FILTRATION

CALIFORNIA STATE UNIVERSITY: SACRAMENTO

WATER TREATMENT PLANT OPERATION VOL. I

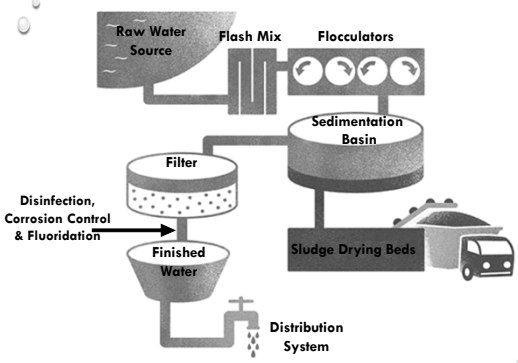
OBJECTIVES

- Filtration Process and Mechanisms
- Types of Filters
- Operational Criteria
- Filter Operation
- Process Performance Considerations

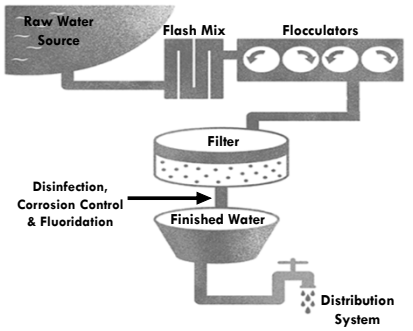
PROCESS DESCRIPTION

- Process of passing water through a material to remove floc and particulate matter (colloids)
  - Filter through a bed of sand, coal, or other granular substances
- Conventional Filtration
  - Coagulation, flocculation, sedimentation and filtration
- Direct Filtration
  - Sedimentation step is omitted

CONVENTIONAL FILTRATION



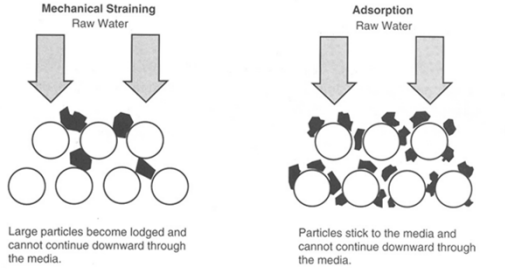
DIRECT FILTRATION



FILTRATION MECHANISMS

- Physical and chemical process
- Removal mechanisms
  - Sedimentation on media
  - Adsorption
  - Biological action
  - Absorption
  - Straining
- Removal mechanisms based on
  - Chemical characteristics of the water being treated
  - Nature of suspension
  - Types and degree of pretreatment
  - Filter type and operation

FILTRATION MECHANISMS



TYPES OF FILTERS

TYPES OF FILTERS

- Gravity filtration
  - Sand, dual media, and mixed media
- Pressure filtration
  - Mixed media
- Diatomaceous earth
  - Precoat filtration
- Slow sand filtration

GRAVITY FILTRATION

- Particulate impurities are removed in/on the media
- Water level or pressure (head) above the media forces water through the filter
- Types of gravity filters (TN Design Criteria)
  - Single media
    - Depth of at least 30 inches
  - Dual media
    - Sand (10 inches) and crushed anthracite (20 inches)
  - Multimedia
    - To be approved by department
- Filtration Rates (average)
  - 2 gpm/ft^2 for turbidity removal
  - 3 gpm/ft^2 for iron removal plants

GRAVITY FILTRATION

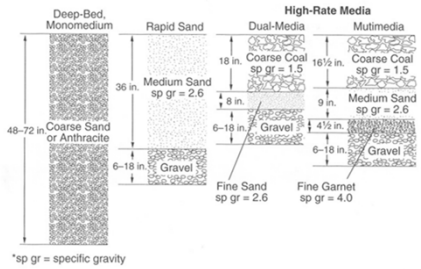
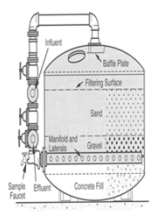


FIGURE 6-8 Comparison of deep-bed, rapid sand, and high-rate filter media

PRESSURE FILTRATION

- Similar to gravity filter except completely enclosed in a pressure vessel
- Lower installation and operation costs ins small filtration plants

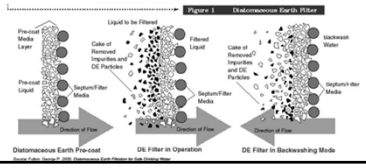


Courtesy of Celite Corporation

FIGURE 6-37 Vertical sand pressure filter tank

DIATOMACEOUS EARTH (DE) FILTRATION

- Aka precoat filtration
- Filter media is added to the water as a slurry, then collected on a septum or screening device
- After the initial precoat application, water is filtered by passing it through the coated stream
- Primarily a straining process
- Can be operated as gravity, pressure, or vacuum filter



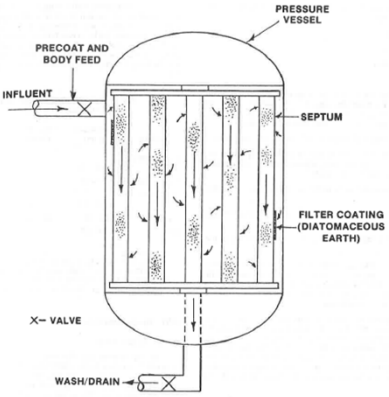
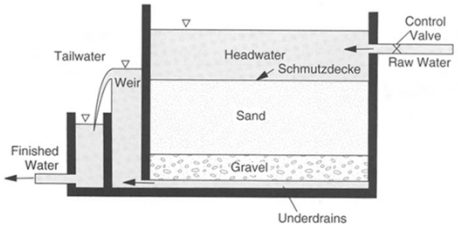


Fig. 6.5 Diatomaceous earth filter

SLOW SAND FILTRATION

- Water drawn through the filter media by gravity
- Filtration rates are very low
- Most particulate matter removed in top several inches of sand
- Entire layer must be physically removed when filter becomes clogged
  - No backwashing
  - No chemical pretreatment
  - Schmutzdecke – fine sand and a sticky mat of suspended matter that forms on the sand surface

SLOW SAND FILTRATION



Source: Barrett et al. (1991).

FIGURE 6–7 Schematic cross section of a slow sand filter

OPERATIONAL CRITERIA

FILTER MEDIA CLASSIFICATION

- Effective size (ES) – size of a sieve opening that permits 10% of the particles to pass through
  - If limiting head loss is a problem, but turbidity breakthrough is not, consider larger media size
  - If turbidity breakthrough is a problem but not limiting head loss, smaller media may be considered
  - If both head loss and turbidity breakthrough are a constant problem, use a deeper filter bed with larger media
- Uniformity coefficient (UC) – the ratio of particle diameters comprising 60% and 10% media weight
  - Media with lower uniformity coefficients are composed of more uniform particles
- Specific gravity
- Hardness

FILTER PRODUCTION & FILTRATION RATE

- Measures of the amount of water that can be processed through an individual filter in a given period of time
- Filter Production
  - Measured in MGD (millions of gallons per day)
- Filtration Rate (aka hydraulic loading)
  - Used to measure flow of water through a filter
  - Measured in gallons per minute per square foot (gpm/ft^2)
  - Average filtration rates
    - 2 gpm/ft^2 for turbidity removal
    - 3 gpm/ft^2 for iron removal plants

FILTRATION EFFICIENCY

- Measured by overall plant reduction in turbidity
- Removal efficiency depends on
  - The quality of the water being treated
  - The effectiveness of the pretreatment (coag/floc) processes
  - Filter operation
  - Filter design
  - Media type and thickness
    - Sand filters have fine, light grains on top that stop all particulates at the surface
    - Dual media filters have lighter larger diameter grains at the top that stop the larger particles; smaller particles are usually stopped farter down in the filter

FILTER OPERATION

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FILTRATION MODE

- Water containing suspended solids is applied to the surface of the filter media
- Clogging – buildup of head loss (pressure drop) across the filter media
  - Total design head loss ranges from 6 to 10 feet
  - Terminal head loss is considered to be at 10 ft, but this will be different from plant to plant
- Clogging leads to breakthrough – a condition in which solids are no longer removed
  - Solids pass into the filter effluent where they appear as increased turbidity

BACKWASHING

- Process of reversing the flow of water through the filter media to remove entrapped solids after
  - Maximum head loss reached
  - Breakthrough occurs
  - Specified time period has passed
- Filter media must be fluidized (expanded) by reversing flow
- Backwash rates of 10-25 gpm/ft^2 required
- Insufficient backwashing may not adequately clean filter
- Too high backwash rate may cause excessive loss of media
- Higher backwash rates are required at higher temperatures due to less viscous water
- 50% bed expansion (TN Design Criteria)

BACKWASHING

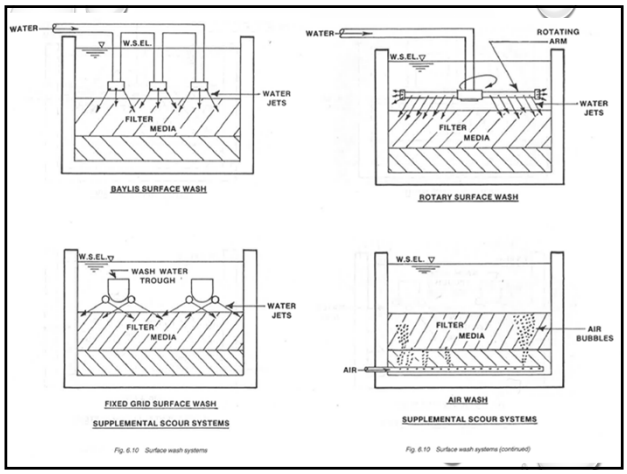
Filter Backwash Video

https://youtu.be/QrWXJ25wEkU

- Water use for backwashing may be recycled directly to the headworks (ahead of the flash mix)
- Filter Backwash Rule requires that recycled filter backwash water, sedimentation basin sludge thickener supernatant, and liquids from sludge dewatering processes be returned upstream of all conventional treatment systems
  - Systems may apply to the State for approval
  - Purpose is to improve performance at filtration pants by reducing opportunity for microbes such as *Cryptosporidium* to pass through the treatment process

SURFACE WASH

- Provides additional scrubbing action to remove attached floc and other entrapped solids from the filter media
- 4 types:
  - Baylis
  - Fixed grid
  - Rotary
  - Air scour



FILTER CONTROL SYSTEMS

- Regulate flow rates through the filter
- Control system types
  - Rate-of-flow
    - Each filter effluent control valve is connected to a flow meter
    - As the media begins to clog, the control valve opens to maintain a constant flow
    - All filters operate at same flow rate
  - Split-flow
    - Equal flow to each filter influent is split or divided by a weir
    - Effluent valve position controlled by water level in the filter

FILTER CONTROL SYSTEMS

- Regulate flow rates through the filter
- Control system types
  - Declining-rate
    - Flow rate varies with head loss
    - Each filter operates the same but has variable, water surface levels
  - Self-backwashing (or Streicher design)
    - Influent flow to each filter is divide by a weir
    - Water surface level varies according to head loss while flow rate remains constant
    - Reduces amount of equipment needed

PROCESS PERFORMANCE CONSIDERATIONS

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PROCESS PERFORMANCE

- Activated Carbon Contactors
  - High adsorptive capacity of activated carbon enables it to remove taste and odor causing compounds and other organics
- Importance of Pretreatment
  - Floc particles carried over into the filter must be small enough to penetrate the upper filter media
  - Floc that is too large will clog the top portion of the filter bed rapidly
  - Floc removal is accomplished by contact with the media grains
    - Ripening period - time after initial coating of media surfaces with floc; subsequent applications of floc will build up on the material previously deposited
      - High effluent turbidities may occur during the ripening period

IN-LINE FILTRATION

- The addition of coagulant chemicals immediately before the water enters the filtration system
- Filter aids are added directly to the filter inlet pipe and mixed by the flowing water
  - Separate flocculation and sedimentation facilities are eliminated
- Not as efficient as conventional or direct filtration
- Important process control guidelines
  - Filter influent water quality – turbidity
  - Filter performance - head loss buildup rate and filter run time
  - Filter effluent water quality - turbidity

NORMAL OPERATING CONDITIONS

- Filter effluent turbidities will give a good indication of overall process performance
- Operator should monitor filter influent turbidity as well as filter effluent turbidity levels
- Monitor head loss buildup and filter effluent color
- Guidelines would help evaluate normal process conditions and in recognizing abnormal conditions

PROCESS ACTIONS

- Measurement of head loss buildup can indicate performance of solids removal process
  - Total designed head loss in a gravity filter is usually about 10 feet
  - Loss-in-head – actual head loss from a point above the filter media to a reference point in the effluent
  - Sudden increase in head loss may indicate surface sealing of the filter media (lack of depth penetration)
- Ripening period - time after initial coating of media surfaces with floc; subsequent applications of floc will build up on the material previously deposited
  - High effluent turbidities may occur during the ripening period

PROCESS ACTIONS

- Filter Run Time or Length
  - Should be calculated based on head loss, effluent turbidity and/or elapsed run time
  - A predetermined value set for each parameter as a cutoff point for filter operation
    - When any one of these levels is reached, the filter is backwashed
  - Filter run length not a satisfactory basis for comparing filter runs without considering filtration rate as well

PROCESS ACTIONS

- Unit Filter Run Volume (UFRV)
  - Volume of water produced by the surface area of the filter during the course of the filter run divided by the surface area of the filter
  - Expressed in gallons per square foot (gal/ft^2)
  - UFRV > 5,000 gal/ft^2 is good
  - UFRV > 10,000 gal/ft^2 is better
- Examine and evaluate filter media annually
  - Measure media thickness
    - Can be lost during backwash
  - Measure mudball accumulation
    - Indicates insufficient backwashing

PROCESS ACTIONS

- Observe backwash process to assess process performance
  - Watch for media boils, media carryover, waste wash water clarity
- Never “bump” filter to avoid backwashing
  - Bumping is the act of opening the backwash valve during the course of a filter run to dislodge the trapped solids and increase the filter run
- Observe the condition of the media surface and check for filter sidewall or media surface cracks
  - After completion of backwash cycle

INDICATORS OF ABNORMAL CONDITIONS

- Rapid changes in head loss buildup or turbidity breakthrough may be indicators of abnormal operation conditions:
  - Mudballs in filter media
  - Media cracking or shrinkage
  - Media boils during backwash
  - Excessive media loss or visible disturbance
  - Short filter runs
  - Filters that will not come clean during backwash
  - Algae on walls and media

PROCESS ACTIONS

- If filter turbidity removal efficiency is decreasing, evaluate coag/floc process and coagulant dosage
- Increases in source water turbidity may require a decrease in filtration rates or backwash filters more frequently
- Adding filter aids chemicals can help when pretreatment processes don't readily respond to source water quality changes
  - Overdosing can cause sealing of the filter media
- Decrease in alkalinity and pH can affect filtration since the coag/floc process performance can decrease

PROCESS ACTIONS

- Increases in filter effluent turbidity may also result from floc carryover from the sedimentation process
- Short filter runs can be caused by increased solids loading, filter aid overdosing, excessively high filtration rates, excessive mudball formation, or clogging of the filter underdrain system
- Backwash problems can be resolved by adjusting backwash flow rates, surface wash flow rates or duration, or adjusting the time sequence or duration of the backwash cycle
- Improper backwashing can result in mudball formation or filter cracks and shrinkage

AIR BINDING

- Caused by the release of dissolved air in saturated cold water due to a decrease in pressure
- Air is released from the water when passing through a filter bed by differences in pressure produced by friction through the bed
- The released air is entrapped in the filter bed
- Whenever a filter is operated to a head loss that exceeds the head of water over the media, air will be released
  - Occurs more frequently when large head losses are allowed to develop in filter
- Causes shortened filter runs due to water flow being restricted due to bound air

EXCESSIVE HEAD LOSS

- Filter underdrain system and head loss measurement equipment should be checked if excessive head losses remain after backwashing
- Can be caused by reduction in size and number of underdrain openings
  - Due to media clogging, corrosion, or chemical deposits

START UP PROCEDURES - BACKWASH

- Filters should be washed before placing them in service
  - Check length of cycle times set for backwash and surface wash cycles are correct
  - Surface wash should be activated before the backwash cycle starts and stopped before completion of the backwash cycle
  - Filter wash should begin slowly and provide uniform expansion of the filter bed
  - When backwash water coming up through filter becomes clear, media is clean (3-8 minutes)
  - Reduce backwash rate if media carryover or flooding of water troughs occurs
  - Waste backwash water is either recycled or sent to settling basin
    - Supernatant is then recycled through the plant

PARTICLE COUNTERS

- A device which counts and measures the size of individual particles in water
  - Particles are divided into size ranges and the number of particles is counted in each of these ranges
- One of the best monitoring tools available to optimize plant performance for the removal of particles
  - i.e. *Giardia* and *Cryptosporidium*
  - Monitors the removal efficiency of particles in the same size range as *Giardia* and *Crypto*
- Cannot replace other analytical tests for *Giardia* and *Crypto*
  - Cannot tell difference between clay particle and microorganism

RECORDKEEPING

- Accurate records should be maintained
  - Process water quality
    - Turbidity and color
  - Process operation
    - Filters in service, filtration rates, loss of head, length of filter runs, frequency of backwash, backwash rates, UFRV
  - Process water production
    - Water processed, amount of backwash water used, and chemicals used
  - Percent of water production used to backwash filters
  - Process equipment performance
    - Types of equipment in operation, equipment adjustments, maintenance procedures performed, and equipment calibration

SURFACE WATER TREATMENT RULE (SWTR)

- Set of treatment technique requirements that apply to all water systems using surface water and those using groundwater that is under the influence of surface water (subpart H systems)
- Defines surface water as "all water open to the atmosphere and subject to surface runoff"
- Requires that all systems properly filter the water
- Requires that all systems using surface water to disinfect the water (no exceptions)
- At least 99.9% (3-log) removal and/or inactivation of *Giardia* cysts
- At least 99.99% (4-log) removal and/or inactivation of enteric (intestinal) viruses

TURBIDITY REQUIREMENTS

Type of Filtration	Monitoring Frequency	Turbidity Level
Conventional	Every 4 hours	< 0.3 NTU
Direct	Every 4 hours	< 0.3 NTU
Diatomaceous Earth	Every 4 hours	< 1.0 NTU
Slow Sand	Once per day*	< 1.0 NTU

- All filtration systems must meet these standards in 95% of the measurements taken for each month (0400-45-01-.31)

*For any system using slow sand filtration or filtration treatment other than conventional treatment, direct filtration, or diatomaceous earth filtration, the Department may reduce the sampling frequency to once per day if it determines that less frequent monitoring is sufficient to indicate effective filtration performance.

Filtration
Vocabulary

A. Absorption

B. Activated Carbon

C. Adsorption

D. Air Binding

E. Backwashing

F. Breakthrough

G. Colloids

H. Conventional Filtration

I. Diatomaceous Earth

J. Diatoms

K. Direct Filtration

L. Fluidized

M. Head Loss

N. Uniformity Coefficient

_____ 1. Adsorptive particles or granules of carbon usually obtained by heating carbon.

_____ 2. A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation, minimal flocculation, and filtration.

_____ 3. The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls, or restriction caused by fittings.

_____ 4. The ration of the diameter of a grain of a size that is barely too large to pass through a sieve that allows 60% material (by weight) to pass through

_____ 5. The process of reversing the flow of water back through the filter media to remove the entrapped solids.

_____ 6. Very small, finely divided solids that remain dispersed in a liquid for a long time due to their small size and electrical charge.

_____ 7. A fine, siliceous (made of silica) “earth” composed mainly of the skeletal remains of diatoms.

_____ 8. The clogging of a filter due to the presence of air released from water.

_____ 9. The gathering of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

_____ 10. A method of treating water that consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration.

_____ 11. Unicellular (single cell), microscopic algae with a rigid internal structure consisting mainly of silica.

_____ 12. A mass of solid particles that is made to flow like a liquid by injection of water or gas

_____ 13. A crack or break in a filter bed allowing the passage of floc or particulate matter through a filter.

_____ 14. The taking in or soaking up of one substance into the body of another by molecular or chemical action.

Answers

1. B
2. K
3. M
4. N
5. E
6. G
7. I
8. D
9. C
10. H
11. J
12. L
13. F
14. A

Filtration
Review Questions

1. What is the major difference between conventional filtration and direct filtration?

2. List the particle removal mechanisms involved in the filtration process.

3. List the four specific classes of filters.

4. What material is used for precoat and body-feed operations?

5. Filtration rate is commonly expressed in what units?

6. What is the major operation difference between sand and dual-media filters?

7. What two main factors influence the time period before a filter becomes clogged?

8. Under what conditions is the filtration process stopped and the filter taken out of service for cleaning or backwashing?

9. List four types of surface wash systems for filters.

10. What is the primary purpose of using activated carbon (granular form) as filter media?

11. What is in-line filtration?

12. When and where are filter aid chemicals used?

13. What factors must an operator measure to control the performance of the filtration process on a day to day basis?

14. What is the most important water quality indicator used to monitor the filtration process?

15. List some of the typical functions performed by operators in the normal operation of the filtration process.

16. What could cause a sudden increase in head loss through a filter?

17. What types of records should be kept when operating a filtration process?

18. How would you identify an upset or failure in the filtration process or pretreatment processes?

19. List the indicators of abnormal filtration process conditions.

20. How could you make a quick determination of filtration removal efficiency?

21. What problems may be encountered during backwash?

22. How does a filter become air bound?

23. What is the SWTR definition of surface water?

24. Particle counters can be used as a substitute for indicating the potential removal of what two microorganisms that are a threat to public health when found in drinking water?

Filtration
Review Question Answers

1. Filtration, preceded by coagulation, flocculation, and sedimentation, is commonly referred to as conventional filtration process, the sedimentation step is omitted. Flocculation facilities are reduced in size or may be omitted.

2. Sedimentation on media, adsorption, biological action, absorption, straining

3. Gravity filtration, pressure filtration, diatomaceous earth filtration, slow sand filtration

4. Diatomaceous earth

5. Gallons per minute per square foot

6. Sand filters require more frequent backwashing because of their smaller media grain size. Dual media filters permit a higher filtration rate without a high head loss.

7. The amount of suspended solids in the water being treated and the filtration rate

8. A filter is operated until just before clogging or breakthrough occurs, a specified time period has passed or a specific head loss is reached.

9. Baylis, fixed grid, rotary, air scour

10. To remove taste and odor causing compounds, as well as other trace organics from the water

11. Inline filtration refers to the addition of filter aid chemicals immediately prior filtration. Chemicals are added directly to the filter inlet pipe and are mixed by the flowing water

12. Filter aid chemicals are usually added just prior to filtration in the solids removal process during normal operation and during periods of pretreatment process upset, or when operating at high filtration rates.

13. Filter influent water quality (turbidity), filter performance, filter effluent water quality

14. Filter influent and effluent turbidity

15. Monitor process performance, evaluate water quality conditions and make appropriate changes, Check and adjust process equipment, backwash filters, evaluate filter media conditions, visually inspect facilities

16. Surface sealing of the filter media

17. Process water quality, process operation, process water production, percent of water production used to backwash filters, process equipment performance

18. Rapid changes in head loss buildup in the filter or turbidity breakthrough

19. Mudballs in filter media, media cracking or shrinkage, media boils during backwash, excessive media loss or visible disturbance, short filter runs, rapid head loss buildup, turbidity breakthrough, filters that will not come clean during backwash, algae on walls and media

20. Comparing filter influent and effluent turbidity levels with those of recent record

21. Media boils, media loss, and failure of the filter to come clean during the backwash process

22. By the release of dissolved air in saturated cold water due to the decrease in pressure

23. All water open to the atmosphere and subject to surface runoff

24. *Giardia* and *Cryptosporidium*