Wisconsin Department of Natural Resources
Wastewater Operator Certification

Introduction to Tertiary Filtration Study Guide

November 1991 Edition

Subclass H

Wisconsin Department of Natural Resources
Bureau of Science Services
Operator Certification Program
P.O. Box 7921, Madison, WI 53707

http://dnr.wi.gov

Preface

This operator's study guide represents the results of an ambitious program. Operators of wastewater facilities, regulators, educators and local officials, jointly prepared the objectives and exam questions for this subclass.

Note: Key knowledges 2.1.9 and 2.1.10 were edited July 2013.

How to use this study guide with references

In preparation for the exams you should:

1. Read all of the key knowledges for each objective.

2. Use the resources listed at the end of the study guide for additional information.

3. Review all key knowledges until you fully understand them and know them by memory.

It is advisable that the operator take classroom or online training in this process before attempting the certification exam.

Choosing A Test Date

Before you choose a test date, consider the training opportunities available in your area. A listing of training opportunities and exam dates is available on the internet at http://dnr.wi.gov, keyword search "operator certification". It can also be found in the annual DNR "Certified Operator" or by contacting your DNR regional operator certification coordinator.

Acknowledgements

Special appreciation is extended to the many individuals who contributed to this effort.

Thomas A. Kroehn, Director of Office of Operations and Maintenance, DNR.

Thomas P. Mickelson, Coordinator, Operator Certification and Training, DNR.

Wastewater operators were represented by:

Bob Anderson - Brooklyn
Jerry Carroll - Lancaster
Berger Enstad - Sun Prairie
Phil Hoopman - Ripon
Pat O'Flahrity - Mineral Point
Phil Hoopman - Ripon
Cheryl Janny - Watertown
Mike Kelly - Jefferson

Dave Paulson - Monroe
Kevin Pub - Watertown
Joel Sampson - Lomira
Brian Schepp - Waupun
Mark Sillmon - Waterloo
Steve Swiggum - Marshall
Dennis Westhuis - Waupun

VTAE and educational interests were represented by:

Glen Smeaton, Environmental Education
Pat Gomez, Moraine Park Technical College
Bill Hughes, Mead & Hunt

DNR district offices were represented by:

Tom Mugan, Southern District, Fitchburg

DNR central office was represented by:

Lori Eckrich, Madison
Ron Wilhelm, Madison

Table of Contents

Chapter 1 - Principle, Structure and Function

Section 1.1 - Principle of Tertiary Filtration

1.1.1 Discuss the primary purpose of tertiary filtration.

Tertiary filtration is used to reduce BOD, total suspended solids and phosphorus in the final effluent. Suspended solids will have BOD and phosphorus associated with it so by removing suspended solids to very low levels will also significantly reduce the BOD and phosphorus. Filtration may be required to consistently achieve stringent effluent limits for BOD, TSS and phosphorus.

1.1.2 Describe receiving stream water quality/quantity characteristics that would require tertiary filtration.

Stream water quality classifications describe the use that the water course should achieve. The general classifications are exceptional waters (no discharge allowed), high quality (trout streams with strict effluent limits), normal fish and aquatic life (majority of water courses), intermediate (low quality), and marginal (basically effluent streams). Tertiary filtration could be required on almost any of these classifications in order to meet the stream classification requirements. The flow quantity in the stream is used to determine the allowable loading without affecting the intended stream use (low flow streams would have strict effluent limits while larger streams may need only secondary limits).

1.1.3 Define the terms headloss and terminal headloss.

Headloss is defined as the loss of flow energy of the water as it passes through a filter. The greater the vertical difference between the upstream water levels and the downstream water levels, the greater the headloss. Terminal headloss is the maximum headloss allowed prior to backwashing.

Section 1.2 - Structure and Function

1.2.1 Describe where water enters and leaves a filter during the following functions:

A. During a filter run
B. During a backwash cycle

A. During a filter run: after secondary treatment the final effluent flows to the filter via various piping arrangements; liquid flow to the filter is normally controlled by weirs or valving arrangements; the water leaves the filter after passing through the media using an underdrain system

B. During a backwash cycle: during a backwash cycle the flow through the filter is reversed, with the backwash water entering the underdrain system and flowing upward through the media; the backwash water is directed to a waste drain line that goes to a spent backwash tank or to the head of the treatment plant

1.2.2 Describe the function of the following parts of a filter:

A. Media
B. Underdrains
C. Washwater troughs
D. Media support

A. Media: the function of the media is to provide filtering to remove suspended solids; the suspended solids are "trapped" in the media

B. Underdrains: the function of the underdrains is to collect the filtered water and convey the water to downstream treatment units; the underdrains are also used during backwash to convey the backwash water to the filter media

C. Washwater troughs: the washwater troughs are channel-like devices located above the media used to convey backwash water from the filter to a waste drain line

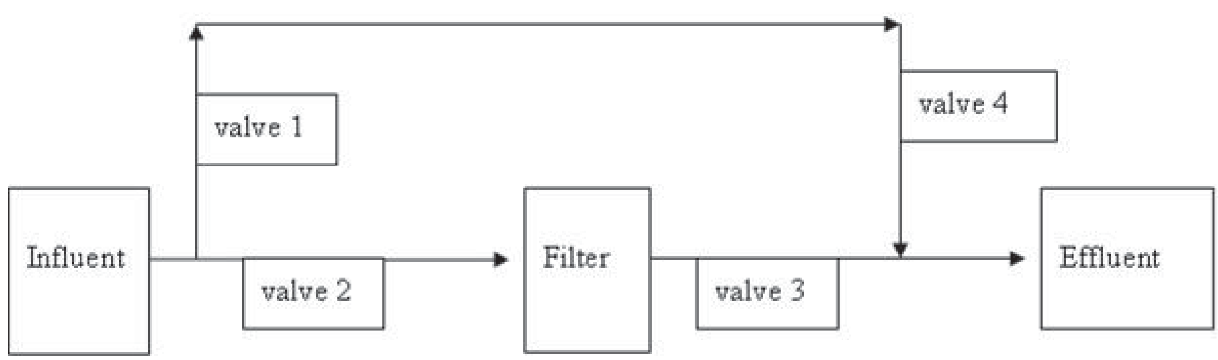
D. Media support: the media support is used to prevent the media from entering the underdrain system; depending on the type of filter, the support system can include a gravel bed on top of the underdrains, the top of the underdrain systems that provides media retaining strainers, or in the case of shallow bed filters various forms of porous plates.

1.2.3 Diagram a piping by-pass arrangement for a filter and indicate the valving required to isolate the filter.

With either deep bed or shallow bed filters, the filter is by-passed using piping, and valving arrangements to isolate the filter.

To isolate the filter close valves 2 and 3 and open valves 1 and 4.

Figure 1.2.3.1



1.2.4 Identify the common media materials used for filtration.

Coarse sand, fine sand, anthracite, and garnet are commonly used as filter media. The purpose of using these materials is to remove as much suspended solids as possible. The media present a barrier with pore size smaller than the suspended solids.

1.2.5 Describe the location of the various media in multi-media filters.

Stratified deep bed multi-media filters use various materials as media. During backwash with the bed fully expanded (fluidized) the media is redeposited in order of specific gravity and size (lightest and finest on the top). Specific gravity values are anthracite 1.6 to 1.7 with an effective size of 1.0-1.2 mm, sand 2.65 with an effective size of 0.5-0.6 mm, and garnet 4.0 to 4.6 with an effective size of 0.3-0.4 mm.

Most multi-media filters would have the following sequence from top to bottom anthracite-sand-garnet. If gravel is used for media support it would be on the bottom above the underdrains. The common dual-media would be anthracite and sand. Large solids would be retained in the upper media with finer solids retained in the lower smaller effective size media.

Typical dual and multi-media filters will have total media depth of 30" to 48". The anthracite in dual-media filters would range between 8" to 24".

Shallow bed filters (less than 18") use just sand with an effective size of 0.5 to 0.6 mm. Single media filters may be stratified or unstratified.

1.2.6 Discuss the common auxiliary cleaning aids that may be used during backwashing to aid in cleaning the media.

Air scour and surface jets may be used to aid in cleaning the media during backwashing. Surface jets are used in some filters to increase shearing action during backwash which aids in the cleaning of the media and surface encrustations. Air scour increases turbulence and bed expansion during the backwash cycle. The increased agitation of the filter bed by the air scour improves the removal of solid particles from the media. Air scour reduces the formation of mudballs and reduces the amount of backwash water needed.

Chapter 2 - Operation and Maintenance

Section 2.1 - Operation

2.1.1 List the items to consider in starting-up a filter that is new, replaced, or has been stored dry.

1. Check for tools/debris that may have been left in the filter
2. Check mechanical equipment
3. Fill slowly from the bottom to push air from the media (it may help to soak dry media)
4. Start filter operation
5. Observe an entire filter cycle

Note: With shallow bed filters start-up is accomplished by filling the effluent channel with clean water (chlorinated final effluent or city water). With deep bed filters this is accomplished with the backwash system. Operators should be especially careful in starting stratified bed multi-media filters to avoid upsetting (de-stratifying) the media.

2.1.2 Explain the operating principles of deep bed filters.

In deep bed filters some of the media is coarser and porosity is higher than with shallow bed filters. Multi-media filters may contain anthracite, coarse sand, or multiple layers of different types of media. The particles penetrate from top to bottom of the media and filter runs are longer. Individual filters are taken out of operation during backwash and air scour or surface jets are sually used for cleaning.

2.1.3 Describe the operating principles of shallow bed filters.

In shallow bed filters the media, usually sand, is relatively fine and porosity is lower. Particles are collected on or near the media surface and do not penetrate the media as far. Media clogging occurs faster. Backwash is usually continuous and is performed on thin sections of the filter allowing the filter to remain in operation during backwash. The backwash uses only water.

2.1.4 Discuss the expected ranges of effluent quality limits from a properly functioning plant with tertiary filtration.

Effluent quality limits of BOD and/or suspended solids should range from 2 - 15 mg/L. Range varies according to the season, secondary treatment efficiency, and flow rate.

Note: The range is somewhat higher (2 - 25 mg/L) for lagoon systems where algae is a problem.

2.1.5 State the normal filter run flow rates and run duration for deep bed filters.

Filter run flow rates add water slowly from the bottom of the filter. About 5-8 gpm/sq ft. The duration of filter runs may range from 12 hours to a week. A common interval would be several days depending on the flow rate and influent quality.

2.1.6 State the normal filter run flow rates and run duration for shallow bed filters.

Filter run flow rates are slightly less than deep bed filters 1.5-2.0 GPM/sq ft. with peak flows of about 4.0 GPM/sq ft. The duration of filter runs are generally shorter. Duration ranges from 1 to 3 hours. Filters are generally backwashed at least twice per day depending upon flow rate and influent quality.

2.1.7 Discuss the situations when an operator would bypass a filter or the entire filtration process.

It may be necessary to bypass a particular filter when individual cells are taken out of service for repair or maintenance. Deep bed filters are taken out of service for backwashing. Individual situations may warrant bypassing the entire process by some or all of the flow (e.g. power failure or extremely high flow rates). Bypassing should be employed to avoid damage to equipment. The entire filtration process could be bypassed when secondary effluent meets discharge permit limits without tertiary filtration.

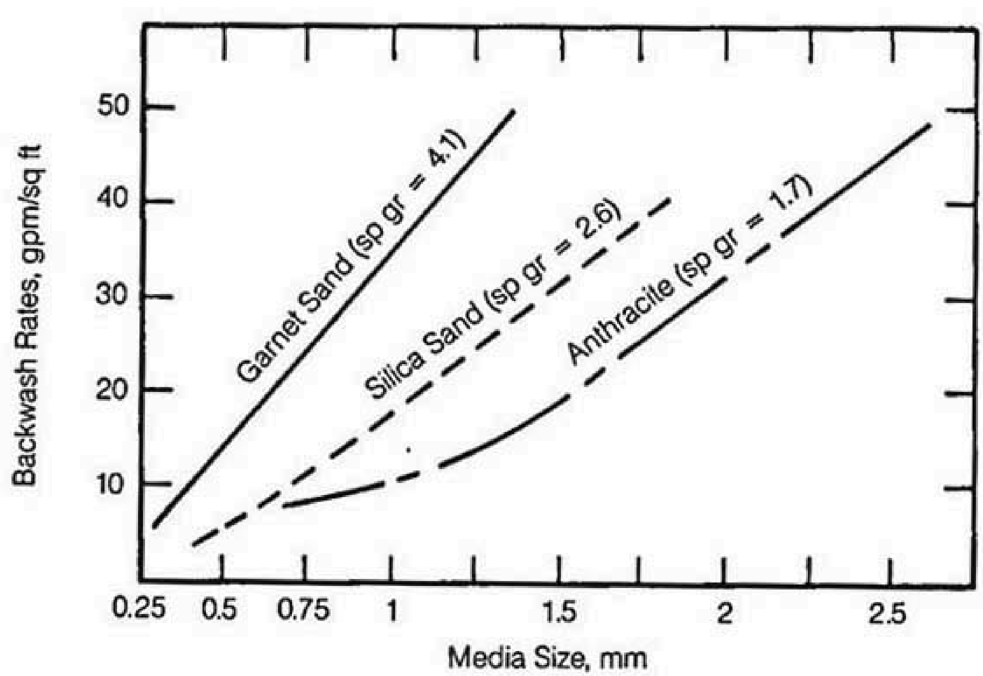
2.1.8 Explain the purpose of backwashing a filter.

The purpose of backwashing a filter is to remove solids that are trapped in the media. The backwash process is also used during start-up to ensure removal of air trapped in the media.

2.1.9 Discuss backwash rates for filter medias.

Filters are either single, dual, or multi-media beds. Backwash rates are dependent upon the media and media size (see figure 2.1.9.1). Typical backwash rates are 10 – 20 gpm/sq ft. Generally, backwash cycles are about 6 – 10 minutes for deep bed filters and 4 – 5 minutes for shallow bed. In total the backwash process requires approximately 100 gal/sq ft. The most effective cleaning mechanism during backwash is the erosive collisions of particles against one another. This is accompanied by upward water flow and agitation through air scour. Minimum air scour rates typically range from 3 – 5 scfm/sq ft and are dependent on the depth of the filter bed.

Figure 2.1.9.1



WEF Manual of Practice No. 8 Diagram

2.1.10 Key Knowledge deleted

2.1.11 Identify the range of backwash water used as a percentage of plant flow.

The normal amount of backwash water would be 1 - 5% of plant average daily flow.

2.1.12 State the maximum recommended time a deep bed filter should run before being manually backwashed.

The running time prior to backwash ranges from 40-80 hours before an operator should manually start the backwash cycle. Most operators with multiple filters would evaluate the need to backwash on a daily basis. Backwash would be scheduled based on headloss, time in service, or total flow through the filter.

2.1.13 State the maximum recommended time a shallow bed filter should run before being manually backwashed.

The running time prior to backwash is usually 24 hours before an operator should manually start the backwash cycle.

2.1.14 Outline the proper deep bed filter backwash sequence.

1. Close the influent and effluent valves
2. Open the backwash waste valve to drain the troughs
3. Start the backwash pumps to raise the bed (1-2 min)
4. Turn on the air scour (or surface jets) (4-6 min)
5. Turn the air off and backwash until the water is clear (2-4 min).
6. Stop the backwash water
7. Close the washwater waste valve
8. Open the effluent and influent valves

2.1.15 Outline the proper shallow bed filter backwash sequence.

1. Do not shut-off the influent

2. Start the backwash pump and washwater pump carriage (backwash is normally initiated automatically); the carriage runs across the filter usually stopping with one pass

3. If the filter bed is very dirty the headloss through the filter will cause the process to repeat

4. If manually backwashed the operator can make as many passes as deemed necessary

2.1.16 List the operational situations when it is not good procedure to allow filter headloss to activate the automatic backwash.

1. When it is suspected that mudballs have formed
2. When solids are breaking through before occurrence of terminal headloss
3. When too much organic material is collecting in the filter media indicating a need for more thorough backwashing

2.1.17 List the possible reasons for a filter being able to go for more than seven days before headloss activates the automatic backwash.

Terminal head loss (the point at which automatic backwash starts) may not be reached on time for the following reasons:

1. Breakdown in the filter bed is allowing water to channel through the media
2. Flows are very low
3. Influent solids are low
4. Media is too coarse and is not catching enough solids
5. Improper activation set-point

2.1.18 Describe how spent backwash water is handled.

Backwash is returned to the head of the treatment plant similar to other sidestreams and passed through the plant for treatment. To moderate the flow of backwash wastewater tanks are often used to hold flows until they can be treated. Low flow periods can be used to minimize influent plant loadings.

2.1.19 List the reasons for chlorinating a filter.

1. To prevent clogging of media and support with biological growth
2. To control odor
3. To control hatching of aquatic insects

2.1.20 List the best procedure for removing and returning a deep bed filter to service.

1. Clean throughly (backwash longer than normal); this cleaning may include chlorination
2. Leave the filter flooded (with chlorinated water if possible)
3. Before returning the filter to service it should again be backwashed

2.1.21 List the best procedure for removing and returning a shallow bed filter to service.

1. Shut-off the influent channel
2. Shut-off the effluent channel to isolate
3. Superchlorinate
4. Run backwash system without using washwater pump for a period of a day or two
5. Allow chlorine to dissipate before pumping washwater back to the head of the plant
6. Leave the filter flooded
7. Before returning the filter to service it should again be backwashed

Section 2.2 - Maintenance

2.2.1 List the items to consider in establishing a maintenance program for both deep bed and shallow bed tertiary filters.

A. Deep bed:

1. Maintain the compressed air supply system
2. Maintain all valves
3. Maintain the backwash pumps and electric drive motors
4. Inspect the underdrain system for presence of media
5. Check (measure) for possible media loss; measure from a fixed point (such as the lip of a backwash trough) to the surface of the media
6. Check all gauges and controls
7. Check surface scour mechanisms

B. Shallow bed:

1. Maintain the alignment of the traveling bridge mechanism
2. Lubricate the traveling bridge drive mechanism and rollers
3. Change oil on the gear drive for the traveling bridge
4. Adjust the spring tension and check for wear on the backwash valve water chamber assembly (boot)
5. Replace the lost and shifted media

6. Inspect the underdrain system for presence of media
7. Maintain the backwash pumps and electric drive motors

2.2.2 Discuss reasons for keeping backwash water storage basins free of leaves and other debris.

Backwash basins should be free of leaves and other debris to avoid plugging the backwash system. If leaves or debris are present they can enter the backwash pumps and underdrains causing plugging as well as reducing the effectiveness of backwashing.

2.2.3 List what to look for during filter underdrain inspections.

1. Filter media
2. Organic matter

2.2.4 Explain the reasons for periodically cleaning and inspecting underdrain orifices of a deep bed filter including how it is done.

Why - the orifices should be cleaned to remove organic growth and improve efficiency of the air scour and backwash

How - backwash with chlorinated water and/or physically uncover and inspect orifices

2.2.5 List the consequences of having a spare parts inventory that is too small and/or too large.

1. Too small - extended downtime waiting for parts
2. Too large - too much capital tied-up with excess parts that may never be used

Chapter 3 - Monitoring and Troubleshooting

Section 3.1 - Monitoring

3.1.1 Describe the daily quantitative and visual observations of the filter that the operator should make.

A. The headloss through the filter
B. The turbidity of the effluent
C. The suspended solids in the effluent
D. The loss of filter media in the effluent, underdrains, and backwash basins
E. All gauges and flow meters
F. The quality of the filter influent
G. Any floating solids (including any oil/grease)

3.1.2 Discuss what filter's flows should be measured.

An operator should measure filter throughput and the amount of backwash water used.

3.1.3 State what to observe to determine if backwashing is effective.

A headloss of 0.5 ft. to 1.5 ft. after backwashing indicates the filter has been properly cleaned. Visual observations help the operator determine if the washwater is clean or if media is being washed out of the filter. Good operator observation can ensure quality backwashing and can reduce backwash volume returned to the plant for treatment.

3.1.4 List ways an operator can monitor filtration to determine if the media is being adequately backwashed.

1. Perform a clean media test
2. Visually examine the media
3. Visually examine the backwash process watching for uniform water flow through the filter bed and clear backwash water

3.1.5 Explain how to use the results from BOD and suspended solids test to determine filter effectiveness.

When total BOD or suspended solids from a tertiary filter plant exceed 10 parts per million an operator should inspect the operation of the filter system. In the event of higher BOD readings the operator should check for soluble BOD which may indicate problems with the secondary process.

Section 3.2 - Troubleshooting

3.2.1 Discuss the provisions for emergency overflows for filters.

When the water level rises to a certain point the filter goes into an automatic backwash mode. If the water continues to rise there is normally an overflow structure that would carry water to the outfall. It is highly recommended that there be a high water level alarm and a float operated pump shut-off switch activated when high water levels occur.

3.2.2 Define the term "mudball" and state where they are located in a filter.

The term mudball refers to accumulations of organic solids in the media binding the media together. The organic solids can come from biological activities occurring in the filter caused by poor secondary treatment allowing high soluble BOD to reach the filter. When plants remove phosphorus mudballs may also include chemical floc materials. Mudballs cause headloss to build-up rapidly by restricting flow through portions of the filter. Mudballs would be located within the sand media layer for single media filters and beneath the anthracite at the surface of the sand layer of dual media filters.

3.2.3 Outline the corrective steps for excessive media fouling.

In the event of a media fouling problem the operator should:

A. Improve the performance of secondary treatment units
B. Increase the backwash frequency
C. Employ air scour and/or surface jetting (if possible)
D. Put additional filters on line (if possible)
E. Change the media (as a last resort)

Media fouling may also be caused by low surface loading rates resulting in infrequent automatic backwashing of the filter.

3.2.4 List the causes and problems of surface binding of a filter.

A. Possible causes of surface binding are:

1. Excessive loading rates
2. Large particle size in relation to media size
3. Use of excess chemical dosage
4. Media effective size is too small

B. Problems of surface binding are:

1. Surface binding causes short filter runs
2. Increases the cost of operation
3. May overload upstream processes
4. May cause a condition known as "negative head"; this causes air entrapment in lower levels which can cause media loss or mixing during backwash

3.2.5 List the causes and corrective actions for solids breakthrough in a tertiary filter.

A. Causes:

1. Inadequate and/or infrequent backwashing
2. An overloading of the filter (including use of filter aids)
3. A breakdown of the media resulting in channeling

B. Corrective actions:

1. Improve backwash operations
2. Increase the performance of the secondary process
3. Correct the dosage of the filter aid

3.2.6 List some common operational problems related to filter backwashing.

1. An excessive length of backwash cycle could cause hydraulic overloading of the plant; this would result in a higher treatment cost and possibly a reduction in effluent quality

2. The operator has to have experience in knowing when to stop backwashing the filter

3. The possibility of damage to the underdrain system and/or the loss of stratification (of multi-media filter) if backwash is initially turned-on or shut-off too rapidly

4. A lack of appropriate backwash might cause build-up of solids in the filter if the media is not properly cleaned

5. The operator might fall victim to inadequate overall operator observation habits if automatic backwashing is used exclusively

6. There could be a loss of media resulting from excess backwash rates

3.2.7 List the causes and corrective actions for excessive backwash rates in the following situations:

1. Loading excessive solids to the filter
2. Excessive solids build-up in the media
3. Poor quality effluent from the filter

1. Loading excessive solids to the filter:

Cause: due to poor up-stream treatment
Correction: improve performance of up-stream treatment units

3. Excessive solids build-up in the media:

Cause: excessive solids loading, too short a backwash cycle, or infrequent backwashing
Correction: improve effectiveness of the backwash (more often and longer cycle); better secondary treatment operation

C. Poor quality effluent from the filter:

Cause: the operator is relying solely on the automatic backwash cycle
Correction: evaluate the filter effluent and initiate manual backwash as necessary; it may be necessary to change the automatic backwash cycle to correct this problem

3.2.8 Describe the causes and corrective actions for the following:

A. Excessive air released during backwashing
B. High effluent suspended solids
C. Air binding of the filter

A. Excessive air released during backwashing:

1. Cause: improper adjustment on blower discharge; use of air scour with backwash water can cause loss of media

Correction: adjust the blower output and use air scour first (2-5 CFM/sq ft.); apply a small amount of backwash water, shut-off air, and finish backwashing

2. Cause: too much air directed to one filter
Correction: control air flow to the filters; adjust the blower speed to produce less air

B. High effluent suspended solids:

1. Cause: small particle size
Correction: change the media or use chemicals (filter aids) to increase the particle size

2. Cause: channeling of the media causing excess flow velocities in portions of media
Correction: vigorously clean the media to eliminate mudballs and any solid media

aggregation

C. Air binding of filter:

1. Cause: when filter influent contains air dissolved at or near saturation and when pressure is reduced below atmospheric (known as negative head) in the media, the air can come out of solution with the formation of gas bubbles; the accumulation of these bubbles will greatly reduce filter flows

Correction: more frequent backwashing at lower rates to reduce media loss due to buoyancy of gas bubbles attached to the media (especially, anthracite)

2. Cause: starting-up a dry filter
Correction: fill with water from the bottom at a slow rate to remove all air from the media prior to placing in service; if the media is dry it should be filled from the bottom and allowed to soak for 8 hours before backwashing

3. Cause: surface binding is causing a negative head condition
Correction: backwash for a longer time at slow rates

3.2.9 Discuss possible causes and corrective actions for excessive loss of media in a deep bed filter.

A. Cause: too much air applied with the backwash water
Correction: properly backwash the filter by starting with a low water flow rate turn-on the air scour; turn-off the air scour before increasing backwash flow to the normal flow rate

B. Cause: hydraulic short circuiting sweeping the media into the backwash trough
Correction: baffle or block portions of the backwash trough where the solids are carried over; correct the cause of short circuiting or redesign backwash troughs

C. Cause: damaged filter underdrain and media loss through the bottom
Correction: replace and repair as needed

D. Cause: excessive backwash flow rates which is causing media to be washed out
Correction: reduce the backwash flow rate to reduce backwash velocity

E. Cause: improper start-up of the dry filter
Correction: fill slowly from the bottom and soak if necessary to remove air from the filter

Chapter 4 - Safety and Calculations

Section 4.1 - Safety

4.1.1 List the items of personal safety to consider in the operation of tertiary filters.

1. Turn-off, lock-out, and tag the electricity when performing maintenance or repair
2. Before entering filter tanks check for safe atmosphere
3. Prevent falls by securing ladders when entering filter tanks

4. Wear protective clothing (if appropriate)
5. If chlorine is used be aware of chlorine safety procedures
6. Maintain safety railings

Note: A deep bed tertiary filter tank can be a Class 1 or Class 2 confined space area especially if the tanks are shut-down for painting or repair.

4.1.2 List the precautions that should be taken when chlorinating a filter with a gas chlorination system or when using calcium hypochlorite.

1. Do not improvise with hook-ups when using chlorine gas
2. Adhere to standard chlorine safety precautions
3. Avoid discharge of highly chlorinated water directly to the receiving stream or to the biological treatment process
4. Use protective clothing if contact with a chlorine solution is expected as this is a strong oxidant that could cause burns or respiratory problems

Section 4.2 - Calculations

4.2.1 Given data, calculate the percent of average daily flow that is used for backwash.

Given:
Average daily flow = 0.3 MGD
Number of filters = 2
Backwash flow rate = 1,000 GPM
Length of backwash = 8 minutes
One filter is backwashed each day

Formula:

percent backwash = (backwash flow (GPM) x backwash length (min)) ÷ daily flow (gal) x 100

backwash = (1,000 x 8) ÷ 300,000 x 100

= 2.7%

4.2.2 Given data, calculate the flow rate through a filter in gallons per minute per square foot.

Given:
Number of filters in service = 2
Size of filters - length = 12 feet
Width = 10 feet
Flow to filters = 0.8 MGD

Formula:

flow rate (GPM/ft²) = (flow rate to filters (GPM) ÷ 1,440 (min/day)) ÷ (number of filters x filter area) flow rate = (800,000 ÷ 1,440) ÷ (2 x 12ft x 10 ft)

flow rate = 555.6 ÷ 240

= 2.3 GPM/ft²

4.2.3 Given data, calculate the amount of backwash water used.

Given:
Backwash pump flow = 1,200 GPM
Filter backwash time = 8 minutes

Formula:

water used (gal) = flow rate (GPM) x time (min)

= 1,200 x 8

= 9,600 gallons

References and Resources

1. **ADVANCED WASTE TREATMENT.**

   1st Edition (1987), Kenneth D. Kerri. California State University, 6000 J Street, Sacramento, CA 95819-6025. Phone (916) 278-6142.

   http://www.owp.csus.edu/training/

2. **CONTROLLING WASTEWATER TREATMENT PROCESSES.**

   (1984). Cortinovis, Dan. Ridgeline Press, 1136 Orchard Road, Lafayette, CA 94549.

3. **OPERATION OF MUNICIPAL WASTEWATER TREATMENT PLANTS.**

   Manual of Practice No. 11 (MOP 11), 2nd Edition (1990), Volumes I, II, and III. Water Environment Federation (Old WPCF), 601 Wythe Street, Alexandria, VA 22314-1994. Phone (800) 666-0206.

   http://www.wef.org/

4. **OPERATION OF WASTEWATER TREATMENT PLANTS.**

   Manual of Practice No.11 (MOP 11) (1976). Water Pollution Control Federation, 601 Wythe Street, Alexandria, VA 22314-1994. Phone (800) 666-0206. (Probably out-of-Print, See Reference Number 3)

   http://www.wef.org/

5. **FILTRATION OF WASTEWATER SERIES:**

   Young, James C. Iowa State University, Ames, IA 50011.
   FILTRATION OF WASTEWATER USING SINGLE-MEDIA UNSTRATIFIED BEDS (1975).
   OPERATING PROBLEMS WITH GRANULAR-METER FILTERS USED FOR WASTEWATER TREATMENT (1978).
   COMPARISON OF SHALLOW-BED AND DEEP-BED FILTERS FOR WASTEWATER TREATMENT (1979).