Drinking Water Operator Certification Training

Module 15:
Direct Filtration

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Unit 1 – Direct Filtration Overview

Learning Objectives

As a result of this unit, the learner will:

- Be able to list the pretreatment and treatment steps of direct filtration.
- Be able to describe the characteristics of source water that are appropriate for direct filtration.
- Receive information on the six mechanisms at work in granular media filtration.

The purposes of the direct filtration process include: compliance with treatment technique regulatory requirements; targeting impurities; and producing safe and aesthetically pleasing drinking water.

Compliance with Treatment Technique Regulatory Requirements

The USEPA (U.S. Environmental Protection Agency) Surface Water Treatment Rule requires continuous filtration and disinfection as treatment techniques for all surface waters, including groundwater sources designated by the DEP as groundwater under the direct influence of surface water (GUDI).

The Pennsylvania Surface Water Filtration Rule, which requires filtration, was finalized December 28, 2002. With the passage of this rule, many supplies that had only been chlorinated prior to entering the distribution system were now required to use filtration as well.

Treatment Technique Log Removal/Inactivation Requirements

	Disinfection and Filtration	Filtration *
Giardia lamblia Cysts	99.9% (3-log) inactivation/removal	99% (2-log) removal
Enteric Viruses	99.99% (4-log) inactivation/removal	99% (2-log) removal
Cryptosporidium Oocysts	99% (2-log) removal **	99% (2-log) removal **

* Portion of log inactivation/removal that is required to be designed into the filtration process
** For systems serving at least 10,000 people

Turbidity Requirements

Turbidity is the measurement of the cloudiness of water through scattering and absorption of a light beam by colloidal and suspended particles. The EPA requires that the scattered light be measured at a 90º angle to the light beam.

A **turbidimeter** is an instrument that measures turbidity. Some shortcomings of turbidimeters include:

- They are not effective for detecting the passage of activated carbon fines since the black color does not reflect light.
- They are not sensitive for detecting biological matter having an index of refraction similar to the index of refraction for water.
- They do not identify or size the particles that contribute to the turbidity reading.

Turbidity and the Conventional Treatment Process

Source water can contain high turbidity; in this case, complete and conventional water treatment is necessary.

- The conventional process includes a clarification, or sedimentation, step that is designed to remove about 90% of the solids prior to filtering.
- The clarification process provides a more uniform water quality for the filters.
- The clarified water turbidity is usually in the range of 1 to 2 NTU if the process is optimized.

Turbidity and the Direct Filtration Process

When source water is generally within the turbidity range of 1 to 2 NTU, it may be a candidate for direct filtration.

- Pilot tests for each season of a year are required in order to demonstrate that the filtration technique will be successful in meeting the turbidity removal requirements under varying conditions, and that the process will be able to meet minimal performance efficiency goals.
- The abbreviated facilities (direct filtration facilities) are less expensive to construct and operate than conventional treatment facilities.
- Direct Filtration facilities must meet the treatment technique requirements within the following rules:
    - Surface Water Treatment Rule
    - Interim Enhanced Surface Water Treatment Rule (IESWTR)
    - *Proposed* Long Term 1 Enhanced Surface Water Treatment Rule (LT1-ESWTR)
    - *Proposed* Long Term 2 Enhanced Surface Water Treatment Rule (LT2-ESWTR).

Compliance with Turbidity Requirements

- The combined filter effluent turbidity of all filters must be ≤0.3 NTU in 95% of all samples monthly, with a minimum of six samples per day.
- The maximum combined effluent turbidity of any sample must be ≤1 NTU at all times.
- The turbidity from individual filters must be monitored continuously using online turbidimeters.
    - If the online turbidimeters fail to operate correctly, grab sampling for bench turbidity analysis must be conducted every four hours until the equipment is repaired.
        - Repairs must be completed within five working days.
    - The online turbidimeter must record turbidity at an interval not exceeding every 15 minutes.

- Individual filter effluent turbidity measurements require reporting to DEP and could trigger follow-up activities if any one of the following events should occur:
    - Any filter's turbidity exceeds 1.0 NTU in two consecutive measurements taken 15 minutes apart.
    - Any filter's turbidity exceeds 0.5 NTU in two consecutive measurements taken 15 minutes apart *after the first four hours of operation.*

- If, following a backwash, the raw water turbidity is less than 1.0 NTU, the filter effluent turbidity must be no greater than 50% of the raw water turbidity prior to returning the filter to service from the filter-to-waste period.
    - Otherwise, the filter effluent turbidity must be less than 0.5 NTU prior to returning the filter to service.

How many of the monthly samples from all filters must be ≤0.3 NTU?

Produce Safe and Aesthetically Pleasing Drinking Water

The three criteria for the second purpose of direct filtration, which is to provide safe and aesthetically pleasing water, include:

- Free of disease-causing organisms
- Free of toxic substances
- No disagreeable taste, odor, or appearance

Free of Disease-Causing Organisms

- The maximum turbidity requirements discussed earlier are intended to provide and demonstrate a high assurance that the drinking water delivered to the system is free of pathogenic microorganisms such as *Giardia* and *Cryptosporidium* (parasitic cysts) and enteric viruses.
    - No filter process can remove these contaminants with 100% assuredness.
    - Therefore, all filtration processes must include an additional disinfection barrier, which is typically a form of chlorination.
- *Cryptosporidium* cannot be inactivated by chlorine.
    - Therefore, if the filters are in compliance with turbidity rules, the filtration process is given credit for 99% reduction of *Cryptosporidium*.
    - It is assumed that high quality source waters will be low in *Cryptosporidium*.

Free of Toxic Substances

- Toxic substances are contaminants for which there are Primary Maximum Contaminant Levels (MCL). The list for MCL's can be found at: *http://www.dep.state.pa.us/dep/deputate/watermgt/wsm/WSM_DWM/PA-MCLs.pdf*
- Contaminants may be organic or inorganic in nature.
- Toxic substances are generally not present in high quality source waters (where direct filtration would be used).
    - If there is a risk of organic contaminants in the supply, there may be a process that can adsorb the contaminants designed into the treatment plant.
    - One example of an adsorption process is the addition of powdered activated carbon (PAC) upstream of all treatment processes. The PAC is subsequently removed by filtration.
    - Oxidation and coagulation are required for the removal of inorganic contaminants.
        - Oxidation and coagulation are always part of the direct filtration process.
        - These processes render the contaminants into precipitated and coagulated particles that can then be removed by the filters.

No Disagreeable Taste, Odor, and Appearance

- Tastes and odors are most often due to metabolites of algae present in the raw water supply.
    - These are organic compounds and may be controlled with existing treatments such as the addition of PAC or an oxidant.

Target Impurities

Targeting impurities is the third, and final, purpose of the direct filtration process. The key constituents in the source water that are targeted by an "abbreviated" (filtration) process include:

- Suspended Particles
    - These are silts and clays that occur naturally in the watershed.
    - They are washed into the supply sources during precipitation.
- Colloids
    - These are extremely small (<1.0 µm) particles that cannot settle naturally because of the electrostatic repulsive forces of particle surface charges.
    - A large component of the colloidal mass may be due to organic materials.
- Microbial Contaminants
    - These can be harbored in the suspended solids and, therefore, shielded from chemical disinfectants.
- Dissolved Contaminants
    - These are naturally-occurring minerals and organic matter.

General Characteristics of Appropriate Source Waters

Direct filtration is used for source waters with the following general water quality characteristics.

- Turbidity is generally less than 2 NTU.
  - Higher values can be treated for short periods, but very short filter runs may result. Generally the limit for raw turbidity is less than 25 NTU.
- True color is less than 20 c.u.
  - True color is an indicator of colloidal solids, typically consisting of naturally-occurring organic material.
  - These likely require a higher coagulant dose than suspended solids to coagulate.
    - The combination of the colloidal particles and the typically higher coagulant doses generally required to treat colloids results in a high solids loading onto the filters.
    - A short filter run will result.
- Algal blooms are less than 2000 asu/mL.
  - This level is approximate.
    - Above this level, filter run times may be impacted negatively.
    - Growth of algae in natural bodies of water is most successfully controlled by adding copper sulfate.
- Iron is less than 0.3 mg/L (average).
- Manganese is less than 0.05 mg/L (average).
- Coagulant demand is below 15 mg/L.

Pilot Testing of Source Waters

To verify that a source water can be treated with direct filtration, the DEP requires that pilot testing be performed prior to the design of the facility. This demonstrates the ability of the process to perform in accordance with all drinking water regulations.

Operators should familiarize themselves with the study and conclusions that supported the design of their facilities.

The abbreviated direct filtration process does not include the following processes that are components of the conventional filtration process:

- Flocculation (occasionally not included)
  - Normally this process is included; however, for some extremely high quality waters, this stage is eliminated.
  - The water is coagulated and then flows directly to the filters.
  - This is called direct in-line filtration; flocculation occurs within the filter bed.
  - The floc particle size in direct filtration is smaller than the floc particle in size in conventional filtration.
- Clarification or Sedimentation
  - These processes are not included because the solids content of the water is low.
    - Therefore, a reduction of solids is not necessary to provide long filter runs.
  - The absence of this process step represents the primary cost savings in a direct filtration facility.
  - A solids contact chamber in direct filtration is also called an upflow clarifier.
- Differences in log inactivation granted by DEP
  - Since the clarification or sedimentation step is absent, the overall direct filtration process is not acknowledged to have as great a removal efficiency as conventional filtration.
  - The conventional process is granted 99.68% (log 2.5) efficiency; the direct filtration process is granted only 99% (log 2) removal efficiency.
    - The direct filtration facility must therefore provide at least a 90% (1 log) inactivation with disinfection at all times to achieve the total 3-log removal/inactivation that is required.

A typical direct filtration process includes the following steps. Most of these steps are described in other training modules, as referenced. The descriptions in the training modules, however, may not necessarily apply to direct filtration.

Source Water
(Covered in Modules 2 and 3)

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Chemical Addition
(Covered in Module 21)

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Pretreatment including Mixing/Coagulation and Flocculation
(Covered in Module 14—Units 2 and 3)

↓

Filtration
(Covered in Module 14—Unit 4)

↓

Finished Water Storage and Disinfectant Contact Time
(Covered in Modules 5 and 24-27)

↓

Corrosion Control
(Covered in Module 20)

↓

Water Distribution
(Covered in Modules 8, 9, and 28)

Process Description

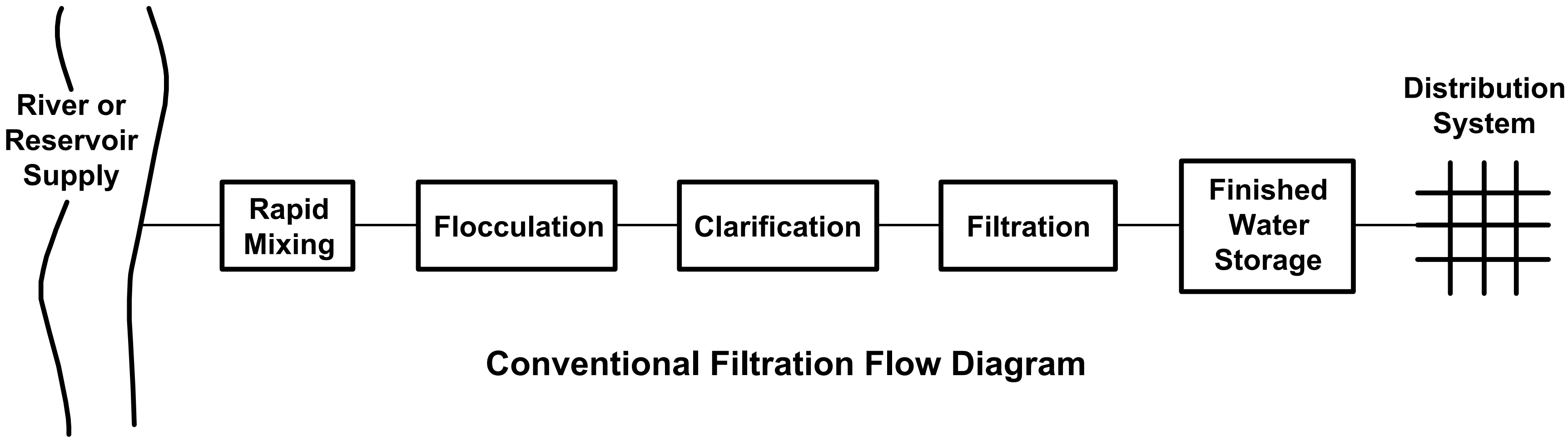
Direct filtration can be accomplished through different types of media. ***This training module focuses on granular media filtration.*** Other types of direct filtration processes described in detail in other modules include:

- Diatomaceous Earth (D.E.) Filtration (Module 16)
- Slow Sand Filtration (Module 17)
- Bag or Cartridge Filtration (Module 18)
- Membrane Filtration (Module 19)

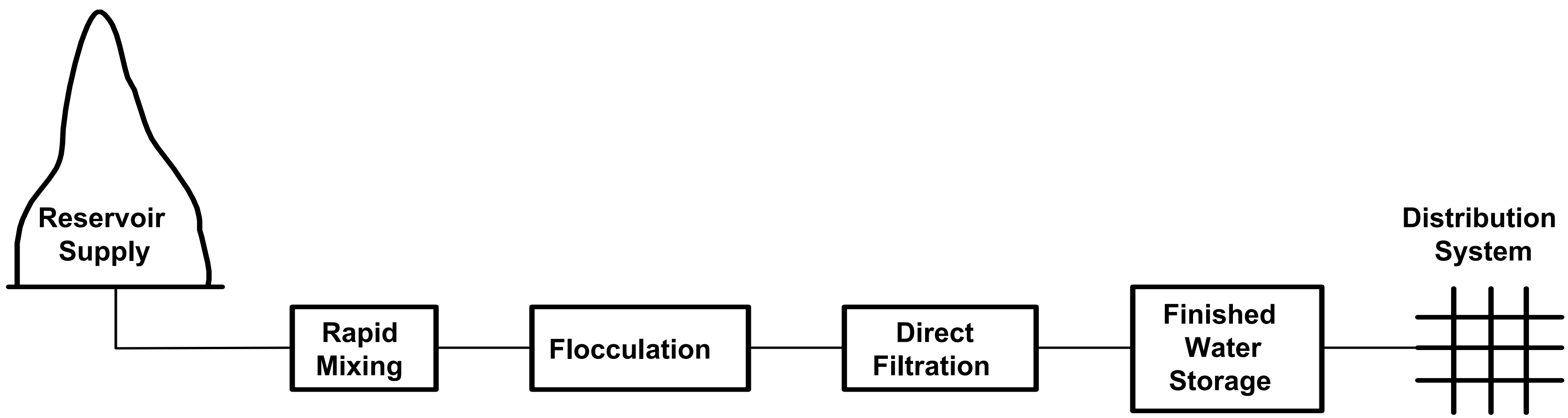
Filter Process Objectives

The objectives of any filter process are to:

- Produce effluent with the highest quality possible.
- Maximize the production of filtered water by encouraging long filter run times.
- Create efficient backwash processes with low backwash water requirements.



Conventional Filtration Flow Diagram



Direct Filtration Flow Diagram

Granular Media Filtration

The primary mechanism at work in granular media filtration is particle attachment to the media grains. Another important, but less significant, removal mechanism is the physical straining of particles.

- Particle attachment is preceded by transport and collision between particles, allowing them to agglomerate to form small (pin) floc.
    - This occurs due to neutralization of particle repulsive forces (electrostatic charges) following the addition of a coagulant chemical.
    - This mechanism enables depth filtration to occur.
        - Without this process, direct filtration would not be feasible.
- Straining is the primary physical/mechanical removal process for particles larger than the interstitial spaces between the media grains.
    - The particles are separated from the water as it passes through the small pore spaces formed between media grains.
        - However, the typical filter sand would not be able to remove particles much smaller than 75 µm by straining alone.
        - *Giardia* and *Cryptosporidium* are less than 10 µm in size.
- Adsorption due to chemical attachment of substances to the surface of the media may occur.
    - Examples of this are coating the media with certain metal oxides, such as manganese dioxide, or adsorption of organics within the pores of granular activated carbon media.
- Flocculated water enters the filter vessel.
    - Some of the floc will be deposited on top of the media bed.
    - Large and heavy floc result in minimal depth filtration, causing short filter runs.
- Micro-flocculation occurs as coagulated water travels through the media bed and is intermixed, allowing particles to coalesce into larger floc.
- Biological growth (bacterial colonies, algae, etc.) may occur in the media bed.
    - The beds are especially vulnerable when no disinfectant residual is present.
    - The biological growth may consume (assimilate) natural organic matter, converting the organic matter into a form that downstream processes can more easily remove.

Depth Filtration

Depth filtration refers to the way in which solids penetrate into the media bed, as opposed to solids simply being strained from the flow stream at the surface. Depth filtration is the desired mode of operation in a properly designed and operated granular media filtration system.

Optimally, when a clean filter is placed in service, the particles will initially penetrate into the media and fill pore spaces deeper in the bed. As the filter run progresses, the "particle storage" volume represented by the media porosity will fill from the bottom up, thereby taking advantage of all the storage volume and maximizing the filter run time.

- ❖ Excessive surface straining will form a mat on the filter, binding it and causing high headloss and short filter runs.
- ❖ The pretreatment process and coagulation chemistry should be optimized to form small, strong floc particles that can penetrate the media but will not break through into the effluent.

Filter Backwash

Backwash is the process of reversing water flow through the media bed at a very high rate as the solids are removed to waste.

Exercise

Unit 1 – Exercise

Multiple Choice – Choose the best answer

1. Which of the following pretreatment/treatment processes are parts of direct filtration? *(Choose all that apply)*

   a. rapid mixing (coagulation)
   b. flocculation
   c. sedimentation/clarification
   d. direct filtration

2. Select the characteristics of source water that are appropriate for direct filtration. *(Choose all that apply)*

   a. Turbidity is less than 2 NTU
   b. True color is less than 40 c.u.
   c. Algal blooms are less than 20,000 asu/ml
   d. Iron is less than 0.3 mg/L
   e. Manganese is less than 0.05 mg/L
   f. Coagulant demand is below 15 mg/l

3. One of the mechanisms at work in granular media filtration is the particle attachment to the __________ grains. *(Choose the best answer to fill in the blank)*

   a. media
   b. turbidity
   c. organic

4. Some of the criteria of safe and aesthetically pleasing drinking water are: *(Select all that apply)*

   a. Free of toxic substances
   b. Free of disease-causing organisms
   c. Disagreeable taste and odor.

5. To verify that a source water can be treated with direct filtration, the DEP requires that ______ testing be performed prior to the design of the facility. *(Choose the best answer to fill in the blank)*

   a. pressure
   b. sedimentation
   c. pilot

Unit 1 Summary

Key Points:

- The Interim Surface Water Treatment Rule was enacted to primarily control turbidity.
- Direct Filtration consists of the 3 treatment steps of coagulation, flocculation, and direct filtration.
- Conventional Filtration consists of the treatment steps of coagulation, flocculation, sedimentation, and filtration. Direct Filtration differs from conventional filtration in that it is missing the treatment step of sedimentation.
- Collodial particles in water do not settle readily.
- To verify that a source water can be treated with direct filtration, DEP requires that pilot testing be performed prior to the design of the facility.
- Source waters that are appropriate for direct filtration have low turbidity, low color, low algal blooms, low iron, low manganese, and low coagulant demand.
- Adding copper sulfate most successfully controls growth of algae in natural bodies of water.
- The use of direct filtration is generally limited to average raw water turbidities of less than 25 NTU.
- The floc particle size in direct filtration is smaller than the floc particle in size in conventional filtration.
- A solids contact chamber in direct filtration is also called an upflow clarifier.
- The purposes of the direct filtration treatment process includes:
    - Treatment Technique Log Removal/Inactivation of *Giardia,* Viruses, and *Cryptosporidium*.
    - Compliance with turbidity requirements
    - Free of toxic substances
    - No disagreeable taste, odor, or appearance.
- 3 log means the removal of 99.9% removal of a target organism.

Unit 2 – Pretreatment

Learning Objectives

As a result of this unit, the learner will:

- Be able define the term "pretreatment" and how it differs from the term "treatment".
- Be able to list the reasons for pretreatment of source water prior to filtration.
- State the purpose of rapid mixing and slow mixing in the direct filtration pretreatment process.

Pretreatment conditions source water for filtration by (1) oxidizing soluble metals to form precipitates, and (2) coagulating suspended and colloidal solids to form larger, dense particles (floc) that can be filtered out with granular media. Pretreatment methods include chemical addition, flash mixing, and slow mixing (flocculation).

Chemical Addition

Oxidation

Analyze for the presence of soluble forms of iron and/or manganese in the water. Run the analysis often enough to recognize changes that might require adjustments to chemical feed rates.

Source waters that are used for direct filtration are typically of consistent quality, but periodic variations can be expected. These changes will require adjustments to the chemical feed rates. Where oxidation is required, it is most often accomplished with chlorine and/or potassium permanganate.

Oxidation of Soluble Iron with Chlorine

The ratio of chlorine to soluble iron is approximately 0.64 mg: 1.0 mg of iron.

Oxidation of Soluble Iron with Potassium Permanganate

The ratio of potassium permanganate to soluble iron is approximately 0.94 mg: 1.0 mg of iron.

Oxidation of Soluble Manganese with Chlorine

The ratio of chlorine to soluble manganese is approximately 1.30 mg: 1.0 mg of manganese

Oxidation of Soluble Manganese with Potassium Permanganate

The ratio of potassium permanganate to soluble manganese is approximately 1.92 mg: 1.0 mg of manganese.

The above relationships will help establish initial chemical feed rates. However, there are generally competing constituents that may increase the oxidant demand. Therefore, after calculating a theoretical oxidant dose, an operator should jar test a range of oxidant doses that encompass the theoretical dose.

Overdosing with the Oxidation Method

- Overdosing chlorine will result in free chlorine residual that may contribute to the formation of chlorine disinfection by-products.
- Overdosing potassium permanganate may result in the presence of purple water and the addition of manganese from the oxidant itself.

pH Adjustments with the Oxidation Method

- Oxidation of soluble manganese is pH dependent and occurs most rapidly when the pH is greater than 9.0.
  - Since a pH this high is not compatible with most coagulation chemical reactions, the pH may need to be decreased following the oxidation step.
- An operator must measure the pH of the water to be oxidized and add or increase the alkaline chemical dose, as necessary, to raise pH to the desired level.
  - The amount of alkaline chemical that must be added can be determined by titration of a water sample with the alkaline chemical to be used, while monitoring the sample with a pH meter.
- The most common chemicals for raising pH are lime, caustic soda, and soda ash.
  - Lime is the least expensive chemical, but it is the most difficult to feed typically using a dry volumetric feeder that is prone to clogging.
    - It causes persistent clogging and scaling of lime feeders.
    - In addition to increasing pH, lime also increases bicarbonate alkalinity and calcium levels.
  - Caustic soda, which is more expensive than lime, is a liquid chemical that can be easily metered to the process stream.
    - It is also very caustic, and an operator must exercise extreme care when handling it. When handling and preparing water treatment chemicals, wearing appropriate personal protective equipment is critical.
    - pH, caustic soda also increases hydroxide alkalinity and sodium levels.
  - Soda ash, which has a unit cost between lime and caustic soda, does not provide as much pH increase per equivalent dose.
    - Soda ash does increase bicarbonate alkalinity.

When working with chemicals you should know where to find the Material Safety Data Sheets (MSDS). In an emergency refer to the MSDS on first aid procedures.

Coagulation

The optimum dose for direct filtration is the lowest dose that achieves filtrate quality and production goals. The purpose of adding a coagulant aid is to increase floc strength and density.

- Pilot or full scale filter runs must be performed in order to determine the best coagulant dose for optimum filter performance. That dose is dependent on solids concentrations (usually measured as turbidity), and by the concentration of soluble organics (measured by true color or total organic carbon (TOC).

The most commonly used chemicals to achieve coagulation in this type of process are:

- Aluminum sulfate (alum)
  - Alum is the most pH-dependent coagulant.
    - It may require supplementation of raw water alkalinity.
  - Alum reacts much more slowly under cold water conditions.
    - This may result in a significant degradation in direct filtration performance.
  - The most efficient filter performance is achieved when the alum requirement is approximately 5 mg/L or less.
  - Dry alum must be stored in a dry place.
- Ferric chloride or ferric sulfate
  - Ferric chloride and ferric sulfate have slower reaction times under cold water conditions, although not as slow as alum's reaction time.
  - Either chemical can contribute to a less than desirable filter run time.
  - An overdose of either coagulant may result in the passage of iron compounds into the effluent.
- Polyaluminum chloride (PACl)
  - Polyaluminum chloride may prove to be particularly beneficial as a coagulant for direct filtration.
  - It has a faster reaction time under cold water conditions than the coagulants presented above.
    - This is particularly valuable for plants that typically have short flocculation detention times.
  - It contributes to longer filter run times due to a lower solids-loading contribution from the coagulant.
  - It requires minimal or no pre-alkalinity addition.
  - It frequently develops a more filterable floc than with alum or ferric salts.

Supplementary Alkalinity

The amount of supplementary alkalinity required can be determined by the amount of alkalinity that will be consumed by the formation of the primary coagulation product.

Operators should be aware of the amount of alkalinity consumed during coagulation.

Coagulant	Alkalinity Consumed per 1.0 mg/L fed
Alum	0.5 mg/L
Ferric Chloride	0.9 mg/L
Ferric Sulfate	0.4 mg/L
Polyaluminum Chloride	Minimal

If there is adequate raw water alkalinity to assure a stable, well-buffered water after coagulation, alkaline chemical additions may not be required. If, however, an alkalinity increase is necessary, the addition of lime, caustic soda, or soda ash is common.

Additions	Alkalinity Added per 1.0 mg/L fed
Lime fed as $Ca(OH)_2$	Adds 1.21 mg/L of alkalinity as calcium carbonate ($CaCO_3$)
Caustic Soda fed as NaOH	Adds 1.55 mg/L of alkalinity as calcium carbonate ($CaCO_3$)
Soda Ash fed as Na_2HCO_3	Adds 0.90 mg/L of alkalinity as calcium carbonate ($CaCO_3$)

- A water treatment plant is using alum as its coagulant. Lime could be added to the flash mixer to replace alkalinity lost during the coagulation process.
- If heavy rains have occurred, causing source water turbidity to increase significantly, and additional alum is added, a chemical to increase alkalinity may also be added to optimize coagulation.

Supplementary Acidity

A low pH is necessary for most effective coagulation of organics; pH adjustment may be necessary with an acid addition.

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Addition	Optimum Turbidity Reduction	Optimum Reduction of TOC (Total Organic Carbon)
Alum	6.8 to 7.5 pH range (temperature dependent)	5.5 to 6.2 pH range
Ferric Chloride and Ferric Sulfate	6.5 to 8.0 pH range (temperature less important than with alum addition)	5.0 to 6.0 pH range
Polyaluminum Chloride	pH not critical	pH not critical

A water treatment plant operates at a rate of 200,000 gallons per day. If the dosage of alum is 30 mg/L, how many pounds of dry alum are used each day?

- Formula: ? Pounds Per Day = Flow (MGD) x Concentration (mg/L) x 8.34 Pounds Per Gallon
  First calculate flow in GPD to MGD. Divide 200,000 by 1,000,000.

If alum is used for coagulation at a pH above 9.0, increased dissolved aluminum will result in the filtered water.

If an acidic water treatment chemical is spilled in the plant, the operator can obtain information on how to clean up the spill from MSDS sheets. The purpose of a Material Safety Data Sheet is to provide information on chemical handling and chemical properties.

Rapid Mixing

The efficient use of chemicals involves rapid mixing, also known as flash mixing. This is particularly true for the addition of alum and ferric coagulants, whose less complex hydrolysis (dissolution) products react nearly instantaneously with particles in water. A substance must produce an insoluable floc to function satisfactorily as a coagulant.

Add the chemicals at a location of very intense mixing to get the chemicals into the water and dispersed uniformly throughout as quickly as possible.

- Coagulants are typically added in or just prior to the rapid mix process.
- The purpose of the flash mix is to thoroughly disperse all chemicals added at this point.

Rapid mixing is especially important for direct filtration where charge neutralization is the primary goal of coagulation for the subsequent formation of a pin floc.

An appropriate reason to dilute a coagulant prior to addition in water is to make it easier to feed and disperse evenly.

A concern in diluting a chemical prior to feeding is the change of composition and the breakdown of the chemical.

Rapid Mixing Types

Three types of flash mixing include:

- In-line Static Mixing.
- Mechanical Mixing.
- Hydraulic Mixing.

In-line Static Mixing

- This type of mixing is performed with a motionless mixer.
  - The mixer is a pipe with internal baffles to create mixing turbulence.
- The mixing energy is dependent on flow rate and headloss.
  - The higher the flow rate, the higher the energy imparted, but also the higher the headloss.
- No operator action is required to operate these mixers.

Mechanical Mixing

- This type of mixer is motor operated.
  - It typically consists of one or two turbine-type or propeller-type mixer paddles.
- It is usually installed in a concrete basin and is often called a backflow mixer or a batch mixer.
- This mixer can also be located in a pipe as an in-line mechanical mixer.

Hydraulic Mixing

- Hydraulic mixers are not efficient and are no longer incorporated into new plant construction.
- It is possible that you may see one; they are found in older plants only.
- Hydraulic mixers were designed at the beginning of the 20^{th} century.

Rapid Mixing Parameters

The operator cannot adjust any variables for static mixers.

- The mixing intensity varies according to the flow rate, but detention time varies inversely with the flow rate.
  - When the flow rate is low, mixing intensity and headloss decrease but detention time increases.
  - When the flow rate increases, mixing intensity and headloss increase but detention time decreases.

Typical design parameters for each type of rapid mixer are shown in the table below.

Type	Detention Time (T) (in seconds)	Velocity Gradient (G) (in seconds)	GT (unitless)
Static	1 – 3	3000	3000 – 9000
Mechanical	10 – 30	1000	10,000 – 30,000

Instrumentation

Although there are few adjustments that need to be made to the rapid mixing process itself, the operator will assess the effectiveness of chemicals added and, if necessary, will adjust the chemical feed rates. There are some important and useful instruments that aid the operator in providing uniform treatment.

- On-line pH Analyzer
  - The analyzer is often hard-piped so it can draw samples from either raw water or mixed water flow streams.
  - Some facilities have dedicated on-line pH meters for raw and mixed samples.
    - This allows the operator to see changing pH conditions on a continuous basis.
  - The continuous raw water pH analysis will show any changes in source water pH.
    - This allows the operator to make prompt chemical feed adjustments.
  - A mixed water pH analysis provides feedback following chemical addition and mixing.
    - This provides information that is used to confirm hat the feed systems are working correctly.
  - In some plants, the pH measurement may provide a control signal for automatically adjusting the chemical feed rates to maintain a set point pH.
- Streaming Current Detector (SCD)
  - A Streaming Current Detector is an on-line charge-measuring device.
  - SCDs measure the subtle net ionic and colloidal surface charges (positive and negative) that can influence the effectiveness of coagulation.
  - They typical collect samples continuously withdrawn from a point downstream of the coagulant addition.
    - The sample flows into a sensor sample cell where it is drawn into the bore during upstroke of the piston cycle. It is expelled from the bore on the downstroke.
    - A current in picoamperes-AC is momentarily created as electrically charged particles are attached to the piston and bore.
    - As water is moved back and forth by the piston, charges surrounding the particles (positive and negative) are moved downstream to electrodes
  - The measurement can be used to assure that the coagulant system is feeding correctly.
  - The movement of like charges is called streaming current.
    - The amount of current generated is proportional to the charge remaining after the coagulant is added.
  - Benefits of SCD are many.
    - It provides a quick indication as to whether a coagulant adjustment is necessary during changing raw water quality conditions.

- It indicates in which direction the coagulant feed pump should be adjusted. A negative reading calls for increased coagulant.
- The SCD tracks the required coagulant dose.
- An immediate alarm sounds if the coagulant feed is interrupted.
- The SCD indicates soon after chemical addition whether sufficient chemical has been added, which allows for a timely change before water reaches the filters.
- It contributes to reduced water treatment costs, particularly during storm runoff conditions.
- It increases net water production due to longer filter runs.
- There is a consistent finished water quality.

- Zeta Potential
  - Zeta Potential (ZP) is a laboratory analytical method that measures electrical potential near the surface of small, colloidal-sized particles. It is related in concept to streaming current.
  - Particles having a negative surface (ZP) charge, typical for most natural waters, are not likely to agglomerate into flocs and settle.
    - Positively charged chemicals such as aluminum salts and iron salts that are used as coagulants bring the ZP closer to a neutral value.
    - This improves the opportunity for particles to stick together during flocculation and, therefore, stick to the filter media.
  - ZP is helpful in direct filtration where the goal is to use a minimal coagulant dose.
  - A slightly electronegative ZP would typically be appropriate.

- A hydrometer is used to test liquid chemical strength by measuring specific gravity.

Velocity, water temperature, detention time, and concentration of coagulant being used can all affect the performance of a coagulation unit.

Flocculation (Slow Mixing)

Flocculation is a slow, mechanical mixing process that promotes the formation of floc particles that are amenable to removal by the downstream filtration process.

- In the flocculation process, gentle eddy currents from the mixing promotes interparticle contact and the growth of floc particles.
- The objective of flocculation in the direct filtration process is to develop a filterable pin floc.
- Flocculation may not always be required, particularly if a consistently high quality supply is used.
  - A high quality supply would be low in color and turbidity.
- Water treatment plants without the flocculation steps are called direct in-line filtration processes.
  - Few in-line filter plants have been constructed because flocculation provides additional treatment flexibility.

Advantages and Disadvantages of Flocculation

- Advantages
  - The filtrate quality is improved prior to breakthrough.
  - The initial improvement period is reduced.
  - The rate of headloss is reduced.
- Disadvantages
  - Earlier breakthrough is a result.

Design Parameters

- Mixing Intensity
  - As water temperature becomes colder, the rate of floc formation slows.
    - Adjust flocculator speeds seasonally, as appropriate, to compensate for these changes.
- Detention time
  - The more plug-flow pattern achieved in the basins (i.e., minimal short-circuiting), the more uniform and fully developed floc will be formed.
  - Direct filtration requires a shorter detention time than conventional treatment since the goal is to develop a small, filterable floc.
    - Flow patterns and minimizing of short-circuiting is controlled by baffling.

Types of Flocculators

- Vertical Turbine
  - This is a vertical shaft, multi-speed, pitched blade (impeller) mixer.
  - It is best suited for direct filtration plants operating at low coagulant doses.
- Reel-type (Paddle) Mixers
  - This is a horizontal shaft mixer.
  - It is considered more appropriate for conventional treatment where formation of large floc is desirable.
- Walking Beam
  - This is a mixer that creates turbulence by the up and down motion of a steel beam that is attached at a 90º to the end of a shaft.
  - It is considered more appropriate for conventional treatment where large floc formation is desirable.
- Hydraulic
  - This was the dominant type of flocculation in the early 20th century.
  - It consists of a flocculation channel that has 90º bends (serpentine) and sometimes contains baffles.
  - It creates turbulence as flow is conveyed around the bends to promote floc particle interaction and growth.

Raw Intake Design Parameters

- Inlets or gates should be located at least three different depths in a raw water reservoir intake.

- The purpose of intake screening devices is to prevent or minimize the entry of large objects.

Exercise

Unit 2 – Exercise

Multiple Choice – Choose the best answer

1. In drinking water terminology, “pretreatment” is any treatment process that occurs before the filter. For the process of direct filtration, this can involve which of the following: *(Choose all that apply)*
   a. chemical addition
   b. coagulation (rapid mixing)
   c. flocculation (slow mixing)
   d. sedimentation

2. Overdosing of __________ can result in a residual that may contribute to the formation of disinfection by-products. *(Choose the best answer)*
   a. Potassium permanganate
   b. Soda ash
   c. Chlorine

3. The most common chemicals for raising pH are: *(Choose all that apply)*
   a. potassium permanganate
   b. lime
   c. caustic soda
   d. soda ash

4. Alum, ferric chloride, and PAC are the most common chemicals used in the pretreatment process of:
   a. coagulation
   b. flocculation
   c. sedimentation

5. A ____ pH is necessary for most effective coagulation of organics.
   a. high
   b. low

6. The pretreatment step during which a slow, mechanical mixing process promotes the formation of floc particles is called:
   a. coagulation
   b. flocculation
   c. oxidation

PRACTICE: try and solve

7. If 1,000 pounds of dry alum are required to treat 15 million gallons of water, what is the dosage?
   a. 0.125 mg/L
   b. 8 mg/L
   c. 566 mg/L
   d. 1799 mg/L

8. The surface of a sand bed of a filter measures 15 by 25 feet. What is rated total capacity for a rate of 10 gpm/sq ft?
   a. 37.5 gpm
   b. 375 gpm
   c. 3,750 gpm
   d. 3,075 gpm

9. A filter is 5 feet wide and 15 feet long. The desired backwash rate is 5 gallons per minute per square foot. What backwash flow is needed?
   a. 7,075 gpm
   b. 3,075 gpm
   c. 750 gpm
   d. 375 gpm
   e. 75.5 gpm

10. What is the weight of a 3 gallon solution which has a specific gravity of 1.05?
    a. 10 lbs.
    b. 10 mg/L
    c. 26 lbs.
    d. 26 mg/L

11. A filter 5 feet wide by 5 feet long is permitted to operate at a rate of 2 gpm/$ft.^2$. What is the maximum flow rate within the permit limitations?
    a. .035gpm
    b. .07 mgd
    c. 3.5 mgd
    d. 7.0 gpm

Unit 2 Summary

Key Points:

- In drinking water terminology, treatment that occurs before the filter is known as "pretreatment"
- Source water is pretreated prior to filtration to oxidize soluble metals to form precipitates and to coagulate suspended and colloidal solids to form larger, dense floc (that can then be filtered out).
- Direct Filtration pretreatment includes coagulation and flocculation.
- The purpose of adding a coagulant aid is to increase floc strength and density.
- The three most commonly used coagulants are aluminum sulfate (alum), ferric chloride, and ferrous sulfate.
- A water treatment plant is using alum as its coagulant. Lime could be added to the flash mixer to replace alkalinity lost during the coagulation process.
- When alum is added, the most likely chemical reaction is for alkalinity to decrease and pH to decrease.
- If alum is used for coagulation at a pH above 9.0, increased dissolved aluminum will result in the filtered water.
- During the coagulation pretreatment process, chemicals are added at a location of very intense mixing to get the chemicals into the water and dispersed uniformly throughout as quickly as possible.
- During the flocculation pretreatment process, gentle eddy currents from the mixing promote inter-particle contact and the growth of floc particles.
- A substance must produce an insoluable floc to function satisfactorily as a coagulant.
- An appropriate reason to dilute a coagulant prior to addition in water is to make it easier to feed and disperse evenly.
- A concern in diluting a chemical prior to feeding is the change of composition and the breakdown of the chemical.
- The process of rapid or flash mixing for coagulation/flocculation occurs in a few seconds.
- A hydrometer is used to test liquid chemical strength by measuring specific gravity.
- Velocity, water temperature, detention time, and concentration of coagulant being used can all affect the performance of a coagulation unit.

Unit 3 – Direct Filter Components

Learning Objectives

As a result of this unit, the learner will:

- Be able to differentiate between mono, dual, and mixed media filters.
- Be able to list the four criteria of water quality that direct filtration plant operators must take into account.
- Receive information on filter performance.

Types of Filters

There are two types of filters: gravity and pressure.

- Gravity Filters
  - Water moves downward through the filter media by gravity.
  - This is accomplished either by slow rate gravity filtration or rapid rate gravity filtration.
- Pressure Filters
  - Water is forced through the media under pressure.

Filter Bed Materials

Basis for Media Selection

- The size of the media grains is important to assure their retention within the filter box.
- The size of the media grains is important for correctly specifying the backwash rate.
- Smaller media grains tend to pack together more tightly than larger media grains.
  - This creates smaller void spaces than would occur with larger media grains.
  - For any given depth of media, the smaller media grains will produce greater restriction to flow and higher initial (clean bed) differential pressure loss (headloss).
  - The smaller media grain bed will produce higher solids retention due to the smaller voids and greater media surface area.
- Larger media grain beds need to be deeper to provide an equivalent solids removal capacity as the bed containing smaller media grains.
  - This enables greater depth filtration due to larger void spaces.
  - This is particularly advantageous for floc particles containing filter clogging algae that would otherwise bind a filter containing small media grains.
  - Filter beds containing larger media grains will increase production, provided it is of sufficient depth to prevent breakthrough.

Standards for specifying and testing granular filter media are available in the document, *ANSI/AWWA B100-96 Standards for Filtering Material.*

Types of Filter Bed Materials

- Anthracite
  - Anthracite media grains are processed from a hard coal that is black with a silvery sheen.
  - This is commonly the single media in mono media-type filters.
  - The top layer (or cap) of dual and mixed media filters are commonly anthracite.
- Granular Activated Carbon (GAC)
  - GAC consists of grains of carbon, most commonly processed from either lignite or bituminous coals.
  - This is often used in place of anthracite for its enhanced capability of reducing TOC and tastes and odors.
- Filter Sand
  - Filter sand contains grains of silica dominated by translucent and/or yellow-orange transparent colors.
  - This is typically the bottom filtering material in dual media filters and the middle layer in mixed media filters.
- Garnet Sand
  - Garnet is a term used for a collection of silicate materials differing in chemical composition and color, but having a higher density than filter sand. The common form used in water treatment is red/burgundy in color.
  - It is typically used as the bottom filter material in a mixed (or tri-media) filter.
- Ilmenite Sand
  - This is an opaque, black mineral with a metallic, greasy luster.

Media Properties

Effective Size (ES) is the sieve size opening that will just pass 10% (by dry weight) of a representative media sample. This is referred to as the d_{10} value.

Uniformity Coefficient (UC) is the ratio, calculated as the size opening that will just pass 60% (by dry weight) of a representative sample of the filter material (referred to as the d_{60} size) divided by the size opening that will just pass 10% (by dry weight) of the same sample.

- Typical UC values specified are 1.4 to 1.5, which minimizes media grain size intermixing, without making the cost of the media uneconomical.
- The unit cost of filter media will likely rise as the UC decreases.
- Calculate: d_{60} / d_{10}

Roundness (media grain shape) assesses whether grains have retained sharp edges or corners, or if the media has become worn due to repeated backwashing.

Sphericity (media grain shape) is the ratio of an eqivalent volume sphere to the surface area of the media grain. The media sphericity relates inversely to the porosity of the filter bed.

Density/Specific Gravity is an important factor for detrmining the rate of backwash flow required to achieve a specific bed expansion for a given water temperature.

- ❖ This information is used in addition to media grain size for determining backwash flow requirements.
- ❖ It is important to know density for dual and triple media filter beds so that the different types of filtering materials resegregate following a backwash.
    - ▪ The filter top layer, generally anthracite or GAC, has grain densities in the range of 1.4 to 1.7 g/cm^3 and 1.3 to 1.5 g/cm^3, respectively, following a wetting period of at least 24 hours.
    - ▪ Silica sand has a grain density of 2.65 g/cm^3, while garnet and ilmenite sand have a density of approximately 3.9 g/cm^3.

Bulk Density is the mass of media in a filter bed, divided by the volume occupied. This measurement approximates the weight of media required to fill a filter.

Bed Porosity (Voidage) is the percent of overall bed volume not occupied by the media grains.

- ❖ Porosity affects the clean bed headloss.
    - ▪ Filters having greater void spaces will have a lower initial headloss.
- ❖ Angularity affects the amount of porosity in the bed.
    - ▪ The more angular anthracite media grains create a filter layer of greater porosity than the rounder sand layer, and occupies a greater volume.
- ❖ The media grain volume is calculated by dividing the weight of a media sample by its density.
- ❖ The voidage is calculated by subtracting the mrdia grain volume from the bed volume and subsequently dividing by the bed volume.

Hardness of filter media grains relates to its suitability for long service life. The MOH Scale of Hardness is used to determine relative hardness of filtering material.

- ❖ Silica sand and Garnet sand tend to be hard materials.
- ❖ GAC and Anthracite are softer materials that may be more susceptible to degradation during air scouring and backwashing.

Acid Solubility of a filter material assesses whether the media consists of aggregates of finer material cemented together, or contains excessive mineral coatings such as calcium carbonate or manganese dioxide.

It is recommended that the d_{90} media size be used for determining effective backwash rates. Calculate: d_{10} $(10^{1.67 \log uc})$

The velocity of the water is an important criterion for media backwash. Two factors must be considered. First, determine the minimum velocity required to just suspend the media grains. Second, determine the velocity necessary to achieve the desired bed expansion. Remember that colder water is denser than warmer water and, therefore, will require a lower backwash rat for a given media expansion.

Media Bed Configurations

Any one of the following filter bed configurations might be found in a direct filtration plant:

- Mono Media
  - Mono media filter beds not usually found in treatment plants, but the deepest beds are generally mono media beds.
  - They are inexpensive, but difficult.
  - Anthracite or GAC would be the media used in this filter bed configuration.
- Deep Bed
  - Deep bed filters are generally mono.
  - The L.A. Aqueduct Plant is a deep mono media filter bed plant.
    - The filters there consist of large anthracite media (ES = 1.5 mm), which are six feet in depth and have a design loading rate of 13.5 gpm/sf.
- Dual Media
  - These filters typically consist of a lower layer of silica sand, 8 to 12 inches in depth, with a layer of anthradite or GAC, 18 to 30 inches in depth, that serves as the filter cap.
- Mixed Media
  - Mixed media filters typically consist of a bottom layer of garnet sand, 2 to 3 inches deep, with a middle layer of silica sand (6 to 9 inches), and a top layer of either anthracite or GAC, which is 18 to inches in depth.

Underdrains

Underdrains collect filtered water during normal operation and distribute backwash water during the backwash process. Several types are available, as listed below:

- Perforated Pipe System
  - These are old-fashioned and not often used in plants today.
  - A small plant might use this system because it is economical to install.
  - The do not provide an even a wash as desired because there are not as many holes as the newer tile versions.
- Wheeler Bottom
  - These types are rather uncommon today.
- Glazed Tile Filter Blocks
  - This system was very popular in the past, and is occasionally installed today.
  - The plastic block version operates on the same principle, but is more economical.
- Plastic Filter Blocks
  - This is the most common type used in modern plants.
  - It operates on the same principles as the glazed ceramic version, but the PVC plastics are more economical than ceramic tiles.
- Porous Plates and Nozzle and Strainer
  - These two types contain a plenum, or a hollow space between the plates and the slab underneath.
  - The nozzle version has nozzles that extend down into the plenum.
  - The porous plates version has a plate with holes in it rather than nozzles to move the water.

Backwash Components

- Backwash Supply
  - The backwash supply may be pumped from a washwater storage tank.
    - The storage tank is elevated and utilizes a small pump.
    - Storage tanks can only accommodate one or two backwashes in a row because the tank empties quickly.
    - The tank is economical to install and operate.
  - The backwash supply may come from a clearwell.
    - A clearwell is a better option than the storage tank because more water is available for repeated washings.
    - The clearwell is a more expensive choice for a plant.
    - The filter-to-waste process prevents water of inferior quality and/or high turbidity water from reaching the clearwell following filter backwash.
- Supplementary Scouring
  - Supplementary scouring is intended to enhance the backwash process by causing media grain to rub against one another.
    - Surface Wash System
    - Air Scour System
- Washwater Troughs
  - The troughs collect wastewater.
  - They are located at the surface to collect the dirty water and discharge it to the process wastewater area.

Filter Valves

- Influent Valve
  - This valve allows water into the filter; it effectively puts the filter on-line.
- Effluent Valve
  - This is an on/off valve and allows effluent to flow.
- Effluent Throttling Valve
  - This valve adjusts the flow going through the filter.
- Washwater Supply Valve
  - This on/off valve allows clean backwash water in.
  - The flow cannot be controlled beyond the on/off variables.
- Washwater Throttling Valve
  - This valve is also known as the Backwash Throttling Valve.
  - The backwash flow rate is adjusted with this valve.
- Drain Valve
  - The valve controls the wastewater drain.
  - When the backwash trough collects process wastewater, the valve is opened to let out the water.
- Surface Wash Valve
  - If the filter has an auxiliary surface wash, this valve will be present.
- Air Scour Valve
  - If there is an auxiliary air scour, this valve allows air in to perform the scour.
  - This valve is located under the underdrain or plenum.
- Rinse Valve
  - After the backwash is complete, but before the filter is placed on-line, all valves are open except the effluent valve, and the rinse valve is then opened also.
  - The rinse valve directs the remaining residuals to the process wastewater facility.
- Other Valve
  - A check valve is not normally part of a filtering system.
  - Foot valves are used in connection with centrifugal pumps in order to prevent water in the suction line from flowing back.

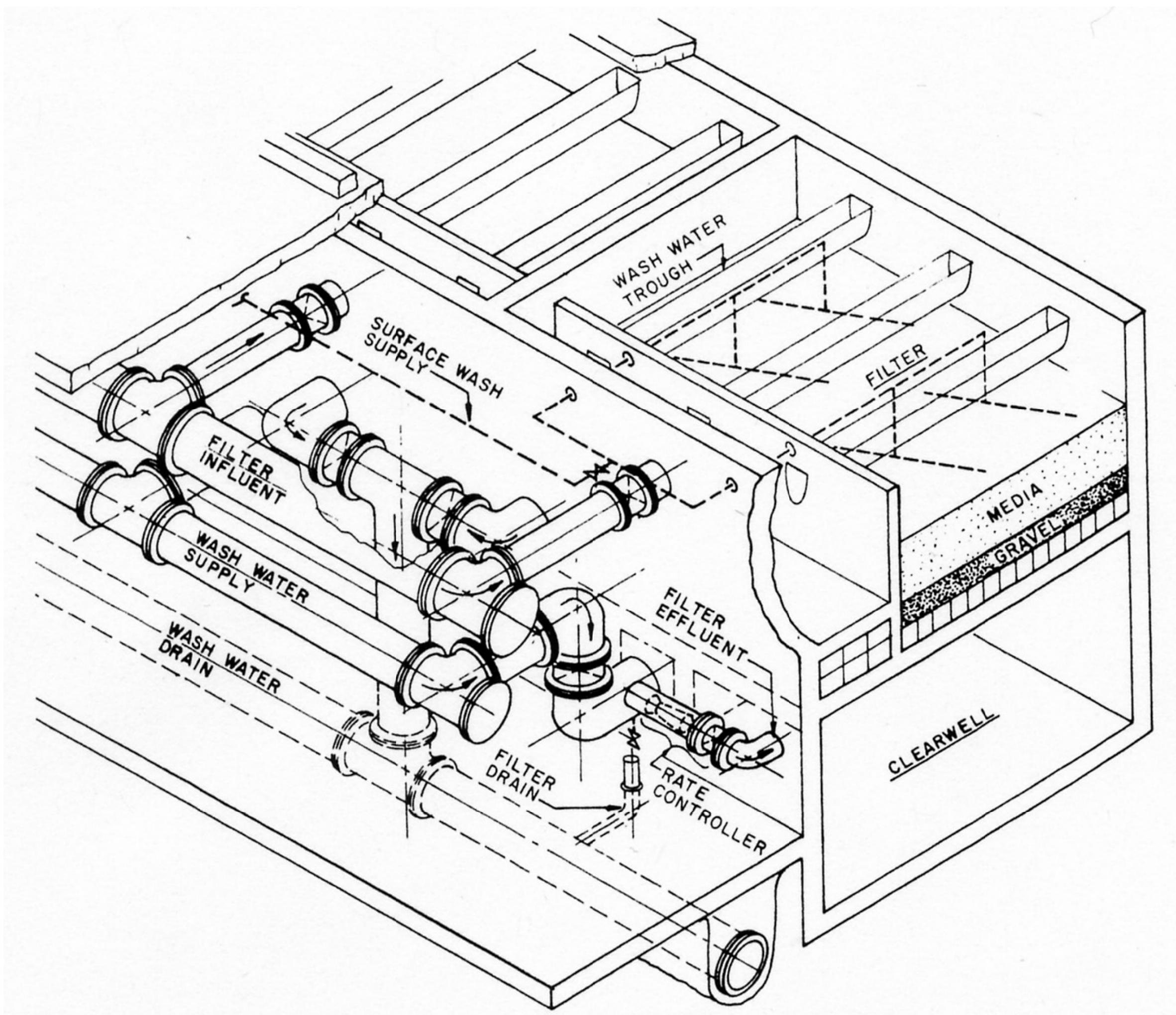

Figure 3.1 Typical Gravity Filter Piping

Courtesy of Camp Dresser & McKee

Filter Control Systems

Flow Controls

- Flow controls regulate the forward flow rates by maintaining adequate head above the media surface.
- They prevent a sudden forward flow increase (surge), which could dislodge trapped solids.
- They maintain an even flow distribution between the filters.
- The purpose of a rate-of-flow controller on the effluent piping of a filter is to control the rate of flow to the filter.
- If the weir overflow rate for a clarifier is higher than the design specifications, an operator could reduce the weir overflow rate by decreasing the flow rate.
    - If the weir overflow rate for a clarifier is too high, floc carry over will occur.

Types of Filter Control Systems

- Equal Flow Rate
    - Proportional Level and Equal Flow Rate
        - This is the most common method for controlling flow rate.
        - It splits the flow evenly between filters and maintains the level in the filter influent channel within a preset band.
    - Proportional Level and Influent Flow Split
        - This uses a modulating filter effluent valve to maintain the water level above the filters within a preset band.
    - Variable Level and Influent Flow Split
        - This type of flow control provides an equal flow rate through each filter.
- Declining Flow Rate
    - Variable Level Declining Rate
    - Proportional Level Declining Rate

Filter Backwash

- Sequence
  - Auxilliary Scour—Three Alternatives
    - A surface wash/backwash is followed by backwash only.
    - Alternately, an air scour could be followed by a backwash.
    - The third alternative is a simultaneous airwash/backwash followed by backwash only.
  - First Low Backwash
    - This is slightly more than the minimum fludization velocity.
    - This flow rate allows any entrained air to safely escape from the filter bed, thereby avoiding damage to the underdrain or upsets to the support gravel and filter media.
  - High Backwash
    - This flow rate is used to fully expand the bed.
    - It allows most of the solids to be transported and removed.
  - Second Low Backwash
    - This rate allows the media to restratify effectively.
  - Filter Rinse
    - The filter rinse conditions the media to minimize the potential for passage of pathogenic microorganisms.
    - The rinse typically continues until the filter effluent reaches the turbidity goal prior to returning to service.

- A filter to waste mode should be utilized in filtration after backwash. Therefore, the final step in backwashing a filter before returning it to service is the filter to waste.

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Production Criteria

The production criteria include the filtration rate, filter run time, and filter production and efficiency.

Filtration Rate

The filtration rate is determined by three aspects: flow per unit area; impact on headloss; and impact on quality of the finished product.

- The flow rate per unit area of filter surface area, or hydraulic loading rate, typically is measured in units of gpm/sf.
- Impact on headloss (increases or decreases) corresponds to changes in the flow rate.
- The impact on quality is affected by several characteristics.
  - Increased flow rates make filtration more sucseptible to breakthrough due to higher shearing forces on the previously retained material.
  - Sudden flow changes make the filter even more susceptible to shearing forces; this could result in short duration breakthrough.

Filter Run Time

Note the typical run times according to:

- Hours to turbidity breakthrough.
- Hours to terminal headloss.

Filter Production and Efficiency

- Measure water produced per cycle per square foot of filter area (UFRV) to compare productivity between different filter sizes.
- Measure net water production.
  - Net water production = gross filter production per cycle – (volume of backwash wastewater + volume of filter-to-waste water)
- Measure the percent wastewater.
  - Net water production / the gross water production during that run
  - This result is a good indicator of filter efficiency.

Keep records of net water production and UFRV for each filter. You will observe subtle changes in long-term filter performance that can be addressed before they cause a serious problem.

The four criteria of water quality that direct filtration plant operators must take into account include: filter effluent turbidity; filter particle counts; quality versus run-time and headloss; and microscopic particulate analysis (MPA).

Filter Effluent Turbidity

Regulatory requirements provide maximum values for turbidity and monitoring requirements.

- Maximum Values
  - The combined filter effluent turbidity must never exceed 1 NTU and must be less than or equal to 0.3 NTU for 95% of the monthly samples.
  - Individual filter effluent turbidity must be reported whenever it exceeds 1.0 NTU and if it exceeds 0.5 NTU for two measurements occurring 15 minutes apart after 4 hours of operation (following backwashing or reinitiation of operations).
- Monitoring Requirements
  - The combined filter effluent must be monitored at least every four hours.
  - Individual filter effluent turbidity must be continuously monitored and must be recorded at least every 15 minutes.

Filter Particle Counts

There are no regulatory standards for particle counts, nor are particle counters required by any proposed drinking water regulations. The DEP does have optimized performance goals, however.

Particle Size	Optimized Performance Goals
Cryptosporidium sized, 3-5 µm	≤10 particles per mL
Giardia sized, 5-15 µm	≤10 particles per mL
Particles greater than 2 µm	≤25 particles per mL from individual filters

There are benefits to particle count monitoring for the evaluation of operational criteria and individual filter performance. They are listed below.

- Monitoring provides increased "particle resolution" at low turbidities (less than 0.10 NTU) when optimizing filter performance.
- Particle monitoring is more responsive than turbidity monitoring for indicating the impact of an operational change on filter effluent quality.
- Particle count trending can help determine the cause of a rapid increase in particle counts if correlated with other operational information such as flow, headloss, and chemical feed changes.
- Monitoring is an effective tool for screening and optimizing coagulant and/or filter aids, especially for colloidal matter treatability.
- Particle monitoring provides the operator with precise information for determining when a filter is fully ripened following backwash (prior to returning to service) by monitoring water quality during the rinse period.
- It provides the operator with an early warning that a filter is starting to experience breakthrough.
- Particle count sensors that are able to count particles within discrete size ranges can serve as a QA/QC check for assessing the quality of the data.
- It is accepted in the drinking water industry that there is a correlation between an increase in total particle count and an increase for the potential risk of passage of *Giardia* and *Cryptosporidium*, if these microorganisms are present in the source supply.
    - Therefore, optimizing filter performance based on minimizing the number of particles in the filter effluent can be a valuable tool for assuring the viability of filters as a barrier to passage of microbial contaminants.

Quality versus Run Time and Headloss

The quality of the filtration process changes over run time.

- During the Initial Improvement Period (filter ripening), an increased risk exists for the passage of pathogens. One or more operating techniques should be used to minimize the initial spike of turbidity and particle counts. These techniques may include:
  - Filter-to-waste (FTW), or rewash.
  - Delayed start (filter rest), which allows media to settle and compact.
  - Slow start, in which the flow is ramped up to minimize shearing of residual material in the filter bed.
  - Coagulant or polymer addition to the portion of backwash water that will remain in the filter box.
  - Polymer/filter aid addition during the ripening period only.
- During the Steady State Period, you will notice optimized water treatment and stable effluent quality.
- In the Terminal Period, water quality indicators start to trend upwards. This is near the end of a filter cycle.
- Sometimes anthracite coal is added to the sand filter because it allows longer filter runs.

Microscopic Particulate Analysis (MPA)

MPA is a laboratory technique used for determining if a groundwater source is under the influence of surface water. It also evaluates the filter treatment efficiency of systems using surface water supplies. The technique consists of conducting a microscopic analysis of a water sample to determine the presence of particles and microorganisms.

Impact of Other Variables

Water Temperature

- Cold water temperatures, particularly below 40º F, result in slowing down the oxidation and/or coagulation reactions which may negatively impact filtration due to relatively short detention time prior to filtration.
- The impact can be sufficient to negatively affect filtration performance.

Influent Water Quality

- Higher than normal turbidity and color may be present in the influent water.
- This results in a need for higher coagulant dose, which may significantly degrade filter performance.

Exercise

Unit 3 – Exercise

Matching: Match the letter of the corresponding filter system component with the number of the correct statement.

A. mono media-type filter
B. dual media filter
C. mixed media filter

1. _______ Commonly has a single media which is anthracite.

2. _______ Typically has a top layer of anthracite or GAC, a middle layer of silica sand, and a bottom layer of garnet sand.

3. _______ Has a has a top layer of anthracite or GAC, and a bottom layer of silica sand.

Listing:

4. List the four criteria of water quality that direct filtration plant operators must take into account.

    ____
    ____
    ____
    ____

True or False: Select the best answer

5. The quality of the filtration process changes over run time.

    a. True
    b. False

6. Increased flow rates make filtration less susceptible to breakthrough.

    a. True
    b. False

Unit 3 Summary

Key Points:

- The term "uniformity coefficient" of filter media refers to the measure of uniformity of filter media size.
- In gravity filters water moves downward through the filter media by gravity. In pressure filters, water is forced through the media under pressure.
- Direct filtration media bed configurations may be mono, dual, or mixed media.
- The correct order of filter materials in a multi-media or mixed media filter from top to bottom is anthracite coal, garnet, and silica sand.
- Direct filtration plant operators must take into account the following water quality criteria: filter effluent turbidity, filter particle counts, quality versus run-time and head loss, and microscopic particulate analysis (MPA).
- The quality of the filtration process changes over run time.
- Cold water temperatures may slow down the oxidation and coagulation pretreatment reactions and negatively impact filtration.
- Higher than normal turbidity and color can result in a need for higher coagulant dose and may significantly degrade filter performance.
- The function of the filter underdrains is to collect treated water.
- The filter-to-waste process prevents water of inferior quality and/or high turbidity water from reaching the clearwell following filter backwash.
- The purpose of a rate-of-flow controller on the effluent piping of a filter is to control the rate of flow to the filter.
- If the weir overflow rate for a clarifier is higher than the design specifications, an operator could reduce the weir overflow rate by decreasing the flow rate.
- If the weir overflow rate for a clarifier is too high, floc carry over will occur.
- The final step in backwashing a filter before returning it to service is the filter to waste.
- Sometimes anthracite coal is added to the sand filter because it allows longer filter runs.

Unit 4 – Filter Operations

Learning Objectives

As a result of this unit, the learner will:

- Review routine parameters for water quality monitoring, headloss, backwashing, and rinse criteria.
- Be able to describe three events that signal abnormal operation.
- Receive and explanation on the importance of record keeping and a list of the minimal types of records that must be kept.

Routine Operation

Routine parameters for water quality monitoring, headloss, backwashing, and rinse criteria are listed in this section.

Water Quality Monitoring

- On-line turbidimeters are required because the ESWT rules require that every filter be monitored at least every 15 minutes.
- The Partnership for Safe Water recommends that every filter plant establish a goal to continuously maintain filtered turbidity below 0.10 NTU. If this is adopted by a plant, then exceeding this goal should be a trigger for removing a filter from service and backwashing.
- Continuous filter effluent monitoring can help to evaluate the performance and condition of individual filters.
- A sampling location to fulfill the ESWT rules for combined filter effluent turbidity monitoring should be located upstream of any post chemical addition to avoid any turbidity contribution from the chemicals themselves.
- Particle counters can supplement turbidity monitoring under routine operating conditions.

Headloss

- The total system head provided to operate a gravity filter is the vertical distance from the water level (hydraulic grade line) in the filter inlet conduit to the downstream water level and the downstream control point.
- The initial, or clean bed headloss, is a measure of pressure drop across the clean filter bed, plus any other flow restrictions.
- Typically, loss of head is measured as the difference in pressures between a location in the top water (above the filter bed), and a second location downstream of the filter box. If a filter's differential pressure gauge is malfunctioning, the result would be incorrect head loss.
- Many factors, including the following, can affect loss of head.
  - Depth of media
  - Filter rate
  - Viscosity of the water
  - Size, uniformity, and shape of the media grains
  - Filter bed porosity
  - Filter aid polymer (anionic polymer will increase head loss on filters)
  - Algae

- Inadequate depth of water on top of a filter, abnormally high algae levels in the raw water, and operation of the filter beyond its normal head loss are all common causes of air binding in a filter.
  - Air binding in a filter will occur more frequently when the headloss is high.
- Gallons treated though the filter, head loss, and time elapsed should all be used as indicators to determine when to backwash the filter. Customer complaints should **not** be used as an indicator to determine when to backwash a filter.
- A loss of head gauge indicates when the filter should be backwashed.

Some plants have filters equipped with multiple taps so that headloss can be measured across various depths of the filter bed. This can provide valuable insight into how deeply floc is penetrating and being retained in the bed.

As solids start to accumulate following a filter being returned to service, loss of head increases above the initial loss of head due to clogging of the pores between the media grains. The rate of increase will tend to be more linear with depth filtration and more exponential with surface filtration.

A predetermined maximum headloss is commonly used as one trigger for a filter backwash. This maximum headloss is called terminal headloss.

- High initial head loss indicates that the backwash rate is too low.

Common Backwashing Criteria

Criterion	**Maximum**
Runtime at 4.0 gpm/sf	24 hours
Runtime, assuming turbidity goal is maintained	96 hours
Terminal headloss	8 feet
Maximum turbidity	0.10 NTU
Particle Counts	25/mL

Rinse Criteria

- Terminate the rinse and return the filter to service when turbidity falls below 0.10 NTU.

Indicators of Abnormal Operation

An operator may notice one or more factors indicating that the plant is not operating at full efficiency.

- Abrupt changes in influent water quality
- Rapid changes in headloss
- Rapid changes in filtered water turbidity during normal filter operations
- Mud balls, media bed cracking, or shrinkage
- Excessive media loss, visible media disturbance, or media boils during backwash
- Short filter runs
- Algae and/or excessive floc on the media and filter box walls

Check and adjust the process and the equipment, as necessary.

- Make pretreatment modifications as necessary.
- Change the filtration rate.
- Add or remove filters from operation as required by water demands.
- Inspect the filter bed, including depths and conditions of media.
  - The maintenance of a filter bed involves a periodic probe check to determine the top of the gravel layer.
  - The amount of media lost through backwashing a multi-media filter can best be determined by measuring the freeboard of the filter.
  - Once filter media has been replaced, the best way to disinfect a filter is use enough chlorine so that a significant residual remains after 24 hours.
- Determine the depth of support gravel.
- Evaluate the condition of the underdrain and auxiliary scour system.

Check and adjust the chemicals, daily.

- Polymers used as filter aids work to improve filter performance by strengthening bonds between particles and coating filter media to improve adsorption.
- Polymers used as backwash aids are injected into the backwash water in very low doses to reduce the ripening time of filters.

Record Keeping

Maintain a daily log of process performance data and water quality analyses.

Maintain accurate records of water quality, operations, water production, percent of water production used for plant, and equipment performance.

- Process Water Quality
    - Temperature
    - pH
    - Alkalinity
    - Turbidity
    - Color
    - Iron
    - Manganese
    - Hardness
- Process Operations
    - Filters in service
    - Filtration rates
    - Loss of head
    - Length of filter runs
    - Frequency of backwash
    - Auxiliary scour
    - Backwash rates and durations
- Process Water Production
- Percent of Water Used by the Plant
    - Filter backwashes
    - Laboratory samples
    - Chemical mixing
    - Wash downs
    - Other plant uses

- Process Equipment Performance
  - Types and number of equipment in operation
  - Equipment adjustments made
  - Maintenance performed
  - Equipment calibration

Log entries should be neat and legible, reflect the time and date of an event, and be initialed by the operator making the entry. The log entries will be worth their weight in gold when a question or problem arises!

Exercise

Unit 4 – Exercise

True or False: Select the best answer

1. Depth of media and filter rate are two factors which can affect filter headloss.

   a. True
   b. False

2. A common filter backwash criteria is to terminate the backwash rinse and return the filter to service when turbidity falls below 10 NTU.

   a. True
   b. False

Fill in the blanks:

3. Some indicators of abnormal direct filtration operations are:
   a. Rapid changes in filtered water _______________ during normal filter operations.
   b. Short __________ runs.

4. Some adjustments that can be made if a direct filtration plant is operating abnormally are:
   a. Make _______________________ modifications as necessary.
   b. Inspect the ___________ bed, including depths and conditions of media.

5. Accurate water quality process records should be kept of the following:
   Temperature, __________, alkalinity, ______________, color, iron, manganese, and hardness.

6. Accurate process operations records should be kept of the following:
   Filters in service, filtration rates, loss of head, length of ___________ runs,
   frequency of filter ___________, auxiliary scour, and backwash rates and durations.

Unit 4 Summary

Key Points:

- An example of a chemical which would increase head loss on filters is an anionic polymer.
- If a filter’s differential pressure gauge is malfunctioning, the result would be incorrect head loss.
- Inadequate depth of water on top of a filter, abnormally high algae levels in the raw water, and operation of the filter beyond its normal head loss are all common causes of air binding in a filter.
- Gallons treated though the filter, head loss, and time elapsed should all be used as indicators to determine when to backwash the filter. Customer complaints should **not** be used as an indicator to determine when to backwash a filter
- A loss of head gauge indicates when the filter should be backwashed.
- Hgh initial head loss indicates that the backwash rate is too low.
- Air binding in a filter will occur more frequently when the headloss is high.
- The maintenance of a filter bed involves a periodic probe check to determine the top of the gravel layer.
- Once filter media has been replaced, the best way to disinfect a filter is use enough chlorine so that a significant residual remains after 24 hours.
- The amount of media lost through backwashing a multi-media filter can best be determined by measuring the freeboard of the filter.
- Polymers used as filter aids work to improve filter performance by strengthening bonds between particles and coating filter media to improve adsorption.
- Polymers used as backwash aids are injected into the backwash water in very low doses to reduce the ripening time of filters.