gases)	146.500 ppmV/4h

Skin corrosion/irritation : CAUSES SEVERE SKIN BURNS AND EYE DAMAGE.
pH: Not applicable.
Serious eye damage/irritation : CAUSES SERIOUS EYE DAMAGE.
pH: Not applicable.
Respiratory or skin sensitization : Not classified
Germ cell mutagenicity : Not classified
Carcinogenicity : Not classified
Reproductive toxicity : Not classified
Specific target organ toxicity (single exposure) : MAY CAUSE RESPIRATORY IRRITATION.
Specific target organ toxicity (repeated exposure) : Not classified
Aspiration hazard : Not classified
Symptoms/injuries after inhalation : Overexposure to concentrations moderately above the TLV of 1 ppm irritates the eyes and respiratory tract. Very brief exposure to a concentration of 1000 ppm may be fatal. Acts as an asphyxiant at high concentrations. Inhalation of high concentrations (e.g., greater than 15 ppm) causes choking, coughing, burning of the throat, and severe irritation of the upper respiratory tract; additionally, pulmonary edema, bronchitis, and pneumonitis may result.

19.4.4.12 Ecological Information

Section 12 of the SDS identifies the environmental impact should the chemical be released (Figure 19.13). It also discusses the possibility of soil and groundwater contamination, the possibility that the chemical will remain in the environment, and any other negative effects.

Figure 19.13 Section 12 of the Safety Data Sheet: Ecological Information



SECTION 12: Ecological information

12.1. Toxicity

Ecology - general : VERY TOXIC TO AQUATIC LIFE.

Chlorine (7782-50-5)	
LC50 fish 1	0.44 mg/l (Exposure time: 96 h - Species: Lepomis macrochirus [flow-through])
EC50 Daphnia 1	0.017 mg/l (Exposure time: 48 h - Species: Daphnia magna)

Chlorine (7782-50-5)	
LC50 fish 2	0.014 mg/l (Exposure time: 96 h - Species: Oncorhynchus mykiss [flow-through])

12.2. Persistence and degradability

Chlorine (7782-50-5)	
Persistence and degradability	Not applicable for inorganic gases.

12.3. Bioaccumulative potential

Chlorine (7782-50-5)	
BCF fish 1	(no bioaccumulation expected)
Log Pow	Not applicable.
Log Kow	Not applicable.
Bioaccumulative potential	No data available.

12.4. Mobility in soil

Chlorine (7782-50-5)	
Mobility in soil	No data available.
Ecology - soil	Because of its high volatility, the product is unlikely to cause ground or water pollution.

12.5. Other adverse effects

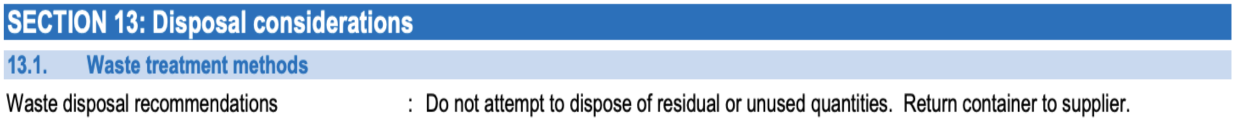
Other adverse effects : May cause pH changes in aqueous ecological systems.

Effect on ozone layer : None.

19.4.4.13 Disposal Consideration

Section 13 of the SDS is not mandatory for all chemicals, so it might not appear on the SDS you receive (Figure 19.14). However, if present, it will provide a description of how to ensure the proper disposal of the chemical and or container. The operator must follow these requirements for proper disposal.

Figure 19.14 Section 13 of the Safety Data Sheet: Disposal Considerations



SECTION 13: Disposal considerations

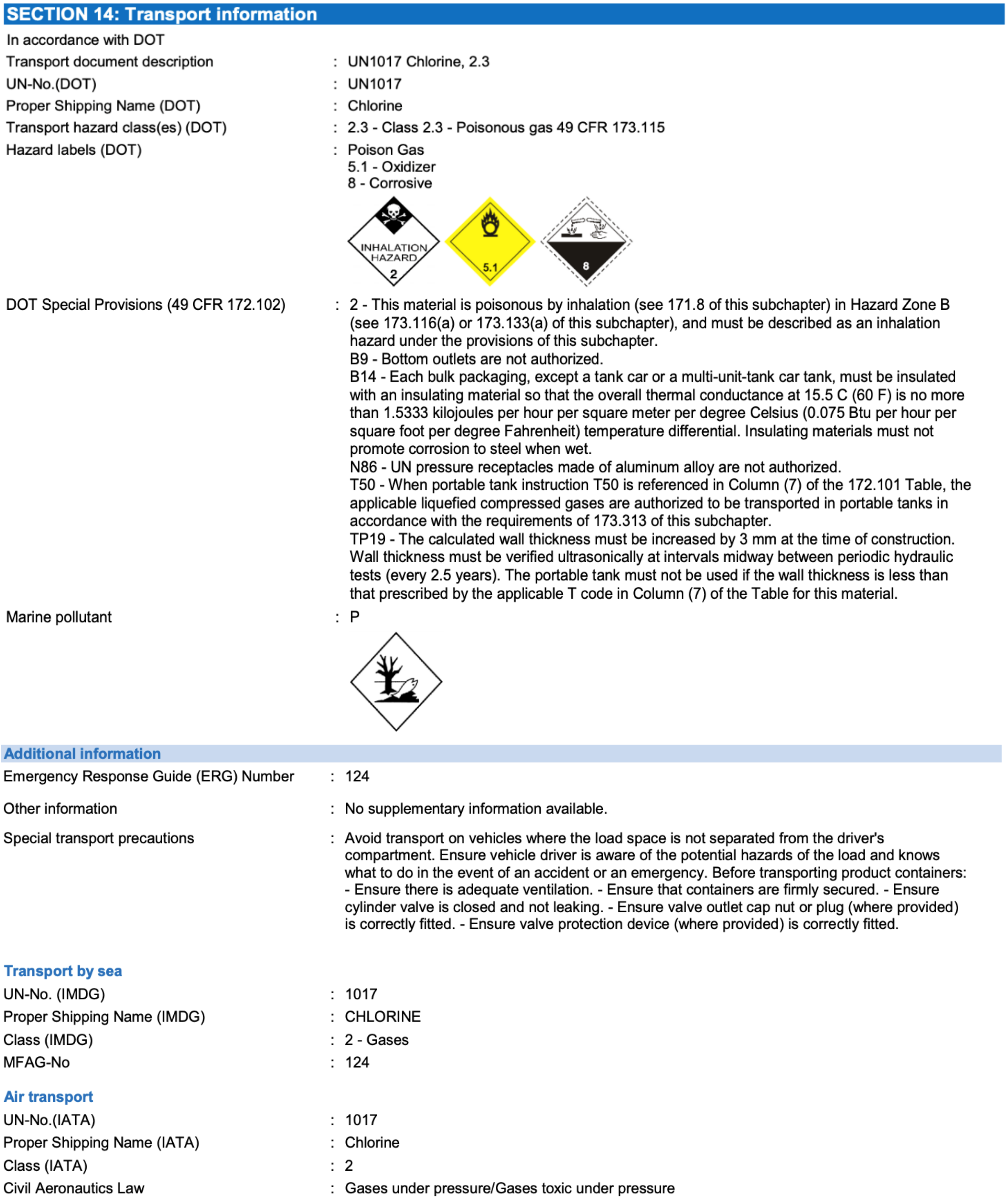
13.1. Waste treatment methods

Waste disposal recommendations : Do not attempt to dispose of residual or unused quantities. Return container to supplier.

19.4.4.14 Transport Information

Section 14 of the SDS is non-mandatory, but if it is present, it identifies information necessary for transporting the chemicals (Figure 19.15). This will include information like how it should be labeled, what it can be transported with, and any precautions that need to be taken during transport.

Figure 19.15 Section 14 of the Safety Data Sheet: Transport Information



SECTION 14: Transport information

In accordance with DOT

Transport document description	: UN1017 Chlorine, 2.3
UN-No.(DOT)	: UN1017
Proper Shipping Name (DOT)	: Chlorine
Transport hazard class(es) (DOT)	: 2.3 - Class 2.3 - Poisonous gas 49 CFR 173.115
Hazard labels (DOT)	: Poison Gas 5.1 - Oxidizer 8 - Corrosive
DOT Special Provisions (49 CFR 172.102)	: 2 - This material is poisonous by inhalation (see 171.8 of this subchapter) in Hazard Zone B (see 173.116(a) or 173.133(a) of this subchapter), and must be described as an inhalation hazard under the provisions of this subchapter. B9 - Bottom outlets are not authorized. B14 - Each bulk packaging, except a tank car or a multi-unit-tank car tank, must be insulated with an insulating material so that the overall thermal conductance at 15.5 C (60 F) is no more than 1.5333 kilojoules per hour per square meter per degree Celsius (0.075 Btu per hour per square foot per degree Fahrenheit) temperature differential. Insulating materials must not promote corrosion to steel when wet. N86 - UN pressure receptacles made of aluminum alloy are not authorized. T50 - When portable tank instruction T50 is referenced in Column (7) of the 172.101 Table, the applicable liquefied compressed gases are authorized to be transported in portable tanks in accordance with the requirements of 173.313 of this subchapter. TP19 - The calculated wall thickness must be increased by 3 mm at the time of construction. Wall thickness must be verified ultrasonically at intervals midway between periodic hydraulic tests (every 2.5 years). The portable tank must not be used if the wall thickness is less than that prescribed by the applicable T code in Column (7) of the Table for this material.
Marine pollutant	: P

Additional information

Emergency Response Guide (ERG) Number	: 124
Other information	: No supplementary information available.
Special transport precautions	: Avoid transport on vehicles where the load space is not separated from the driver's compartment. Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency. Before transporting product containers: - Ensure there is adequate ventilation. - Ensure that containers are firmly secured. - Ensure cylinder valve is closed and not leaking. - Ensure valve outlet cap nut or plug (where provided) is correctly fitted. - Ensure valve protection device (where provided) is correctly fitted.

Transport by sea

UN-No. (IMDG)	: 1017
Proper Shipping Name (IMDG)	: CHLORINE
Class (IMDG)	: 2 - Gases
MFAG-No	: 124

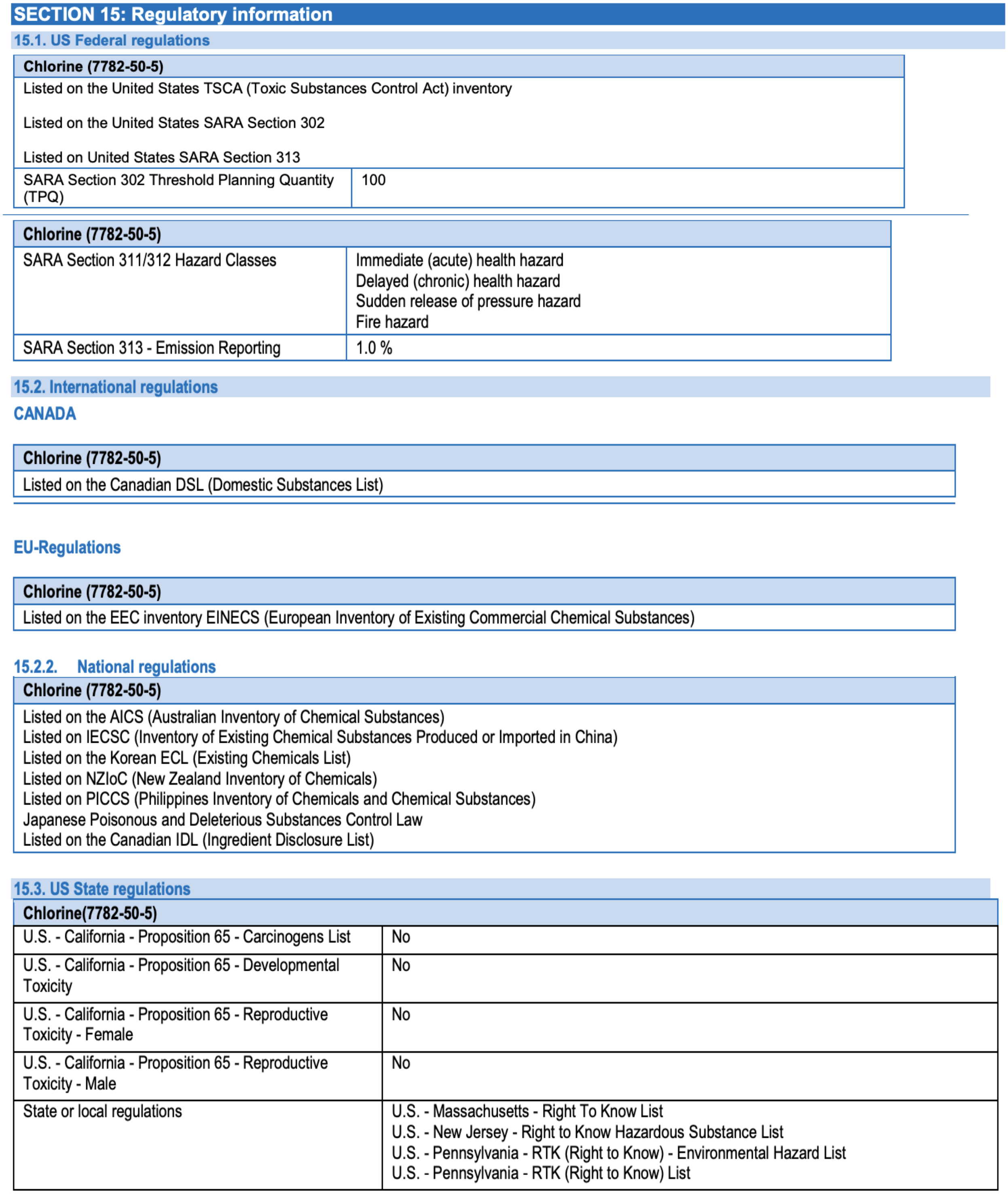
Air transport

UN-No.(IATA)	: 1017
Proper Shipping Name (IATA)	: Chlorine
Class (IATA)	: 2
Civil Aeronautics Law	: Gases under pressure/Gases toxic under pressure

19.4.4.15 Regulatory Information

Section 15 of the SDS includes any regulatory information regarding health, safety and environmental specifications that are not provided elsewhere on the SDS (Figure 19.16).

Figure 19.16 Section 15 of the Safety Data Sheet: Regulatory Information



SECTION 15: Regulatory information

15.1. US Federal regulations

Chlorine (7782-50-5)	
Listed on the United States TSCA (Toxic Substances Control Act) inventory Listed on the United States SARA Section 302 Listed on United States SARA Section 313	
SARA Section 302 Threshold Planning Quantity (TPQ)	100

Chlorine (7782-50-5)	
SARA Section 311/312 Hazard Classes	Immediate (acute) health hazard Delayed (chronic) health hazard Sudden release of pressure hazard Fire hazard
SARA Section 313 - Emission Reporting	1.0 %

15.2. International regulations

CANADA

Chlorine (7782-50-5)
Listed on the Canadian DSL (Domestic Substances List)

EU-Regulations

Chlorine (7782-50-5)
Listed on the EEC inventory EINECS (European Inventory of Existing Commercial Chemical Substances)

15.2.2. National regulations

Chlorine (7782-50-5)
Listed on the AICS (Australian Inventory of Chemical Substances) Listed on IECSC (Inventory of Existing Chemical Substances Produced or Imported in China) Listed on the Korean ECL (Existing Chemicals List) Listed on NZIoC (New Zealand Inventory of Chemicals) Listed on PICCS (Philippines Inventory of Chemicals and Chemical Substances) Japanese Poisonous and Deleterious Substances Control Law Listed on the Canadian IDL (Ingredient Disclosure List)

15.3. US State regulations

Chlorine(7782-50-5)	
U.S. - California - Proposition 65 - Carcinogens List	No
U.S. - California - Proposition 65 - Developmental Toxicity	No
U.S. - California - Proposition 65 - Reproductive Toxicity - Female	No
U.S. - California - Proposition 65 - Reproductive Toxicity - Male	No
State or local regulations	U.S. - Massachusetts - Right To Know List U.S. - New Jersey - Right to Know Hazardous Substance List U.S. - Pennsylvania - RTK (Right to Know) - Environmental Hazard List U.S. - Pennsylvania - RTK (Right to Know) List

19.4.4.16 Other Information

Section 16 of the SDS identifies any other information that might be relevant (Figure 19.17). This section will typically identify the last time the SDS was revised.

Figure 19.17 Section 16 of the Safety Data Sheet: Other Information

SECTION 16: Other information

Revision date : 4/9/2015 12:00:00 AM

19.5 References

1. GLUMRB. (2014). *Recommended Standards for Wastewater Facilities ("Ten State Standards')*, Health Research Inc, Albany, NY, pp. 144.
2. International Labour Organization (ILO). (2000). ***Wastewater Treatment Plant Operator*****.**
3. OSHA (1990). ***29 CFR 1910.147 The Control of Hazardous Energy (Lockout/Tagout) - Inspection Procedures and Interpretive Guidance***.
4. OSHA. (2012). ***Hazard Communication Standard: Safety Data Sheets.***
5. Wikipedia. (2021). **Safety Data Sheet.**
6. OSHA. (2005). ***Hydrogen Sulfide (H2S)***.
7. Wikipedia. (2021). **Methane.**
8. KPSC*.* ***Safety Manual: Wastewater Treatment Plant Operation and Sewage Collection Systems***.

Appendix A

Glossary

Activated Sludge:
The murky brown mass of microorganisms and suspended solids that forms during the aeration stage of wastewater treatment. It is called 'activated' because the microorganisms in the sludge are reproducing rapidly and using the nutrients provided by the suspended solids for growth and energy.

Activated Sludge Process:
A method to remove organic waste from wastewater. Wastewater, that has been screened and initially settled, enters an aeration basin where air is continuously pumped in small quantities to the bottom of the basin. After the aeration basin, water is pumped to the secondary clarifier where the sludge settles out. The clear water continues treatment, and part of the sludge is pumped back into the aeration basin while the rest is wasted to a digester or dewatering system.

Adsorption:
An adsorption treatment process can be used to remove suspended solids and hard to remove organic compounds like MBTE, NDMA, and PFAS. In most cases, such systems work by passing the treated wastewater through a filtration chamber either using gravity or under pressure that contains some type of material that will adsorb the contaminants. The most common material used for this purpose is activated carbon.

Aeration:
The process where air is pumped into the wastewater to increase the level of available oxygen for use by microorganisms.

Aeration Basin:
A basin which is used to grow activated sludge by providing food from the wastewater and oxygen from diffused air or mechanical aeration.

Aerobic Bacteria:
Bacteria that require oxygen to survive and reproduce.

Alkaline:
A solution whose pH is greater than 7.0. Another word for alkaline is basic.

Alkalinity:
The measure of water's ability to buffer changes in pH. Carbonates, bicarbonates, hydroxides, phosphates, borates, and silicates all contribute to the alkalinity of water. It is important NOT to confuse this definition of alkalinity with the pH of a solution.

Anaerobic:
An environment that lacks oxygen. As organisms die and/or waste material decomposes the available oxygen is used up and anaerobic conditions are created.

Anaerobic Bacteria:
Bacteria that do not require oxygen to survive and reproduce. Instead, they use other fermentation or anaerobic respiration systems to derive energy. Oxygen is toxic to strictly anaerobic bacteria.

Anoxic:
An environment that contains very low levels of free molecular oxygen, usually less than 0.5 mg/L.

Bacteria:
Small, single-celled organisms which do not contain a nucleus.

Biochemical Oxygen Demand (BOD):
A measure of the quantity of dissolved organic matter in wastewater that can be removed or oxidized by aerobic bacteria. BOD is normally expressed in term of BOD_5, the amount of oxygen that would be used up by bacteria over a five-day period, normally expressed in units of mg/L.

Bulking Sludge:
Sludge that will not settle properly and has an expanded or inflated texture. Bulking sludge is frequently caused by the presence of filamentous bacteria.

Calibration:
The process where adjustments of the physical or digital components of a piece of equipment are made so that that the equipment performance or measurements accurately reflect the true parameter value.

Chain of Custody:
A document that records the path of sample transfers from the time of collection to the time of analysis.

Chemical Oxygen Demand (COD):
A measure of the amount of chemically oxidizable material in a sample.

Chlorination:
The addition of chlorine to wastewater to disinfect and kill the bacteria and potential pathogens in the wastewater after it has passed through primary and secondary treatment.

Chlorine Demand:
The different between the amount of chlorine added to the wastewater and the amount of residual or remaining chlorine after a specific contact time.

Clarifiers:
Basins where solids have time to settle. See Sedimentation tanks.

Coagulation:
The process where particles attach to each other and form larger masses known as floc, either by increased contact or the introduction of chemicals such as polymers.

Coliform Bacteria:
Microorganisms that are present in wastewater and the environment and in the fecal matter of especially warm-blooded animals. They are often used as indicators of fecal pollution and the possible presence of pathogens (see also *Escherichia coli*).

Combined Sewer:
Conveys both sanitary sewage and storm water run-off within the same conduit.

Composite Sample:
A sample collected over time, either by continuous sampling or by mixing individual grab samples collected at specific intervals over a specified period of time.

Denitrification:
A biological process by which nitrate, and nitrite are reduced, and converted to nitrogen gas by a group of bacteria known as denitrifiers. Denitrification only takes place under anoxic conditions.

Diffused Air:
Method of aeration where bubbles of are pumped into the bottom of an aeration basin. Used to add oxygen to water or provide mixing of wastewater.

Digestion:
The process where microorganisms break down complex organic matter into simpler compounds. It is also the process of treating sludge prior to disposal.

Discharge Monitoring Report (DMR):
To ensure that a wastewater treatment plant is meeting its permitted discharge limits, each facility is required to monitor and sample the discharge from its plant and report the results of the associated readings and laboratory analyses to the KDOW via a formal report known as the Discharge Monitoring Report.

Disinfection:
Disinfection is the primary cleaning process that kills, inactivates, or lowers the numbers of any pathogens found in wastewater.

Dissolved Oxygen (DO):
The amount of dissolved free oxygen in a body of water or activated sludge.

Dissolved Solids:
The organic or inorganic molecules, ions, and minerals, that dissolve in wastewater.

Effluent:
The water or wastewater that leaves a treatment unit (e.g., clarifier, aeration basin). Ultimately in the context of wastewater treatment, it is the treated wastewater that leaves the plant after completing the treatment process.

Escherichia coli (E. coli):
A species of fecal coliform bacteria found in the intestinal tract of most animals and used to indicate the presence of pathogens in water. *E. coli* from warm-blooded animals used to indicate the presence of pathogens in water.

Eutrophication:
The process by which an entire body of water, or parts of it, become progressively enriched with minerals and nutrients which eventually causes a dense growth of plant life and death of animal life from lack of oxygen.

Extended Aeration:
A type of activated sludge wastewater treatment that uses large aeration basins to hold wastewater for a long period of time. The extended time allows for the greater digestion of sludge within the aeration basin, reducing the amount of output sludge normally associated with more conventional activated sludge processes.

Facultative Bacteria:
Bacteria that prefer oxygen but can survive without it.

Facultative Ponds:
The most common type of ponds used in wastewater treatment. They are usually 4 to 8 feet deep and consist of an aerobic layer overlaying an anaerobic layer of sludge at the bottom of the pond.

Floc:
Large masses of wastewater suspended solids that form from smaller particles. The formation of which aids in the settling of particles in a sedimentation basin or clarifier.

Flocculation:
The process where smaller particles stick together into larger particles for form floc. This process is sometimes facilitated by the addition of chemicals to the water such as polymers.

Grease:
The fats, waxes, long chain fatty acids, soaps, oils, and other non-fatty materials that tend to float on top of wastewater.

Grit:
Sand, pebbles, and other heavy inorganic matter in wastewater.

Hardness:
A measure of the total concentration of the cations Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) in the water.

Heavy Metals:
Metals that have a high atomic weight or are toxic to life at relatively low concentrations. While a few heavy metals are necessary for human health, above certain levels they all become toxic. Heavy metals are one of the most persistent pollutants in wastewater.

Hydraulic Retention Time (HRT):
Also known as detention time, HRT is the average time it takes for the water component of wastewater to move through either the aeration basin or the secondary clarifier.

Inorganic Material:
Inorganic materials generally come from non-living sources and lack carbon-carbon bonds. Inorganic compounds do not readily burn.

Infection:
The result of and invasion or ingestion of an organism by disease causing agents such as pathogens or parasites.

Lagoons (see ponds):
A type of treatment basin for treating wastewater that are typically greater than 8 feet deep.

Mean Cell Residence Time (MCRT):
The average time that the microorganisms or biomass remain in the system.

Microorganisms:
Small, single, or multi-cell organisms like bacteria, protozoa, metazoans, and fungi.

Mixed Liquor:
A mixture of wastewater and microorganisms.

Mixed Liquor Suspended Solids (MLSS):
The concentration total suspended solids in activated sludge that are contained in an aeration basin or clarifier. MLSS are usually measured in mg/L.

Mixed Media Gravity Filter:
A filter that uses more than one type of filtering media such as sand and gravel, that relies on gravity to pull water through it.

National Pretreatment Program:
The National Pretreatment Program is a cooperative effort of federal, state, and local regulatory environmental agencies established to protect water quality. The program is designed to reduce the level of pollutants discharged by industry and other non-domestic wastewater sources into municipal sewer systems, and, thereby, reduce the amount of pollutants released into the environment through wastewater.

Nitrification:
The process where aerobic nitrifying bacteria convert nitrogen-containing material (i.e., ammonia) into nitrates and nitrites. This process, unlike denitrification, it requires a lot of oxygen.

Nitrogen:
An essential element for life that is present in wastewater as ammonia, nitrates, nitrites, nitrogen gas, and organic nitrogen.

Nutrient:
Any substance that can be used by organisms to grow and reproduce.

Open Channel:
Any device that conveys water with the water surface open to the air.

Organic Matter:
Any matter of plant or animal origin. Matter which contains carbon-carbon bonds.

Orthophosphate:
A biologically available form of phosphorus (i.e., PO_4). The presence of excessive orthophosphates in water can trigger blooms of algae and cyanobacteria (blue-green algae).

Oxidation:
The process where a molecule loses an electron. In the context of wastewater treatment, the term is used to refer to the process whereby microorganisms, like bacteria, break down organic

material to use in the creation of new cellular material and energy production. It is also defined as the use of oxygen or other chemicals to convert organic material into a more stable form.

pH:
A logarithmic based scale to measure of the acidity or basicity of a solution. A pH below 7 is acidic, pH above 7 is basic, and a pH of 7 is neutral. A pH of 6 is ten times more acidic than a pH of 7 and a pH of 8 is 10 times more basic than a pH of 7.

Pretreatment:
The process of treating wastewater (typically done industrial sites) to prevent the discharge of toxic chemicals into the collection system.

Primary Treatment:
Primary treatment of wastewater includes both the separation of grit and other materials from the wastewater and then the subsequent settling of additional solids in a settling basin or a primary clarifier. Most primary treatment can remove 50% to 60% of the total suspended solids and 20% to 40% of the BOD_5 load.

Raw Wastewater:
The water that enters the plant prior to any treatment.

Reactor:
A tank where wastewater is mixed with microorganisms to facilitate the breakdown of the organic material and a reduction of the BOD_5 load.

Receiving Waters:
A body of water that receives the effluent from the wastewater treatment plant.

Return Activated Sludge (RAS):
The sludge that has settled out in the secondary clarifier and is pumped back into the aeration tank to help continue or re-seed the breakdown of the organic matter in the incoming wastewater.

Secondary Treatment:
Following primary treatment, the wastewater is biologically treated to further reduce the organic load or BOD_5. Different strategies for secondary treatment include activated sludge, ponds and lagoons, trickling filters, and rotating biological contactors.

Sedimentation Tanks (see Clarifiers):
A larger basin where solids have time to settle. Solids collect at the bottom, forming sludge, while grease and scum float on the top and is skimmed off. Water exits the tank via weirs and is move to the next stage of treatment. The sludge is pumped out of the bottom of the tank and either recycled or wasted to a digester.

Sewage:
Wastewater from residential, commercial, and industrial institutions.

Sewers:
The conveyance system used to collect wastewater and storm water.

Sludge:
The solids that settle at the bottom of tanks and basins.

Sludge Age:
How long, in days, sludge has been in the secondary treatment process.

Sludge Digestion:
A process that decreases sludge volume by further allowing microorganisms to consume any remaining organic material. It also aids in the drying of sludge.

Sludge Volume Index (SVI):
A measure of the settling characteristics of the sludge. It is used to determine the recycle rate of sludge or Q_{was}. It is the volume of solids that have accumulated in the bottom of a settling column after standing for 30 minutes.

Solids Retention Time (SRT):
The average time that the total suspended solids (TSS) remain in the system.

Specific Conductance:
A measure of the ability of water to pass an electrical current.

Specific Oxygen Uptake Rate (SOUR):
Represents the amount of oxygen that is used by microorganisms to break down and remove the organic material in the wastewater.

Suspended Solids:
Solids that are suspended in water and that are filtered out (retained by) a filter with a pore size of 2.0 µM.

Tertiary Treatment:
An additional treatment step after secondary treatment used to remove a specific pollutant such as nitrogen or phosphorus. The exact type of treatment will be dependent upon the specific pollutant to be removed.

Total Residual Chlorine (TRC):
The amount of measurable chlorine remaining after treating water with chlorine.

Total Solids:

All the solids that exist in the wastewater, either dissolved, suspended, or settleable.

Trickling Filter:

A secondary treatment strategy where wastewater is sprayed over rocks or other material that are coated with a film of microorganisms. These microorganisms are used to break down the organic matter in the wastewater. This unit is typically followed by a secondary clarifier for the removal of any residual solids.

Turbidity:

A measure of the clarity of water that is directly related to the concentration of the suspended solids.

Waste Activated Sludge (WAS):

The portion of sludge from the secondary clarifier that does not get pumped back to the aeration basin but moves on to additional sludge treatment before disposal.

Wastewater:

See Sewage. It normally consists of about 99.9% water and just 0.1% solids, however, it is a potential source of pathogens and could pose a risk to human health if not treated properly.

Water Pollution:

Anything (microorganisms, chemicals, waste, sewage, and heat) that enters a water stream that poses a risk to the potential users.

Appendix B

Basic Mathematics Skills

Merriam-Webster Dictionary defines mathematics as "the science of numbers, quantities, and shapes as the relations between them." Mathematics is the language we use to relate, convert, and convey information about our world. Mathematics lets us express measurement, amount, number, etc. in a way that is explicit.

All mathematical concepts are built on four fundamental operations: addition, subtraction, multiplication, and division. This chapter will use these operations to help build confidence in basic mathematical concepts which apply to Wastewater Treatment.

B.1 Math Confidence

Mathematics is like a language, or any skill, if it is not used regularly or put into practice often, it can be forgotten, or skills get rusty. This section is intended to provide a refresher for those who might need it to gain some practice in mathematics.

B.1.1 Order of Operations

Operations means things such as addition, subtraction, multiplication, division, squaring, etc. Equations can look like…

$$8 \div 2\, x\, (2 + 2)$$

How do we calculate the correct answer? Does it start on the left? Does it start on the right? Doing the calculations in different orders provides different answers. This means that there needs to be a standard way of doing a mixed equation so that everyone gets the same answer.
The agreed upon rules is known as the **Order of Operations,** sometimes known as PEMDAS. One way to remember this order is to use the mnemonic (a tool to help us remember things): **P**lease **E**xcuse **M**y **D**ear **A**unt **S**ally.

P → Solve everything in parentheses ( ) first
E→ Exponents such as X^2, we will talk about this more in a bit
MD→ Multiplication (X) and Division (÷) (left-to-right)
AS→ Addition (+) and Subtraction (-) (left-to-right).

This means we would solve the above equation like this:
First, perform everything in the parentheses, regardless of its position in the equation. That is why we add the two numbers in the parenthesis first, even though they are on the right-hand side of the equation:

$$8 \div 2\, x\, (2 + 2)$$

Which gives us:

$$8 \div 2\, x\, 4$$

Next, since we have reduced the equation by doing the addition in the parentheses, we will now solve the next level of operations (either multiplication or division).
In this case, we will start on the left-hand side of the equation and first do the division.

8 ÷ 2 *X* 4

Which give us:

4 *X* 4

Now, the only thing that is left is 4 *X* 4, which give us: 16

Example B.1

How do you work out 3 + 6 *x* 2?

Solution

Multiplication before Addition. So, first 6 *x* 2 = 12, then 3 + 12 = 15

Example B.2

How do you work out (3 + 6) *x* 2?

Solution

Parentheses first:

First 3+6 = 9, then 9 *x* 2 = 18.

B.1.2 Fractions/Ratios/Percentages

Fractions look at equal parts of a whole. Ratios relate parts of one thing to parts of another. Percentages relate back to 100%. Each of these are about identifying partial relationships.

B.1.2.1 Fractions

Fractions can be understood when a pizza is sliced into equally sized pieces. This pizza is cut into 8 equally sized pieces.

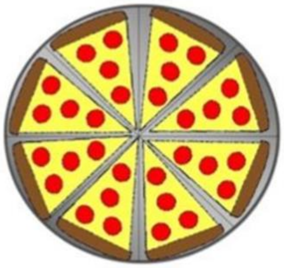


Figure 1 Pizza cut into 8 pieces.

When we take a piece of pizza, we can express that as a fraction.

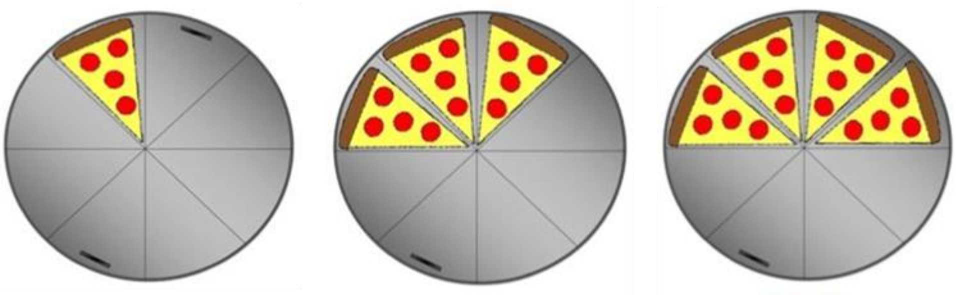


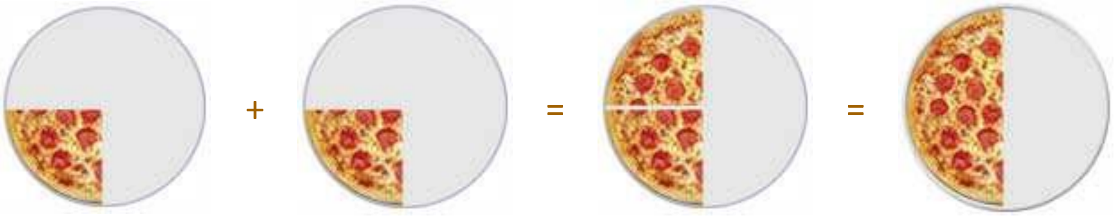
Figure 2 A look at 1/8, 3/8 and 1/2 of a pizza.

The **numerator** (top number) identifies how many slices we have. The **denominator** (bottom number) identifies the total number of slices into which the pizza was cut.

To add or subtract fractions, the denominator must be the same. Using our pizza:

Example B.3

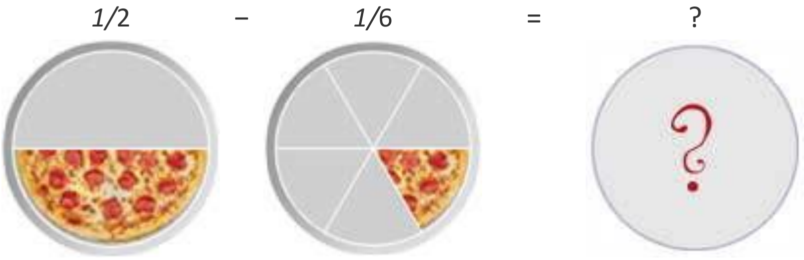
$^{1}/_{4}$	+	$^{1}/_{4}$	=	$^{2}/_{4}$	=	$^{1}/_{2}$
(One-Quarter)		(One-Quarter)		(Two-Quarters)		(One-Half)



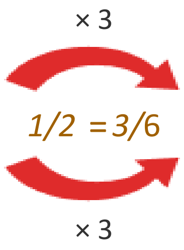
One-quarter plus one-quarter equals two-quarters, equals one-half.

If the denominator is the same, it is very easy to add, you just add the numerators and leave the denominator alone. But what if the denominator is not the same?

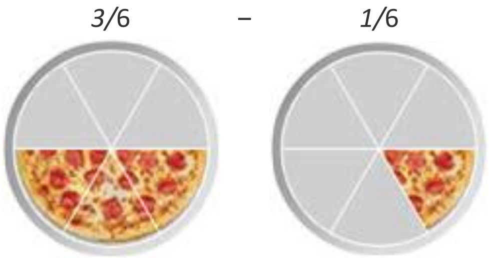
Example B.4



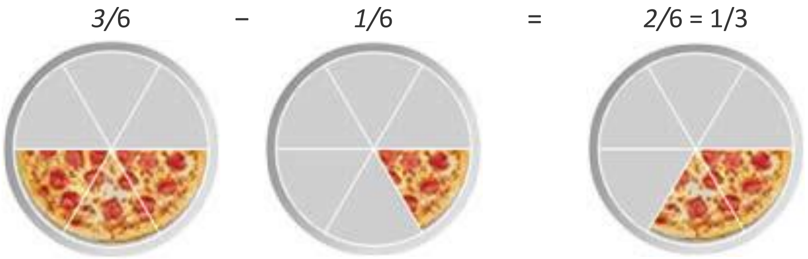
To make the bottom numbers the same, multiply the top and bottom of the first fraction ($^1/_2$) by **3** like this:



And now our question looks like this:

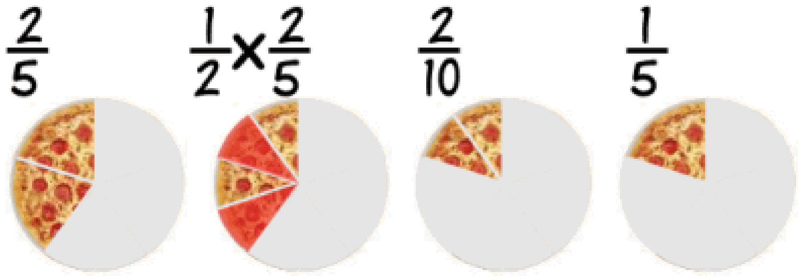


Now that our denominators are the same, we can use the same operation we used before.



To multiply fractions, we just multiply the numerator and the denominator.

Example B.5



To divide fractions, we flip the second fraction over, using the reciprocal and then multiply.

Example B.6

$$\frac{1}{2} \div \frac{1}{6}$$

becomes

$$\frac{1}{2}\ x\ \frac{6}{1} = \frac{1\ x\ 6}{2\ x\ 1} = \frac{6}{2} = 3$$

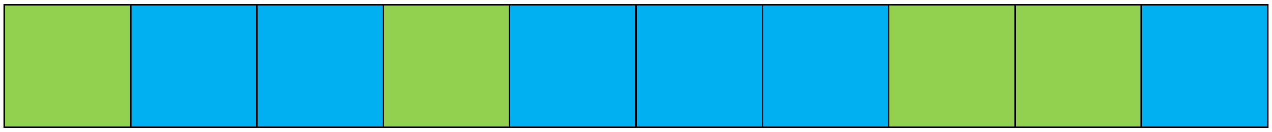
If you would like to learn more, check out the Khan Academy Video Series or the Math is Fun websites in the Section B5 Resources.

B.1.2.2 Ratios

Ratios compare the amount of one thing to the amount of another thing. Ratios are often written as fractions.

Example B.7

What is the ratio of green blocks to blue blocks?



There are 4 green blocks and 6 blue blocks making the ratio 4: 6.

Or:

$$\frac{4\ green\ blocks}{6\ blue\ blocks}$$

For more practice with ratios check out the examples at:
https://www.mathsisfun.com/numbers/ratio.html or at Khan Academy
https://www.khanacademy.org/math/cc-sixth-grade-math/cc-6th-ratios-prop-topic

B.1.2.3 Percentages

Percent means a comparison to 100. Thus,

$$50\% = \frac{50}{100}$$

A percentage is obtained by multiplying a quantity of something by a percent.

Example B.8

What is 10% of 80 apples?

Solutions

$$10\% = \frac{10}{100}$$

To get percentage, multiply 80 by 10%

$$80\ x\ \frac{10}{100} = \frac{80\ x\ 10}{100} = \frac{800}{100} = 8$$

B.1.3 Decimal Places and Scientific Notation

B.1.3.1 Decimal Places

We can think of a decimal as being a whole number on the left side of the decimal point, and a part of a whole on the right side of the decimal point. Decimals are used to give us more precision than whole numbers can provide (**https://byjus.com/maths/decimals-in-daily-life/**). We use it daily with money, weight, mileage, etc.

The location of the decimal is important. The location of the decimal helps to identify if a number is large or small (**https://www.splashmath.com/math-vocabulary/place-value/place-value**). The more numbers to the left side of the decimal, the larger the number. While numbers far to the right of the decimal indicate a very small fraction of the whole. The table below shows an example of 21.045 written to show the place value of each digit.

thousands	hundreds	tens	ones		tenths	hundredths	thousandths
		2	1	.	0	4	5

Example B.9

The image below shows a specific amount of money.

Counting the money in the image indicates that I have $5.80. Meaning that I have 5 whole dollars and $\frac{80}{100}$ of a dollar.

If you would like to learn more, check out the Khan Academy Video Series or the Math is Fun websites in the Section B5 Resources.

B.1.3.2 Scientific Notation

Scientific notation lets us write very large or very small numbers in a way that makes it easier to understand. For example, when we see the number 1,490,000,000, we recognize that it is a large number, but it is hard to work with. A way to make this easier to work with is to use scientific notation.

Scientific notation comes in 2 parts. Just the digits, followed by a 10 to some power.

$$1.49\ x\ 10^9 = 1{,}490{,}000{,}000$$

The 1.49 are our non-zero digits compressed to a simple decimal and then we are multiplying by 10 to the 9th power, which will give us the zeroes needed to reach our larger number. Essentially, we are moving the decimal around to make our numbers easier to work with.

When we have a large number (greater than 10), we move our decimal to the left until we have one digit to the left of the decimal and our power is the number of places, we moved our decimal.

When we have a small number (less than 1), we move the decimal to the right until we have moved our decimal.

To learn more about scientific notation visit **https://www.mathsisfun.com/numbers/scientific-notation.html** or watch videos at Khan Academy **https://www.khanacademy.org/math/pre-algebra/pre-algebra-exponents-radicals/pre-algebra-scientific-notation/v/scientific-notation-old**

B.1.4 Divisibility/Remainders/Rounding/Significant Figures

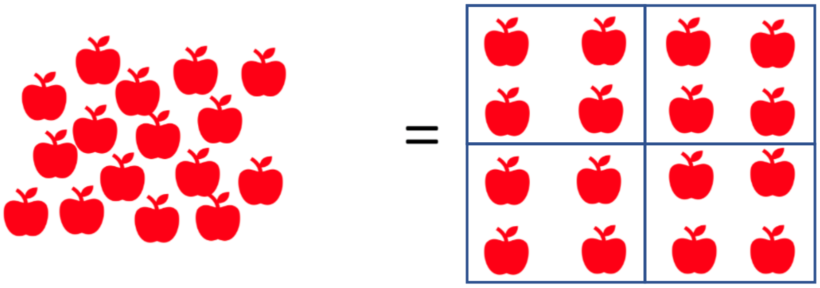
Division is about splitting things into equal parts.

B.1.4.1 Divisibility

In some cases, the division results in a whole number. For example, if I have 16 apples the four (4) of us in my family would each get four apples. This is an example of an exact division.

Example B.10

$$16 \div 4$$



Where, 16 apples can be divided in to 4 equal sets of 4 apples each.

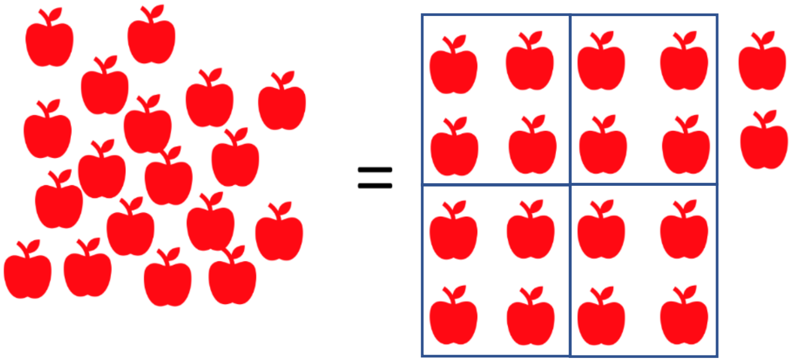
Divisibility tests whether one number can be exactly divided by another without having to do the entire calculation. There are many different tests for divisibility that can be found at: https://www.mathsisfun.com/divisibility-rules.html

B.1.4.2 Remainders

Often, we will find that divisibility into whole numbers is not possible. Thus, we end up with remainders. For Example, if there are 18 apples the four (4) of us in my family would get 4 apples each, with 2 apples left over.

Example B.11

$$18 \div 4 = 4\ \text{R2}$$



Where 18 apples can be divided into 4 equal sets of 4 with 2 apples left over.

We can write remainders as fractions with the remainder on top and the divisor on the bottom, for example:

$$18 \div 4 = 4 \text{ R2} = 4\ 2/4 = 4\ 1/2$$

You can get more information about remainders and practice problems at the **Math is Fun Site** or the **Khan Academy Site**.

B.1.4.3 Rounding

Rounding makes a number that looks complicated (i.e., 46.7483920) simpler by keeping it close to what it was (i.e., 47). This is less accurate than using the complete number, but it is easier to use in calculation. This is also necessary for ensuring significant figures (which we will discuss in B.1.4.4).

Rounding involves several steps.

Step 1: Decide on the last digit to keep.
Step 2a: Leave it the same if the following digit is less than 5 (rounding down)
Step 2b: Increase it by one if the following digit is 5 or more (rounding up)

Example B.12

Round 423 to the nearest 10.

Solution

We are looking at the 10's digit so, in 423 that would be the 2. Since the ones digit in 423 is 3, the 2 remains a 2 and the one's digit becomes 0, making our rounded number 420.

Rounding decimals works the same way.

Example B.13

Round 40.2354 to the nearest 100th.

Solution

We are looking at the 100th's place, so in 40.2354 that would be the 3. Since the 1000th's place has a value of 5 (40.2354), it rounds up, making the 3 a 4, resulting in 40.24.

You can get more information on rounding and practice problems at the **Math is Fun Site** or the **Khan Academy Site**.

B.1.4.4 Significant Digits

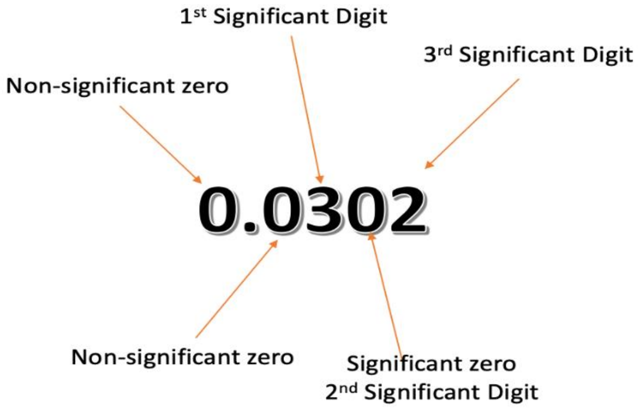
Keeping track of significant digits is important because they represent what we can measure. For example, if I have a circular clarifier with a diameter of 35 feet, when I plug the numbers into my calculator, I get a value of 962.11938 square feet. I can't measure area to the 100,000ths place. So, I would need to round this value to something I could accurately measure.

The basic rules for significant figures are:

1) All non-zero digits are significant.
2) All zeroes between significant digits are significant.
3) All zeroes which are both to the right of the decimal point and to the right of all non-zero significant digits are themselves significant.

Example B.14

How many significant digits does the number 0.0302 have?



The number 0.0302 has 3 significant digits. There are 2 non-zero digits and one zero that is between the two non-zero significant digits.

B.1.5 Data Statistics/Averages

A collection of numbers, measurements, observations, etc. is called data. We use this information to describe the nature of things. We can collect data in many ways, including sampling through direct measurement. Once we have collected the data, we can run various analysis and statistics on it to get further information.

B.1.5.1 Data Statistics

Statistics is the analysis and interpretation of the collected data. We can use the collected data to determine things like a frequency of occurrence (25-year rainfall), patterns (height vs. weight), and the average. We are most interested in averages, so we will spend some time on that, but should you need to know more about probability (frequency of occurrence), patterns, etc. you can get more information at **https://www.mathsisfun.com/data/index.html#stats.**

B.1.5.2 Averages

Averages are widely used to provide a single representative number to quantify a large number of collected data. In wastewater treatment, one of the pieces of information that must be tracked is the Average Daily Flow in MGD.

The average is fairly easy to calculate. You simply add up all the numbers in the list and then divide by the number of numbers that there are in the list.

Example B.15

The flow rate of water entering the wastewater treatment plant was sampled 5 times in a day. The measured flow rates (in MGD) were 35.2, 41.8, 36.3, 28.1, and 40.8. Calculate the average flow rate for the day.

Solution

First, we add up the all the numbers:

$$35.2 + 41.8 + 36.3 + 28.1 + 40.8 = 182.2$$

Then we count the number of numbers in the list, in this case 5.

Then we divide the total we calculated by the number of numbers:

$$\frac{182.2}{5} = 36.44\ MGD$$

For more information on averages you can visit the **Math is Fun Site** or the **Khan Academy Site.**

B.1.5.3 Geometric Mean

The average number of bacteria in a given water quality sample (e.g., E coli) are normally represented using something called a **Geometric Mean** instead of an arithmetic mean. For example, let's say we have three numbers: 2, 8, 4.
As we have just seen, the **Arithmetic average** of the three numbers is equal to the sum of the numbers divided by the total number of numbers being added together.

Arithmetic average = (2 + 8 + 4) /3 = 14/3 = 4.67

The Geometric mean of a set of numbers is equal to the Nth Root of the product of the n numbers.

The formal equation for a geometric mean = $\sqrt[n]{N1\ x\ N2\ x \ldots\ Nn}$.

This expression can be evaluated using a calculator that allows for the *n*th root of a series of N numbers.

An easier way to think of a geometric mean is to find the one number to substitute into the boxes on the right-hand side of the equation that will make the equation equal. Using our example of the three numbers 2 ,8 and 4 we can substitute them in the boxes on the left and then multiply them to get the number in the middle (i.e., 64).

$$\boxed{2}\ \text{x}\ \boxed{8}\ \text{x}\ \boxed{4} = \boxed{64} = \boxed{?}\ \text{x}\ \boxed{?}\ \text{x}\ \boxed{?}$$

Now, by trial and error, you can continue to try the same number in the right-hand boxes until their product gives you the same answer: i.e., 4 x 4 x 4 = 64. Thus, the geometric mean of 64 is just 4.

Note: the number of boxes on the right-hand side will always be equal to the number of boxes (or numbers) on the left-hand side. So, if we were finding the geometric mean of 4 numbers, we would have four boxes, on each side, etc.

B.2 Areas and Volumes of Different Shapes

Geometry is the area of math that looks at the size and shapes of things. In wastewater treatment, this would include things like identifying the volume of the clarifier, the surface area of the aeration tank, or the length of the weir. These values are used repeatedly in many of the basic formulas for loading, concentration, and overflow rate.

B.2.1 Perimeter

Very simply, perimeter is the length around the outside of an object. The calculation for this will change depending on the shape of the object.

B.2.1.1 Circle

The perimeter of a circle is also called the circumference and is calculated using the formula:

$$Perimeter\ of\ a\ circle = 2\ x\ \pi\ x\ radius$$

Where π =3.14 and $radius = \frac{diameter}{2}$ and diameter is the length across the center of the circle.

Example B.16

What is the circumference of a circle with a diameter of 4 ft?

Solution

We know that the circumference of a circle uses an equation that needs the radius. This means that we will need to find the radius from the diameter. So,

$$radius = \frac{4\ ft}{2} = 2\ ft$$

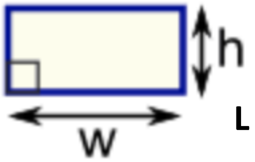
Now that we have the radius, we can calculate the circumference using our equation above.

$$Perimeter\ of\ a\ circle = 2\ x\ \pi\ x\ 2\ ft = 12.56\ ft$$

B.2.1.2 Rectangle

The perimeter of a rectangle is calculated using the formula:

$$perimeter\ of\ a\ rectangle = 2\ x\ width + 2\ x\ length$$



Example B.17

What is the perimeter of a rectangle that has a length of 4 ft and a width of 8 ft?

Solution

Since we have the length and the width given as part of the question, all we need to do is plug those values into the equation.

$$perimeter\ of\ a\ rectangle = 2\ x\ 4\ ft + 2\ x\ 8\ ft$$

Remembering that we do multiplication first and then addition:

$$perimeter\ of\ a\ rectangle = 8\ ft + 16ft$$

Thus, $perimeter\ of\ a\ rectangle = 24\ ft$

B.2.2 Area

Area is the size of the surface. One way of thinking of this is to ask how big is the top of the clarifier or aeration tank? The calculations for this parameter also change with shape.

B.2.2.1 Circle

The area of a circle is given by the equation.

$$Area = \pi\ x\ radius\ x\ radius$$

Where π =3.14 and $radius = \frac{diameter}{2}$ and diameter is the length across the center of the circle.

Example B.18

What is the surface area of a clarifier that has a diameter of 25 ft?

Solution

Like example B.15, we need to find the radius from the given diameter.

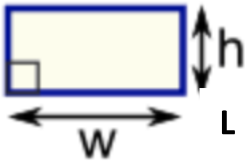
$$radius = \frac{25\ ft}{2} = 12.5\ ft$$

In this case, our radius does not divide evenly giving us a decimal. Now that we have our radius, we can plug that into our area equation and find our area.

$$Area = \pi \; x \; 12.5 \; ft \; x \; 12.5 \; ft = 490.6 \; ft^2$$

B.2.2.2 Rectangle

The area of a rectangle is found by the equation:



$$Area = length \; x \; width$$

Example B.19

What is the surface area of an aeration tank that has a length of 25 ft and a width of 40 ft?

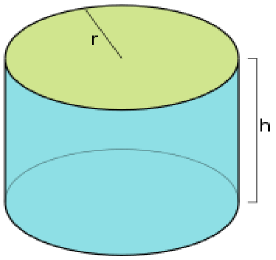
Solution

Using the equation: $Area = 25 \; ft \; x \; 40 \; ft = 1000 \; ft^2$

B.2.3 Volume

Volume is the amount of "stuff" in a container. For example, if we know the surface area and the depth, we can find the volume of water in a clarifier or basin.

B.2.3.1 Cylinder



The calculation for the volume of a cylinder is:

$$Volume = \; 3.14 \; x \; radius \; x \; radius \; x \; height$$

Where $radius = \frac{diameter}{2}$ and diameter is the length across the center of the circle.

Example B.20

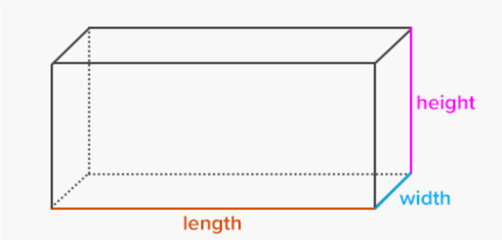
The radius of the clarifier is 15 ft, and the water is 8 ft deep. How much water is contained in the clarifier?

Solution

In this case, we have the radius so all we need to do is plug the information into our equation.

$$Volume = \; 3.14 \; x \; 15 \; ft \; x \; 15 \; ft \; x \; 8 \; ft = 5{,}652 \; ft^3$$

B.2.3.2 Rectangular Box



The calculation for volume for a rectangular box is:

$$Volume = length\ x\ width\ x\ depth$$

Example B.21

The aeration tank has a length of 25 ft and width of 10 ft and a depth of 5 ft. What is the volume of the tank?

Solution

We can put the information we know directly into the equation and thus:

$$Volume = 25\ ft\ x\ 10\ ft\ x\ 5\ ft = 1{,}250\ ft^3$$

For more information on Geometry you can visit the **Math is Fun Site** or the **Khan Academy Site.**

B.3 Important Units

Units are how we scale physical dimensions. For example, if I asked you how far it was from your house to where you work, you could just give me a number like 4, but that would have very little meaning. On the other hand, if I asked you how far it was from your house to where you work and you told me that it was 4 miles, I would have a fairly good idea of the distance.

Units are how we identify the measurements of our samples and the dimensions of our systems. There are several sets of units that we should consider. For more information about units, you can visit the **Math is Fun Site**.

B.3.1 Length, Volume and Time

Operators frequently have to use units of length or time in calculating pollutant loads. Length is often used to calculate areas or volumes of different basins while time is frequently used to calculate flowrate since flowrate is expressed as volume/time. Common units of length are feet or meters while common units of volume are cubic feet (ft^3) or cubic meters (m^3). Volume is also frequently expressed in terms of gallons or millions of gallons (MG). Common units of time are minutes (as in gallons per minute) or days (as in gallons per day).

B.3.2 Mass/Weight

Mass and weight are often interchangeable terms. For the purposes of this manual, we will consider mass and weight to refer to the same thing, how much "stuff" there is. Weight is how we know how hard an object will be to move. For example, something that weighs 10 lbs. will be easier to move than something that weighs 100 lbs.

Often, we measure mass in units of pounds (lbs.), kilograms (kg), grams (g), or milligrams (mg). For more information about mass, you can refer to the **Wikipedia Site.**

B.3.3 Flow rate

In a wastewater treatment plant, flow rate is how much wastewater/sludge/clear water moves through our system over time. Flow rate can be based on volume, $\frac{volume}{time}$ or mass, $\frac{mass}{time}$.

Flow is measured in units of $\frac{}{/}$(GPD), $\frac{million\ gallons}{day}$ (MGD), or $\frac{lbs}{day}$

For more information about flow rate, you can visit the **Wikipedia Site.**

B.3.4 Concentration

Concentration is how much mass of a substance is contained in a particular volume. For example, if I find that there is 150 mg of sludge in a Liter of water, then I have a concentration of 150 mg/L of sludge. By measuring concentrations of the various pollutants in our water, we can identify plant efficiency and water quality.

For more information about concentration, you can visit **Wikipedia Site.**

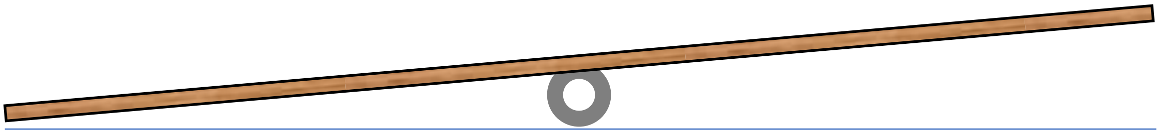
B.4 Equations

Operators frequently have to calculate the values of certain operational parameters that help tell them how well the treatment process is going. Or, they may have to calculate the value of a particular water quality parameter to know whether our plant is meeting the state's water quality standards. Operators often use mathematical equations to do this. We have already used mathematical equations in the previous sections of this Appendix, even though you may not think of it in that way. For example, if I would like to calculate the area of a slab of concrete that is 10 feet long and 5 feet wide, I could express the total area as:

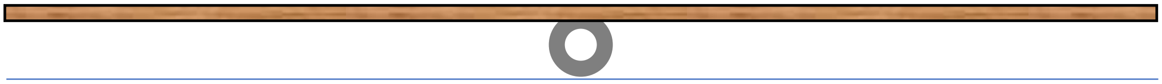
$$10 \text{ feet (length) } x\, 5 \text{ feet (wide)} = 10\ x\, 5 = 50 \text{ ft}^2 \text{ (square feet)}$$

This is just an example of an equation. We have some numbers on left side of the equation and another number on the right side of the equation where both sides are separated by an equal (=) sign. For simple problems like this, we can normally "do the math" in our heads. However, for more complicated problems, writing down the steps in a particular order on paper can help us solve the problem. That is where equations come in handy. Equations just provide us with a way to write out a problem on paper so to help us solve the problem.

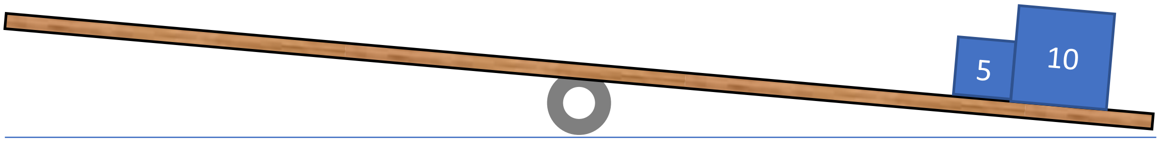
In some ways, you might think of an equation as just a balance beam or a scale where you are trying to balance two sets of numbers on each side of the middle of the balance beam. For example, let's say I put a piece of six-inch diameter PVC pipe on the floor and then placed a six-foot-long 2x6 piece of lumber across it. That might look something like this:



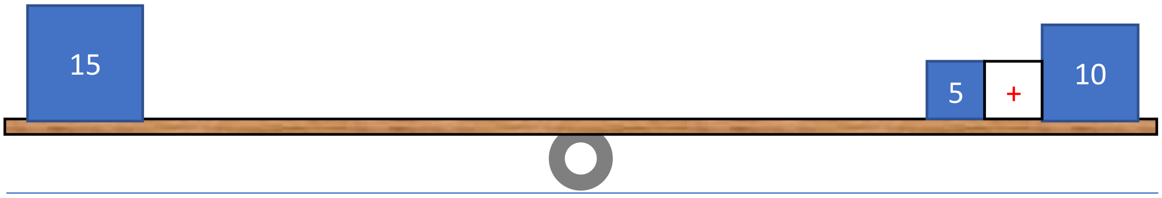
If I am careful, I should be able to balance the 2x6 on the pipe like this:



Now suppose I put some wooden blocks of different weights (represented by the numbers on the blocks) on the right side of the board. What would you expect to happen? You would probably expect the board to drop to the floor on the right.

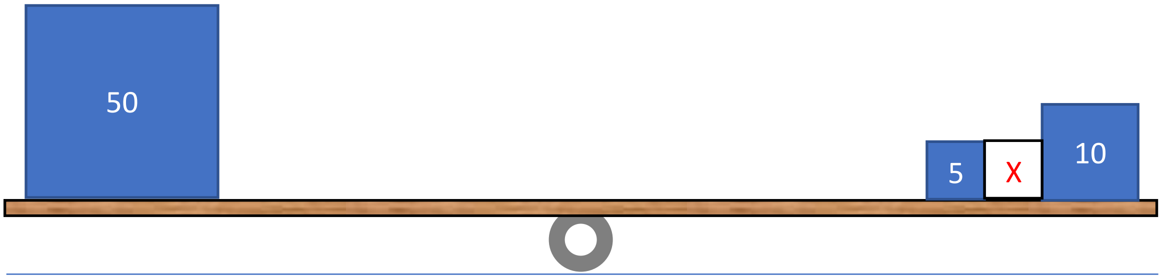


Now, to get the board to balance again, what would you have to do? You would have to add some additional blocks of equal weight the left-hand side as shown.



This is all we are doing when we are solving equations. We are normally given a set of numbers on one side of the board (which we call our known values) and then we are trying to figure out a number on the other side of the board which will make the board balance.

Notice in the last figure, we added a third block with the [+] sign. This sign is important, because it describes the way we will determine the final “weight” on the right-hand side of the equation. In this case we will just add the two “weights” or values of the two blocks. In other cases, we might multiply the two blocks [x] or even divide the two blocks [/]. For example, if we multiple the two blocks, then to balance the board we would need a “weight” on the left-side of the equation equal to the product of the two numbers or a block with a “weight” of 50 as shown.



Technically, it does not matter on which side of the board (or equation) that you place your known values (or blocks) or your unknown values (or blocks). Whichever side you choose, you then know you just need to figure out what to place on the other side. Notice in our original example, we placed the known values on the left-hand side. However, we could have written this equation as follows (which matches the previous figure):

[50 ft^2 (square feet)] = [10 feet (length)] [*X*] [5 feet (wide)]

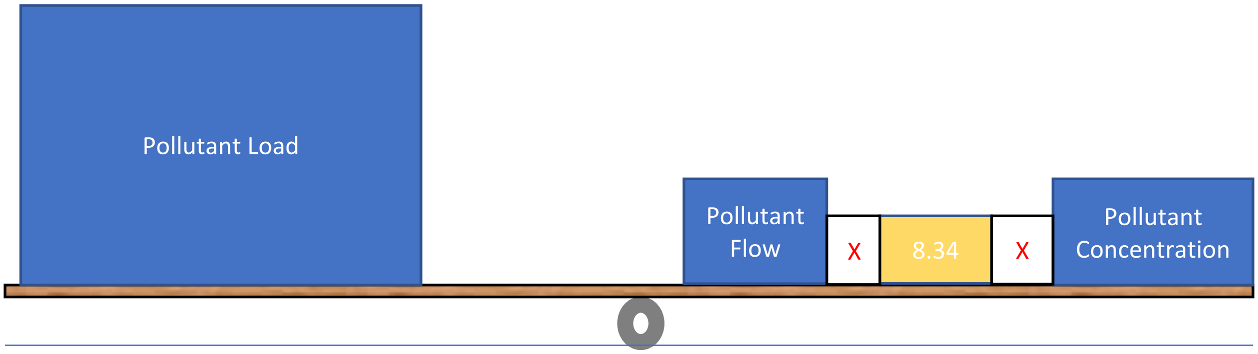
For most of the equations in this book, we typically put the unknown values on the left-hand side and the known values on the right-hand side.

B.5 Algebraic Equations

In the previous examples, we have assigned numbers (corresponding to their relative weights) to each of the blocks or terms in our equation. However, in most of the types of problems that operators are working with, the equations are expressed in terms of descriptions of the blocks instead of the numbers or "weights" that we assign to the blocks. For example, here is an equation we can use to calculate an **unknown** pollutant load (expressed in units of lbs./day) expressed as a function of two **known** parameters: pollutant flow (expressed in units of million gallons per day) and pollutant concentration (expressed in units of milligrams per Liter).

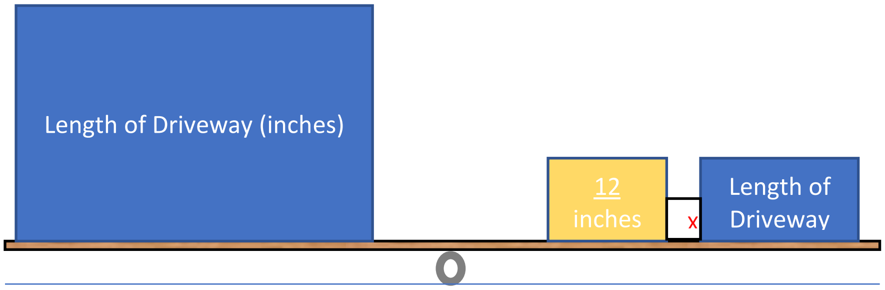
$$[1]\ Pollutant\ load\ \left(\frac{lbs}{day}\right) = pollutant\ flow\ (MGD)\ x\ \ 8.34\ \left(\frac{lb}{MG}\ x\ \frac{L}{mg}\right) x\ pollutant\ concenration\ \left(\frac{mg}{L}\right)$$

This is just an example of an algebraic equation. An algebraic equation is just an ordinary equation in which one of the "blocks" has the name of the block written on it instead of the value or "weight" associated with it. To solve the equation, all we do is to replace the names of the "blocks" with their associated value and then figure out the value of the remaining block so that we can balance the equation. Using our analogy of a balancing board, this equation could be visualized as follows:



Now notice in our figure, I have added another block (the yellow one) on the right-hand side of the board which has the number 8.34 in it. Notice there is also some notation next to that number in the actual equation that looks like this (lb./MG*mg/L). This is a special kind of block called a conversion factor and the number is used to make sure that not only do the "weights" of the blocks balance out but also the "units" associated with the each of the weights. In this example, the 8.34 is multiplied by the values of the "blocks" on the right-hand side of the board which are expressed in terms of million gallons per day (or MGD) and milligrams per liter (or mg/L) in order that the values on the left-hand side of the board come out in units of pounds per day (or lbs./day).

To illustrate what I am talking about, let's assume you want to measure the length of your driveway in inches, but all you had was a measuring tape that measured in feet. In this case, the length in feet would be our known box (on the right-hand side) and the length in inches would be our unknown box (on the left-hand side). We could visualize this with our board example as follows:



So, in this case if we would like to know the length of the driveway in inches, we would first place the value of the driveway in feet in the box named "Length of driveway in feet" and then multiply it by a conversion factor of 12 in order to convert the length in feet to a length in inches so as to match the units on the right hand side of the equation.

For example, let's say we measure the driveway, and its length turns out to be 24 feet. To convert that into inches, we would use the equation above as follows:

[Length of driveway] = [12] [*X*] [24] = 288 inches

So, what length of driveway in inches will match a driveway with a length of 24 feet? Simply the number we get on the right-hand side when we multiple the conversion factor times the length in feet – i.e., 288 inches!

This is all we are doing when we solve algebraic equations. Although it may sound intimidating or confusing, it is really nothing more complicated than simply multiplying two numbers together like this:

$$12\ x\, 24 = 288$$

The only thing different is that we are now adding words to describe what the numbers mean or refer to. But that math is still just arithmetic. If you can remember how to add, subtract, multiply and divide, then you can solve any algebraic equation. Don't be intimated by the addition of words conversion factors that are added in.

B.6 Algebraic Equations with Units

If you look at equation [1] and my previous example with the driveway, you will notice that next to each unknown parameter (or "box") there are some terms in parentheses; (lbs./days), (MGD), (lb./MD*mg/L), (mg/L), (inches), (feet), (inches/feet), etc. While these may look a little intimidating, they really should not be. These are called unit descriptors and simply tell you the units of measure associated with the value that goes in that particular term or "box" of the equation. For example, if you have an equation like this:

[Length of driveway] (feet)

This simply tells you what kind of number goes into that "box" for length. For example, maybe I measure my driveway in units of inches and get a value of 288 inches. While that would be a true measure of the length of my driveway, I could not put that number into this box. I could only put a number in the box that matches the units associated with the box (i.e., feet). Thus, I would have to put 24 in the box instead of 288.

This same convention holds true for all our equations. While feet and inches are easy to explain, some others may at first appear to be more complicated, but once you get the hang of it, you will see it is easy. Consider the following examples:

lbs./day – this would mean the value in the box corresponds to the number of pounds of pollutant that would come out of a plant in a day.

MGD (which is short-hand for writing out "million gallons per day" i.e., MG/day) – this would mean the value in the box corresponds to the amount million gallons of water that enters or leaves a plant in a given day.

mg/L – this is a measure of the concentration of something (typically a pollutant) that is expressed in the number of milligrams of pollutant that one would find in a liter of a water quality sample.

Note: when you see a unit with one set of abbreviations separated by a /, this is simply read or interpreted as mg/L = milligrams PER liter or lbs./day = pounds PER day.

Please note, that both parameters and conversion factor boxes have units associated with them. You will notice for example, that in equation [1] there is a more complicated unit with the conversion factor 8.34 (i.e., lb./MG*mg/L). This notation tells us that the conversion factor 8.34 will convert the product (i.e., what you get when you multiply two numbers together) of the value in a box with units of (MGD) and the value in a box with units (mg/L) into the value in a box with units of (lbs./day). To prove this, you can multiply the units on the right-hand side of the equation together and see if you get the same units shown on the left-hand side of the equation.
For example, for equation [1] we see:

$$\mathit{(lbs/day)} = \mathit{(MG/day)}\ \mathrm{x}\ \mathit{(lb./MG}\ \mathrm{x}\ \mathit{L/mg)}\ \mathrm{x}\ \mathit{(mg/L)}$$

When multiplying the units on the right-hand side of the equation, the rule of thumb is to recognize that everything above the “/” will cancel everything below it. The MG in the first term (MG/day) will cancel the MG in the second term (lb./MG) leaving (lbs./day), and the (L/mg) in the second term with cancel the (mg/L) in the third term. Thus, when we are done, we are left with (lbs./day) on the right-hand side with now matches the (lbs./day) on the left-hand side.

Carrying around the unit terms when solving equations (especially the units on the conversion factors) can be somewhat burdensome, if not annoying. As a result, it might be helpful to simplify the various equations by dropping the various units from the equations if you remember that units are actually still there (even if we don’t write them out). Thus, we could write equation [1] as well as other equations as follows:

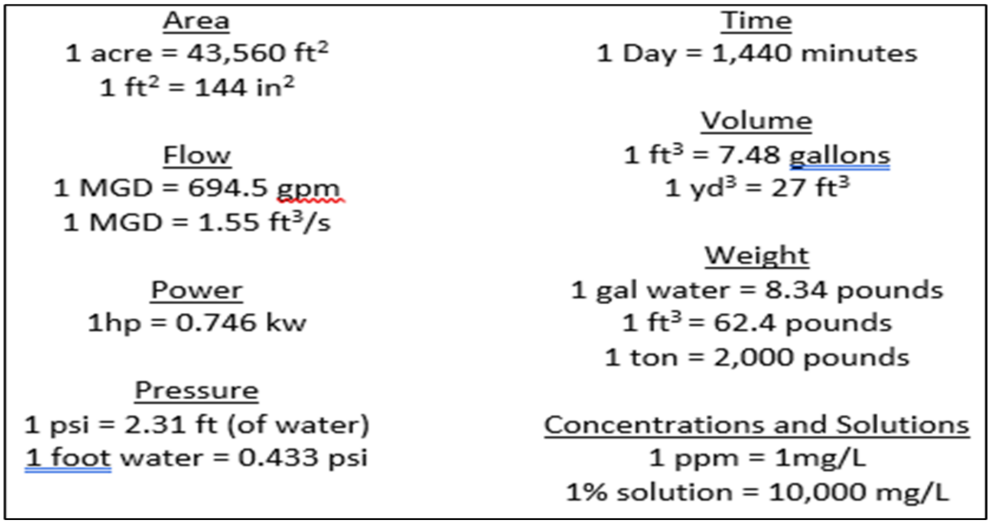
$$[1]\ \mathit{Pollutant\ load} = \mathit{pollutant\ flow}\ \mathrm{x}\ 8.34\ \mathrm{x}\ \mathit{pollutant\ concentration}$$

as long as we remember that the pollutant load will normally be in units of (lbs./day), the flow in units of (MGD) and the pollutant concentration in units of (mg/L).

To help you remember what the associated units with each equation are, we will still include them with the equations in the manual, however, if it helps you to solve the equations without writing them down, that will be fine as well.

B.7 Examples of Common Conversion Units

When converting pollutant measurements from one system of units to another, the operator may need to employ a conversion factor. A list of some of the most common conversion factors is given below.



Area
1 acre = 43,560 ft²
1 ft² = 144 in²

Flow
1 MGD = 694.5 gpm
1 MGD = 1.55 ft³/s

Power
1hp = 0.746 kw

Pressure
1 psi = 2.31 ft (of water)
1 foot water = 0.433 psi

Time
1 Day = 1,440 minutes

Volume
1 ft³ = 7.48 gallons
1 yd³ = 27 ft³

Weight
1 gal water = 8.34 pounds
1 ft³ = 62.4 pounds
1 ton = 2,000 pounds

Concentrations and Solutions
1 ppm = 1mg/L
1% solution = 10,000 mg/L

B.8 Algebraic Equations with Denominators

Thus far, we have only looked at equations with terms on the same level as the equal sign. However, sometimes you will encounter equations with terms above and below a line on the right-hand side of the equation. For example, consider the equation for calculating the Solids Retention Time (SRT). This equation looks like this:

$$[15]\ SRT, days = \frac{lbs, MLSS\ in\ aeration\ basin}{\frac{lbs}{day} TSS\ wasted + \frac{lbs}{day}\ TSS\ in\ secondary\ clarifier\ effluent}$$

You will notice that there is one term or “box” in the top part of the right- hand side and two terms or “boxes” in the bottom part of the right-hand side. The terms in the top part are called the numerator and the terms in the bottom part are called the denominator. While this may look complicated, it is not. Remember the order of operations we discussed in Section B.1.1. We first calculate the number in the numerator and then we determine the number in the denominator and then divide the number in the numerator by the number in the denominator. However, before we can do this, we first must calculate the number in the denominator. We do this by simply adding the two numbers in the denominator together.

Example B.22

If we know that our lbs. of MLSS in the aeration basin is 5000 lbs., our lbs. of TSS wasted per day is 650 lbs. and our lbs. of TSS in the secondary clarifier effluent is 200 lbs. per day, then we can calculate SRT.

Solution

First, calculate the denominator.

$$\frac{lbs}{day} TSS\ wasted + \frac{lbs}{day}\ TSS\ in\ secondary\ clarifier\ effluent = 650\frac{lbs}{day} + 200\frac{lbs}{day}$$
$$= 850\frac{lbs}{day}$$

Next, plug our known MLSS weight in and the denominator that we calculated to solve for SRT in days.

$$[15]\ SRT, days = \frac{5000\ lbs\ MLSS}{850\frac{lbs}{day}} = 5.88\ days$$

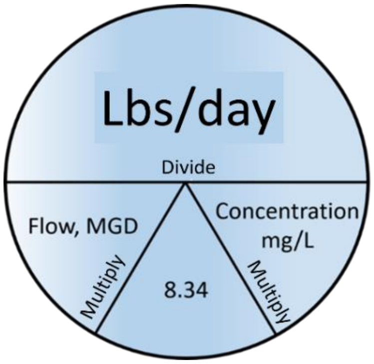
The SRT is 5.88 days and since the lbs. cancel out, the only thing left is 1/1/day, so the day moves to the top.

B.9 Solving Equations with Pie Charts

Recall again equation [1]. Thus far we have examined how we can solve this equation using traditional algebra.

$$[1]\ Pollutant\ load\ (lbs/day) = pollulant\ flow\ (MGD)\ x\ 8.34\ (\frac{lb}{MG} * \frac{L}{mg})x\ pollutant\ concenration\ \left(\frac{mg}{L}\right)$$

Another way to visualize this equation [1], is by using the pound “pie” diagram shown below.



This figure can be used to solve for any one unknown, whether it be load (lbs.), flowrate (MGD), or concentration (mg/L). To use the diagram, just use your fingers to cover the one thing on the diagram that you don't know but want to, and then use the diagram to figure out how to solve the unknown.

Example: The discharge from a wastewater treatment plant is 1.0 MGD. If the measured concentration of total suspended solids (TSS) is 10 mg/L. What is the daily pollutant load of TSS in units of lbs/day?

Solution: Since we are looking for the load in lbs, cover up the top part of the pie chart which has lbs in it. This leaves flow (MGD), 8.34, and Concentration (mg/L) all in the bottom part of the figure. You will note that each of these pie segments in the bottom have the word multiply separating them. This then means that we should multiple all three terms in the bottom to get what we are after and have covered up – lbs. This then yields:

$Load\ (lbs) = Flow\ (MGD)\ x\ 8.34\ x\ Concentration\ (mg/L)$ or

$Load\ (lbs) = 1.0\ MGD\ x\ 8.34\ x\ 10\ mg/L = 83.4\ lbs/day$

Conversely, if we were given lbs and wanted to know the concentration, then we would multiple the flow (MGD) x 8.34 and then DIVIDE both into the value of the know lbs. Or:

$Concentration\ (mg/L) = Load\ (lbs)\ /\ (Flow\ (MGD)\ x\ 8.34)$

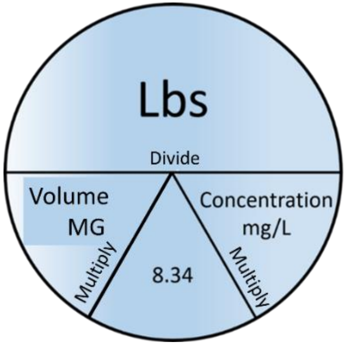
or

$Concentration\ (mg/L) = 83.4\ lbs\ /\ (1\ MGD\ x\ 8.34) = 10\ mg/L$

In addition to converting a concentration and a flowrate into a pollutant loading, an operator may also on occasion need to covert the concentration of a given pollutant in a given volume (typically expressed in MG) into a pollutant load as well. Similar to equation [1], this can be calculated using equation [2] below:

$$[2]\ Pollutant\ load\ (lbs) = volume\ (MG)\ x\ 8.34\ x\ pollutant\ concenration\ \left(\frac{mg}{L}\right)$$

Like equation [1], this equation can also be solved using a similar "pipe" diagram as shown below.



B.10 Other Resources

The internet contains several very helpful resources for use in learning or reviewing the types of mathematical concepts and principles that will be helpful in operating a wastewater treatment plant. Two of the most useful sites are 1) the Khan Academy and 2) Math is Fun. You can directly access these resources from the following websites:

Kahn Academy:
https://www.khanacademy.org/math

Math is Fun:
https://wwwmathisfund.com

Appendix C

List of Equations

$$[1]\ (Pollutant\ load, lbs/day) = (pollutant\ flow, MGD) \text{ x } 8.34 \text{ x } (pollutant\ concentration, \frac{mg}{L})$$

$$[2]\ (lbs\ of\ constituent) = (Volume, MG) \text{ x } 8.34 \text{ x } (Concentration, \frac{mg}{L})$$

$$[3]\ (TDS, mg/L\ ) = \frac{(weight\ of\ dry\ solids\ \&\ dish, g) - (weight\ of\ dish, g)}{(sample\ volume, mL)}\ x\ 1{,}000{,}000 \frac{mg}{L}$$

$$[4]\ (TSS, mg/L) = \frac{(wt. of\ crucible, filter\ \&\ solids, g) - (wt. of\ crucible\ \&\ filter, g)}{(sample\ volume, mL)}\ x\ 1{,}000{,}000 \frac{mg}{L}$$

$$[5]\ (VSS, mg/L) = \frac{(wt. of\ crucible\ \&\ filter\ \&\ ash, g) - (wt. of\ crucible\ \&\ filter, g)}{(sample\ volume, mL)}\ x\ 1{,}000{,}000 \frac{mg}{L}$$

$$[6]\ (BOD_5, mg/L) = (Initial\ DO, mg/L - Final\ DO, mg/L\ ) \text{ x } \frac{(Volume\ of\ BOD\ bottle, mL)}{(sample\ volume, mL)}$$

$$[7]\ Removal\ Efficiency\ (\%) = \frac{influent\ BOD_5, \frac{mg}{L} - effluent\ BOD_5, \frac{mg}{L}}{influent\ BOD_5, \frac{mg}{L}} \text{ x } 100\%$$

$$[8]\ (TRC, mg/L) = (Dosage, \tfrac{mg}{L}) - (Demand, \tfrac{mg}{L})\ )$$

$$[9]\ (SLR, gpd/ft^2) = \frac{(Flow, gpd\ )}{(Clarifier\ Surface\ area, ft^2)} = \frac{(Flow, gpd)}{0.785 \text{ x } Diameter\ (ft) \text{ x } Diameter\ (ft)}$$

$$[10]\ (HRT, days) = \frac{(Tank\ Volume, MG\ )}{(Flow, MGD)}$$

$$[11]\ (HRT, days) = \frac{(Tank\ Volume, ft^3 \text{ x } 7.48 \text{ x } 24\ hr/day)}{(Flow, gpd\ )}$$

$$[12]\ (Pump\ Rate, gpm) = \frac{(Volume\ of\ sludge\ pumped, ft^3 \text{ x } 7.48\ gal/ft^3)}{(pump\ time, \text{min})}$$

$$[13]\ (VLR, \frac{lbs/day}{1000\ ft^3}) = \frac{(BOD_5, lbs/day)}{(Basin\ Volume, 1000\ ft^3)}$$

$$[14]\ \left(MLSS,\frac{mg}{L}\right)=\frac{(wt.\,of\ crucible, filter\ \&\ solids, g)-(wt\ crucible\ \&\ filter, g)}{(sample\ volume, mL)}\ x\ 1{,}000{,}000\,\frac{mg}{L}$$

$$[15]\ \left(MLVSS,\frac{mg}{L}\right)=\frac{(wt.\,of\ crucible, filter\ \&\ solids, g)-(wt.\,of\ crucible, filter\ \&\ ash, g)}{(sample\ volume, mL)}\ x\ 1{,}000{,}000\,\frac{mg}{L}$$

$$[16]\ (SRT, days)=\frac{(MLSS\ in\ aeration\ basin, lbs)}{(TSS\ wasted,\frac{lbs}{day})+(TSS\ in\ secondary\ clarifier\ effluent,\frac{lbs}{day})}$$

$$[17]\ (MCRT, days)=\frac{(MLVSS\ in\ aeration\ basin, lbs)}{(VSS_2\ wasted, lbs/day)+\ (VSS_3\ in\ secondary\ clarifier\ effluent, lbs/day)}$$

$$[18]\ (SA, days)=\frac{(MLSS\ in\ aeration\ basin, lbs)}{(\ TSS_1\ in\ influent, lbs/day)}$$

$$[19]\ \left(F\Big/_{M}\right)=\frac{(Food, lbs/day\ )}{(Microorganisms, lbs\ )}$$

$$[20]\ (SVI, mL/g)=\frac{Settled\ Sludge\ Volume\ (SSV_{30})\ x\ 1{,}000,\frac{mg}{g}}{(MLSS, mg/L\ )}$$

$$[21]\ (Q_{RAS}, MGD)=\frac{(Q\ influent, MGD)\ x\ (MLVSS,\frac{mg}{L}\ )}{(VSS_2,\frac{mg}{L})-\ (MLVSS,\frac{mg}{L})}$$

$$[22]\ (Q_{RAS}, MGD)=\frac{(Q\ influent, MGD)\ x\ (SV_{30}, ml\ )}{1000-(SV_{30}, ml)}$$

$$[23]\ (Oygen\ Uptake\ Rate\!: OUR,\frac{mg}{L}/hr)=\frac{(DO_1-DO_2)}{(Time\ 2-Time\ 1)}\ x\ 60\ (\frac{min}{hr})$$

$$[24]\ (Specific\ Oxygen\ Uptake\ Rate\!: SOUR,\frac{mg}{g}/hr)=\frac{(OUR,\frac{mg}{L}/\,\mathrm{min})}{\left(MLVSS,\frac{mg}{L}\right)}\ x\ 1{,}000,\frac{mg}{g}$$

$$[25]\ (Organic\ Loading, lbs\ BOD/acre/day)=\frac{(Flow, MGD)\ x\ 8.34\ x\ (BOD,\frac{mg}{L})}{(Area, Acres)}$$

[26] $$(Required\ Suface\ Area, acres) = \frac{(Flow, MGD)\ x\ BOD\ _5\ x\ 8.34\ (\frac{lb}{MG})(\frac{L}{mg})}{(Loading\ Rate, \frac{lb}{acre}\ x\ day)}$$

[27] $$(SLRT, days) = \frac{Total\ Sludge\ Mass, lbs}{Solids\ Removed\ per\ Day, \frac{lbs}{day}}$$

[28] $$(Digester\ Loading, lbs/ft^3 - day) = \frac{Volatile\ Solids, \frac{lbs}{day}}{Digester\ Volume, ft^3}$$

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