Industrial Pretreatment Design

by

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Course 444
5 PDH (5 Hours)

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Industrial Pretreatment Design

Course Outline:

Overview of Industrial Pretreatment Systems
Design Criteria and Steps
Wastewater Assessment
Equalization
Treatment Alternatives
Physical Treatment
Chemical Treatment
Biological Treatment
Process Flow Diagram
Hydraulic Profile
Helpful References
Examination

Overview of Industrial Pretreatment Systems

It is common for industrial and commercial facilities to have a wastewater treatment system that partially treats the wastewater before being discharged into the municipal sewer collection system. This is called an “industrial pretreatment system”, or “pretreatment system”. Each pretreatment system is a highly specialized process that should be carefully designed by an experienced Professional Engineer to meet environmental regulations while minimizing costs to the owner.

A comparison of wastewater discharge options is provided in Figure 1. Industrial and commercial entities that have an **indirect discharge** of wastewater are called Industrial Users (IUs) for permitting purposes.

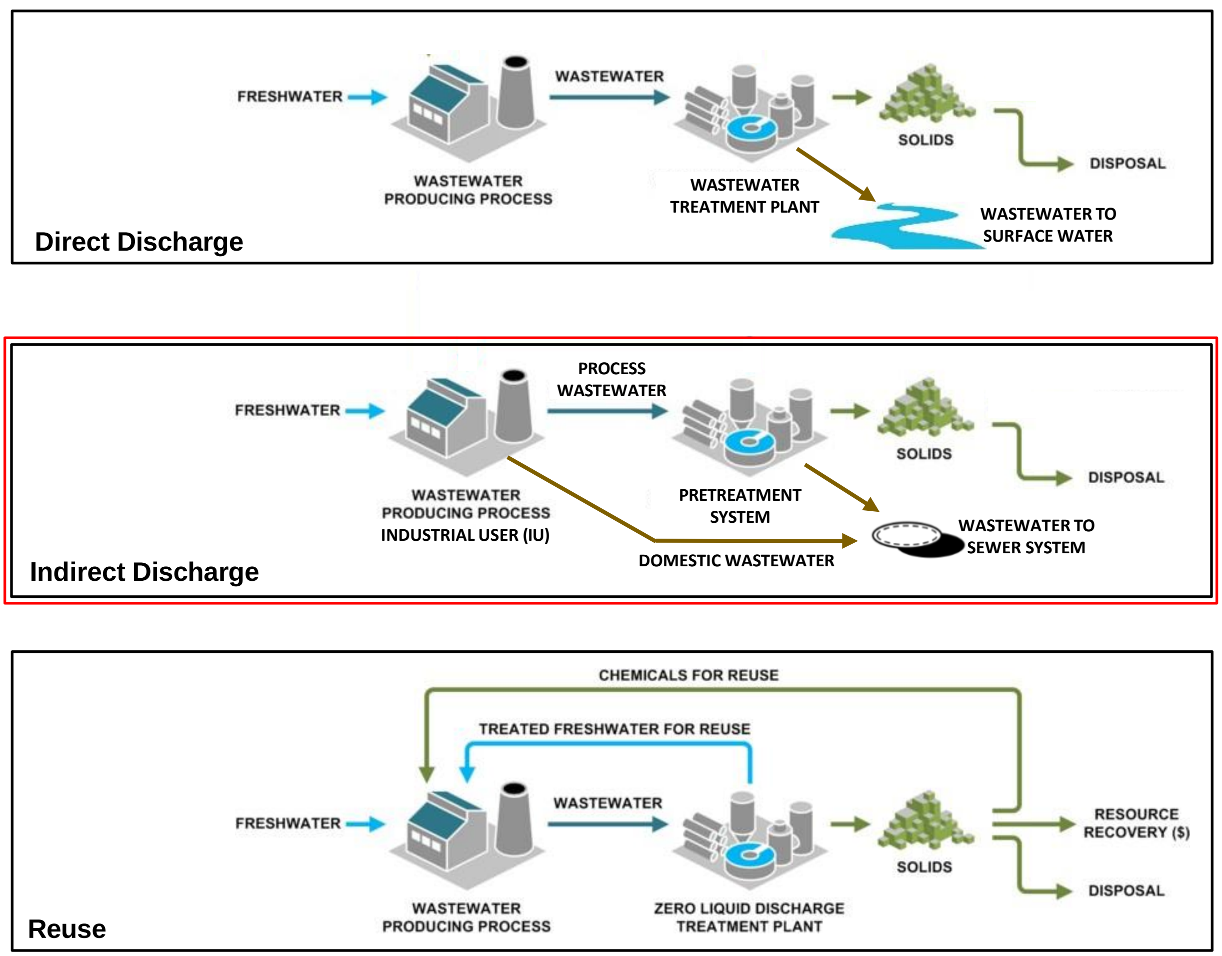

Figure 1: Industrial wastewater disposal options with indirect discharge in red.

Source: https://en.wikipedia.org/wiki/File:What_is_Zero_Liquid_Discharge_Diagram.png, Saltworks Technologies, Modified, CC-BY-SA-4.0

See the SunCam course entitled “Industrial Pretreatment Standards” for details on IU discharge permits, regulations, pretreatment programs, pollutant limits, inspections, sampling, and reporting requirements.

Domestic wastewater (from bathrooms, sinks, drinking fountains, showers, etc) is normally separated from process wastewater (from production processes, chemical storage rooms, etc). Domestic wastewater can be discharged to the sewer system without pretreatment. Stormwater flow, such as roof drains, should also be kept out of the pretreatment system.

Each IU is issued a discharge permit with conditions that include prohibitions, standards, and limits. The permit is normally issued by the local publicly owned treatment works (POTW), which is the owner of the collection system, wastewater treatment plant, and related infrastructure. Large POTWs (over 5 MGD) normally have an Industrial Pretreatment Program and are considered the Control Authority. They set Local Limits for pollutants, issue permits, monitor IUs, and submit annual reports to the Approval Authority (state or Environmental Protection Agency (EPA)).

Purpose of a Pretreatment System

The goal of a pretreatment system is to modify the wastewater so that the water quality consistently meets the permit conditions while also minimizing treatment costs and municipal discharge fees. Commercial and industrial facilities often produce wastewater with toxic pollutants and other non-conventional pollutants that the POTW wastewater treatment plant (WWTP) cannot normally remove. This wastewater can interfere with the WWTP processes and/or pass through into the receiving waterbody.

The main objective of national, state, and local pretreatment programs is to prevent interference and pass through of industrial wastewater. Therefore, each IU is required to “pretreat” the wastewater in accordance with the General Pretreatment Regulations in 40 CFR 403, the categorical standards in 40 CFR 405 to 471, and any Local Limits set by the Control Authority.

Although the main goal of pretreatment is to prevent POTW interference and pass through, the following is a list of additional problems associated with industrial wastewater that can be solved or minimized by a pretreatment system:

- Land Pollution: When sewage sludge is land applied, high concentrations of toxins can pollute the land or limit sludge disposal. Many municipalities apply treated sewage sludge (or soil conditions products) to pastures and parklands.
- Air Pollution: High concentrations of toxins can be released into the air (volatilization) in the POTW collection system, WWTP, or during incineration of sewage sludge.
- Groundwater Pollution: High concentrations of toxins can leak through joints in the collection system, wet wells, and other structures. Any nearby potable water system or raw water well can become contaminated.
- Corrosion: Acidic discharges or high levels of sulfate (which can form corrosive hydrogen sulfide) can degrade the pipes, pumps, and other components in the POTW collection system and WWTP.

Pollutant Limits

Regulated pollutants found in IU permits fit into the following groups:

1. Priority Pollutants:
   - Metals (Fe, Pb) and Toxic Organics (solvents, pesticides)]
   - There are 126 priority pollutants defined in 40 CFR 423, Appendix A. See Table 11 of the SunCam course entitled "Industrial Pretreatment Standards"
2. Conventional Pollutants:
   - BOD_5, TSS, Fecal Coliform, pH, Oil & Grease (O&G), etc.
   - Included in most categorical standards in 40 CFR 405 to 471
   - Included in most Local Limits
3. Nonconventional Pollutants:
   - Temperature, Dissolved Oxygen (DO), Turbidity, Total Residual Chlorine, Nutrients (P, N), etc.
   - Sometimes included in Local Limits.
   - Can be added to individual IU permits where the parameters are a concern.

Most IUs will fit into one of the categories in 40 CFR 405 to 471, which are listed in Table 1 for convenience. Many of the categories have more stringent pollutant limits for new/planned facilities, called Pretreatment Standards for New Sources (PSNS), than for existing facilities, called Pretreatment Standards for Existing Sources (PSES).

When planning for a new facility or a major facility modification, the pollutant limits can be anticipated by reviewing the applicable category in 40 CFR 405 to 471 (under PSNS) and the Local Limits found in the local sewer ordinances or POTW website. Together, these are likely to be the pollutants and limits set in the IU discharge permit.

Treatment Options

Anticipating the pollutant limits helps an engineer to select the treatment methods and technologies needed to maintain the water quality within the limits. There are more than a dozen common treatment methods for industrial pretreatment systems, as detailed in this course. Each IU has a unique combination of production processes that results in unique wastewater streams, and therefore a unique wastewater pretreatment system. Each pretreatment system design is site-specific and project-specific.

Table 1: Industrial Categories with Established Pretreatment Standards					
40 CFR	Industrial Category	40 CFR	Industrial Category	40 CFR	Industrial Category
405	Dairy products processing	425	Leather Tanning & Finishing	444	Waste Combustors
406	Grain mills	426	Glass Manufacturing	446	Paint formulating
407	Canned & preserved fruits & veg.	427	Asbestos Manufacturing	447	Ink formulating
408	Canned & preserved seafood	428	Rubber Manufacturing	454	Gum & Wood Chemicals Mfg.
409	Sugar processing	429	Timber products processing	455	Pesticide Manufacturing
410	Textile Mills	430	Pulp, paper, and paperboard	457	Explosives Manufacturing
411	Cement Manufacturing	431	Builders paper & board mills	458	Carbon black Manufacturing
412	Feedlots	432	Meat products	459	Photographic supplies
413	Electroplating	433	Metal finishing	460	Hospitals
414	Organic Chemicals, Plastics, & Synthetic Fibers	434	Coal Mining	461	Battery Manufacturing
415	Inorganic chemical Manufacturing	435	Oil & gas extraction	463	Plastics molding and forming
417	Soap & Detergent Manufacturing	436	Mineral mining and processing	464	Metal molding and casting
418	Fertilizer Manufacturing	437	Centralized Waste Treatment	465	Coil Coating
419	Petroleum Refining	439	Pharmaceutical Manufacturing	466	Porcelain enameling
420	Iron & Steel Manufacturing	440	Ore mining and dressing	467	Aluminum Forming
421	Nonferrous Metals Manufacturing	441	Dental Office	468	Copper Forming
422	Phosphate Manufacturing	442	Transportation Equipment Cleaning	469	Electrical, electronic components
423	Steam Electric power Generation	443	Paving and roofing materials Mfg.	471	Nonferrous Metal, Form & Powders
424	Ferro allay Manufacturing				

Design Criteria and Steps

The following design criteria are important to keep in mind throughout the pretreatment system planning and design process:

1. Treatment methods proven to reduce wastewater pollutants of concern,
2. Treatment capacity sufficient for anticipated wastewater flow rates,
3. Avoid clogging or buildup of solids or grease.
4. Provide reliable and uninterruptible operation,
5. Allow for easy and safe operation and maintenance of the equipment,
6. Accommodate future capacity expansion,
7. Avoid septic conditions and excessive release of odors,
8. Minimize aesthetic impacts on surroundings,
9. Provide for water reuse when possible, and
10. Avoid flooding or overflows. Note that bypassing of treatment is not allowed per 40 CFR 403.17.

The design of a new pretreatment system is typically done in the following steps:

1. Wastewater Assessment:
    a. Identify industrial category and anticipated pollutant limits
    b. Estimate wastewater flow rates and characteristics
    c. Identify pollutants needing removal
2. Choose treatment methods (perform bench-scale testing as needed)
3. Create a process flow diagram
4. Create a hydraulic profile
5. Size equalization tank
6. Size treatment systems (additional bench-scale testing as needed)
7. Create a site plan
8. Preliminary cost estimate
9. Preapplication meeting with the permit authority
10. Detailed design including drawings, specifications, and final cost estimate
11. Quality review of design
12. Permit submittal
13. Procurement

This course focuses on the first 6 design steps. The order of the steps can be modified. Sometimes the design requires an iterative approach, where an initial selection and sizing of treatment equipment is assumed and then later modified as the design progresses and as bench-scale testing is concluded. A quality review of the treatment methods selection can prevent costly design changes later in the project. In general, this course focuses on the design of a new pretreatment system. However, the same design steps apply for modifying an existing pretreatment system.

Wastewater Assessment

The goal of a wastewater assessment (also called a wastewater survey or study) is to gather sufficient information to make design decisions for a pretreatment system. A wastewater assessment should be able to answer the following questions:

1. What industrial category applies to the facility?
2. What are the anticipated pollutant limits based on the industrial category and Local Limits?
3. What are the process waste sources, production times, ingredients, and cleaning chemicals?
4. What are the anticipated pollutant concentrations or loads?
5. What is the estimated average and peak flow rate for the combined discharge?
6. Is flow or load equalization justified to reduce peaks?
7. Compare anticipated pollutant concentrations or loads with anticipated permit limits.

The following subsections provide details on how a wastewater assessment can answer the above questions.

Industrial Category and Limits

Most IUs will fit into one of the categories in 40 CFR 405 to 471, as listed in Table 1. Some facilities will fit into more than one category, in which case both sets of categorical standards apply, and either combined limits are calculated or the more stringent of the two standards is applied.

Many of the categories have different requirements for new/planned facilities (PSNS) than for existing facilities (PSES). Major modifications of the production process or pretreatment system will typically trigger the more stringent PSNS limits. When planning for a new facility or a major facility modification, the pollutant limits can be anticipated by reviewing the applicable category in 40 CFR 405 to 471 (under PSNS) and the Local Limits found in the local sewer ordinances or POTW website. Together, these are likely to be the pollutants and limits set in the IU discharge permit.

Example Problem 1

Engineer Michael has been consulted to help determine anticipated maximum day pollutant limits for a new facility that will do ductile iron casting and finishing. The facility will produce 100,000 pounds per day of investment castings with an estimated waste stream of 35 gallons per minute (gpm), or 0.05 million gallons a day (MGD) from the casting process and another 35 gpm from the metal finishing process, for a total of 70 gpm (0.1 MGD).

The POTW website provides the following Local Limits:

Parameter	Approved July 12, 2016 Local Limits mg/l	Basis for Current Limits
Arsenic	0.418	Sludge
Cadmium	0.390	Sludge
Chromium, Total	1.90	Current
Copper	0.8	Current
Cyanide	2.34	Current
Lead	2.22	Sludge
Mercury	0.002	1997 Limit
Molybdenum	1.5	Sludge
Nickel	2.699	Current
Selenium	0.441	Sludge
Silver	1.819	Sludge
Zinc	1.900	Current
Oil & Grease	250	SUR

Solution:

Michael looks at the categorical standards (shown in Table 1) and determines that two categories apply, as follows:

A. Metal molding and **casting** in 40 CFR 464, Subpart C (Ferrous Casting Subcategory). Code 40 CFR 464.36 is entitled "Pretreatment standards for new sources (PSNS)", and paragraph (e) is "Investment Casting", which lists the following pollutant limits based on production rates:

Pollutant or pollutant property	Maximum for any 1 day	Maximum for monthly average
	kg/1,000 kkg (pounds per million pounds) of metal poured	
Copper (T)	3.19	1.76
Lead (T)	5.84	2.86
Zinc (T)	10.8	4.07
TTO	13.2	4.3
Oil and Grease (for alternate monitoring)	330	110

B. Metal **finishing** in 40 CFR 433, Subpart A (Metal Finishing Subcategory). Code 40 CFR 433.17 is entitled "Pretreatment standards for new sources (PSNS)" and lists the following pollutant limits in terms of concentration:

Pollutant or pollutant property	Maximum for any 1 day	Monthly average shall not exceed
	Milligrams per liter (mg/l)	
Cadmium (T)	0.11	0.07
Chromium (T)	2.77	1.71
Copper (T)	3.38	2.07
Lead (T)	0.69	0.43
Nickel (T)	3.98	2.38
Silver (T)	0.43	0.24
Zinc (T)	2.61	1.48
Cyanide (T)	1.20	0.65
TTO	2.13	
Oil and Grease	52	26
TSS	60	31
pH	([1])	([1])

[1] Within 6.0 to 9.0.

For category A, since the casting process has production-normalized limits, Michael uses the following loading rate formula with production rates and flow rates to calculate the pollutant concentration limits:

$load\left(\frac{lb}{d}\right)=conc\left(\frac{mg}{L}\right)*flow(MGD)*8.34$, rearranged for concentration:

$$conc\left(\frac{mg}{L}\right)=\frac{load\left(\frac{lb}{d}\right)}{flow\,(MGD)*8.34}$$

$$copper_{limit}\left(\frac{mg}{L}\right)=\frac{copper_{limit}\left(\frac{lb}{d}\right)}{0.05\,MGD*8.34}=\frac{\frac{3.19\,\cancel{lb}}{1\epsilon 6\,\cancel{lb}}*100,000\,\frac{lb}{d}}{0.05\,MGD*8.34}=\frac{0.319\,\frac{lb}{d}}{0.05\,MGD*8.34}$$

$$\text{¿}\,0.76\,\frac{mg}{L}$$

$$lead_{limit}\left(\frac{mg}{L}\right)=\frac{lead_{limit}\left(\frac{lb}{d}\right)}{0.05\,MGD*8.34}=\frac{\frac{5.84\,\cancel{lb}}{1\epsilon 6\,\cancel{lb}}*100,000\,\frac{lb}{d}}{0.05\,MGD*8.34}=\frac{0.584\,\frac{lb}{d}}{0.05\,MGD*8.34}$$

$$\text{¿}\,1.40\,\frac{mg}{L}$$

$$zinc_{limit}\left(\frac{mg}{L}\right)=\frac{zinc_{limit}\left(\frac{lb}{d}\right)}{0.05\,MGD*8.34}=\frac{\frac{10.8\,\cancel{lb}}{1\epsilon 6\,\cancel{lb}}*100,000\,\frac{lb}{d}}{0.05\,MGD*8.34}=\frac{1.08\,\frac{lb}{d}}{0.05\,MGD*8.34}$$

$$\text{¿}\,2.59\,\frac{mg}{L}$$

$$O\wedge G_{limit}\left(\frac{mg}{L}\right)=\frac{lead_{limit}\left(\frac{lb}{d}\right)}{0.05\,MGD*8.34}=\frac{\frac{330\,\cancel{lb}}{1\epsilon 6\,\cancel{lb}}*100,000\,\frac{lb}{d}}{0.05\,MGD*8.34}=\frac{33.0\,\frac{lb}{d}}{0.05\,MGD*8.34}$$

$$\text{¿}\,79.1\,\frac{mg}{L}$$

Michael sums the categorical concentration limits for the two waste streams with the following calculations. He notes that the remaining pollutants are only regulated in category B and therefore can be multiplied by two since the flow rates are equal between the two streams.

$$Con\,c_{limit\ net}=\frac{Con\,c_{limit\ A}*flow_A+Con\,c_{limit\ B}*flow_B}{flo\,w_A+flo\,w_B}$$

$$copper_{limit\ net}=\frac{0.76\ \frac{mg}{L}*0.05\ MGD+3.38\ \frac{mg}{L}*0.05\ MGD}{0.05\ MGD+0.05\ MGD}=2.07\ \frac{mg}{L}$$

$$lead_{limit\ net}=\frac{1.40\ \frac{mg}{L}*0.05\ MGD+0.69\ \frac{mg}{L}*0.05\ MGD}{0.05\ MGD+0.05\ MGD}=1.05\ \frac{mg}{L}$$

$$zinc_{limit\ net}=\frac{2.59\ \frac{mg}{L}*0.05\ MGD+2.61\ \frac{mg}{L}*0.05\ MGD}{0.05\ MGD+0.05\ MGD}=2.60\ \frac{mg}{L}$$

$$O\wedge G_{limit\ net}=\frac{79.1\ \frac{mg}{L}*0.05\ MGD+52\ \frac{mg}{L}*0.05\ MGD}{0.05\ MGD+0.05\ MGD}=65.5\ \frac{mg}{L}$$

Next, Michael compiles the calculated limits and the Local Limits in Table 2. He compares the combined stream limits to the Local Limits, highlights the more stringent for each pollutant, and makes a new column **in blue** with the more stringent limits. These are the **anticipated limits** for the new facility, although the POTW can modify the pollutants and limits as part of the permit development process.
Also, the POTW may decide that the IU needs to report both the production-based mass load and the concentration for copper, lead, zinc, and O&G since these pollutants are in both categorical standards.

Table 2: Maximum Day Pollutant Limits for Example Problem 1							
Pollutant	Casting Stream			Finishing Stream CFR Limits (mg/L)	Combined Stream Limits (mg/L)	Local Limits (mg/L)	**Anticipated Limits (mg/L)**
	CFR Limits (lb/Mlb)	Load Limits (lb/d)	Conc Limits (mg/L)				
Arsenic	-	-	-	-		**0.418**	**0.418**
Cadmium	-	-	-	0.11	**0.22**	0.39	**0.22**
Chromium	-	-	-	2.77	5.54	**1.9**	**1.9**
Copper	3.19	0.319	0.76	3.38	2.07	**0.8**	**0.8**
Cyanide	-	-	-	1.20	2.40	**2.34**	**2.34**
Lead	5.84	0.584	1.40	0.69	**1.05**	2.22	**1.05**
Mercury	-	-	-	-	-	**0.002**	**0.002**
Molybdenum	-	-	-	-	-	**1.5**	**1.5**
Nickel	-	-	-	3.98	7.96	**2.699**	**2.699**
Selenium	-	-	-	-	-	**0.441**	**0.441**
Silver	-	-	-	0.43	**0.86**	1.819	**0.86**
Zinc	10.8	1.08	2.59	2.61	2.60	**1.9**	**1.9**
Oil & Grease	330	33.0	79.1	52	**65.5**	250	**65.5**
TTO	13.2	1.32	3.17	2.13	**3.20**	-	**3.20**
TSS	-	-	-	60	**120**	-	**120**
pH	-	-	-	6.0 to 9.0	**6.0 to 9.0**	-	**6.0 to 9.0**

Process Waste Streams

Each IU has a unique combination of production processes and wastewater streams (also called waste streams). When performing a wastewater assessment, the various waste streams should be identified and listed with known information, such as production times, ingredients, cleaning chemicals, and estimated flow rates. Next, the pollutants from each source should be identified and the concentrations estimated.

For new/proposed production processes, engineers can estimate pollutant concentrations by reviewing reference installations, obtaining vendor data for process equipment and chemicals, and asking staff familiar with the processes. For existing processes, water quality testing can be done to characterize pollutants and flow monitoring can be done to define the flow rates.

Sanitary domestic wastewater should be separated from all other process wastewater and discharged directly to the municipal sewer system. This reduces the load on the pretreatment system, makes maintenance more sanitary, and can reduce surcharge costs. Other flows that can be discharged separately without pretreatment include noncontact cooling water, boiler condensate, and boiler blowdown water.

Flow Rates

It is essential to define the average and peak design flows since these flow rates are critical for choosing the treatment method and to size equipment. Other commonly defined flow rates are as follows:

- Minimum design flow, or minimum hourly flow: This is the smallest flow rate expected to be maintained by the pretreatment system.
- Average design flow (ADF), or average daily flow (ADF): This is the average flow and can be calculated as the volume of fluid discharged over a long time period divided by the number of days.
- Maximum design flow (MDF), or maximum day design flow (MDDF): This is the largest of the various calculated or measured daily flow rates.
- Peak design flow (PDF), peak hourly flow (PHF), or instantaneous peak flow (IPF): This is the highest flow rate anticipated to be experienced by the pretreatment system, measured in a short interval, typically 1 hour. Sometimes this value is estimated by multiplying the average design flow by a peak factor. For example, a peak factor of 2 to 4 is commonly used for wastewater facilities.
- Ultimate design flow (UDF), ultimate average flow (UAF), or ultimate peak flow (UPF): This is the estimated flow rate to be experienced in the future, considering predicted changes or production expansions. Often the pretreatment system is designed based on PDF but with the flexibility to meet the UDF with minor modifications. For example, tanks are sized for UDF while pumps and equipment are sized for PDF with the ability to replace/upgrade them to meet UDF.

The approach depends on if there is an existing facility and if production changes are being proposed:

1. Existing facility, no proposed changes:
    a. Use flow monitoring techniques
2. Existing facility, proposed changes:
    a. Use flow monitoring techniques plus process waste stream estimates
3. New facility:
    a. Use process waste stream estimates

Flow Monitoring

The following are common methods for field measurements to define flow rates:

1. Bucket and stopwatch. This approach is for small pipes with an accessible discharge. Flow can be calculated by taking the volume of the bucket divided by the time it takes to fill it.
2. Float or Dye Method. Gravity flow in a pipe or channel can be estimated as the cross-sectional area of wastewater times the velocity. The velocity is estimated by timing a float dropped in the water over a distance, or by timing the movement of color dye over a distance.
3. Flow meter. Strap-on meters are available for pressure pipes. There are also flow meters for gravity sewers, manholes, and open channels. Multiple meters may be needed to capture multiple sources and to distinguish domestic flows from process flows.
4. Water meter data. For some processes, all of the metered water is discharged to the drain. Therefore, the water consumption data from the water meter(s) can be used to calculate the average and peak flow rates. This approach assumes that there is minimal inflow from stormwater and infiltration from groundwater. To account for these, sometimes a peak factor is utilized to estimate peak flows.
5. Level sensors in tanks or wet wells. Average flow can be calculated by taking the storage volume divided by the time it takes to fill or drain. If being pumped regularly, the flow can be calculated in a program based on level status and pump on/off status. Level readings show the rise rate (when pumps are off) and fall rate (when pumps are on), and with the storage area known, this allows calculation of the volume discharged over each pumping cycle. The volume divided by the cycle time is the flow rate.
6. Pump run times and curves. For lift stations or sumps, the pump flow rate can be confirmed by either a draw-down test (measuring the change in level in the tank or wet well) or by checking the discharge pressure and finding the corresponding operating point on the pump curve. Subtract any elevation difference or significant head loss between the pump and gauge. The ADF equals the pump run time (total number of minutes the various pumps were "on") multiplied by the pump flow rate (from the pump curve) divided by the measuring period.

Water Balance Diagram

The design of a pretreatment system is based on the **overall** (or combined) wastewater flow rate and pollutant loading. However, it is helpful to have all the process flow streams identified and shown in a water balance diagram. This diagram is useful for several reasons and may be requested by the Local Pretreatment Program as part of the permit application process.

Example Problem 2

Engineer Kenny is performing a wastewater assessment for an existing soup canning facility. He took an inventory of the various plant processes and estimated the average daily flow (ADF) for each process. Kenny created a summary in Table 3. Now he needs to draw a water balance diagram and calculate the ADF for the pretreatment system.

Table 3: Summary of Plant Processes and Waste Flows (ADF)

Process	Water Flow In (gpd)	Waste Flow Out (gpd)	Wastewater Type
Boiler System	177,000	40,000	Exempt
Cooking, Washing & Transport	400,000	385,000	Process
Pre-Rinse Sanitary	58,000	55,000	Process
Purification & Product	87,000	15,000	Process
Irrigation	5,000	0	N/A
Office Use	8,000	5,000	Domestic
Total	735,000	500,000 (485,000 w/ losses)	All

Solution:

Using Table 3 and other details gathered during the plant inventory, Kenny draws the water balance diagram in Figure 2. He uses the following colors:

- Blue for municipal water supply,
- Green for the exempt flow streams related to the boiler,
- Red for the process flows subject to pretreatment standards, and
- Brown for sanitary domestic flows.

For both Table 3 and Figure 2, the ADF to the pretreatment system is 455,000 gpd (0.455 MGD), which is the sum of the process wastewater flows.

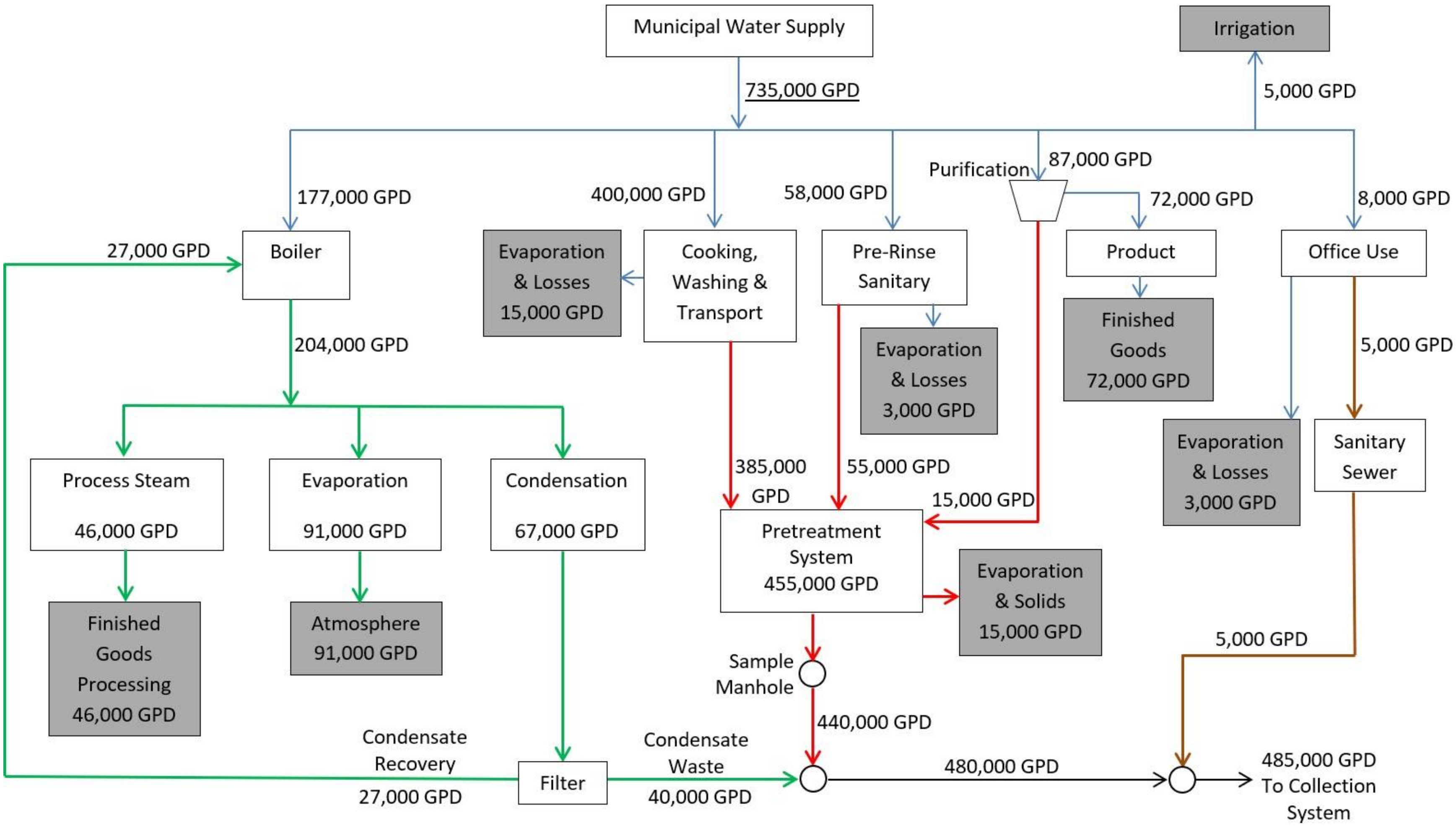

Figure 2: Water balance diagram for Example 2. Flows to and from the pretreatment system are in red.

Pollutant Loads

The pollutants should be determined for each waste stream and the loading rates or concentrations estimated. This can be done by water quality testing (for existing facilities), reviewing reference installations, obtaining vendor data for process equipment and chemicals, and asking staff familiar with the processes. Give focus to the concentrations of the pollutants listed in the relevant industrial categories, the Local Limits, and the IU discharge permit (for an existing facility).

Identify Incompatible Waste Streams

Typically, all process waste streams are combined in a drainage pipe network that feeds into the pretreatment system. However, some incompatible wastes should not be mixed. For example, metal plating processes may produce both acidic streams and a cyanide-containing stream that if combined would produce hydrogen cyanide gas, which is highly toxic and flammable. The cyanide-containing stream should be treated to remove the cyanide before combining the streams. This approach may result in more than one pretreatment system at a single site. Engineers should make an effort to identify incompatible waste streams.

Pollutant Loads versus Anticipated Limits

The pollutant loads for each stream can be added together to give a net or equalized load, assuming there is some form of equalization (as discussed in the next section). The equalized loads can be compared to the permit limits for an existing system or the anticipated limits based on categorical limits and Local Limits for a new system. Any load that is equal or greater than the limit requires removal by the pretreatment system.

Example Problem 3

Continuing with Example Problem 2, Kenny is asked to assessed improvements to the existing pretreatment system based on current pollutant loads. He performs water quality testing on the three process waste streams, as summarized in Table 4. Kenny must calculate the total loads (after equalization), compare them to the permit limits, and determine the percent reduction required for each pollutant.

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Table 4: Waste Stream Pollutant Loads for Example Problem 3				
Pollutant	Cooking Stream (mg/L)	Pre-Rinse Stream (mg/L)	Purification Stream (mg/L)	Permit Limit (mg/L)
Arsenic	0.1	0	0	0.30
Cadmium	1	.8	0.1	1.0
Chromium	2	1	0.1	4.0
Copper	0.2	0.1	2.0	0.5
Cyanide	0.5	0	0	1.0
Lead	8	6	1	10
Mercury	0.1	0.2	0.1	0.20
Molybdenum	5	8	0.1	10
Nickel	1	0	0	2.0
Selenium	0	0	0	0.10
Silver	0	0	0	1.0
Zinc	0.8	0	0	0.5
Oil & Grease	200	150	5	100
TDS	1,200	700	2,000	1,000
TSS	350	300	500	300
pH	5	6	7	6.0 to 9.0
BOD_5	500	200	300	350
Chloride	180	500	250	200
Sodium	500	200	60	250
Sulfate, SO_4	220	10	300	200
Flow (MGD)	0.385	0.055	0.015	N/A

Solution:
Kenny calculates the equalized pollutant loads (as concentrations after equalization) by summing the loads for the three streams and dividing by the flow, as follows:

$$Arsenic_{EQ} = \frac{0.1\,\frac{mg}{L} * 0.385\,MGD + 0\,\frac{mg}{L} * 0.055\,MGD + 0\,\frac{mg}{L} * 0.015\,MGD}{0.455\,MGD} = 0.08\,\frac{mg}{L}$$

$$Cadmium_{EQ} = \frac{1\,\frac{mg}{L} * 0.385\,MGD + 0.8\,\frac{mg}{L} * 0.055\,MGD + 0.1\,\frac{mg}{L} * 0.015\,MGD}{0.455\,MGD} = 0.95\,\frac{mg}{L}$$

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After calculating the equalized loads for each pollutant, Kenny compiles the values in Table 5 along with the permit limits. He makes a column on the right with the percent removal required for the pollutants that exceed the limits: Zinc, Oil & Grease, TDS, TSS, pH, BOD_5, Chloride, and Sodium.

Table 5: Pollutant Loads versus Permit Limits for Example Problem 3

Pollutant	Equalized Loads (mg/L)	Permit Limit (mg/L)	Percent Removal Required
Arsenic	0.08	0.30	-
Cadmium	0.95	1.0	-
Chromium	1.82	4.0	-
Copper	0.25	0.5	-
Cyanide	0.42	1.0	-
Lead	7.53	10	-
Mercury	0.11	0.20	-
Molybdenum	5.20	10	-
Nickel	0.85	2.0	-
Selenium	0	0.10	-
Silver	0	1.0	-
Zinc	**0.68**	0.5	**26%**
Oil & Grease	**188**	100	**47%**
TDS	**1,166**	1,000	**14%**
TSS	**349**	300	**14%**
pH	**5.2**	6.0 to 9.0	**15%**
BOD_5	**457**	350	**23%**
Chloride	**221**	200	**10%**
Sodium	**449**	250	**44%**
Sulfate, SO_4	197	200	-

Industrial Pretreatment Design

<u>**Equalization**</u>

Equalization is when all the waste streams flow into a large tank, wet well, or basin. The large volume allows for mixing of the wastes. The flow is then released to the pretreatment system at a nearly constant rate by pumping or control valve adjustments.

The benefits of equalization are as follows:

- <u>Consistent Loads for Treatment</u>. Waste streams often have high concentrations of one or more pollutants over a short duration. For example, a chemical cleaning process can result in a concentrated acid being dumped down the drain. This makes it very challenging for a treatment system to meet all pollutant limits all the time. Equalization makes pollutant concentrations consistent and greatly reduces the peak loads, thereby making the pretreatment system smaller, more economical, and more reliable. A tank mixing system helps to ensure equalization of pollutant loads.
- <u>Consistent Flow for Treatment</u>. The flow rates of the various waste streams can vary significantly, making it difficult to maintain consistent treatment without equalization. Flow equalization involves storing some of the flow during high flows and releasing this storage during low flows. This greatly reduces the peak flow rate, thereby making the pretreatment system smaller and more economical.
- <u>Mixing Reactions</u>. When waste streams are mixed, chemical reactions occur that change some of the water quality parameters. It is helpful to have these reactions occur in a large equalization tank that can absorb any release of energy. In most cases, the reactions are a benefit as extreme pollutants will be stabilized and conventional parameters will be neutralized. Any incompatible waste streams should be identified and addressed as mentioned earlier.
- <u>Store-Treat Cost Savings</u>. An equalization tank can perform multiple functions including some form of treatment. Examples include oil-water separation, aeration, mixing, screening, floatation, anerobic processes, and settled solids (sludge) removal.

A challenge for engineers designing an equalization tank is to determine the optimal size for the tank. The following steps will help guide an engineer through the process of sizing a tank. The steps and calculations are the same for sizing wet wells and basins.

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Step No.

Step 1 is to obtain and add the flow rates for each of the various process waste streams. This can be done as follows:

1. For each process, estimate the typical waste stream flow for each hour of the day.
2. Add the waste stream flows for each hour of the day.
3. Obtain or calculate the future projected flows from potential plant expansions or production changes. This may be in the form of a factor or percentage. Multiply the hourly flows by this factor.
4. The flow rates for each hour are called the diurnal discharge flows for the facility. They are often plotted as a diurnal flow curve.

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Step 2 is to calculate the Equalization Volume (EQV) based on the diurnal facility discharge flows, as shown in Figure 3. The average daily flow is the horizontal red line, which represents the relatively constant flow out of the tank. In this curve, the tank is draining (drawing down) from 9 pm to 7 am, and the tank is filling from 7 am to 9 pm.

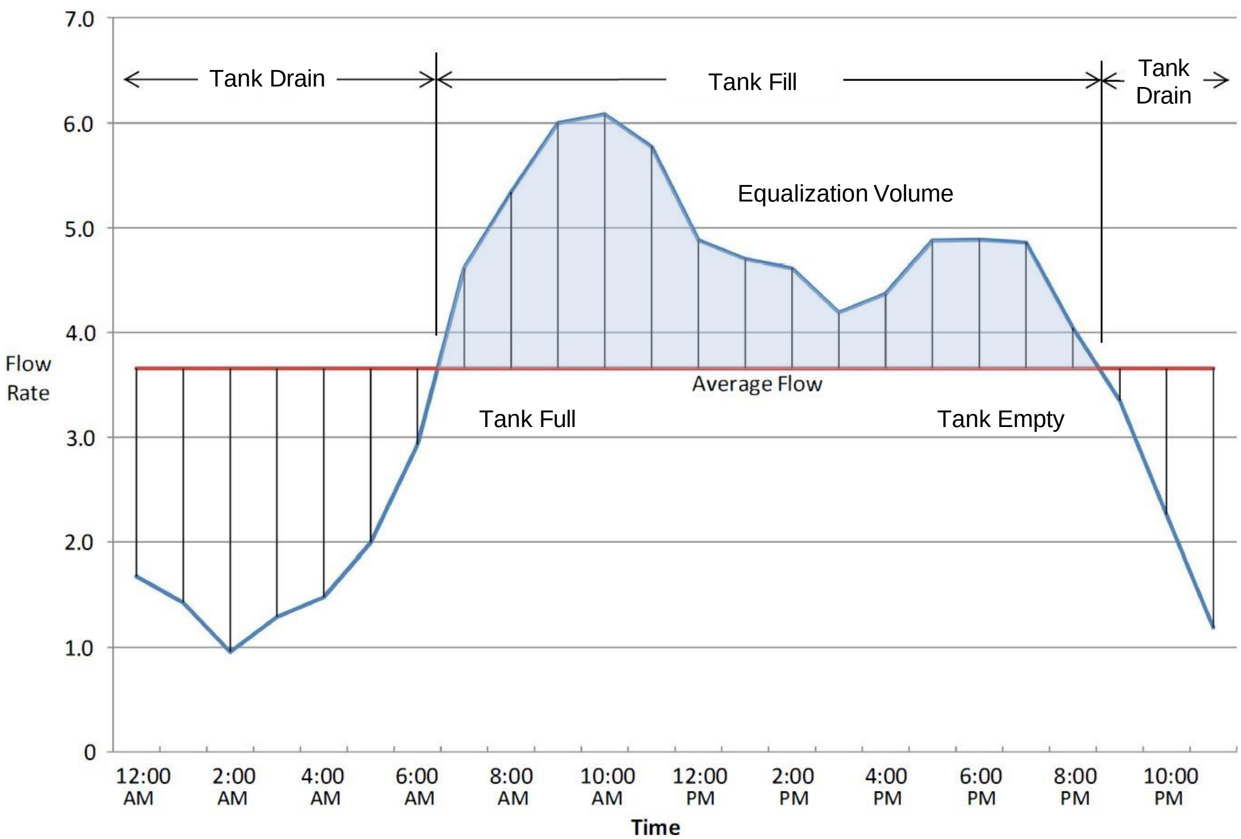

Figure 3: Example equalization curve with diurnal discharge flow in blue and the average daily flow in red.

The area above the red line and below the blue curve represents the required equalization volume. The volume can be calculated as follows:

$$EQV = \frac{\sum |Q_i - Q_{out}| \Delta t}{2} = \frac{1}{2} \sum |Q_{diurnal} - Q_{avg}| \Delta t$$

where:

$Q_{diurnal}$ = *Hourly Diurnal Discharge Flow* (*gpm*)

Q_{avg} = *Average Daily Flow* (*gpm*)

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$$\Delta t = 1\ hr\ (60\ min)$$

The required equalization volume is slightly different for each day since process waste streams vary each day. For example, the diurnal flow curve during a weekday is different from a weekend and different from a holiday. The designer should review diurnal flow data over a variety of days and pick the day with the highest differential between day and night flows. The calculated equalization volume should be rounded up by at least 10% to account for unforeseen variations in diurnal flow and flow monitoring limitations.

Step 3 is to calculate the total storage volume. This accounts for the need for flow equalization (calculated in Step 2), an emergency reserve, and dead storage volume. The total storage volume (TSV) is the sum of these three:

$$TSV = EQV + ERV + DSV$$

$$\begin{aligned} &where: \\ &TSV = Total\ Storage\ Volume \\ &EQV = Equalization\ Volume \\ &ERV = Emergency\ Reserve\ Volume \\ &DSV = Dead\ Storage\ Volume \end{aligned}$$

Total Storage Volume (STV), as a rule of thumb, should be equal to or greater than the average daily flow volume (flow rate divided by 1 day). The ERV can be increased to meet this minimum volume.

Emergency Reserve Volume (ERV) is for unusual events such as stormwater inflow, groundwater infiltration, spills, dumped product, process system failures, pretreatment system failures, or other unusual discharges to drains around the facility. It is common to have an emergency reserve of 50% to 100% of the average daily flow volume. For example, if the average daily flow is 1 MGD, the ERV could range from 0.5 MG to 1 MG.

Estimated Dead Storage (DS) is the excess volume at the bottom of a tank that is not normally usable. And at the bottom of the tank, there is a distance between the minimum water level and the floor of the tank to keep some fluid in the tank for pollutant equalization, to prevent entrained air from entering the outlet pipe and, in some cases, to provide sufficient positive suction head for pumping at the low water level. DS can be estimated as 10% to 20% of the tank volume, and then checked during design.

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Step 4 is to use the total storage volume to define the preliminary tank dimensions. First, decide on the number of equalization tanks. Ideally, there should be two or more tanks to allow for ease of inspection, maintenance, and operational flexibility. However, it is common to have a single tank to minimize capital costs and footprint. If there is insufficient funding available for two tanks, an option is to construct a single tank based on current flows and plan for a future second tank if production increases or the plant expands.

If multiple equalization tanks are selected, they should be designed to have the same maximum water level and overflow elevation. Ideally, they should be the same volume for ease of operation. For example, a selected volume of 2 MG should be provided with two 1 MG tanks.

For circular tanks, the height and/or diameter can be calculated using the formula for the volume of a cylinder:

$$V = \frac{\pi}{4} d^2 h \in typical\ English\ units: V_{gal} = 5.87\, d_{ft}^2\, h_{ft}$$

$$\begin{aligned} &where: \\ &V = Volume \\ &d = diameter \\ &h = height \end{aligned}$$

A tank supplier can be contacted to provide the most economical diameter and height for the tank based on the selected volume. The engineer should utilize the most economical dimensions when possible to minimize construction costs.

Step 5 is to create a profile of the tank(s) with the volumes calculated in Steps 2 and 3 and the preliminary tank dimensions in Step 4. See Figure 4 for an example.

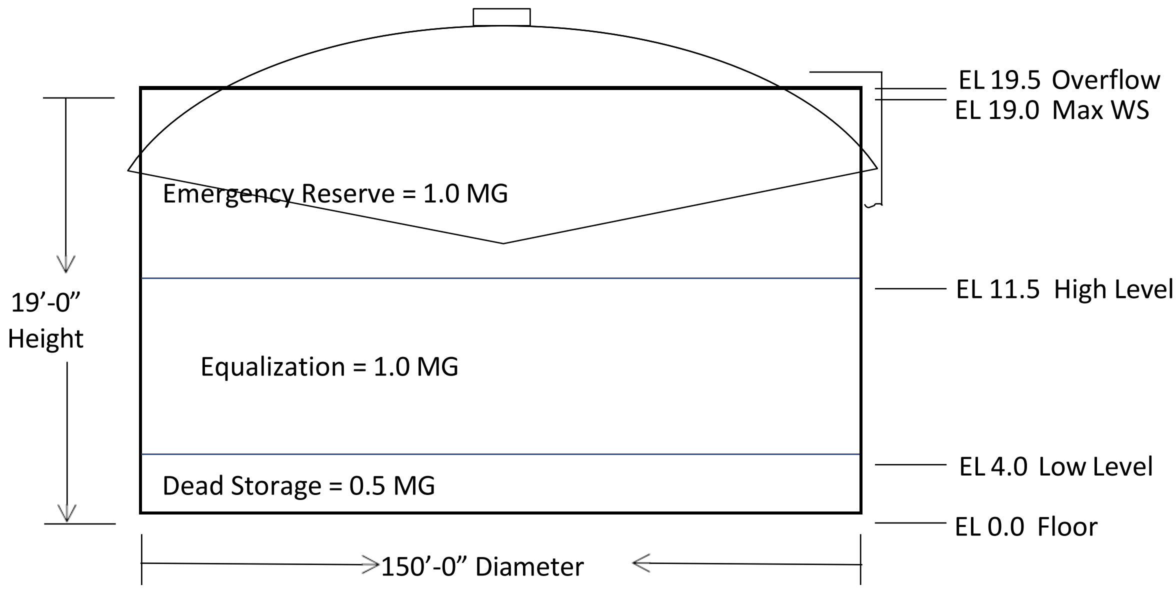

Figure 4: Profile of a 2.5 MG equalization tank with elevations and volumes.

The low and high-level elevations define the normal operating range of the tank. The overflow elevation should be at least a few inches above the maximum elevation to account for variation in level sensor readings, wave action at the water surface, and to give time for operators to assess a high-level alarm prior to an overflow event. Clarify with potential tank suppliers that the nominal tank volume is up to the high WS and should not include the freeboard to the overflow elevation.

The overflow can be piped to the pretreatment system or a storage basin. Untreated overflows are not allowed to bypass the pretreatment system or be discharged to the environment, per 40 CFR 403.17. Providing sufficient emergency reserve volume in the equalization tank will minimize the likelihood of an overflow.

Treatment Alternatives

There are a variety of treatment alternatives that can be incorporated into a pretreatment system. Engineers are asked to assess the alternatives and make recommendations for the unique needs of the facility. This can be a very challenging task as there are many different treatment methods to consider. Also, each facility has unique wastewater characteristics and discharge limits, so it can be difficult to find similar reference installations. Often, after a preliminary comparison of alternatives, bench-scale or jar testing is performed to compare alternatives, as shown in Figure 5.

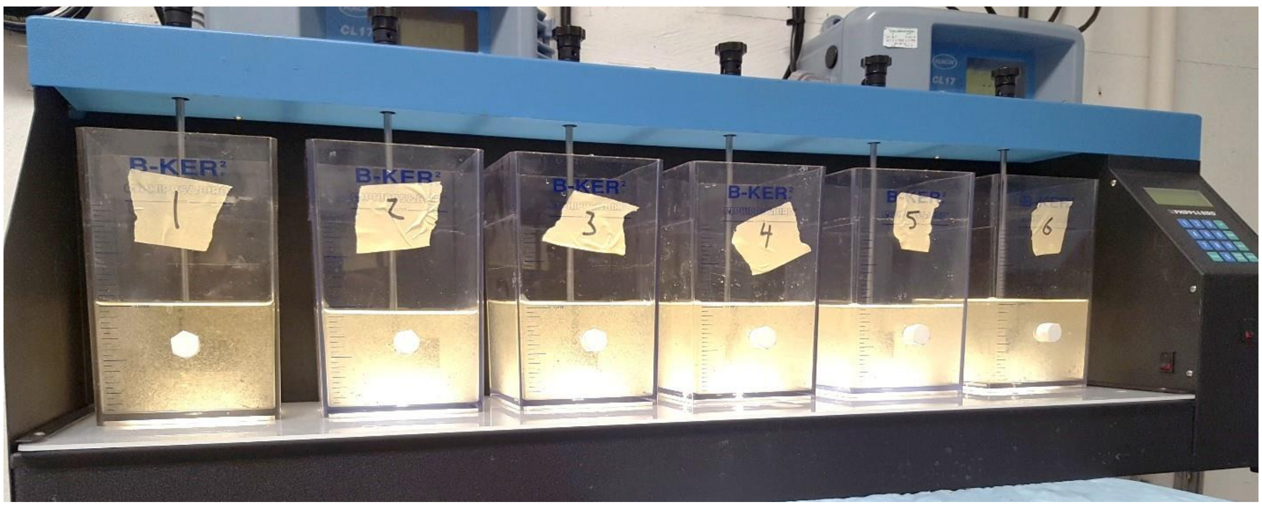

Figure 5: Jar testing with a gang stirrer and six wastewater samples,
each with different chemical dosages. After 30 minutes, supernatant turbidity was measured for each sample, to determine optimal chemical dosage.

A municipal wastewater treatment plant (WWTP) typically includes the following processes, with the main goal to remove conventional pollutants (BOD, TSS, fecal coliform, oil & grease, etc):

- Primary treatment (i.e., screening, grit removal, clarification),
- Secondary treatment (i.e., aeration, settling, activated sludge recirculation),
- Tertiary treatment (phosphorus or nitrogen removal, lagoons, sand filters)
- Disinfection (i.e., chlorination, dechlorination), and
- Solids handling (i.e., thickening, digestion, dewatering, land application).

Industrial pretreatment rarely follows the typical municipal WWTP processes since removing non-conventional pollutants and toxic organics requires different treatment processes. Treatment processes/methods can be grouped as follows: physical, chemical, and biological. See Table 6 for a list of treatment methods for each category. Table 7 lists the methods by pollutants that can be removed and regulated industries.

Table 6: Wastewater Treatment Methods by Categories

Category	Treatment Method	Traditional Process	Main Configurations
Physical	Equalization	Primary	Aboveground, basin, wet well
	Screening	Primary	Fine, course, basket, mechanical
	Sedimentation	Primary	Circular or rectangular clarifiers
	Flotation	Primary, Secondary	Dissolved air (DAF), gravity
	Media Filtration	Primary, Tertiary	Sand filters, downflow, upflow
	Membrane Filtration	Tertiary	MF, UF, NF, RO
	Oil-Water Separator	Primary	Oil interceptor, coalescing, gravity
	Adsorption	Tertiary	Activated carbon, fixed bed
	Evaporation	Tertiary	Pond, mechanical, falling film
	Air Stripping	Tertiary	Packed tower, degasifier, steam
Chemical	pH Neutralization	Tertiary	Base or acid addition, two-stage
	Chemical Precipitation	Tertiary	Flash-mix and settling
	Coagulation/ Flocculation	Secondary, Tertiary	Polymer or coagulant addition, mixing, and settling
	Oxidation-Reduction	Secondary, Tertiary	Chromium, cyanide, iron, arsenic, mercury, selenium removal
	Ion Exchange	Secondary, Tertiary	Anion, cation, fixed bed, moving bed, one or two-stage
	Electrodialysis	Secondary, Tertiary	ED stack, batch, or continuous
Biological	Bioaugmentation	Secondary	Biological additives
	Suspended Growth	Secondary	Activated sludge, oxidation ditch, SBR
	Attached Growth	Secondary	Trickling filter, RBC, packed bed, MBBR
	Membrane Bioreactor	Secondary	iMBR, sMBR, MF, UF
	Anaerobic Processes	Secondary, Solids	Upflow filter, fluidized bed, UASB, digester, anoxic selector
	Lagoons	Secondary, Tertiary	Multi-stage, stabilization ponds
	Constructed Wetlands	Secondary, Tertiary, Solids	Free surface or subsurface flow, horizontal or vertical flow, zero discharge

Industrial Pretreatment Design

Table 7: Wastewater Treatment Methods and Industries by Pollutants		
Pollutant	Treatment Methods	Industries with Categorical Limits
BOD	Biological Processes Membrane Filtration	Dairy, grain, canning, sugar, textile, feedlots, chemicals, soaps, fertilizer, petroleum, leather, glass, rubber, timber, paper, meat, landfill, pharmaceutical, transportation, paving, pesticides, explosives, plastics
COD, TOC	Adsorption Biological Processes Oxidation-Reduction Ion Exchange	Textile, chemicals, soaps, petroleum, non-ferrous metals, glass, asbestos, rubber, timber, paper, pharmaceutical, mining, pesticides, explosives, and battery
Chlorine	Adsorption Air Stripping Chemical Addition	Chemicals, iron & steel, steam power, paper, oil & gas
Fats, Oils & Grease (FOG)	Bioaugmentation Chemical Precipitation Coag./Flocculation Flotation Oil-Water Separator Membrane Filtration	Canning, chemicals, soaps, petroleum, iron & steel, metals, steam power, leather, rubber, timber, meat, oil & gas, transportation, paving, explosives, carbon black, hospitals, battery, plastics, and porcelain
Fluoride	Adsorption Electrodialysis Ion Exchange Membrane Filtration	Chemicals, fertilizer, non-ferrous metals, phosphate, glass, mining, coil coating, and electrical
Heavy Metals	Chemical Precipitation Coagulation Constructed Wetland Electrodialysis Evaporation Ion Exchange Membrane Filtration Oxidation-Reduction	Electroplating, chemicals, iron & steel, metals, electric power, mining, landfills, transportation, waste combustion, paint, battery, porcelain, and electronics
Inorganic Salts (Ca, Cl^-, K, HCO_3, Mg, Na, S^{2-}...)	Coagulation Electrodialysis Ion Exchange Membrane Filtration	Textile, chemicals, petroleum, leather, and pharmaceutical
Nitrogen & Ammonia	Air Stripping Biological Processes Ion Exchange Oxidation-Reduction	Feedlots, chemicals, fertilizer, glass, meat, pharmaceutical, mining, and non-ferrous metal
pH	pH Neutralization	Dairy, grain, canning, beverage, sugar, textile, cement, electroplating, chemicals, soaps, fertilizer, petroleum, iron & steel, metals, phosphate, steam, leather, glass, asbestos, rubber, timber, paper, mining, landfill, pharmaceutical, transportation, paving, waste comb., gum, pesticides, explosives, carbon black, photographic, hospitals, battery, plastics, porcelain, and electronics
Phosphorus	Biological Processes Ion Exchange Chemical Precipitation	Feedlots, fertilizer, phosphate, glass, and coil coating

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Radioactive	Evaporation Ion Exchange Chemical Precipitation Membrane Filtration	Chemicals, nuclear, pharmaceutical, landfill
Temperature	Cooling/Chilling Evaporation	Sugar and cement
Toxic Organics (TTO)	Chemical Precipitation Electrodialysis Ion Exchange Membrane Filtration	Electroplating, iron & steel, metals, paper, oil & gas, landfills, pharmaceuticals, paint, pesticides, electronics
TSS	Coag./ Flocculation Filtration Flotation Sedimentation Screening Biological Processes	Dairy, grain, canning, sugar, textile, cement, electroplating, chemicals, soaps, fertilizer, petroleum, iron & steel, meat, metals, phosphate, steam, leather, glass, asbestos, rubber, timber, paper, mining, landfill, pharmaceutical, transportation, paving, waste combustion, gum, pesticides, explosives, carbon black, hospitals, battery, plastics, porcelain, and electronics
VOC	Adsorption Air Stripping Oxidation-Reduction Evaporation Membrane Filtration Biological Processes	Electroplating, iron & steel, metals, paper, oil & gas, landfills, pharmaceuticals, paint, pesticides, electronics

Block Flow Diagram

It is helpful to draw a block flow diagram for each alternative being considered. Block flow diagrams show treatment processes as rectangles with flow arrows connecting the processes. A series of treatment processes is often called a “treatment train”. See Figure 6 for an example.

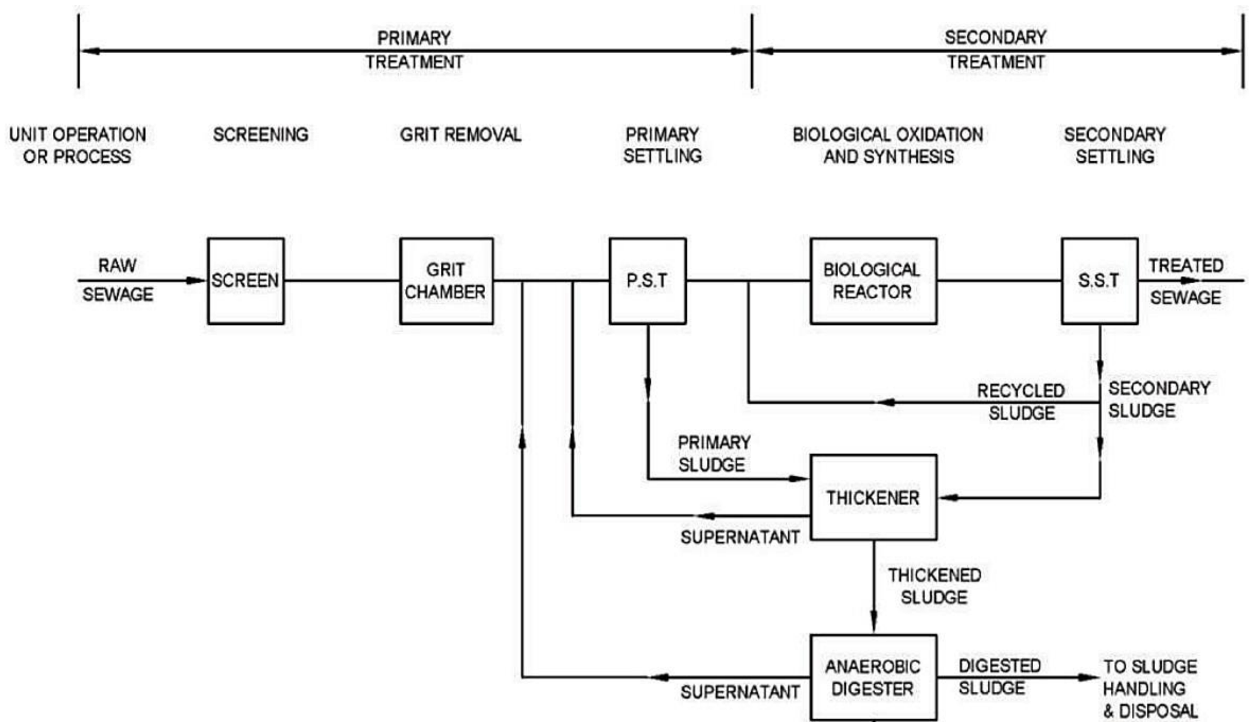


Figure 6: Example block flow diagram with traditional WWTP processes.

Source: “Manual on Sewerage and Sewage Treatment” 2nd Ed, by India Ministry of Urban Development (public domain)

Industrial Pretreatment Design

Example Problem 4

Continuing with Example Problem 3, Kenny needs to identify the treatment methods that can remove the eight pollutants needing reduction: Zinc, Oil & Grease, TDS, TSS, pH, BOD_5, Chloride, and Sodium. Kenny is to develop three alternative treatment trains and draw a block flow diagram for each. Finally, he is to indicate which of the three trains is the simplest.

Solution:

Kenny lists the potential treatment methods for removing the eight pollutants in Table 8. He makes a column called "common methods" to narrow down the list to treatment methods that can remove more than one pollutant. Then, he makes columns for three alternative trains and identifies logical combinations of treatment methods for each alternative.

Table 8: Treatment Methods and Alternatives for Example Problem 4.

Pollutant	Potential Treatment Methods	Common Methods	Alternative 1	Alternative 2	Alternative 3
BOD	Biological Processes	Biological Processes	Activated Sludge	Trickling Filter	Membrane Bioreactor
Inorganic Salts (Cl^-, Na)	Coagulation Electrodialysis Ion Exchange Membrane Filtration	Coagulation Electrodialysis Ion Exchange Membrane Filtration	Coagulation	Ion Exchange	Membrane Filtration
Fats, Oils & Grease (FOG)	Bioaugmentation Chemical Precipitation Coag./Flocculation Flotation Oil-Water Separator Membrane Filtration	Chemical Precipitation Coagulation Membrane Filtration	Coagulation	Bio-augmentation	Membrane Filtration
Heavy Metals (Zn)	Chemical Precipitation Coagulation Constructed Wetland Electrodialysis Evaporation Ion Exchange Membrane Filtration Oxidation-Reduction	Chemical Precipitation Coagulation Electrodialysis Evaporation Ion Exchange Membrane Filtration	Coagulation	Ion Exchange	Membrane Filtration
pH	pH Neutralization	-	pH Neutralization	pH Neutralization	pH Neutralization
TDS & TSS	Coag./ Flocculation Filtration Flotation Sedimentation Screening Biological Processes	Coagulation Filtration Biological Processes	Coagulation	Trickling Filter	Membrane Filtration

Industrial Pretreatment Design

Kenny creates a block flow diagram for each alternative train, as shown in Figure 7.

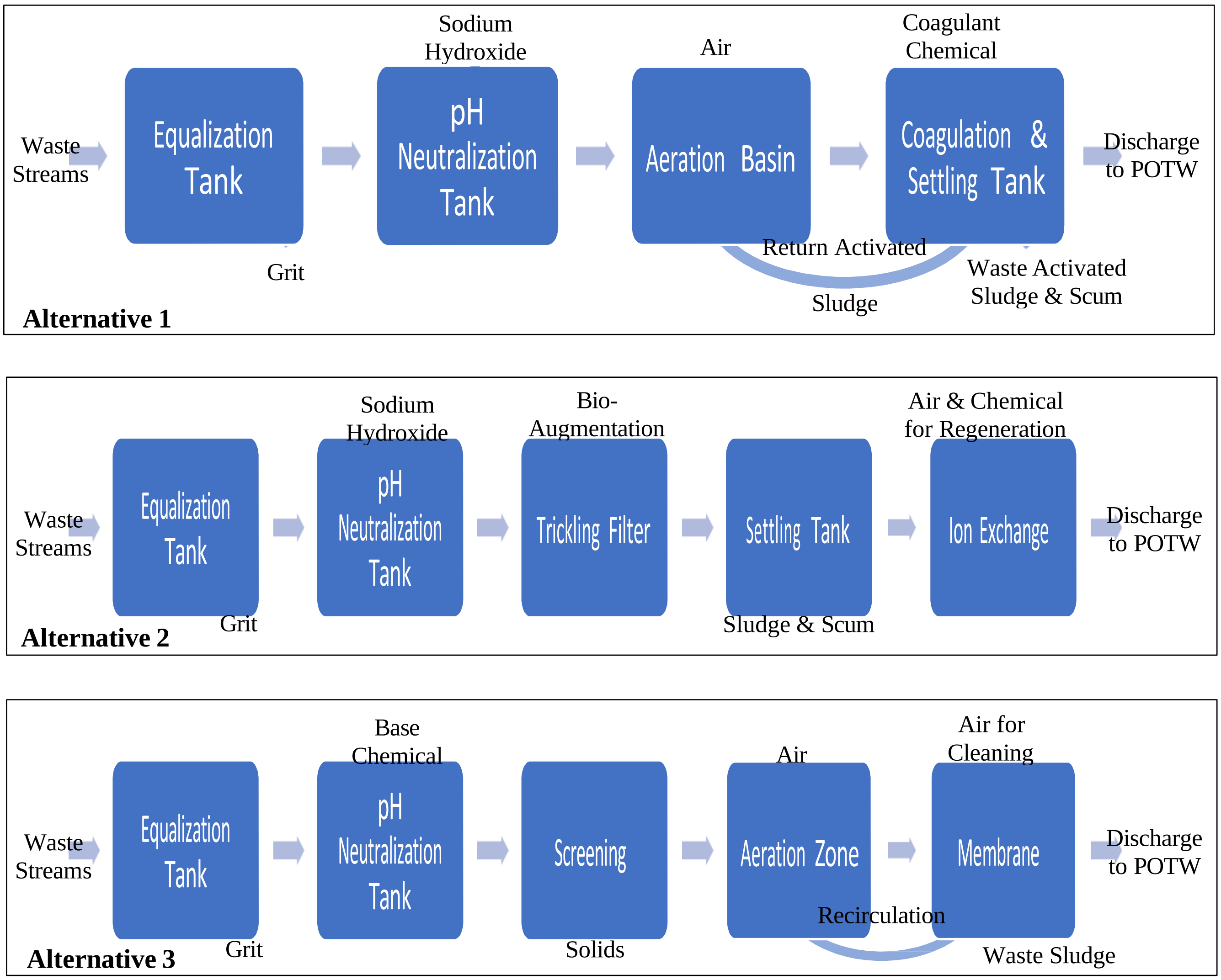


Figure 7: Block flow diagrams for the three alternatives in Example Problem 4.

Comparing the alternatives, Kenny determines that the simplest treatment train is Alternative 1 with the activated sludge system.

Industrial Pretreatment Design

Alternatives Comparison

After identifying potential treatment methods and arrangements, the next step is to do a side-by-side comparison to help decide on the best alternative. There are four general approaches to comparing alternatives:

1. Advantages Comparison: Each alternative is listed with perceived advantages and disadvantages.

2. Qualitative Comparison: Lists several criteria (also called indicators) with a comparison of the alternatives for each. See Table 9 for an example. Note that each alternative has a similar number of best and worst criteria, making it difficult to choose the best alternative.

Table 9: Example of a Qualitative Comparison of Pretreatment Alternatives

Treatment Alternative	Capital Cost	Lifecycle Cost	Footprint	Reliability	Flexibility	Permit Compliance	Chemical Use
Adsorption	Best	Ok	Ok	Worst	Worst	Worst	Best
Ion Exchange	Ok	Best	Best	Ok	Ok	Ok	Worst
Activated Sludge	Worst	Worst	Worst	Best	Best	Best	Ok

3. Quantitative Comparison: Includes numerical values or descriptive details for each criterion. See Table 10 for an example. This table shows details needed for decision making, however, the best alternative may still be unclear.

Table 10: Example of a Qualitative Comparison of Pretreatment Alternatives

Treatment Alternative	Capital Cost	Lifecycle Cost	Footprint	Reliability	Flexibility	Permit Compliance	Chemical Use
Adsorption	$0.5M	$0.6M	125 sf	70%	7 factors	78%	2 gpd
Ion Exchange	$0.7M	$0.5M	100 sf	80%	8 factors	78%	4 gpd
Activated Sludge	$1.0M	$0.7M	200 sf	90%	10 factors	98%	2.5 gpd

4. Multi-criteria Comparison: Includes numerical values for each criterion and uses weight factors to calculate a single total score for each alternative. The scoring approach minimizes subjectivity and provides transparency in showing how the best alternative is chosen.

See Table 11 for an example that uses the quantitative data in Table 10. In this case, higher values are better, with a maximum value of 1.0 (called the normalization index). The ion exchange system has the overall best score and is the winner. However, small changes in the weight factors could change the conclusion. One technique to define the weight factors is the analytic hierarchy process, in which pairwise comparisons are made for each criterion. Input can be obtained from stakeholders in the form of surveys so that a group decision is made transparently.

Table 11: Example Multi-criteria Scoring Table

Indicator	Weight Factor	Adsorption		Ion Exchange		Activated Sludge	
		Normal. Index	Weighted Index	Normal. Index	Weighted Index	Normal. Index	Weighted Index
Capital Cost	15	1.0	15	0.8	12	0.5	8
Lifecycle Cost	30	0.8	24	1.0	30	0.7	21
Footprint	5	0.8	4	1.0	5	0.5	3
Reliability	15	0.8	12	0.9	14	1.0	15
Flexibility	10	0.7	7	0.8	8	1.0	10
Permit Compliance	20	0.8	16	0.8	16	1.0	20
Chemical Use	5	1.0	5	0.5	3	0.8	4
Aggregated Index		-	83	-	**88**		81
Final Score (Normalized to 1)		-	0.94	-	**1.0**		.92

Physical Treatment

Physical treatment methods remove pollutants with simple, physics-based principles. The following tables provide a summary of common physical treatment methods.

Equalization		
Pollutants Targeted	**Function**	**Configurations**
Peaks of all	Storage volume allows for mixing of the waste streams and reducing peak concentrations. Flow is released at a constant rate.	• Above-ground Tank • Basin or Pond • Large Wet Well • One or Two in Parallel

Figure 8: Two 400,000 gallon equalization tanks for landfill leachate pretreatment.

Screening		
Pollutants Targeted	**Function**	**Configurations**
Settleable Solids, TSS	Remove large solids by physical straining, thereby protecting the pretreatment system and reducing settleable solids.	• Fine Screen • Coarse Screen • Basket • Mechanical • Static • Rotary Drum • Vibratory

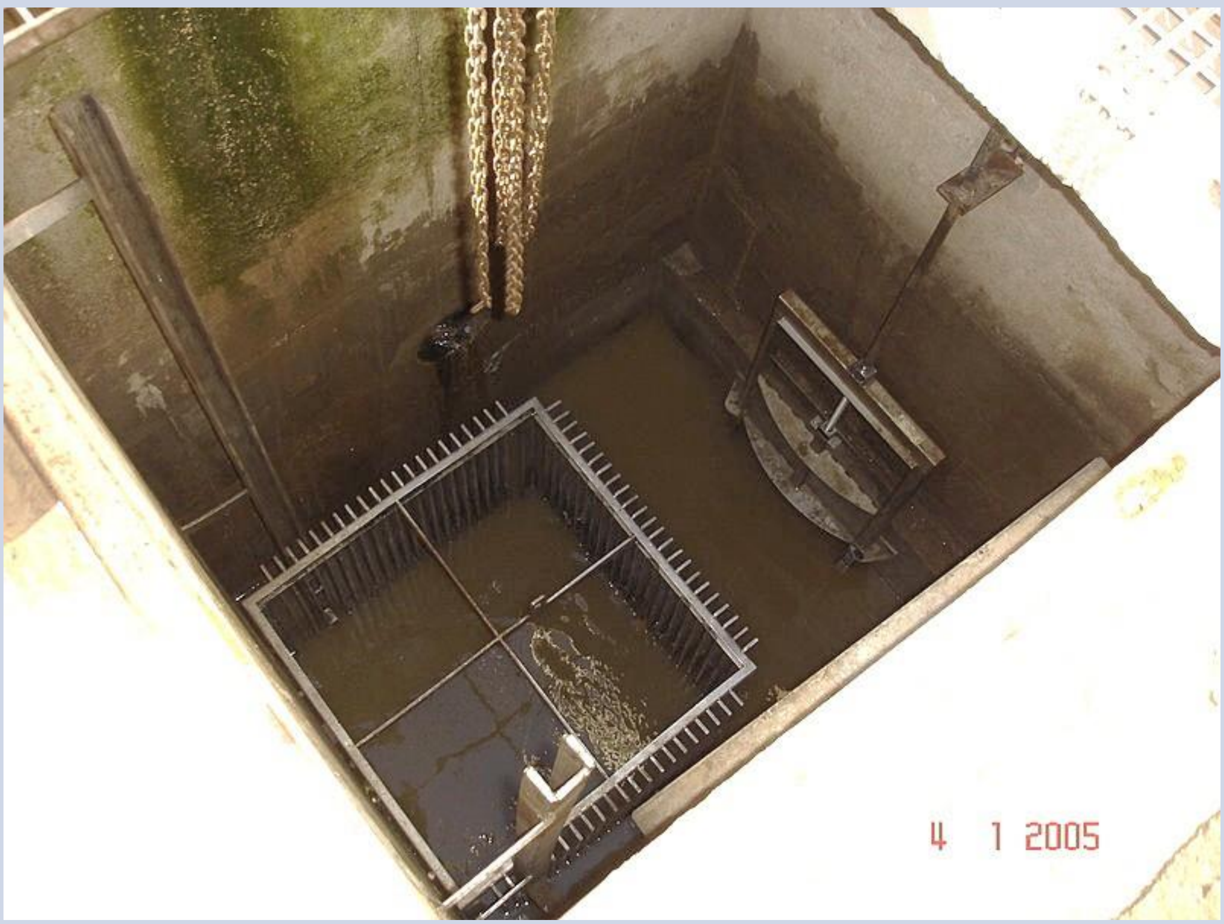


Figure 9: Example of a removable basket screen inside a wet well.
Source: https://commons.wikimedia.org/wiki/File:Pr%C3%A9traitement_(Maroc)_(13264700814).jpg, SuSanA Secretariat, CC-BY-2.0

Sedimentation		
Pollutants Targeted	**Function**	**Configurations**
TSS	Suspended solids settle due to gravity and are removed as sludge. Floating scum is removed from the surface. One of the most common treatment processes. Often used in combination with other treatment methods.	• Circular • Rectangular • Inclined plate • Chemical enhanced • Primary or secondary • With coagulation or flocculation zones • Gravity thickener

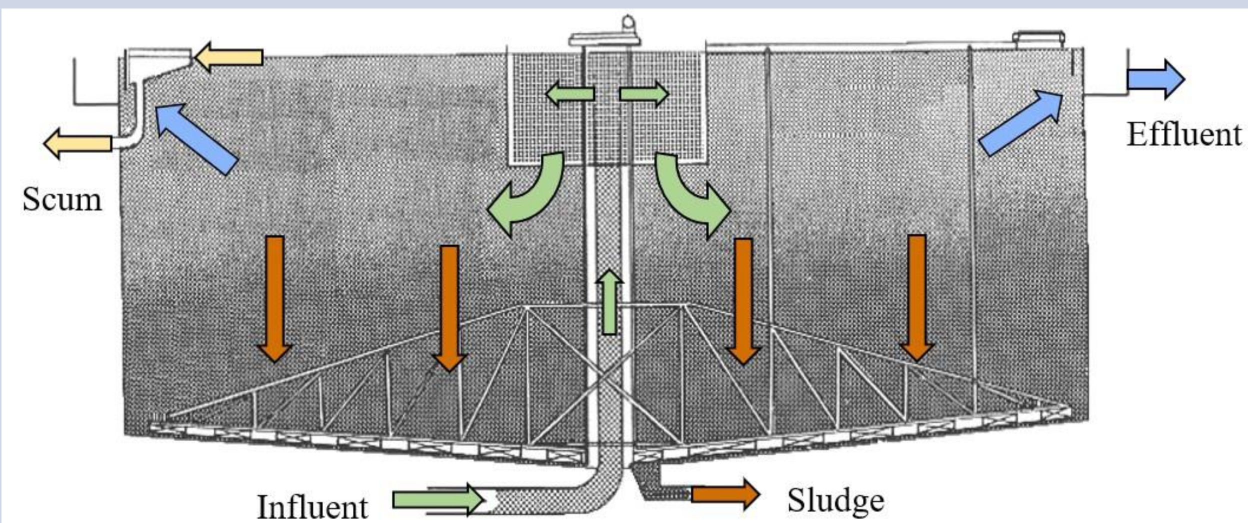


Figure 10: Section view of a circular clarifier with flow direction arrows. Chemical feed and a mixer can be added in the center well to create a coagulation or flocculation zone.

Flotation		
Pollutants Targeted	**Function**	**Configurations**
TSS, Oil & Grease	Removes suspended solids and oil by causing them to rise to the surface, where they are collected.	• Dissolved air flotation (DAF) • Gravity flotation

Figure 11: Example of a DAF system. Air is added to the influent and small air bubbles form and attach to oil and suspended solids, floating them to the surface where they are skimmed off as solids. DAFs are common at oil refineries, chemical plants, and paper mills.

Media Filtration		
Pollutants Targeted	**Function**	**Configurations**
TSS	Blocks suspended solids from passing through openings in the media and removes these solids through a backwash process.	• Downflow gravity • Downflow pressure • Upflow continuous backwash • Automatic backwash, shallow-bed • Media: sand and/or coal

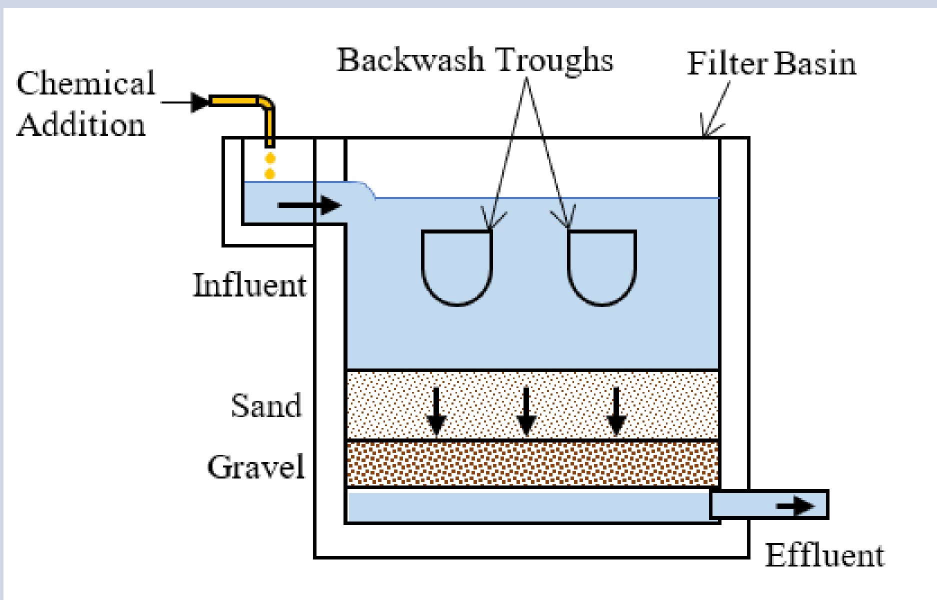
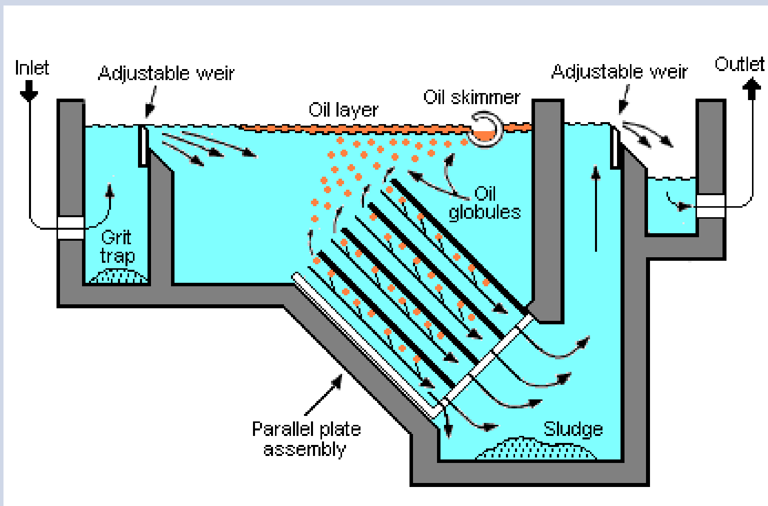


Figure 12: Section view of a downward gravity filter with chemical addition. During a backwash, the flow enters from the bottom, rises through the media, and exits through the backwash troughs.

Membrane Filtration		
Pollutants Targeted	**Function**	**Configurations**
BOD, Flouride, FOG Inorganic Salts Toxic Organics, Radioactive, TSS, VOC	Blocks a variety of pollutants from passing through small very openings, and removes these pollutants through a concentrate stream. Permeate has reuse potential.	• Micro-filtration (MF) • Ultra-filtration (UF) • Nano-filtration (NF) • Reverse osmosis (RO) • Membrane bioreactors

Figure 13: Ultrafiltration membranes (horizontal green tubes) for wastewater treatment.
Source: https://commons.wikimedia.org/wiki/File:Wastewater_UF_membrane_system,_Aquabio.jpg, Aquabio Ltd., CC-BY-SA-3.0

Oil-Water Separator		
Pollutants Targeted	**Function**	**Configurations**
Fats, Oil & Grease (FOG)	A large chamber calms the wastewater and allows FOG to float and agglomerate. The FOG is removed periodically.	• Oil interceptor/ grease trap • Coalescing gravity • Parallel plate • Chemically enhanced



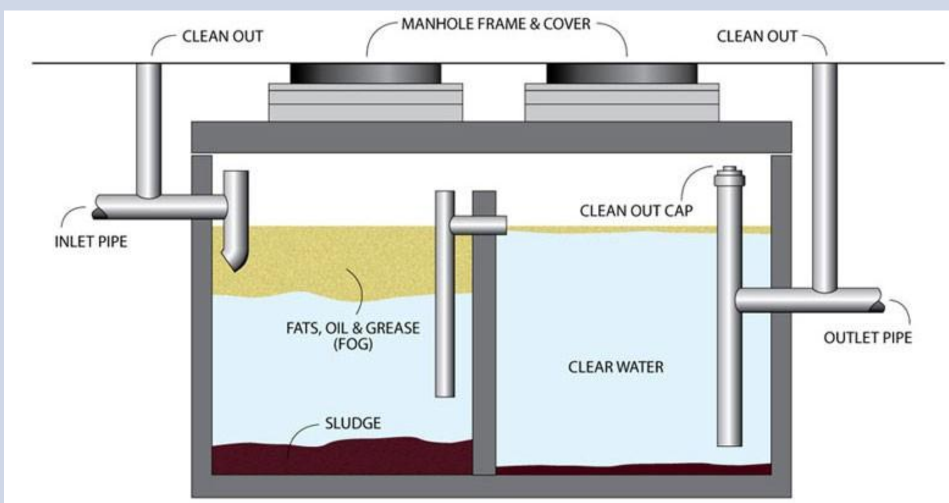


Figure 14: Top: A parallel plate oil-water separator for large flows.
Bottom: An oil interceptor, commonly called a grease trap. These are often installed on drain pipes from rooms with fuel storage or cooking oil.
Source: https://commons.wikimedia.org/wiki/File:Parallel_Plate_Separator.png, Mbeychok, CC-BY-SA-3.0
https://abilenetx.gov/718/Grease-Traps-101

Adsorption		
Pollutants Targeted	**Function**	**Configurations**
Arsenic, Cl_2, COD, Flouride, TOC, VOC	Organics are adsorbed (adhered) to the media and removed by backwash.	• Fixed-bed • Fluid-bed • Media: activated carbon, activated alumina, modified clay

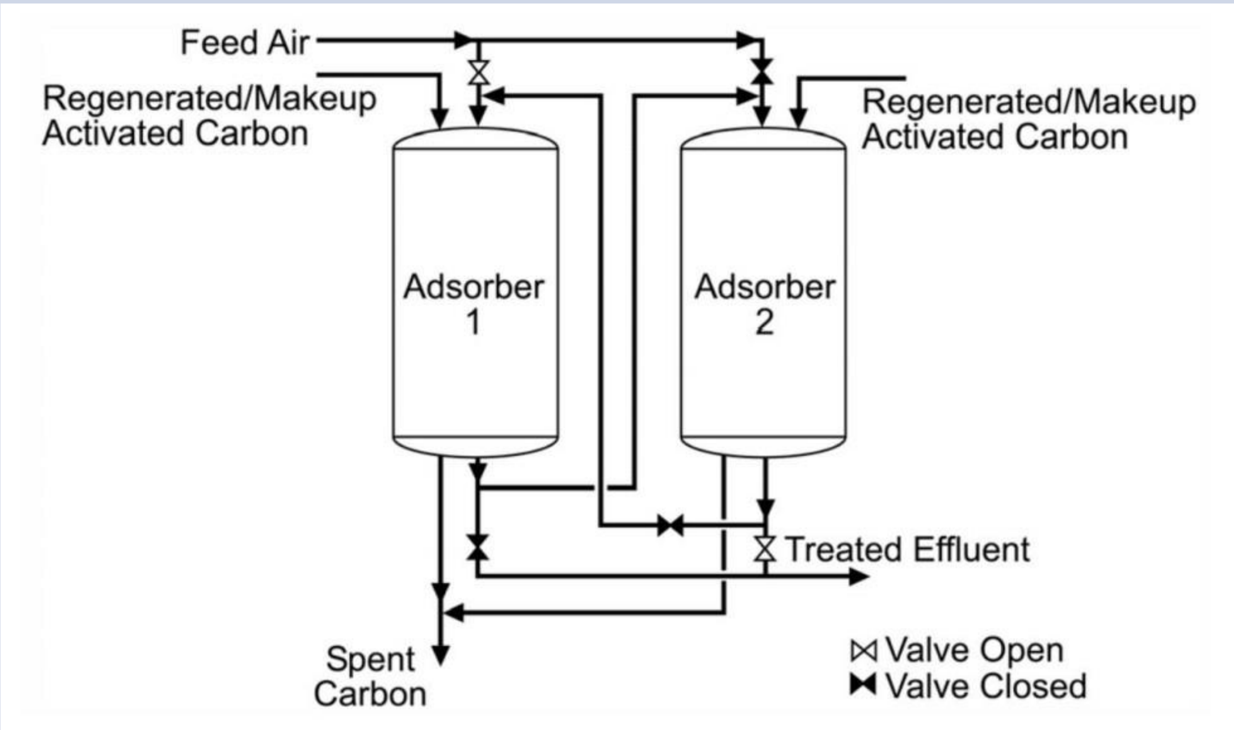


Figure 16: Schematic of a fluid-bed adsorption system with two vessels. Media is continuously transferred to and from a regeneration chamber (not shown).

Source: EPA Air Pollution Control Cost Manual, Chapter 1, EPA/452/B-02-001

Evaporation		
Pollutants Targeted	**Function**	**Configurations**
Flow, Radioactive, Volume, VOC	Wastewater is sent to a large evaporation pond or through a mechanical evaporator where water and VOCs evaporate. This can minimize or eliminate wastewater discharge (zero discharge). In mechanical evaporators, the vaporized water can be condensed back to liquid water for reuse.	• Pond • Mechanical Heat Transfer • Vertical-Tube Falling Film • Horizontal-Tube Spray Film • Forced Circulation

Figure 17: Mechanical evaporator (left) and evaporation pond/lagoon (right)

Sources: commons.wikimedia.org/wiki/File:Evaporator.jpg, Harald the Bard, CC-BY-SA-4.0
commons.wikimedia.org/wiki/File:Facultative_pond_(6898410678).jpg, SuSanA Secretariat, CC-BY-2.0

Air Stripping		
Pollutants Targeted	**Function**	**Configurations**
Ammonia Cl_2, Cyanide CO_2, H_2S Sulfites Solvents VOC	Remove pollutants by passing wastewater down through a vessel while air (or steam) is forced upward. Volatile pollutants are transferred into the air, which may need treatment before being released into the atmosphere.	• Stripping tower, packed tower, or degasifier • Steam stripper • Ammonia stripper

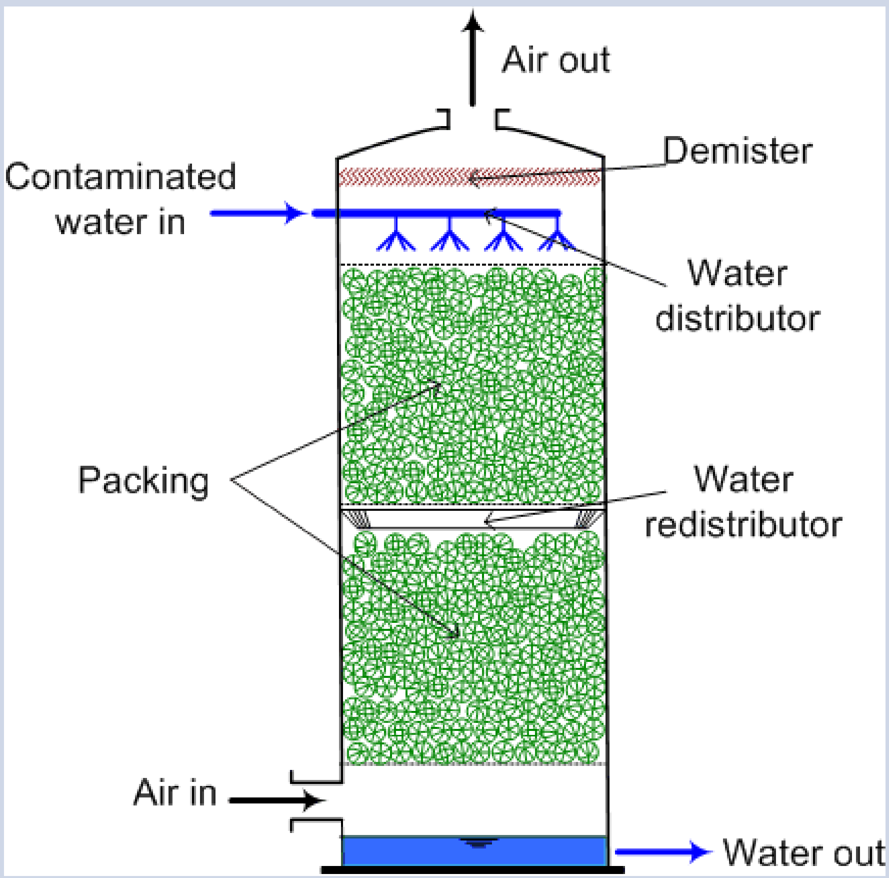


Figure 18: Packed tower air stripper. Media with a large surface area per volume provides for better gas-liquid interaction and increases contact time.
Source: https://commons.wikimedia.org/wiki/File:Air_Stripper_for_Wikipedia.png, Free Art License.

Chemical Treatment

Chemical treatment methods remove pollutants by chemical reactions. The following tables provide a summary of common chemical treatment methods.

pH Neutralization		
Pollutants Targeted	**Function**	**Configurations**
High/Low pH	Wastewater pH is adjusted to within the desired range by adding a base to increase the pH or an acid to decrease the pH.	• pH increase: sodium hydroxide (caustic soda), calcium hydroxide (lime), calcium carbonate, sodium carbonate (soda ash), calcium oxide • pH decrease: sulfuric acid or CO_2 • Batch or continuous • One or two-stage

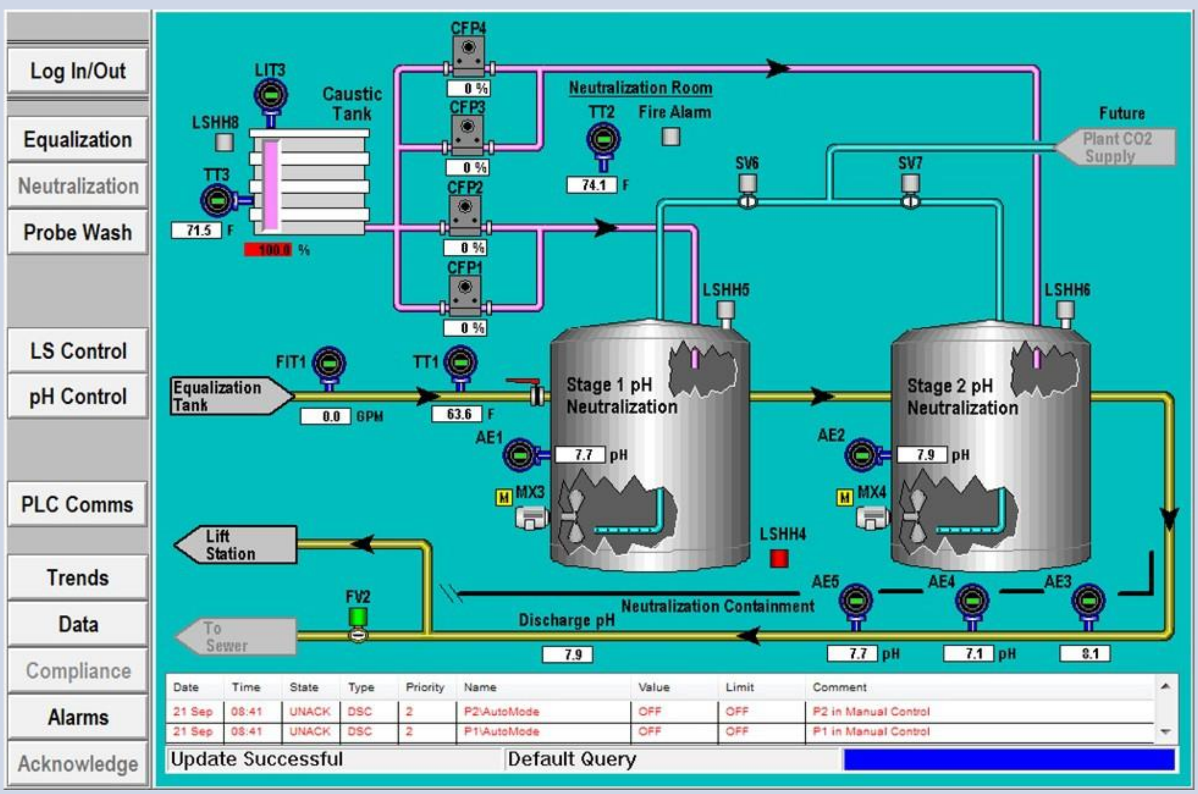
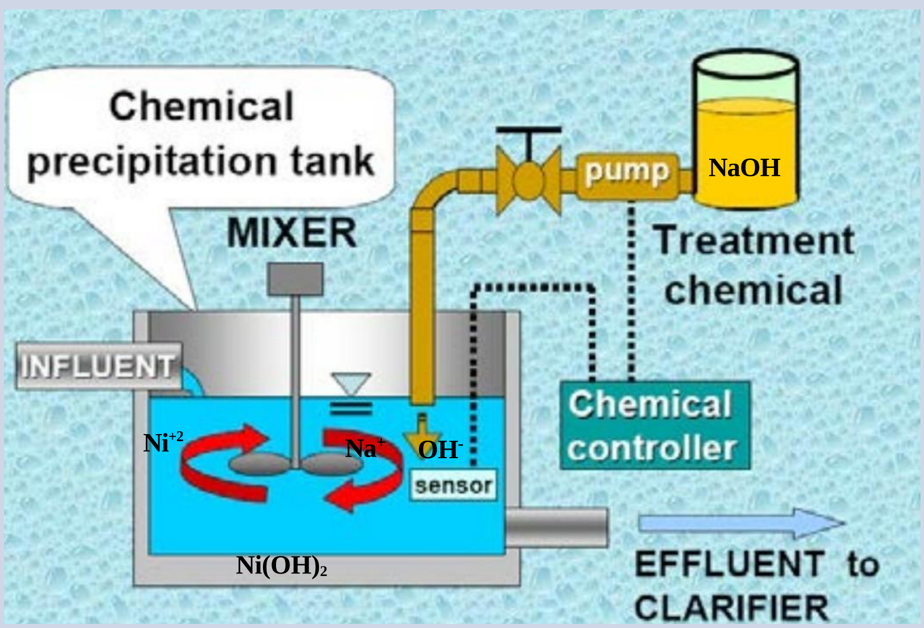


Figure 19: HMI control screen for a continuous two-stage pH neutralization system.

Industrial Pretreatment Design

Chemical Precipitation		
Pollutants Targeted	**Function**	**Configurations**
Heavy Metals, FOG, Phosphates, Radioactive, Sulfides	Chemicals are added to react with pollutants and create a precipitant that is removed by settling or filtration. Solubility charts can be used to identify the proper chemical for making the pollutants insoluble.	• Chemicals: iron salts, aluminum salts, lime, sodium bicarbonate, sodium carbonate, sodium hydroxide, and sulfide salts • Automatic, constant, or manual feed • Flash-mix and settling



Ni^{+2}	+	NAOH	=	Na^{+}	+	$Ni\ (OH)_2\ (s)$
Soluble Nickel		Caustic Soda		Sodium		Nickel Hydroxide

Figure 20: Mixing tank and chemical formula for precipitation of nickel (Ni). The nickel hydroxide, $Ni(OH)_2$ is settled and collected as sludge in the clarifier.

Source: https://www.michigan.gov/documents/deq/3_WastewaterTreatment-Jankowski-Outline_625329_7.pdf

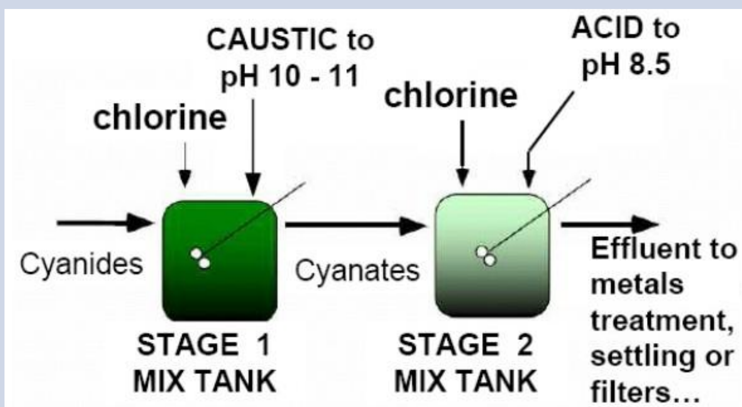
Coagulation / Flocculation		
Pollutants Targeted	**Function**	**Configurations**
Heavy Metals, Phosphates, FOG, TSS	With coagulation, chemicals are added and rapid mixed to form ionic bonds with pollutants. With flocculation, slow mixing causes pollutant compounds to stick together and form floc. The pollutants are then removed by flotation, settling, or filtration.	• Coagulants: lime, alum, polyaluminum chloride, ferric chloride, ferrous sulfate, ferric sulfate, and sodium aluminate • Flocculents: polymer • Automatic, constant, or manual feed • Enhanced clarification • Flocculation zone

Figure 21: Example of a flocculation well/zone in a circular clarifier. Polymer can be added to the influent pipe to encourage flocculation in the well.

Source: https://www.winenv.com/flocculating-clarifiers.html

Oxidation-Reduction		
Pollutants Targeted	**Function**	**Configurations**
Ammonia, Heavy Metals, Cyanide, Dissolved Organics, VOC	Remove toxic metals and cyanide by adding a reducing and/or oxidizing chemical, thereby allowing the pollutant to precipitate. This is normally done on individual waste streams due to the high chemical costs. Oxidation = loss of electrons Reduction = gain of electrons (reduction in oxidation state)	• Chromium reduction • Cyanide destruction • Iron coprecipitation • Sodium borohydride reduction • Arsenic removal • Mercury removal • Selenium removal • Chemicals: chlorine, hydrogen peroxide, potassium permanganate, sodium hypochlorite, ozone

Cyanide Destruction



Chromium Reduction

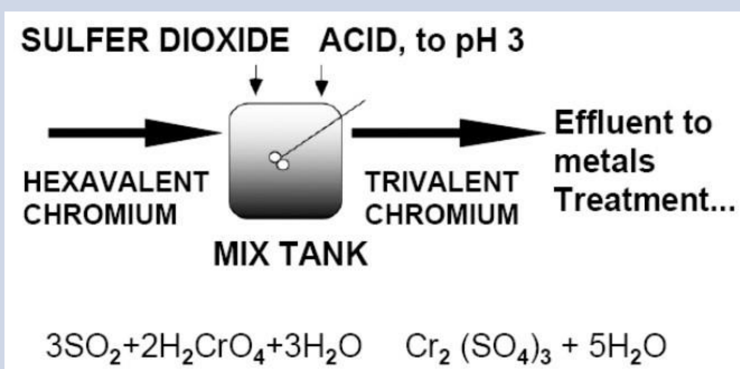


Figure 22: Schematics of cyanide destruction by oxidation and chromium reduction.

Source: https://www.michigan.gov/documents/deq/3_WastewaterTreatment-Jankowski-Outline_625329_7.pdf

Ion Exchange		
Pollutants Targeted	**Function**	**Configurations**
Ammonia, Fluoride, Inorganic Ions, Heavy Metals, Nitrate, Nitrite, Phosphorus, Radioactive	Special resin exchanges its ions for ionic pollutants that have a similar electrostatic charge. Ion exchange can remove cations (e.g., metals) or anions (e.g., nitrates and sulfates) from wastewater. Pilot testing is normally required to choose the proper resin.	• Anion or Cation • Fixed bed • Moving bed/ suspended • Magnetic (MIEX) • One stage or two-stage • Mixed bed

Acid or
Brine
Regenerant

t

Figure 23: Schematic of a two-stage ion exchange system with both cation and anion exchangers in series. The cation resin attracts positive ions while the anion resin attracts negative ions. It is common to have multiple vessels in parallel to allow for a vessel to be out of service during regeneration.

Source: Author

Electrodialysis		
Pollutants Targeted	**Function**	**Configurations**
Heavy Metals, Salt	Dissociated ions are attracted and caused to pass through electrically charged membranes. There are alternating anion and cation membranes placed between positive and negative electrodes. Applying a voltage across the electrodes causes the ions to move towards the positive and negative electrodes and pass through the membranes for removal.	• ED Stack • Batch with recirculation • Continuous

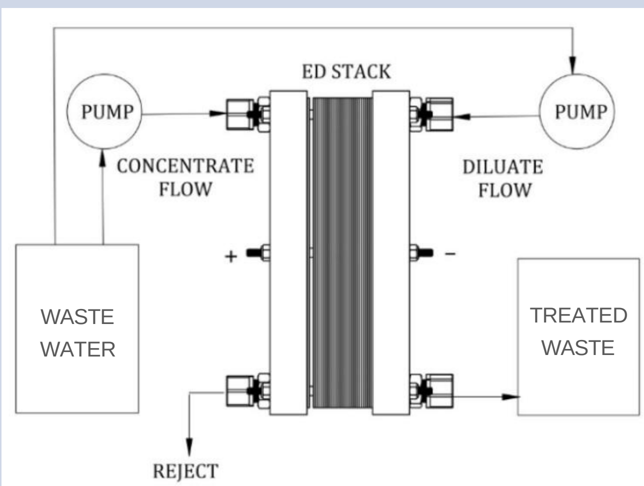


Figure 24: Example of an electrodialysis (ED) stack.

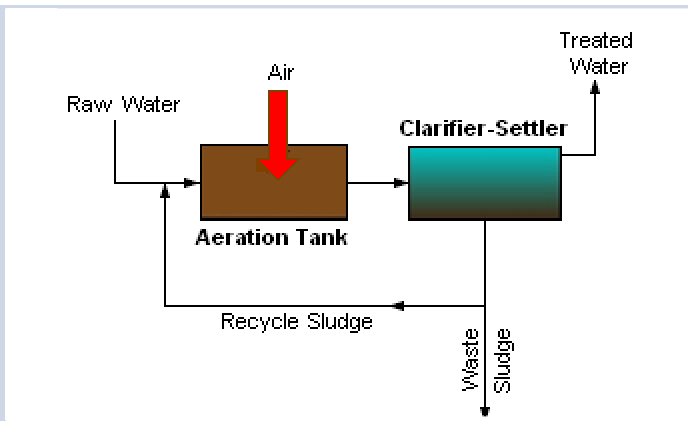
Source: https://www.usbr.gov/research/bgndrf/win2018/15Costello.pdf (modified)

Biological Treatment

Biological treatment methods use microorganisms to convert soluble pollutants into solids. The following tables provide a summary of biological treatment methods. Bioaugmentation can be added to each process. Bioaugmentation is the addition of specific bacteria cultures to degrade a targeted pollutant (e.g. FOG) more rapidly.

Suspended Growth		
Pollutants Targeted	**Function**	**Configurations**
BOD, Phosphorus, TSS, VOC	A highly aerobic environment is provided to encourage aerobic bacteria and other organisms to break down organics. The microbes are suspended in the agitated wastewater.	• Activated sludge • Oxidation ditch • Sequencing Batch Reactor (SBR)

Activated Sludge



Sequencing Batch

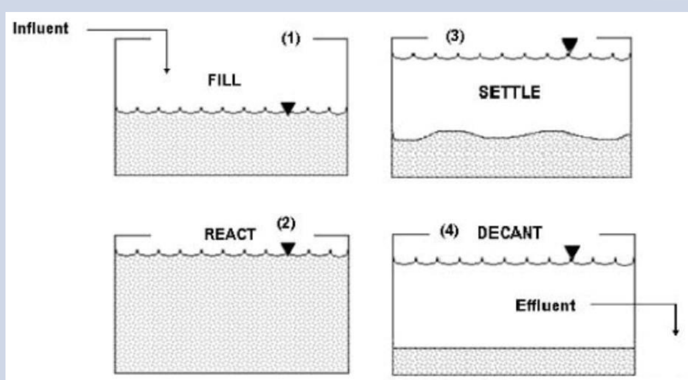
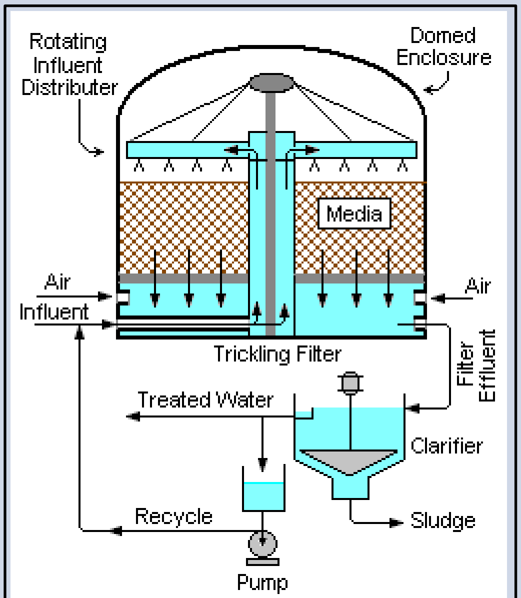
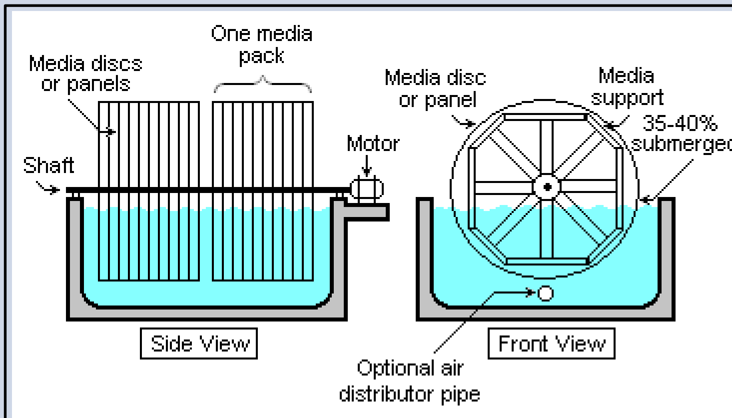


Figure 25: Basic activated sludge arrangement (top).
Sequences in an SBR process (bottom).
Source: https://dnr.wi.gov/regulations/opcert/documents/studyguidesuspendedgrowth.pdf

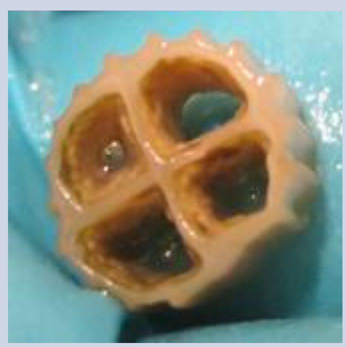
Attached Growth		
Pollutants Targeted	**Function**	**Configurations**
BOD, Phosphorus, TSS, VOC	Like suspended growth, an aerobic environment is provided to encourage aerobic bacteria and other organisms to break down organics. For attached growth systems, the microbes grow on the surface of media submerged in the wastewater.	• Trickling filter • Rotating biological contactor (RBC) • Packed bed bioreactor • Moving bed bioreactor (MBBR)



Trickling Filter



RBC



MBBR Media with Biofilm

Figure 26: Examples of attached growth treatment systems.

Source: https://commons.wikimedia.org/wiki/File:Carrier_MBBR.png, Pesten, CC-BY-SA-4.0

Membrane Bioreactor		
Pollutants Targeted	**Function**	**Configurations**
BOD, COD, Heavy Metals, FOG, Nitrogen, Phosphorus, TTO, TSS, VOC	Membranes are placed in a suspended growth tank with aeration. Both solids and microorganisms are blocked by the membranes and only filtered wastewater passes through as permeate.	• Immersed (iMBR) • Sidestream (sMBR), aka External • Hollow fiber membranes • Plate membranes • Microfiltration (MF) • Ultrafiltration (UF)

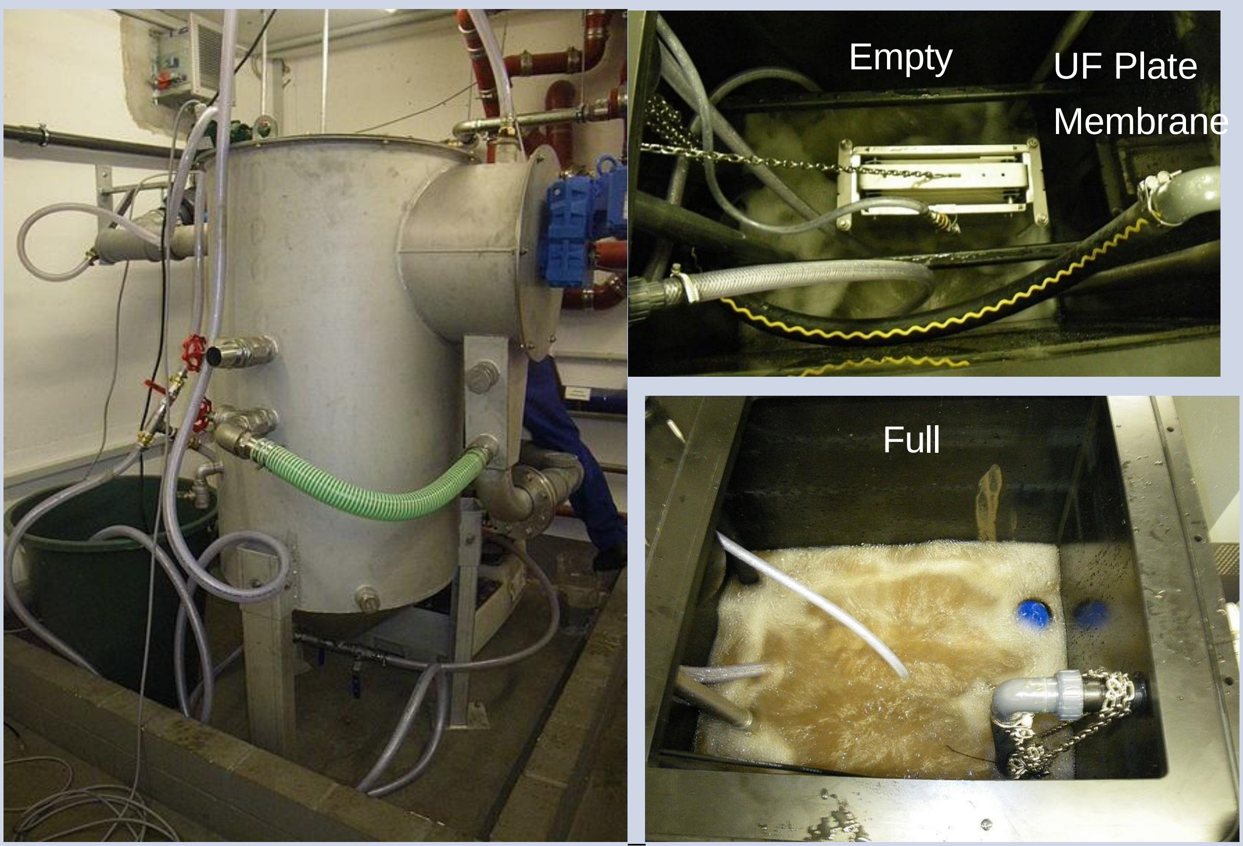
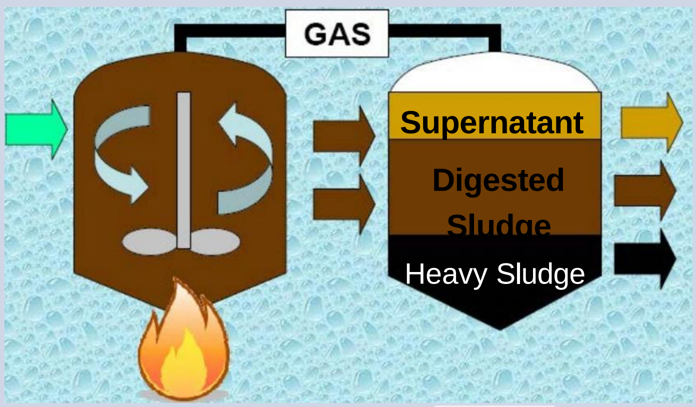


Figure 27: Example of a small industrial submerged membrane bioreactor. The pretreatment & storage tank is on the left and the aerated membrane tank is on the right. Flow is recirculated between these tanks.

Source: https://commons.wikimedia.org/wiki/File:Brownwater_treatment-_Intermediate_storage_tank_with_preliminary_treatment_ (5597700655).jpg, SuSanA Secretariat, CC-BY-2.0

Anaerobic Processes		
Pollutants Targeted	**Function**	**Configurations**
BOD, COD, Nitrogen, Phosphorus, Sulfates, TSS, VOC	In the absence of oxygen and at an elevated temperature, microorganisms break down complex pollutants into volatile fatty acids, acetate, hydrogen, hydrogen sulfide, and methane. Anaerobic digestion can produce valuable biogas and fertilizers.	• Upflow filter • Fluidized bed reactor • Upflow anaerobic sludge blanket (UASB) • High rate or low rate • Anaerobic digester • Anoxic/anaerobic selector

Anaerobic Digester



Upflow Anaerobic

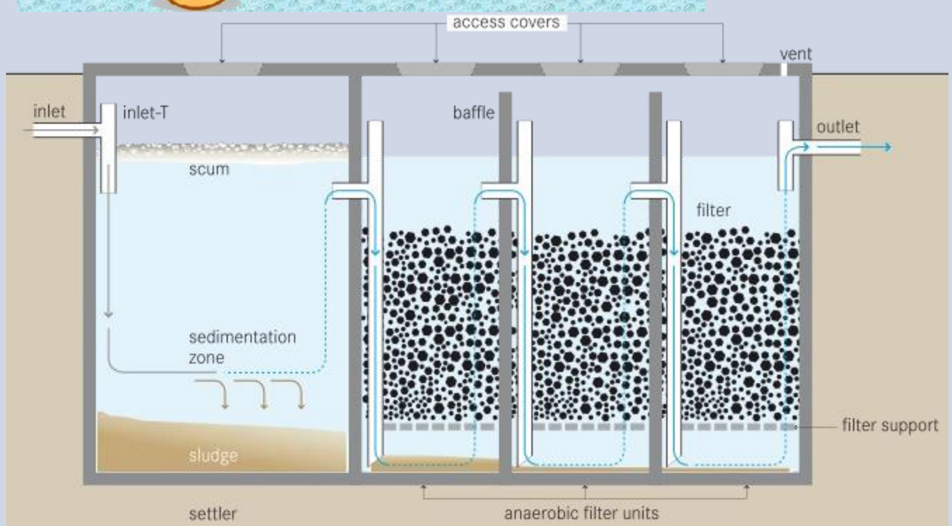


Figure 28: Examples of anaerobic treatment methods.

Source: https://commons.wikimedia.org/wiki/File:Anaerobic_Filter_diagram.svg, Eawag, CC-BY-3.0

Lagoons		
Pollutants Targeted	**Function**	**Configurations**
BOD, COD, Sulfates, TSS, VOC	A combination of aerobic and anaerobic zones results in a variety of microorganisms to break down organics. The microbes are suspended in the agitated wastewater. Functions poorly in cold/freezing weather.	• Multi-stage lagoons • Stabilization pond • Aerated/ aerobic • Anaerobic • Nutrient enhanced

Figure 29: Operator taking a sample from a wastewater lagoon at a hog farm operation. Earthen basins require composite liners to isolate from groundwater. Settled sludge is to be removed periodically.

Source: https://commons.wikimedia.org/wiki/File:NRCSIA99038_-_Iowa_(2781)(NRCS_Photo_Gallery).jpg, Tim McCabe, public domain

Constructed Wetlands		
Pollutants Targeted	**Function**	**Configurations**
Heavy Metals, Nitrates, TOC, TSS, Flow	Organic waste naturally attenuates and degrade, metals are adsorbed by plant root systems. Harvest and dispose of vegetation. Helps achieve zero discharge. Functions poorly in cold/freezing weather.	• Free surface flow • Subsurface flow • Horizontal flow • Vertical flow • Zero discharge

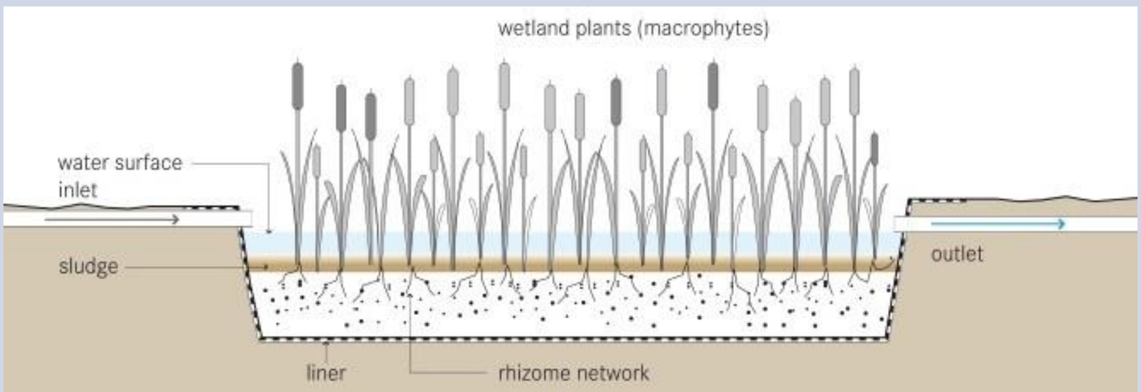


Figure 30: Design (top) and installation (bottom) of a constructed wetland at a slaughterhouse facility.

Sources: commons.wikimedia.org/wiki/File:Constructed_Wetland_(6558660149).jpg, SuSanA Secretariat, CC-BY-2.0
commons.wikimedia.org/wiki/File:Schematic_of_the_Free_Water_Surface_Constructed_Wetland.jpg, Tilley, E, CC-BY-SA-3.0

Process Flow Diagram

In the planning process, it is important to make block flow diagrams of alternative treatment trains, as described earlier and shown in Figures 6 and 7. Once a treatment train is selected and design begins, it is important to create a process flow diagram for the selected treatment methods. A process flow diagram (PFD) is a drawing with symbols for major components such as pumps, tanks, mixers, and flow meters, and lines representing piping between the components. It is very helpful to add arrows to the lines indicating the normal flow direction.

A process flow diagram may start as a back-of-the-envelope sketch with boxes and lines. As the design develops, a more formal diagram should be developed and drawn in CAD. Ideally, all major components should be identified, including instrumentation. Manual operated valves are not required, however important isolation valves and control valves should be identified. Pipe fittings do not need to be identified. It is helpful to label pipes and to show sizes of pipes and tanks, if known.

See Figures 31 and 32 for an example. PFDs are often given to electrical and controls engineers to create instrumentation and controls diagrams (P&IDs). P&IDs include symbology for the controls features, such as instrumentation, control panels, and communications.

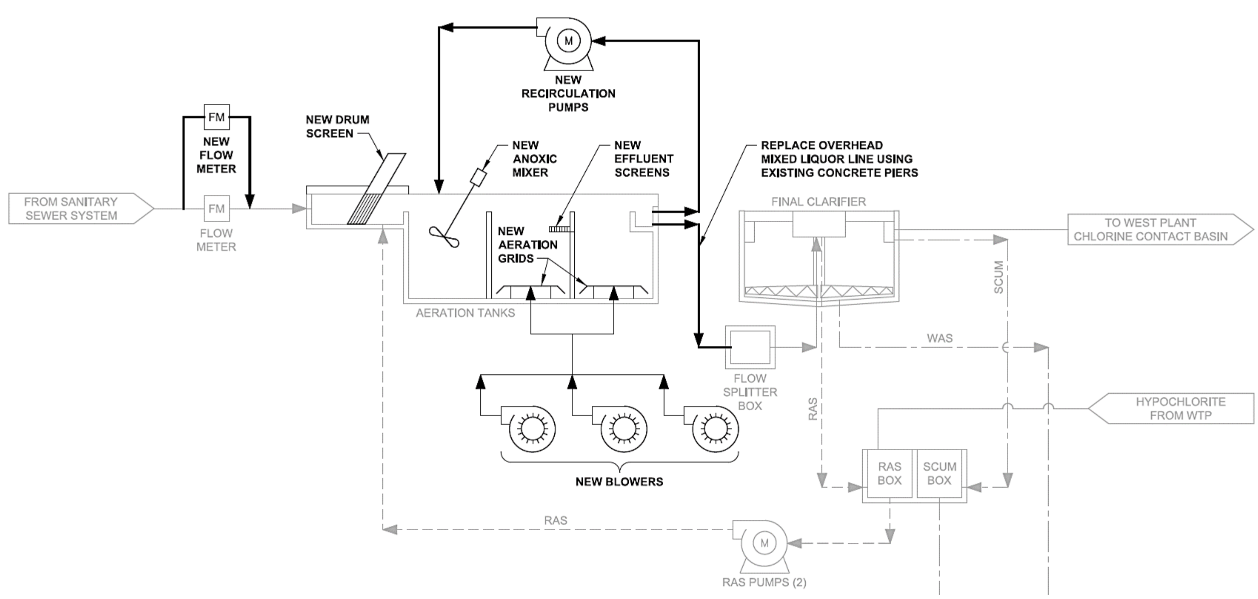


Figure 31: Example PFD of a treatment train with a proposed screen and aeration system. Items in bold are new/proposed and items in light grey are existing.

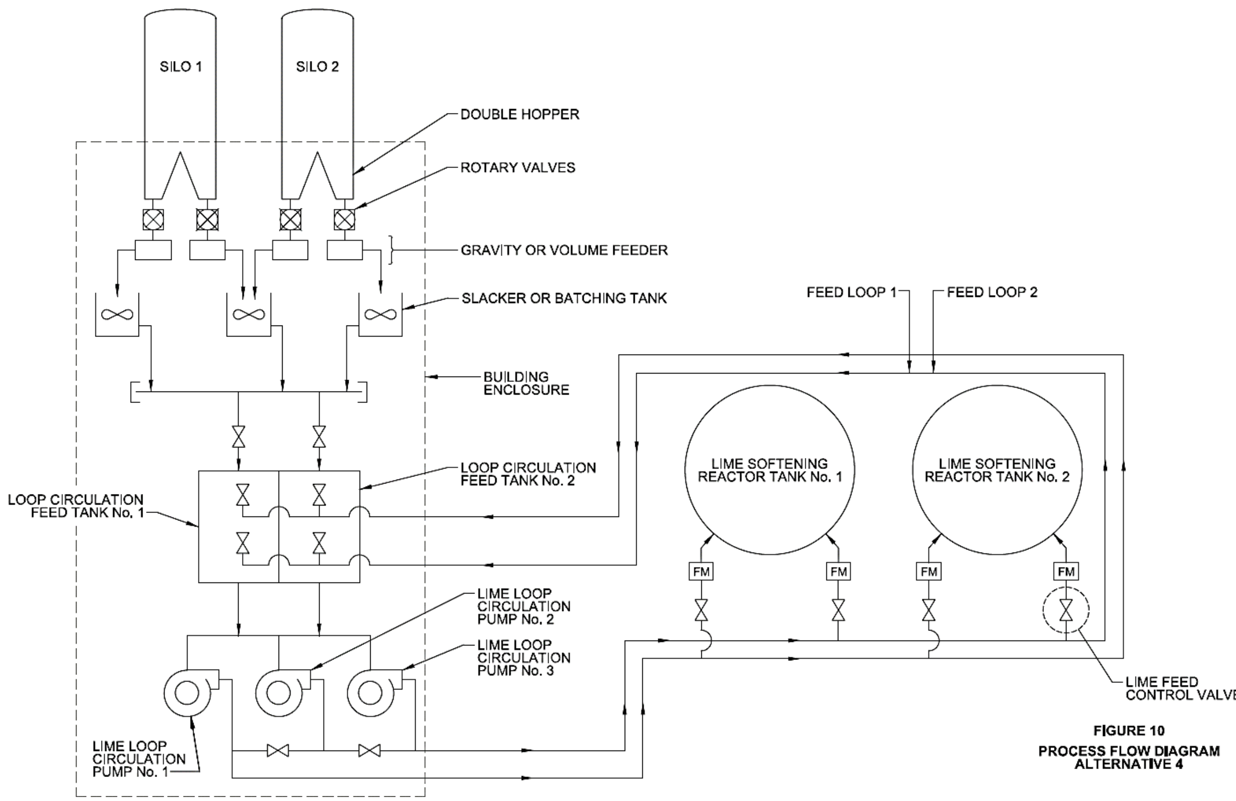


Figure 32: Example PFD of a new lime feed system.
Additional details should be added as the design progresses,
such as pipe labels, pipe sizes, tank sizes, level sensors, pressure sensors.

Hydraulic Profile

A hydraulic profile is a schematic elevation view of main processes or components with a hydraulic grade line drawn at one or more flow rates, as shown in Figure 33. The hydraulic grade line (HGL) is the water level in tanks, gravity pipes, and channels. For pressure pipes, the HGL is the pipe elevation plus the pressure head. It does not include the velocity head (which would be the energy grade line). Components are shown to scale in the vertical but not horizontal direction.

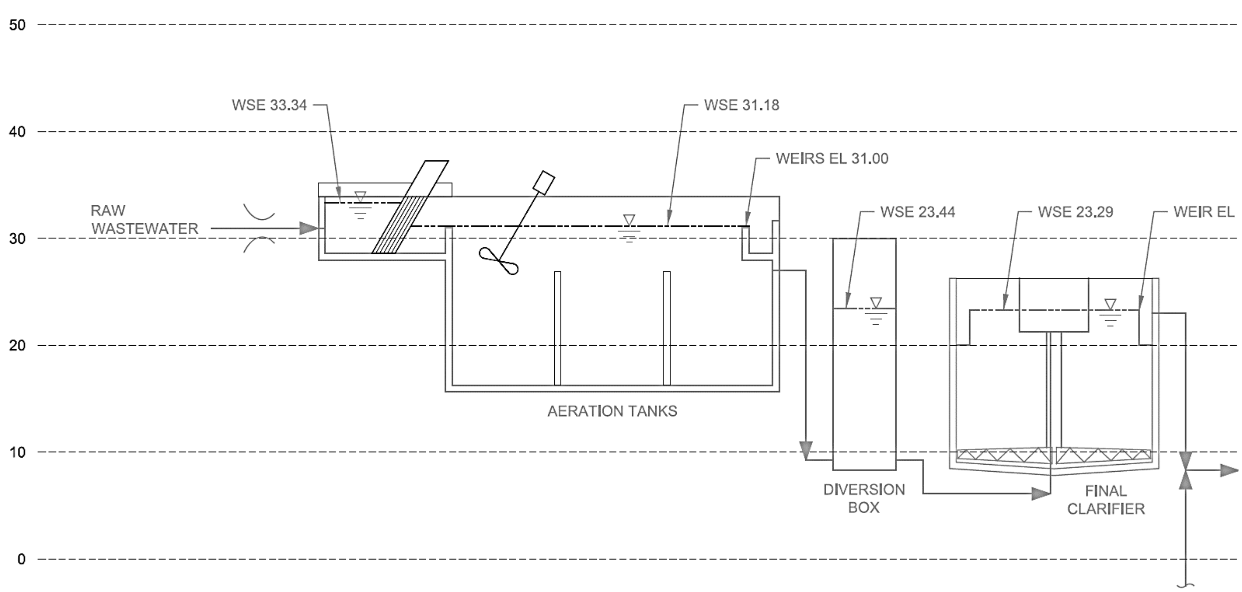


Figure 33: Example hydraulic profile for the aeration system in Figure 31.
Note the headloss across the screen at the design flow is 33.34 – 31.18 = 2.16’ (25.92 inches). This should be confirmed with the screen manufacturer.

The hydraulic profile can help to size pumps, tanks, and equipment. For example, a design engineer may recommend a minimum of 12 inches of freeboard on a basin to prevent overflows, splashing, or foaming. The hydraulic profile shows the high water level, and thus the freeboard. If there is insufficient freeboard, the discharge pipe may need to be lowered, and potentially the entire basin lowered to maintain treatment capacity. These changes would be very costly if done after construction.

After creating a PFD and hydraulic profile, the following design steps can be taken:

- Sizing of components such as treatment equipment, tanks, and pumps
- Creating a site plan layout including locations of major components and piping
- Creating a preliminary cost estimate

Industrial Pretreatment Design

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