Conventional and Direct Filtration

Focus on Public Health

Oregon Health Authority
OFFICE OF ENVIRONMENTAL PUBLIC HEALTH
Drinking Water Services

Class Outline

9 AM	Introduction/Overview
10:15 AM – 15 minute break	
10:30 AM	Coagulation/Flocculation
12 noon – Lunch (on your own)	
1 PM	Clarification/Sedimentation
2 PM	Filtration
2:15 PM – 15 minute break	
2:30 PM	Filtration (continued)
3:30 PM	General Operations
4:30 PM - End	

2

As we go through this training…

How you would answer the following questions?

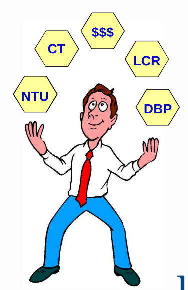
How do you define optimized performance?

What does a well managed plant look like?

How do you set priorities?

What is a basis for setting priorities in optimizing your treatment plant?

- Finished water quality?
- Production?
- Budgets?
- Time?

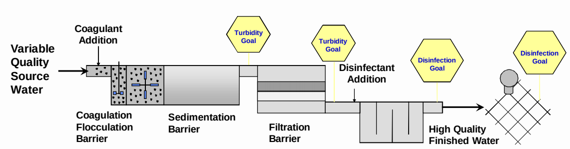


What Problem-Solving Tools Do You Have?

- Training
- Operational Guidelines
- Water quality goals
- Management support to conduct optimization studies often needed to meet those goals

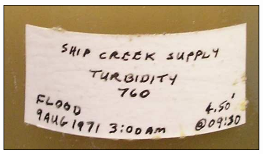
How do you interpret the data you have?

- Is it valid data?
- Is it enough (or too much) data?
- What are you trying to determine?
- Is there anything to compare it to (optimization goals, level of service, etc.)?



Are you prepared for unusual events?

- What happens if your streaming current meter stops working?
- Can you operate in fully manual mode?
- Can you treat water during a flood?

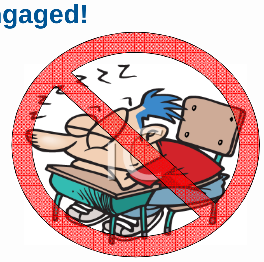


Sample of 760 NTU water taken from the Ship Creek supply Aug 9, 1971 – Fort Richardson, AK

Hopefully we can help you answer some of those questions today

Hopefully we can help you answer some of those questions today

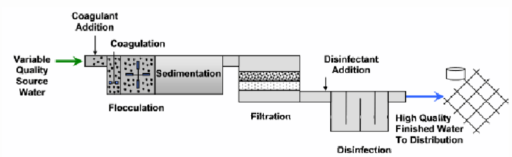
But you have to be engaged!



Overview

Conventional Filtration Treatment

"means a series of processes including coagulation (requiring the use of a primary coagulant and rapid mix), flocculation, sedimentation, and filtration resulting in substantial particle removal."



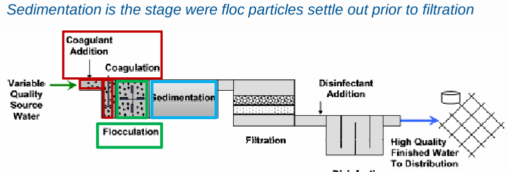
Overview

In conventional filtration treatment..

A coagulation chemical is added and rapidly mixed to neutralize particle charges

Flocculation is a stage of gentle mixing so that a larger settleable floc forms

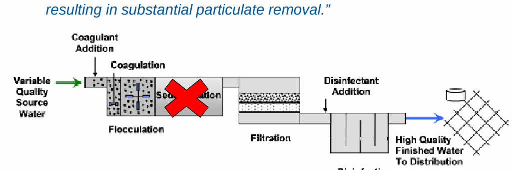
Sedimentation is the stage were floc particles settle out prior to filtration



Overview

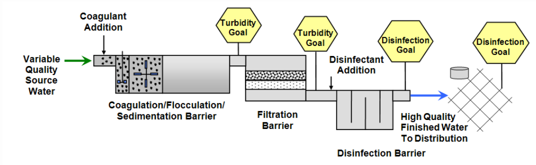
Direct Filtration Treatment

"means a series of processes including coagulation (requiring the use of a primary coagulant and rapid mix) and filtration but excluding sedimentation resulting in substantial particulate removal."



Overview

Regardless of the filtration type, the multiple barrier approach to public health protection applies – i.e., optimize barriers to Giardia and Crypto.



Overview - Giardia

Giardia lamblia is a protozoan which occurs in cyst form in the environment.

This is an image of Giardia lamblia showing the red outline of the cyst wall, which makes the cyst somewhat resistant to disinfection.

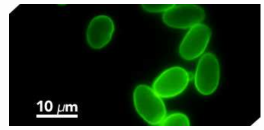


Photo Credits: H.D.A. Lindquist, U.S. EPA

Overview - Giardia

- Giardia are protozoan parasites which occur in a trophozoite and an oval-shaped cyst form.
- The trophozoite causes diarrheal disease of the small intestines called Giardiasis.

Image from CDC's site: http://www.cdc.gov/parasites/crypto/index.html

- Cysts excreted in the feces of an infected host move passively through the environment. If cysts are subsequently ingested, infection may be transmitted to another vertebrate host.
- Cysts can survive for 2 to 3 months in water temperatures of less than 10°C, and almost a month at 21°C. Cysts are killed in 10 minutes at 54°C and almost immediately at boiling.

Overview - Giardia

How infective is Giardia and what is the incubation time of Giardiasis?

- Giardia cysts are highly infective.
  - As few as ten human-source Giardia cysts produced infection in a clinical study of male volunteers. (EPA, *Giardia: Drinking Water Fact Sheet*, September 2000)
  - Each year 4,600 persons with giardiasis are estimated to be hospitalized in the United States. Hospitalized cases are primarily children under five years of age, and dehydration is the most frequent co-diagnosis (EPA, 2000).
- The incubation period (time interval between ingestion and the first appearance of symptoms) can range from 3 to 25 days.

Overview - Giardia

What are the symptoms of Giardiasis?

- Giardia infection may be acquired without producing any symptoms, and this is often the case for children.
- In symptomatic patients, acute diarrhea is the predominate feature.
- In some instances, diarrhea may be transient and mild, passing without notice, while in others diarrhea can be chronic.
- Stools may be pale, greasy, and malodorous.

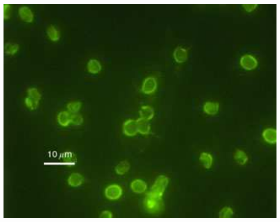
Overview - Giardia

What are the symptoms of Giardiasis?

- Other symptoms may include:
  - Abdominal cramps, bloating, and flatulence;
  - Weight loss;
  - Vomiting;
  - Death is rare.
- A potentially serious consequence is nutritional insufficiency which may result in impaired growth and development of infants and children.
- In otherwise healthy people, symptoms of giardiasis may last 2-6 weeks, however, occasionally they may last for months or years. Medications can help decrease this time.

Overview - Cryptosporidium

Cryptosporidium is another protozoan which occurs in cyst form.



This is an image of Cryptosporidum parvum oocysts (C. parvum), stained to show the intense green outline of the oocyst wall, which makes the oocyst very resistant to disinfection – optimal coagulation/filtration is critical to their removal.

Photo Credit: H.D.A. Lindquist, U.S. EPA

Oregon Health Authority

19

Overview - Cryptosporidium

- The infective stage of Cryptosporidium is called an oocyst. The oocyst consists of a very tough "shell" surrounding four individual parasites.
- After the oocyst is swallowed, the shell breaks open and the parasites are released.

Image from CDC's site: http://www.cdc.gov/parasites/crypto/index.html

Oregon Health Authority

20

Overview - Cryptosporidium

The parasites enter the cells that line the lower small intestine and begin to develop. After the parasite cells reproduce, two kinds of oocysts are produced:

1. Thin-walled oocysts that start another cycle of infection
2. Thick-walled oocysts that enter the environment in the feces and can then infect other animals

The disease is called cryptosporidiosis

Oregon Health Authority

21

Overview - Cryptosporidium

What are the symptoms and the incubation time of Cryptospordiosis?

- Symptoms may appear anytime from two to ten days after infection, with the average being from four to six days.
- The nature of acute disease (having a rapid onset and following a short but severe course) associated with C. parvum is
  1. Intestinal,
  2. Tracheal (trachea ('windpipe') associated) or
  3. Pulmonary (lung-associated) cryptosporidiosis.
- The most common symptom of cryptosporidiosis is watery diarrhea. Other symptoms may include stomach cramps, nausea, vomiting, dehydration, low-grade fever (99-102°F), fatigue, weakness and weight loss.
- Pulmonary and tracheal cryptosporidiosis in humans is associated with coughing and low-grade fever.
- Some people will be asymptomatic (will not develop any symptoms).

Oregon Health Authority

22

Overview - Cryptosporidium

How long do symptoms last?

- The C. parvum infection is self-limiting, and people with healthy immune systems are usually ill with cryptosporidiosis for one to two weeks before the infection begins to resolve.
- Some infected individuals may not even get sick
- In immune-compromised patients (elderly, very young, people with certain illnesses or organ donor recipients taking anti-rejection medications) symptoms are more severe and may last for several weeks with hospitalization being required.
- It is also possible for the infection to become chronic, and in some cases fatal.
- Those who are infected may shed oocysts in their feces for months, even after they no longer appear to be ill.

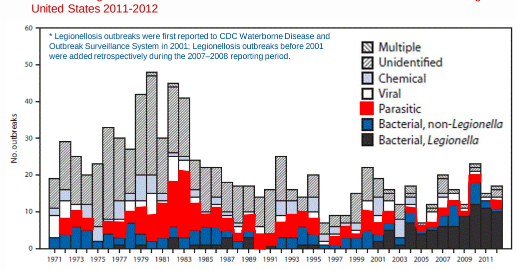
Oregon Health Authority

23

Overview - Outbreaks

How many drinking water associated disease outbreaks have there been from 1971-2012? ....

885 according to CDC's Surveillance for Waterborne Outbreaks Associated with Drinking Water – United States 2011-2012



Oregon Health Authority

24

Overview – Outbreaks

So how can you help protect your community from pathogens and avoid outbreaks?

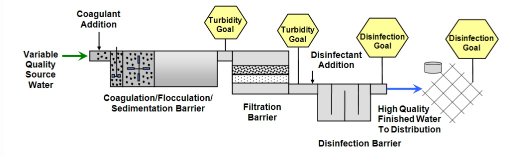
Health Oregon Authority

25

Overview – Outbreaks

So how can you help protect your community from pathogens and avoid outbreaks?

Optimize treatment for pathogen removal by optimizing particle removal (i.e. turbidity)



Health Oregon Authority

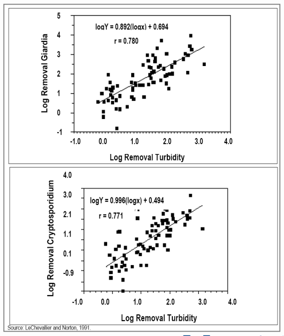
26

Overview – Optimization Goals

Why turbidity?

Turbidity removal is strongly correlated to removal of Giardia and Cryptosporidium.

- Emelko (2000) - Pilot scale work to assess *Cryptosporidium* removal through filtration *(University of Waterloo)*
  - Stable operation: 5 to 6 log (turbidity ~ 0.04 NTU)
  - End-of-run: 2 to 3 log (turbidity increase to 0.10 NTU)
  - Breakthrough: 1.5 to 2 log (turbidity increase to 0.3 NTU)



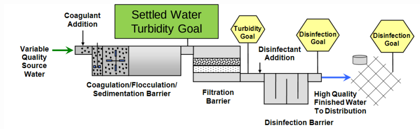
Health Oregon Authority

27

Overview – Optimization Goals

Settled water turbidity optimization goals (for conventional systems base on maximum daily raw & settled water turbidity taken from grab samples or on-line instrumentation)

- Settled turbidity ≤ 1 NTU, 95% of the time if average annual raw water turbidity is ≤ 10 NTU
- Settled turbidity < 2 NTU, 95% of the time if average annual raw water turbidity is > 10 NTU



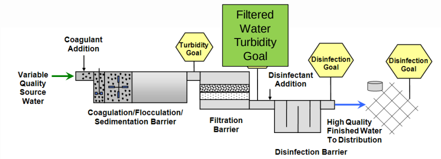
Health Oregon Authority

28

Overview – Optimization Goals

Filter effluent turbidity optimization goals (based on continuous 1-minute readings of individual filter effluent (IFE) and combined filter effluent (CFE) readings)

1. IFE & CFE Turbidity ≤ 0.10 NTU 95% time
2. Maximum IFE & CFE Turbidity: ≤ 0.30 NTU



Health Oregon Authority

29

Overview – Optimization Goals

Post backwash turbidity optimization goals

3. Minimize spike during filter-to-waste period (< 0.30 NTU)
4. Return to ≤ 0.10 NTU within 15 minutes
5. Return to service at ≤ 0.10

Health Oregon Authority

30

Overview – Goals Summary

Filter effluent turbidity optimization goals

1. Turbidity: ≤ 0.10 NTU 95% time
2. Maximum turbidity: ≤ 0.30 NTU

Post backwash turbidity optimization goals

3. Minimize spike during filter-to-waste period (≤ 0.30 NTU)
4. Return to ≤ 0.10 NTU within 15 minutes
5. Return to service at ≤ 0.10 NTU

31

Overview – Goals Summary

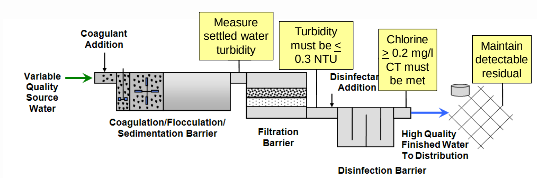
Why not just meet the regulatory turbidity standards?

- Regulatory standards are there to help protect against major pathogen breakthrough (e.g. up to 90% removal of Cryptosporidium at 0.3 NTU), but they do not reflect optimized pathogen removal (e.g. ≥ 95% removal at 0.1 NTU).
- Filter performance that exceeds regulatory standards for turbidity requires notification to the State, corrective action, and public notification (either a boil notice, notice within 30 days, or in the Consumer Confidence Report, depending upon the level of turbidity).
- Barely meeting the regulatory standards is generally not good practice.

32

Overview – Regulatory Requirements

Regulatory requirements also employ the multiple barrier approach



33

Overview – Regulatory Requirements

Well operated systems that achieve substantial particle removal (turbidity reduction) should be able to meet the Giardia and Cryptosporidium removal credits shown below.

Regulated Pathogen	Total Treatment Required	Filtration Type	Credit for Filtration	Treatment Needed Through Disinfection
Viruses	99.99% (4-log) removal/inactivation	Conventional and direct	0	4-log
Giardia	99.9% (3-log) removal/inactivation	Direct & some conventional w/inadequate sedimentation	99% (2-log)	1-log (0.5-log must be after disinfection)
		Conventional	99.5% (2.5-log)	0.5-log (all after disinfection)
Cryptosporidium	99% (2-log) removal	Conventional and direct	2-log	None in most cases depending upon levels of cryptosporidium in source water.

34

Overview – Turbidity Requirements

OAR 333-061-0030(3)(b)(A) – Maximum turbidity limits

Maximum contaminant levels for turbidity in drinking water measured at a point representing filtered water prior to any storage:

1. *Turbidity must be ≤ 0.3 NTU in at least 95% of the measurements taken each month.*
2. *Turbidity must not exceed 1 NTU at any time.*

35

Overview – Turbidity Requirements

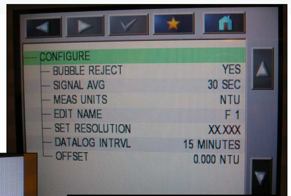
OAR 333-061-0040(1)(d) – Turbidity > 5 NTU

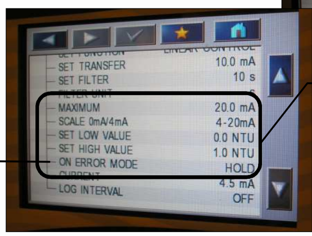
All surface water systems that provide filtration must report within 24 hours after learning that the filtered water turbidity exceeds 5 NTU.

Make sure your instruments can record data up to 5.49 NTU (e.g. 0-10 NTU)

36

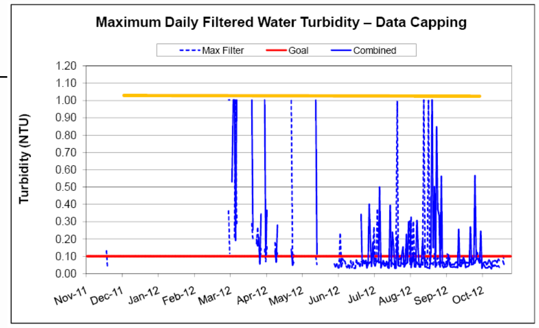
Error Mode is set to "Hold"
This means that the controller will send the last turbidimeter reading to SCADA should an error in the meter occur





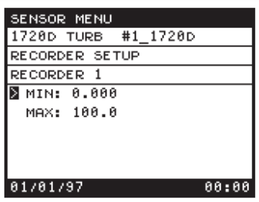
Low and high values of the on-line turbidimeters are set to 0 – 1.0 NTU
This means that the signal output is "read" by SCADA as
4 mA = 0 NTU
20 mA = 1 NTU

Scaling limited to 1 NTU may show up as "Data Capping"



Caution!

- The 4-20 mA scale must be set in both the turbidimeter controller and the PLC
- Example, the scale is changed in the controller to send a 20 mA signal when the turbidity is 10 NTU, but the change was not made in the PLC.
- A spike to 10 NTU occurs at which point the PLC receives a 20 mA signal. This spike will be stored in the SCADA system as a 1 NTU spike



Overview – Turbidity Requirements

OAR 333-061-0036(5)(b) – Settled Water Turbidity Monitoring

Conventional filtration systems must measure settled water turbidity every day.

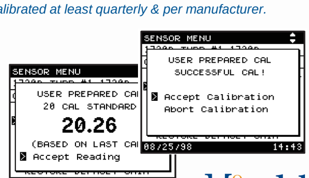
Individual Settled Water Turbidimeters
Seaside Roberts Pacer II contact adsorption clarifier plant 2015

Overview – Turbidity Requirements

OAR 333-061-0036(5)(b) – Combined Filter Effluent (CFE) Monitoring

Conventional & Direct Filtration Treatment Systems must:

1. *Measure combined filter effluent (CFE) water turbidity (prior to storage) every four hours (or more frequently).*
2. *Turbidimeters must be calibrated at least quarterly & per manufacturer.*

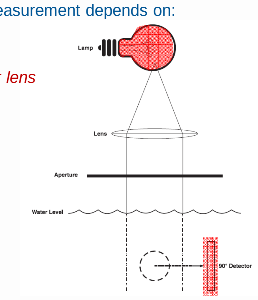


Overview – Turbidity Requirements

Accurate turbidity measurement depends on:

Strength of bulb

Clean photo detector lens



Overview – Turbidity Requirements

Accurate turbidity measurement depends on:

Strength of bulb

Clean photo detector lens

Photocells can leak fluid in 1720D and E, which may cause erratic readings

"The filling solution establishes a common refractive index so as the light passes through to the photocell it is as though there is no window. If only air were in the space of course the light would refract. One can typically see a bubble when the photocell is laid face up but not always. But if the area is void (the solution has leaked out) it is normally pretty obvious. The 1720D is now obsolete so I don't know whether or not we can still supply replacement photocells. If it seems to work okay, I wouldn't worry about it."

Terry Engelhardt
Application Sales Engineer - HACH
tengelhardt@hachhst.com

Overview – Turbidity Requirements

Accurate turbidity measurement depends on:

Strength of bulb

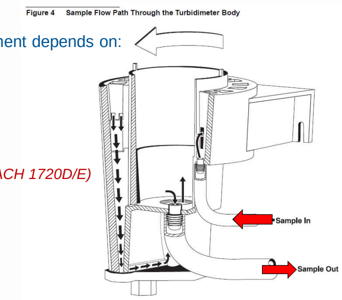
Clean photo detector lens

Sufficient flows

(e.g. 250-750 ml/min for HACH 1720D/E)

Good calibration

Good sample point



Overview – Turbidity Requirements

Accurate turbidity measurement depends on:

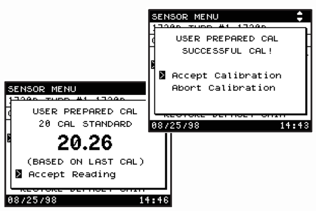
Strength of bulb

Clean photo detector lens

Sufficient flows

Good calibration

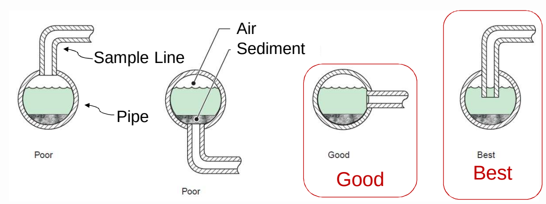
Good sample point



Overview – Turbidity Requirements

Accurate turbidity measurement depends on:

Good (or "Best") sample point



Poor Sample Taps

Overview – Turbidity Requirements

Accurate turbidity measurement depends on:

Strength of bulb

Clean photo detector lens

Sufficient flows

Good calibration

Good (or "Best") sample point

Attentive Operator

Overview – Turbidity Requirements

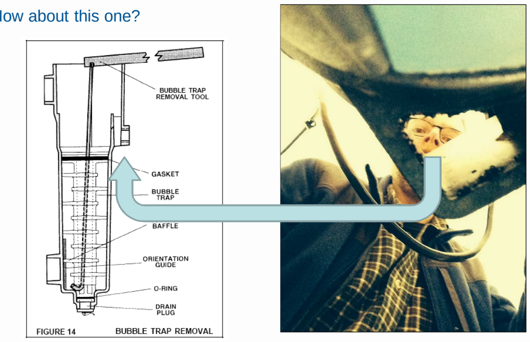
Anything wrong with this picture?

Overview – Turbidity Requirements

Anything wrong with this picture? How about now?

Introduction/Overview

How about this one?



Turbidity Data Integrity

- Data provided by instruments provides the basis for assessing water quality – important to get it right!
- Common problems
  - Sampling location
  - Measurement techniques
  - Calibration frequency and approach
- Possible solutions
  - May require investigations (special studies)
  - Modifications to sample lines
  - Establish guidelines on sample line cleaning
  - Establish calibration procedure

Overview – Turbidity Requirements

OAR 333-061-0036(5)(d) – Individual Filter Effluent (IFE) Monitoring

Conventional & Direct Filtration Treatment Systems must also:

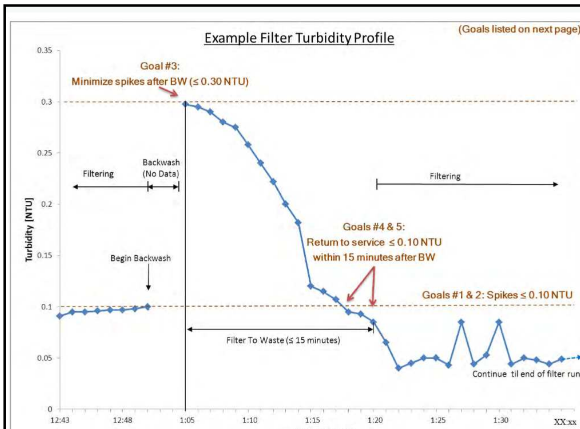
1. *Conduct continuous turbidity monitoring for each individual filter. IFE results must be recorded every 15 minutes. Turbidimeters must be calibrated at least quarterly & per manufacturer.*
2. *If there is a failure in continuous monitoring equipment, grab samples must be taken every 4 hours until the equipment is repaired and back on-line. Systems serving 10,000 people or more have 5 days to repair equipment while systems serving less than 10,000 people have 14 days.*
3. *Systems having only 1 or 2 filters may conduct continuous monitoring of CFE turbidity in lieu of IFE monitoring, although the recording and calibration requirements of -0036(5)(d) still apply*

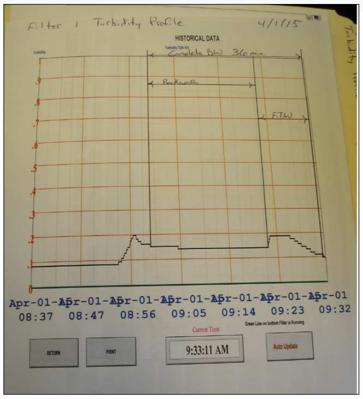
Overview – Turbidity Requirements

OAR 333-061-0036(5)(b) – Turbidity Profile

Conventional & direct filtration systems must develop turbidity profiles for individual filters every calendar quarter.

Profiles consist of a graph showing turbidity over a complete filter run, including filter start-up, duration of the run, backwash, and filter-to-waste.





This is a good example of a filter profile of the backwash and filter-to-waste process in that:

- The scale is readable,
- The start and end of backwash and filter-to-waste are clearly labeled;
- It shows that a backwash was initiated at 0.2 NTU.
- After the backwash, it was filtered to waste until turbidity dropped to 0.1 NTU.

Overview – Turbidity Requirements

OAR 333-061-0040(1)(e)(B)(ii) and -0040(1)(e)(C)(i) – Turbidity Triggers

1. Certain circumstances or "triggers" require water systems to take corrective actions, based on population served.
2. *If a system only has one or two filters and only measures CFE turbidity, these triggers also apply to the CFE readings.*
3. *There are 4 turbidity triggers.*
4. *Corrective actions may include developing or performing a:*
   - *Filter Turbidity Profile*
   - *Filter Self-Assessment*
   - *Comprehensive Performance Evaluation*

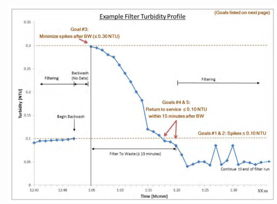
IFE Turbidity Triggers	Required Actions: Serving 10,000 or more people	Required Actions: Serving fewer than 10,000 people
1. IFE turbidity > 1.0 NTU in 2 consecutive measurements taken 15 minutes apart	Report: 1. Filter number, name, or identifier 2. Turbidity values over 1.0 NTU 3. Dates of occurrence 4. Cause of occurrences 5. A filter turbidity profile may be needed	
2. IFE turbidity > 1.0 NTU in 2 consecutive measurements taken 15 minutes apart for 3 consecutive months	1. Report filter number, turbidity level, and date of occurrence. 2. Conduct a filter self-assessment within 14 days of the third high turbidity level.	1. Conduct a filter self-assessment within 14 days of the third high turbidity level. 2. A Comprehensive Performance Evaluation (CPE) may be conducted in lieu of a filter self-assessment.
3. IFE turbidity > 2.0 NTU in 2 consecutive readings taken 15 minutes apart for 2 consecutive months.	1. Report filter number, turbidity level, and date of occurrence. 2. Arrange to have a CPE conducted within 30 days of the 2nd month of the high turbidity. 3. Submit the CPE report within 90 days of the 2nd month of high turbidity.	1. Report filter number, turbidity level, and date of occurrence. 2. Arrange to have a CPE conducted within 60 days of the 2nd month of the high turbidity. If you wish to have the State conduct the CPE, the request must be made by the 10th of the third month. 3. Submit the CPE report within 120 days of the 2nd month of high turbidity.
4. IFE turbidity > 0.5 NTU in 2 consecutive readings taken 15 minutes apart within the first 4 hours of continuous operation after the filter has been backwashed or during startup after the filter has been off-line.	1. Report filter number, turbidity level, and date of occurrence. 2. Produce a filter turbidity profile within 7 days of the incident. 3. Report the reason for the abnormal performance if known.	No required action for these systems.

Adapted from *Pipeline* article – OHA, Summer 2008

Overview – Turbidity Requirements

Explanation of Turbidity Trigger Actions

1. Filter Turbidity Profile – previously described, this includes a graph showing turbidity over a complete filter run, including filter start-up, duration of the run, backwash, and filter-to-waste.



See "Preparing a Filter Turbidity Profile" under "Forms & Tools" on-line at www.healthoregon.org/swt

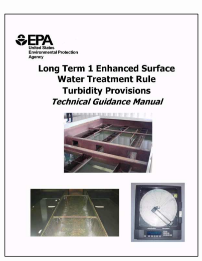
Overview – Turbidity Requirements

Explanation of Turbidity Trigger Actions

2. Filter Self-Assessment

Consists of a written report assessing filter performance, including

- A filter turbidity profile;
- Identification and prioritization of factors limiting filter performance; and
- Assessment of the applicability of corrections.



http://www.epa.gov/safewater/mdbp/pdf/turbidity/chap_05.pdf

See link under "Filtration" at www.healthoregon.org/swt

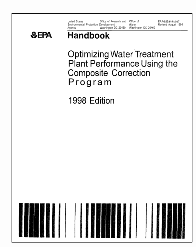
Overview – Turbidity Requirements

Explanation of Turbidity Trigger Actions

3. Comprehensive Performance Evaluation

Consists of a written report is a thorough evaluation of an existing treatment plant, including a review of the design as well as operational, and managerial practices that may limit the plant's performance.

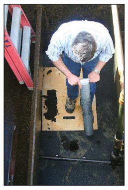
The results of the evaluation establish the plant capacity and identify a set of prioritized factors that limit performance.



http://public.health.oregon.gov/HealthyEnvironments/DrinkingWater/Operations/Treatment/Documents/1998CCPManual.pdf

See link for EPA's 1998 Handbook for Optimizing Water Treatment Plant Performance Using the Composite Correction Program under "Filtration" at www.healthoregon.org/swt

Overview – Turbidity Requirements



Filter Coring
Corvallis CPE
2007

Evaluating Media Depth
Warm Springs CPE
2008

Measuring Filter Bed Expansion
Ilwaco CPE 2012

Sludge Solids Analysis
Albany CPE 2012

Measuring Backwash Trough Turbidity
Midland CPE 2015

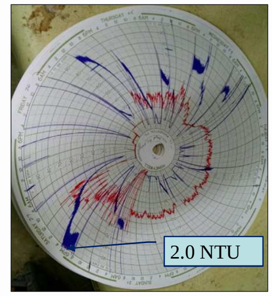
These are some of the activities performed at CPEs in Oregon

61

Overview – Turbidity Requirements

This is an example of a circle chart for a system in Oregon in which IFE triggers were exceeded enough to require a CPE (Turbidity on a scale of 0-2 NTU is shown in Blue; red is chlorine residual).

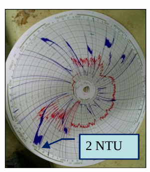
- Filtered water turbidity exceeded 1.0 NTU in 2 consecutive 15-minute readings for 3 consecutive months (actually exceeded for 4 months).
- Filtered water turbidity exceeded 2.0 NTU in 2 consecutive 15-minute readings for two consecutive months.



62

Overview – Turbidity Requirements

The turbidity exceedances occurred due in part to power interruptions resulting in improper SCM-controlled coagulant feed pump, heavy rains, and un-manned operation which resulted in significant delays in responding to high turbidity alarms.



63

Overview – Turbidity Requirements

The resulting CPE identified many issues in addition to inadequate coagulation control including:

- Inoperable surface wash arm.
- Improperly installed and calibrated plant effluent flow meter.
- Non-compliant pH meter.
- Poor filter bed expansion during backwash (<15%).
- Excessive backwash times.
- Inadequate disinfection at the plant (required "do not drink" signs to be posted at the plant)
- Insufficient budgeting practices and availability of operations staff without automated safeguards.

Positive findings included supportive management and willingness of operator to seek help and make improvements as needed.

64

CFE Turbidity Monitoring (summary)

- Combined filter effluent (CFE) turbidity
  - Applies to all SW systems
  - Location: post all filtration prior to chemical addition and any storage
  - Frequency: At least every 4 hours for conventional/direct filtration
  - Limits:
    - 95% of 4-hr readings ≤ 0.3 NTU (9 or less out of 180 readings in a month)
    - All readings less than 1 NTU

65

IFE Turbidity Monitoring (Summary)

Individual filter effluent (IFE) turbidity

- Applies to all conventional & direct systems (membrane systems also)
- Location: after each individual filter
- Frequency: continuous (every 15 minutes)
- Know what the IFE triggers are!

IFE Sample Tap
City of Seaside, 2011

66

IFE Triggers (Summary)

- Report the following events immediately and conduct a filter profile within 7 days (if no obvious reason exists) if the IFE turbidity is:
  - > 1.0 NTU in 2 consecutive 15-min readings
  - > 0.5 NTU in 2 consecutive 15-min readings within 4 hours of being backwashed or taken off-line
- Report the following events and conduct a filter self assessment within 14 days if the IFE turbidity is:
  - > 1.0 NTU in 2 consecutive 15-min readings at any time in each of 2 consecutive months.
- A CPE must be done within 30 days if the IFE turbidity is:
  - > 2.0 NTU in 2 consecutive 15-min readings at any time in each of 2 consecutive months.

Oregon Health Authority

67

Overview – Disinfection Requirements

OAR 333-061-0032(5) – Disinfection Requirements

a. Disinfection must be sufficient to ensure that the total treatment process, including filtration credit, achieves:
   - 3-log (99.9%) inactivation and/or removal of Giardia lamblia cysts (2.0 to 2.5-log is achieved through filtration)
   - 4-log (99.99%) inactivation and/or removal of viruses

Oregon Health Authority

68

Overview – Disinfection Requirements

OAR 333-061-0032(5) – Disinfection Requirements

a. Disinfection must be sufficient to ensure that the total treatment process, including filtration credit, achieves:
   - 3-log (99.9%) inactivation and/or removal of Giardia lamblia cysts (2.0 to 2.5-log is achieved through filtration)
   - 4-log (99.99%) inactivation and/or removal of viruses
b. The residual disinfectant concentration of water entering the distribution system (entry point or "EP") cannot be less than 0.2 mg/l for more than 4 hours.
   - » Continuous (on-line) monitoring if > 3,300 population
   - » 4x/day if serving 2,501 – 3,300 people
   - » 3x/day if serving 1,001 – 2,500 people
   - » 2x/day if serving 501 – 1,000
   - » 1x/day if serving < 500 people

Oregon Health Authority

69

Overview – Disinfection Requirements

OAR 333-061-0032(5) – Disinfection Requirements

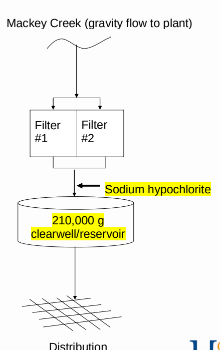
a. Disinfection must be sufficient to ensure that the total treatment process, including filtration credit, achieves:
   - 3-log (99.9%) inactivation and/or removal of Giardia lamblia cysts (2.0 to 2.5-log is achieved through filtration)
   - 4-log (99.99%) inactivation and/or removal of viruses
b. The residual disinfectant concentration of water entering the distribution system (entry point or "EP") cannot be less than 0.2 mg/l for more than 4 hours.
   - » Continuous (on-line) monitoring if > 3,300 population
   - » 4x/day if serving 2,501 – 3,300 people
   - » 3x/day if serving 1,001 – 2,500 people
   - » 2x/day if serving 501 – 1,000
   - » 1x/day if serving < 500 people
c. The residual concentration in the distribution system, cannot be undetectable in more than 5% of samples each month, for any two consecutive months that the system serves water to the public.

Oregon Health Authority

70

Entry Point Residual

Where would you measure the chlorine residual entering the distribution system?



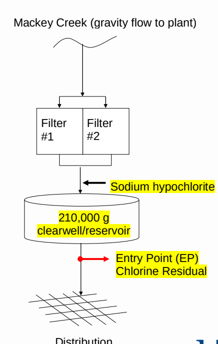
Oregon Health Authority

71

Entry Point Residual

After the clearwell and prior to the distribution system.

"Clearwell" in this case refers to a storage tank or reservoir used to hold chlorinated water for a sufficient amount of time for effective disinfection.



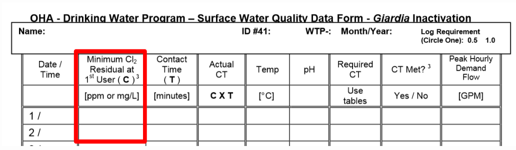
Oregon Health Authority

72

Entry Point Residual

What EP residual would you report?

Report the lowest daily residual on the "Surface Water Quality Data Form"



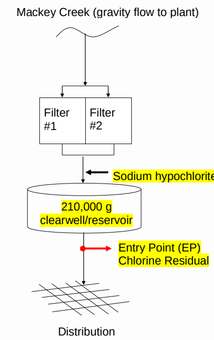
OHA - Drinking Water Program – Surface Water Quality Data Form - *Giardia* Inactivation

Name: **ID #41:** **WTP-:** **Month/Year:** **Log Requirement (Circle One): 0.5 1.0**

Date / Time	Minimum Cl_2 Residual at 1st User (**C**) [3]	Contact Time (**T**)	Actual CT	Temp	pH	Required CT	CT Met? [3]	Peak Hourly Demand Flow
	[ppm or mg/L]	[minutes]	**C X T**	[°C]		Use tables	Yes / No	[GPM]
1 /								
2 /								

Distribution Residual

Where would you sample in the distribution system?

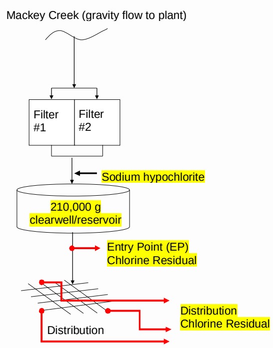


Distribution Residual

Where would you sample in the distribution system?

A. "At one or more representative points at a frequency that is sufficient to detect variations in chlorine demand and changes in water flow but in no case less often than twice per week" OAR 333-061-0036(9)(a)(A)

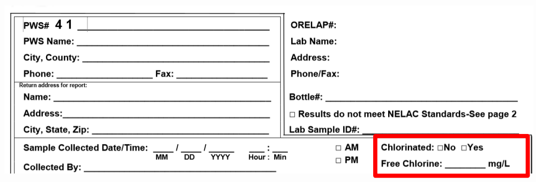
B. "At the same points in the distribution system and at the same times as total coliforms are sampled" -0036(9)(a)(B)



Distribution Residual

What distribution residual would you report?

- Keep semiweekly residuals on-site for two years
- Use the coliform sample lab form to report residual at the time of coliform sampling.



PWS# 4 1 ______
PWS Name: ______
City, County: ______
Phone: ______ **Fax:** ______
Return address for report:
Name: ______
Address: ______
City, State, Zip: ______
Sample Collected Date/Time: ___ / ___ / ___ (MM DD YYYY) ___ : ___ (Hour : Min) ☐ AM ☐ PM
Collected By: ______

ORELAP#:
Lab Name:
Address:
Phone/Fax:
Bottle#: ______
☐ **Results do not meet NELAC Standards-See page 2**
Lab Sample ID#: ______
Chlorinated: ☐**No** ☐**Yes**
Free Chlorine: ______ **mg/L**

Overview – Disinfection Requirements

Do not exceed these limits…

OAR 333-061-0031(1) – Maximum Residual Disinfectant Levels (MRDLs)

Disinfectant Residual	MRDL in mg/l
Chlorine	4.0 (as Cl_2)
Chloramines	4.0 (as Cl_2)
Chlorine Dioxide	0.8 (as ClO_2)

Overview – Disinfection Requirements

OAR 333-061-0036(5)(b) – Monitoring CT

Conventional & Direct Filtration Treatment Systems must calculate **CT** each day the plant is in operation.

CT is a way to measure if disinfection is adequate

How do we calculate CT?

Do not confuse "CT" and "Contact Time"

CT = Chlorine **C**oncentration x Contact **T**ime

- The chlorine concentration is from daily measurements taken at or before the entry point to the distribution system or "1st user".
- More on CT later….

79

Overview – NTU and Disinfection Reporting Requirements

OAR 333-061-0040(1)(d) – Reporting requirements

All surface water systems that provide filtration must report within 24 hours after learning:

1. *That the filtered water turbidity exceeds 5 NTU.*
2. *Of a waterborne disease outbreak potentially attributable to the water system*
3. *That the disinfectant residual of the water entering the distribution system fell below 0.2 mg/l and whether or not the residual was restored to at least 0.2 mg/l within 4 hours.*

80

Overview – NTU and Disinfection Reporting Requirements

OAR 333-061-0040(1)(d) – Reporting requirements, continued

Conventional & Direct Filtration Treatment Systems must also report within 10 days after the end of each month:

1. *The total number of filtered water turbidity taken each month (min of every 4 hours);*
2. *The number and percentage of results exceeding 0.3 NTU; and*
3. *The date and value of any turbidity that exceeded 1 NTU.*

81

Overview – NTU and Disinfection Reporting Requirements

Use the State's Turbidity Monitoring Report form to help fulfill reporting requirements - maintain records for at least three years.

Form is available on-line under "Forms & Tools" link at www.healthoregon.org/swt

OHA - Drinking Water Services – Turbidity Monitoring Report **County:**
Conventional or Direct Filtration

Name: **ID #41:** **WTP-:** **Month/Year:**

DAY	12 AM [NTU]	4 AM [NTU]	8 AM [NTU]	NOON [NTU]	4 PM [NTU]	8 PM [NTU]	Highest Reading of the Day[1] [NTU]
1							
2							
3							
4							
5							
6							

82

Overview – NTU and Disinfection Reporting Requirements

Form is available on-line under "Forms & Tools" link at www.healthoregon.org/swt

There are 4 forms:
- Conventional/Direct
- Slow Sand / Membrane / DE / Unfiltered
- Cartridge
- UV (if used for Giardia credit)

Must use the correct form because each has questions that must be answered that are specific to filtration type.

83

Overview – NTU and Disinfection Reporting Requirements

CFE Turbidity

OHA - Drinking Water Services – Turbidity Monitoring Report **County:**
Conventional or Direct Filtration

Name: **ID #41:** **WTP-:** **Month/Year:**

DAY	12 AM [NTU]	4 AM [NTU]	8 AM [NTU]	NOON [NTU]	4 PM [NTU]	8 PM [NTU]	Highest Reading of the Day[1] [NTU]
1			0.34				0.50
2			0.24				0.66
3			0.44				
4							
5							
6							

Notify the State if NTU > 1 NTU.
Notify the State within 24-hrs if turbidity > 5 NTU (includes after hours)
Public Health After Hours Duty Officer:
Cell (971) 246-1789
Oregon Emergency Response System:
1-800-452-0311

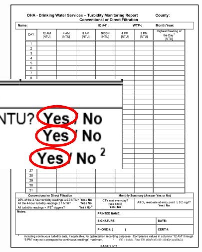
- Chose time closest to when daily turbidity is measured and enter results
- Enter highest turbidity of all measurements for the day (e.g., online instrument or highest of multiple daily grab samples)

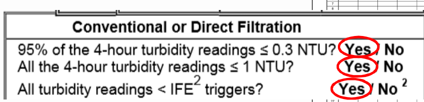
84

Overview – NTU and Disinfection Reporting Requirements

CFE & IFE Turbidity

Based on the results entered for the month, circle "yes" or "no" to the three questions at the bottom of the form.





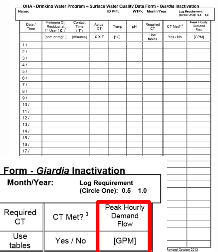
85

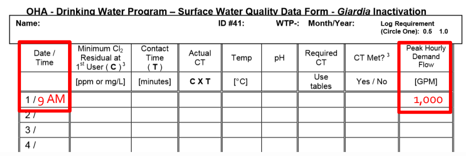
Overview – NTU and Disinfection Reporting Requirements

Peak hourly demand flow (gpm)

Enter peak hourly demand (PHD) flow and the time that the PHD flow occurred.

This flow should not exceed 10% above the peak flows replicated at the time of the tracer study.



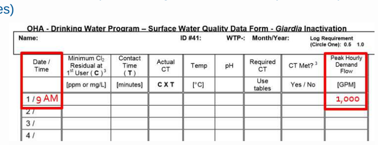


86

Overview – NTU and Disinfection Reporting Requirements

What is peak hourly demand flow?

- The greatest volume of water passing throught he system during any one hour in a consecutive 24 hr period
- Not the same as Peak Instantaneous Flow
- Report demand flow (flow leaving the clearwell, not plant flow (in most cases)



87

Overview – NTU and Disinfection Reporting Requirements

How do you determine peak hourly demand flow?

For systems with a totalizing flow meter only:

- Spot check throughout the day to determine the time of peak demand (e.g. 9 am or 9 pm for residential or mid-day for industrial uses)
- Then record how much water is used during that hour in gallons and divide by 60 minutes to get the peak hour demand in gpm.

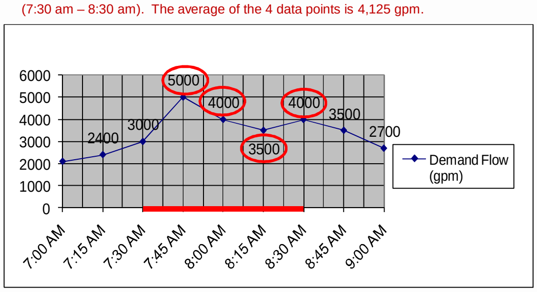
For systems that can measure and record flow rate:

- On a daily basis, use the best available operational data to identify the hour within the 24 hr period that had the highest demand flow.
- For the hour of highest demand flow:
  - Calculate the average flow rate within the one hour period (i.e., add the flow rates and divide by the number of data points).
  - Use as many data points as possible, preferably no less than four data points taken at 15 minute intervals.

88

Overview – NTU and Disinfection Reporting Requirements

The red line represents the span of 1 hour with the highest demand (7:30 am – 8:30 am). The average of the 4 data points is 4,125 gpm.

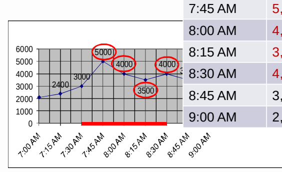


89

Overview – NTU and Disinfection Reporting Requirements

Think of it like a running hourly average of demand flow measurements…

Time	Demand Flow (gpm)	Running Hourly Average (gpm)
7:00 AM	2,000	
7:15 AM	2,400	
7:30 AM	3,000	
7:45 AM	5,000	3,100
8:00 AM	4,000	3,600
8:15 AM	3,500	3,875
8:30 AM	4,000	**4,125**
8:45 AM	3,500	3,750
9:00 AM	2,700	3,425



90

Overview – NTU and Disinfection Reporting Requirements

Minimum chlorine residual and contact time

- The minimum chlorine residual is measured at the end of the disinfection segment at the entry point prior to or at the first user
- Contact time is the time that the disinfectant is in contact with the water within the disinfection segment.

OHA - Drinking Water Program – Surface Water Quality Data Form - *Giardia* Inactivation

Name: ID #41: WTP-: Month/Year: Log Requirement (Circle One): 0.5 1.0

Date / Time	Minimum Cl_2 Residual at 1st User (**C**) [3]	Contact Time (**T**)	Actual CT	Temp	pH	Required CT	CT Met? [3]	Peak Hourly Demand Flow
	[ppm or mg/L]	[minutes]	**C X T**	[°C]		Use tables	Yes / No	[GPM]
1 / 9 AM	???	???						1,000
2 /								
3 /								
4 /								

Overview – NTU and Disinfection Reporting Requirements

How is contact time determined?

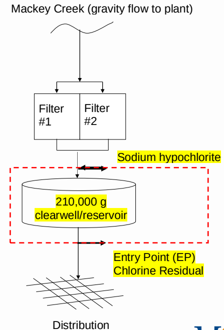
- Tracer studies are used to determine contact time (T) which is used in calculating CT achieved, where

CT = chlorine Concentration x contact Time.

- Contact time is the time that chlorine is in contact with the water from the point of injection to the point where it is measured (sometimes referred to as the "CT segment")
  - May be at or before the 1st user
  - May be more than one CT segment
- Tracer studies are often conducted to simulate a worst-case scenario where peak hour demand flows are high and reservoir levels are low. This gives a conservative (i.e. lower) contact time than would normally be expected.

Overview – NTU and Disinfection Reporting Requirements

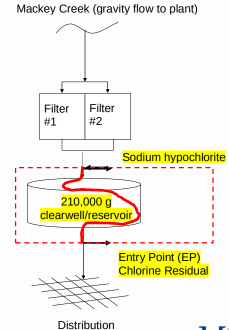
Remember, the disinfection segment is between the point of chlorine injection and the entry point.



Overview – NTU and Disinfection Reporting Requirements

Remember, the disinfection segment is between the point of chlorine injection and the entry point.

So if we were conducting a tracer study, this is the segment showing the potential flow path we would be looking at and determining the contact time T for.



Overview – NTU and Disinfection Reporting Requirements

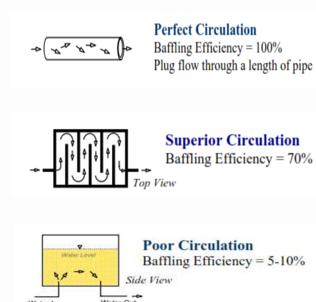
What impacts contact time?

- The more efficient the mixing is in a reservoir or tank, the more contact time is available for disinfection.
- Estimates of contact time based on tank or reservoir design are not allowed for calculating CT's for surface water!

Overview – NTU and Disinfection Reporting Requirements

What impacts contact time?

- Mixing efficiency improves with high flow path length to width ratios, found in pipelines and simulated in tanks with the use of baffles (hence the term baffling efficiency or factor).



Tracer studies

Conducting a tracer study:

1. If water is pumped from the clearwell at different rates depending on time of year, do tracer study at each of those flow rates
2. Conduct study at typical winter/summer peak hour demand flows
3. Otherwise use "worst-case scenario" parameters:
   - Highest flow rate out of clearwell (conduct during peak hour or conditions that simulate e.g. open a hydrant)
   - Keep flow rate constant
   - Keep clearwell water level close to normal minimum operating level

Tracer studies (continued)

Conducting a tracer study:

4. Community water systems with populations <10,000 and non-profit non-community systems can use the circuit rider to perform a tracer study
5. Must submit a proposal to the state for approval prior to conducting the tracer study (even if using the circuit rider).
6. Must redo tracer study if peak hour demand flow increases more than 10% of the maximum flow used during the tracer study

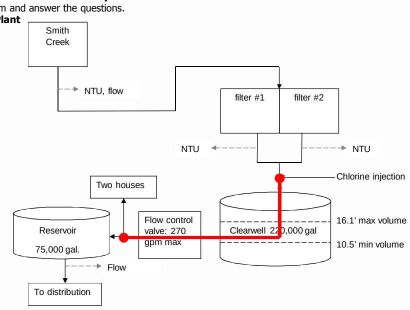
Example

Conducting a tracer study

Example: Tracer studies

Directions: Look at the diagram and answer the questions.

Figure 1: Water Treatment Plant



Questions:

1. If this was your treatment plant, highlight the part of the plant where you might conduct a tracer study.
2. In a "worst-case scenario" tracer study, what would the flow rate be? **270 gpm**
3. In a "worst-case scenario" tracer study, what would the clearwell level be? **10.5-ft**

Where do I report contact time?

- Use the time T from the tracer study on the monthly reporting form in the "Contact time (min)" column
  - Use the smallest T (highest flow) if the tracer study was done at multiple flow rates

OHA - Drinking Water Program – Surface Water Quality Data Form - *Giardia* Inactivation

Name: **ID #41:** **WTP-:** **Month/Year:** **Log Requirement (Circle One): 0.5 1.0**

Date / Time	Minimum Cl_2 Residual at 1st User (**C**) 3	Contact Time (**T**)	Actual CT	Temp	pH	Required CT	CT Met? 3	Peak Hourly Demand Flow
	[ppm or mg/L]	[minutes]	**C X T**	[°C]		Use tables	Yes / No	[GPM]
1 /								
2 /								

- This may not be your exact time, but it represents your worst case (as long as the peak flow is less and clearwell volume is more than they were at the time of the tracer study)

Can I use a baffling factor?

- Once you know the time T from the tracer study, you can back-calculate to determine the baffling factor of the clearwell
  - Baffling factor (%) = $\frac{\text{Time (min) x Flow During Tracer Study (gpm)}}{\text{Clearwell Volume During Tracer Study (gal)}}$
- T can be adjusted based on flow (at <110%) with the following equation:
  - T = $\frac{\text{Current clearwell Volume (gal) x Baffling Factor (\%)}}{\text{Peak Hourly Demand Flow (gpm)}}$
- If tracer study includes pipeline segments or multiple tanks, contact the state for guidance on using baffling factors

Overview – NTU and Disinfection Reporting Requirements

Now we can enter the min chlorine residual, contact time, and CT_{actual}

– The minimum chlorine residual is measured at the end of the disinfection segment at the entry point prior to or at the first user

– Contact time is the time that the disinfectant is in contact with the water within the disinfection segment.

– **CT_{actual}** = **C**hlorine residual x contact **T**ime

OHA - Drinking Water Program – Surface Water Quality Data Form - *Giardia* Inactivation

Name: ID #41: WTP-: Month/Year: Log Requirement (Circle One): 0.5 1.0

Date / Time	Minimum Cl_2 Residual at 1st User (C)[3]	Contact Time (T)	Actual CT	Temp	pH	Required CT	CT Met?[3]	Peak Hourly Demand Flow
	[ppm or mg/L]	[minutes]	C X T			Use		
1 / 9 AM	0.6	100	60					
2 /								
3 /								
4 /								

Notify the State within 24-hrs if chlorine residual < 0.2 mg/l
Public Health After Hours Duty Officer:
Cell (971) 246-1789
Oregon Emergency Response System:
1-800-452-0311

How do I know if CT_{actual} is adequate?

- We use the EPA tables to determine the CTs needed to inactivate *Giardia* ($CT_{required}$)

  In order to use the EPA tables, we need to know the log Giardia inactivation required to meet a total removal/inactivation of 3.0-log (generally either 0.5-log or 1-log). 0.5-log Giardia inactivation will also achieve 4.0-log virus inactivation.

  We also need to know the following parameters, measured each day at or before the first user or entry point:
  - pH,
  - temperature, and
  - free chlorine residual

- Then we compare $CT_{required}$ with Ct_{actual}
- Must keep $CT_{actual} \geq CT_{required}$

Overview – NTU and Disinfection Reporting Requirements

Now enter the pH, temperature, and circle the appropriate log removal required

Log removal required is for Giardia and is always going to be at least 0.5-log.

Although the requirement can vary from plant to plant, generally for conventional plants, 0.5-log is needed and for direct plants, 1.0-log is needed (check with your regulator if uncertain)

OHA - Drinking Water Program – Surface Water Quality Data Form - *Giardia* Inactivation

Name: ID #41: WTP-: Month/Year: Log Requirement (Circle One): 0.5 1.0

Date / Time	Minimum Cl_2 Residual at 1st User (C)[3]	Contact Time (T)	Actual CT	Temp	pH	Required CT	CT Met?[3]	Peak Hourly Demand Flow
	[ppm or mg/L]	[minutes]	C X T	[°C]		Use tables	Yes / No	[GPM]
1 / 9 AM	0.6	100	60	12	6.8			1,000
2 /								
3 /								
4 /								

Calculating $CT_{required}$

- You should know how to use the EPA tables to determine the CTs needed to inactivate *Giardia* ($CT_{required}$) – more on that later!
- You can also use "regression" equations determined by EPA
- Regression equations are built into the Microsoft Excel reporting forms on-line under the "Forms and Tools" section of our surface water treatment page on-line at www.healthoregon.org/swt

Calculating $CT_{required}$ Using Regression Equations

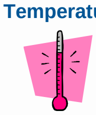
Regression equations can be programmed into plant SCADA or spreadsheets

- **Regression Equation (for Temp < 12.5°C)**
  $CT = (0.353*L)(12.006 + e^{(2.46-0.073*T+0.125*C+0.389*pH)})$
- **Regression Equation (for Temp > 12.5°C)**
  $CT = (0.361*L)(-2.261 + e^{(2.69-0.065*T+0.111*C+0.361*pH)})$
- **Variables:**
  CT = Product of Free Chlorine Residual and Time required
  L = number of log inactivation for Giardia (L = 1 for slow sand)
  T = temperature, in Celsius
  C = chlorine residual in mg/L
  pH = pH of water
  e = 2.7183, base for natural log

(Smith, Clark, Pierce and Regli, 1995, from EPA's 1999 Guidance Manual for Disinfection Profiling and Benchmarking)

Calculating $CT_{required}$ Using EPA CT Tables - Temperature

You should all be able to use the CT tables to calculate $CT_{required}$



- There are six EPA CT tables based on temperature
- Find the correct table based on your water temperature in degrees Celsius.
  °C = 5/9 x (°F – 32)
- If water temp is between values, then round down
- *Disinfection is less effective at colder temperatures.*

Calculating $Ct_{required}$ Using EPA CT Tables - Temperature

If the water temperature = 12°C

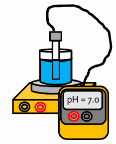
CT VALUES FOR INACTIVATION OF GIARDIA CYSTS BY FREE CHLORINE AT 10° C — 10°C – 14.9°C

6.1 – 6.5 · 6.6 – 7.0 · 7.1 – 7.5

Use 10°C table for T = 10 – 14.9°C (round down for temp)

Calculating $CT_{required}$ Using EPA CT Tables - pH

There are 7 sections for pH on each table



- Find the section that corresponds to your water's pH level
- If your pH is between the choices, then round up to the higher pH
- *Disinfection is less effective at higher pH*
- *Rounding up is more conservative (leads to a higher $CT_{required}$)*

Calculating $CT_{required}$ Using EPA CT Tables, Continued

Assume the pH = 6.8°C

CT VALUES FOR INACTIVATION OF GIARDIA CYSTS BY FREE CHLORINE AT 10° C — 10°C – 14.9°C

Use pH = 7.0 column
For pH = 6.6 – 7.0
(round up for pH)

Calculating $CT_{required}$ Using EPA CT Tables – Log

Assume the required log inactivation of Giardia for a conventional treatment plant is 0.5-log

CT VALUES FOR INACTIVATION OF GIARDIA CYSTS BY FREE CHLORINE AT 10° C — 10°C – 14.9°C

Use the 0.5-log column

Image from CDC's site: http://www.cdc.gov/parasites/crypto/index.html

Calculating $CT_{required}$ Using EPA CT Tables – Chlorine

Match up your chlorine residual with the log inactivation column as shown below. Where they intersect is the $CT_{required}$.

CT VALUES FOR INACTIVATION OF GIARDIA CYSTS BY FREE CHLORINE AT 10° C — 10°C – 14.9°C

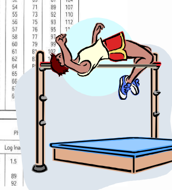
If residual falls between values in the table, round up to yield a higher $CT_{required}$

Calculating $CT_{required}$ Using EPA CT Tables – Chlorine

Match up your chlorine residual with the log inactivation column as shown below. Where they intersect is the $CT_{required}$.

CT VALUES FOR INACTIVATION OF GIARDIA CYSTS BY FREE CHLORINE AT 10° C — 10°C – 14.9°C

If you get confused on which way to round, think about how you want to set the bar ($CT_{required}$) as high as possible to be the most conservative and most protective of public health.



Overview – NTU and Disinfection Reporting Requirements

Now enter Required CT and indicate if CT was met
(i.e. put “Yes” if $CT_{actual} \geq Ct_{required}$)

OHA - Drinking Water Program – Surface Water Quality Data Form - *Giardia* Inactivation

Name: ID #41: WTP-: Month/Year: Log Requirement (Circle One): 0.5 1.0

Date / Time	Minimum Cl_2 Residual at 1st User (C) 3	Contact Time (T)	Actual CT	Temp	pH	Required CT	CT Met? 3	Peak Hourly Demand Flow
	[ppm or mg/L]	[minutes]	C X T	[°C]		Use tables	Yes / No	[GPM]
1 / 9 AM	0.6	100	60	12	6.8	18	Yes	1,000
2 /								
3 /								

Notify the State within 24-hrs if CT was not met.
Public Health After Hours Duty Officer:
Cell (971) 246-1789
Pager (503) 938-6790
Oregon Emergency Response System:
1-800-452-0311

Overview – NTU and Disinfection Reporting Requirements

Everyone needs to fill out the CT section of the Monthly Summary

Monthly Summary (Answer Yes or No)	
CT's met everyday? (see back) Yes No	All Cl_2 residual at entry point ≥ 0.2 mg/l? Yes No
PRINTED NAME:	
SIGNATURE:	DATE:
PHONE #: ( )	CERT #:

Overview – NTU and Disinfection Reporting Requirements

Be sure your reports are complete before sending them in by the 10th of each month

OHA - Drinking Water Services – Turbidity Monitoring Report
Conventional or Direct Filtration County: Clatsop

Name: XWZ Water System ID #41: 99999 WTP-: A Month/Year: 09/2015

DAY	12 AM [NTU]	4 AM [NTU]	8 AM [NTU]	NOON [NTU]	4 PM [NTU]	8 PM [NTU]	Highest Reading of the Day 1 [NTU]
1	0.08	0.90	0.75	0.78	0.82	0.95	0.12 NTU
2							
3							

Conventional or Direct Filtration	Monthly Summary (Answer Yes or No)	
95% of the 4-hour turbidity readings ≤ 0.3 NTU? Yes / No All the 4-hour turbidity readings ≤ 1 NTU? Yes / No All turbidity readings < IFE 2 triggers? Yes / No 2	CT's met everyday? (see back) Yes No	All Cl_2 residuals at entry point ≥ 0.2 mg/l? Yes No
Notes:	PRINTED NAME: Evan Hofeld	
	SIGNATURE: [signature]	DATE: 09/26/15
	PHONE #: (971) 322-8027	CERT #: 12345

OHA - Drinking Water Program – Surface Water Quality Data Form - *Giardia* Inactivation

Name: XWZ Water System ID #41: 99999 WTP-: A Month/Year: 09/15 Log Requirement (Circle One): 0.5 1.0

Date / Time	Minimum Cl_2 Residual at 1st User (C) 3	Contact Time (T)	Actual CT	Temp	pH	Required CT	CT Met? 3	Peak Hourly Demand Flow
	[ppm or mg/L]	[minutes]	C X T	[°C]		Use tables	Yes / No	[GPM]
1 / 9 AM	0.6	100	60	12	6.8	18	Yes	1,000

Overview – NTU and Disinfection Reporting Requirements
Common Mistakes

- Not calculating CT's daily
  - Don't wait until the end of the month to do the calculations because if you discover you didn't meet CT's, it's too late!
- If adjusting contact time according to flow rate, use the demand flow, not the plant flow.
- Failure to answer questions at bottom of form correctly (or at all)
- Always answering “Yes” to the questions at the bottom of the form without actually looking at the numbers

Overview – NTU and Disinfection Reporting Requirements
Common Mistakes, Continued

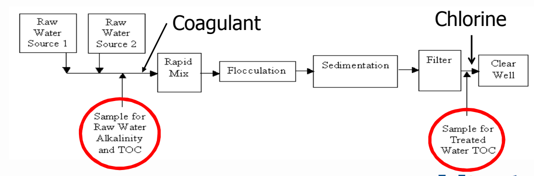
- Rounding errors when using EPA tables to determine $CT_{required}$
  - Must round <u>down</u> for temperature
  - Must round <u>up</u> for pH
  - Must round <u>up</u> for free chlorine residual
- Bad CT formulas in excel spreadsheets:
  - Make sure you understand your formula
  - Wilkes Equation not allowed, must use Regression Equation

Overview - TOC

OAR 333-061-0036(5)(n) – Total Organic Carbon (TOC)

Conventional Filtration Treatment Systems must:

1. *Monitor source water TOC and alkalinity prior to treatment (this can be from a combined header after blending of more than one source water)*
2. *Monitor combined filter effluent (CFE) water TOC.*



Overview - TOC

OAR 333-061-0036(5)(n) – Total Organic Carbon (TOC)

Conventional Filtration Treatment Systems must:

1. *Monitor source water TOC and alkalinity prior to treatment (this can be from a combined header after blending of more than one source water)*
2. *Monitor combined filter effluent (CFE) water TOC.*
3. *Source TOC and alkalinity and CFE TOC must be taken at the same time as a "paired" sample set used to determine TOC removal efficiency.*
4. *Sampling must be done each month*
5. *Reductions to quarterly sampling can occur if average CFE TOC < 2.0 mg/l for 2 consecutive years or < 1 mg/l for one year*
6. *If annual average treated water TOC ≥ 2.0 mg/l*

Overview - TOC

OAR 333-061-0032(10)(d) – TOC removal requirements

Community (e.g., year-round residents) and Non-transient Non-community (e.g. schools, businesses, etc.) using conventional filtration must operate with enhanced coagulation or enhanced softening to achieve certain total organic carbon (TOC) percent removal levels specified in -0032(10)(e) unless at least one of the following alternative compliance criteria are met:

1. *Source water TOC < 2.0 mg/l (calculated quarterly as a running annual average (RAA)).*
2. *Treated water RAA TOC < 2.0 mg/l*
3. *Source water RAA TOC < 2.0 mg/l & RAA alkalinity > 60 mg/l & TTHM & HAA5 < ½ the MCL (TTHM MCL = 0.080 mg/l, HAA5 MCL = 0.060 mg/l)*
4. *TTHM & HAA5 < ½ the MCL and chlorine is the only disinfectant used*
5. *Source water RAA SUVA ≤ 2.0 L/mg-m*
6. *Finished water RAA SUVA ≤ 2.0 L/mg-m*

Note: Softening systems have additional criteria – SEE OAR 333-061-0032(10(d)(B)

Overview – Recycle Streams

OAR 333-061-0032(11) – Recycled water requirements

Both conventional and direct plants that recycle spent filter backwash water, thickener, supernatant, or liquids from dewatering processes must notify the State and will generally be expected to return these flows to the head of the treatment plant prior to coagulant injection

Overview – Significant Deficiencies

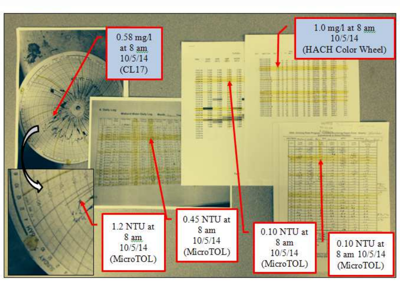
In addition to other rule violations, significant deficiencies identified during a water system survey would include the following commonly found issues:

1. Monitoring not completed as required;
2. Incorrect location for compliance turbidity monitoring;
3. Turbidimeters not calibrated quarterly;
4. Regardless of size, no auto-dial, call-out alarm or auto-plant shutoff for high turbidity when no operator is on-site;
5. Settled water turbidity not measured daily for conventional plants;
6. For systems serving more than 3,300 people, no auto-dial, call-out alarm or auto-plant shutoff for low chlorine residual;
7. No means to adequately determine flow rate on clearwell;
8. No means to determine disinfection contact time under peak flow and minimum storage conditions;
9. Failure to calculate CT correctly; and
10. Inadequate written Operations and Maintenance procedures

Overview – Homework!

Trace data from the sample tap to regulatory reporting forms.

What did you find?

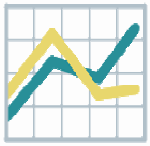


Overview – Homework!

- Write an SOP for CT determination
  - Check how T is calculated at your plant
  - Do all treatment plant operators understand it?
  - Review spreadsheet equation for CTs (if applicable)
  - Arrange for a tracer study if necessary
  - Calculate CT and fill out monthly report daily
- Know what to do and who to call when things go wrong (contact State regulator & refer to Emergency Response Plan)

Overview – Homework!

- Make data reliability a plant goal
- Establish protocols for collection and recording of data. Only collect data used for process control or compliance reporting
- Establish a data verification process that can be routinely used to confirm data integrity
- Turn data into information (e.g., draw the graph).



Oregon Health Authority

127

Class Outline

9 AM Introduction/Overview

10:15 AM – 15 minute break

10:30 AM Coagulation/Flocculation

12 noon – Lunch (on your own)

1 PM Clarification/Sedimentation

2 PM Filtration

2:15 PM – 15 minute break

2:30 PM Filtration (continued)

3:30 PM General Operations

4:30 PM - End

Oregon Health Authority

128

Class Outline

9 AM Introduction/Overview

10:15 AM – 15 minute break

10:30 AM Coagulation/Flocculation

12 noon – Lunch (on your own)

1 PM Clarification/Sedimentation

2 PM Filtration

2:15 PM – 15 minute break

2:30 PM Filtration (continued)

3:30 PM General Operations

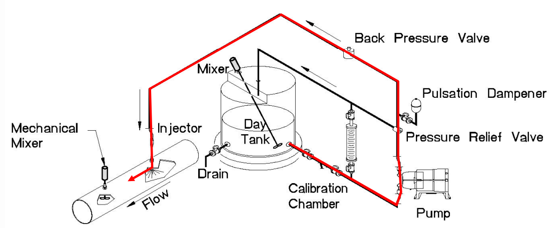
4:30 PM - End

Oregon Health Authority

129

Coagulation

Typical coagulant feed system

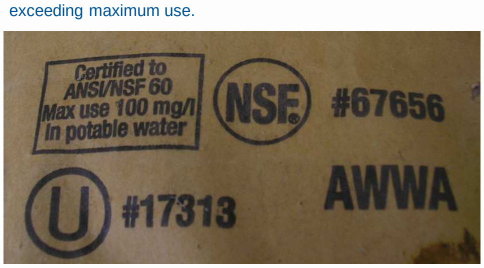


Oregon Health Authority

130

Chemicals must meet ANSI/NSF 60

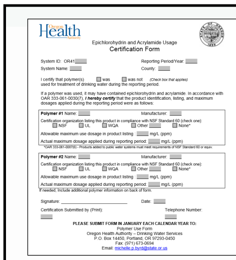
Make sure product meets ANSI/NSF Standard 60 and you are not exceeding maximum use.



Solvay Dense Soda Ash (Sodium Carbonate, Anhydrous)

Oregon Health Authority

131



Epichlorohydrin & Acrylamide (ANSI/NSF 60)

1. Do not exceed maximum use identified by ANSI/NSF 60.
2. NSF, UL, and WQA all specify a maximum use that ensures compliance.
3. A form will be mailed out each year to help you meet the reporting requirements of OAR 333-061-0030(7)

(7) Acrylamide and Epichlorohydrin. For every public water system, the water supplier must certify annually to the state in writing, using third party certification approved by the state or manufacturer's certification, that when acrylamide and epichlorohydrin are used in drinking water systems, the combination, or product, of dose and monomer level does not exceed the levels specified as follows:
- (a) Acrylamide: 0.05 percent dosed at 1 ppm or equivalent.
- (b) Epichlorohydrin: 0.01 percent dosed at 20 ppm or equivalent.

Stat. Auth.: ORS 448.131
Stats. Implemented: ORS 448.131, 448.150

Oregon Health Authority

132

Epichlorohydrin & Acrylamide (ANSI/NSF 60)

Epichlorohydrin and Acrylamide Usage
Certification Form

System ID: OR41____ Reporting Period/Year: ____
System Name: ____ County: ____

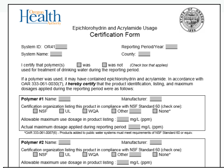
I certify that polymer(s) ☐ was ☐ was not *(Check box that applies)* used for treatment of drinking water during the reporting period.

If a polymer was used, it may have contained epichlorohydrin and acrylamide. In accordance with OAR 333-061-0030(7), ***I hereby certify*** that the product identification, listing, and maximum dosages applied during the reporting period were as follows:

Polymer #1 Name: ____ Manufacturer: ____
Certification organization listing this product in compliance with NSF Standard 60 (check one):
☐ NSF ☐ UL ☐ WQA ☐ Other ____ ☐ None*
Allowable maximum use dosage in product listing : ____ mg/L (ppm)
Actual maximum dosage applied during reporting period: ____ mg/L (ppm)
*OAR 333-061-0087(6) - Products added to public water systems must meet requirements of NSF Standard 60 or equiv.

A form will be mailed out each year to help you meet the reporting requirements of OAR 333-061-0030(7)

Epichlorohydrin & Acrylamide (ANSI/NSF 60)



1. Do not exceed maximum use identified by ANSI/NSF 60.

http://info.nsf.org/Certified/PwsChemicals/

2. Beware of product name changes and loss of NSF-60 certification.

Polyamines[PY]

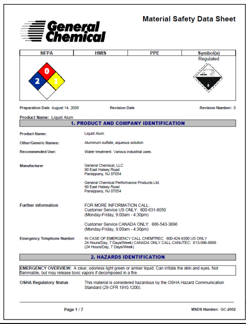
Trade Designation	*Product Function*	*Max Use*
Superfloc 730G	Coagulation & Flocculation	20mg/L
Superfloc 781G	Coagulation & Flocculation	20mg/L
Superfloc C-568	Coagulation & Flocculation	20mg/L
Superfloc C-572	Coagulation & Flocculation	20mg/L
Superfloc C-573	Coagulation & Flocculation	20mg/L
Superfloc C-573 PWG	Coagulation & Flocculation	20mg/L
Superfloc C-576	Coagulation & Flocculation	22mg/L
Superfloc C-577	Coagulation & Flocculation	20mg/L
Superfloc C-581	Coagulation & Flocculation	20mg/L
Superfloc C-583	Coagulation & Flocculation	20mg/L
Superfloc C568	Coagulation & Flocculation	20mg/L
Superfloc C578	Coagulation & Flocculation	20mg/L

[PY] Polyamines Certified by NSF International comply with 40 CFR 141.111 requirements for percent monomer and dose.

40 CFR 141.111 is the federal rule citation for acrylamide and epichlorohydrin addressed under -0030(7) in OAR.

Maintain current MSDS & Product Specs

Maintain current MSDS and product specification sheets



Liquid Alum
PRODUCT PROFILE

CHARACTERISTICS

Liquid aluminum sulfate (liquid alum) is a clear, light green to light yellow aqueous solution. Iron-free and food-grade liquid alums are clear and colorless.

TYPICAL PROPERTIES

Dry Alum Equivalent, as $Al_2(SO_4)_3 \cdot 14H_2O$	*48.5 % (approx.)*
Molecular Weight of Dry Alum	*594*
Product Density	*11.1 - 11.2 lbs./US gallon*
Specific Gravity	*1.335 - 1.337*
pH, 1% Dry Alum Basis Solution	*3.5 (approx.)*
Boiling Point	*214 °F (101 °C) (approx.)*
Freezing Point	*5 °F (-15 °C)*
Freezing Temperatures of Solutions	*See Figure 1*

Acidified Alum also available

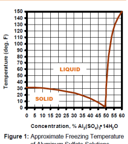
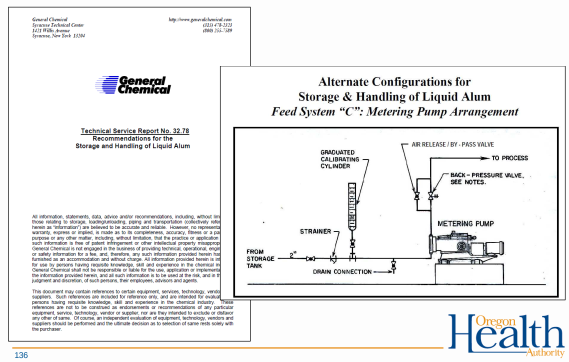


Figure 1: Approximate Freezing Temperature of Aluminum Sulfate Solutions

Store and Handle Per Manufacturer



Clearly Label Tanks

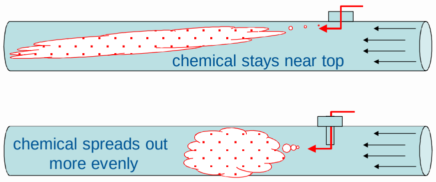
City of Vernonia, 2010

Coagulation

- Objectives depend on raw water quality
- Most particles found in source waters are negatively charged (e.g., clay, organics, algae cells)
  - Particles repel each other
- Coagulant(s) added to destabilize particles (neutralize negative charge)
  - Neutralized particles collide and build floc

Coagulation Depends on Mixing

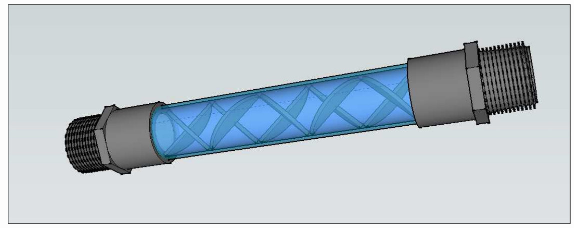
Injection quills can help evenly disburse chemical and improve mixing



139

Coagulation Depends on Mixing

- Static mixers have veins or "elements" that promote mixing.
- The more water is pushed through a static mixer, the higher the head loss and better mixing you have.



140

Factors Affecting Coagulation

- Dosage: determined by jar test for optimum qualities of floc: (size, settling rate).
- Mixing: Mechanical or static. Need to rapidly mix chemicals.
- Alkalinity: 50 mg/l or less can shift pH downward.
- Temperature: Colder water slows coagulation.
- Color: Pre-oxidation may be required.
- Turbidity: Changing conditions require more frequent jar tests.

Coagulants

- Aluminum sulfate (alum): very common, only effective in narrow pH range (typically pH = 6.0 – 7.4). Consumes about 0.5 mg/l alkalinity for every 1 mg/l of alum dosed.
- Ferric chloride: More expensive, but works in wider pH range (pH = 4.0 – 11.0). Consumers about 1 mg/l alkalinity for every 1 mg/l ferric chloride dosed.
- Poly aluminum chloride (PAC): not affected by pH, doesn't change pH, works well with low alkalinity, leaves less sludge because dosage is low.
- Aluminum Chlorohydrate (ACH): similar to PAC.

Flocculation

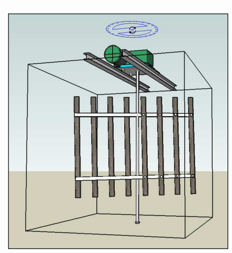
- Objectives depend upon subsequent processes (sedimentation, type of filtration, etc.)
- Generally the objective is to:
  - Develop settleable or filterable floc particle.
  - Optimize flocculation detention time and energy

Typical Hydraulic Detention Times		
		Hydraulic Detention Time
Single-Stage	Temp <= 5°C	30 minutes
	Temp > 5°C	25 minutes
Multiple Stages	Temp <= 5°C	20 minutes
	Temp > 5°C	15 minutes

143

Flocculation

Flocculation mixing can be accomplished using paddle-wheel flocculators, mounted horizontally or vertically.



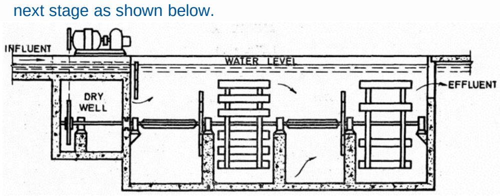
Flocculation paddles - photo from 2007 CPE at Sweethome, OR

144

Flocculation

Flocculation usually involves multiple stages of progressively lower mixing intensity.

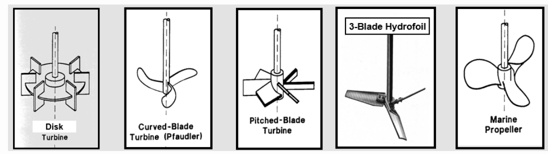
This can be accomplished by having fewer paddle boards in the next stage as shown below.



145

Flocculation

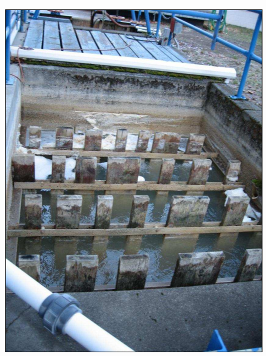
Mixing can also be accomplished using a variety of turbines and hydrofoils.



146

Flocculation

Mixing can also be accomplished hydraulically, using baffle walls



147

Common Coagulants and Flocculants

- Several types of coagulants available (often source of confusion):
  - Metal salts (alum and ferric)
  - Blended Products: Polyaluminum Chloride (PACl), Aluminum Chlorohydrate (ACH)
  - Polymers:
    - Cationic
    - Anionic
    - Non-ionic

Alum and Ferric Considerations

- Know the product strength:
  - Alum: 48 %wt ~5.4 lb per gal
  - Ferric chloride: 30 %wt ~3.4 lb per gal
- Don't forget alkalinity:
  - Every 1 mg/L alum consumes ~0.5 mg/L alkalinity
  - Every 1 mg/L ferric chloride consumes ~0.75 mg/L alkalinity
  - Maintain 5 to 10 mg/L alkalinity or add alkalinity (e.g., lime, soda ash)

Blended Product Considerations (e.g., PACl)

- Contains either aluminum or iron.
- Product strength typically same as product weight.
  - Equivalent dosages determined by % metal concentration (Al_2O_3, Fe) if known.
- Basicity is term used to describe product's relative charge.
  - Higher basicity products have higher positive charge.
- These products typically consume less alkalinity (i.e., less impact on pH).
  - Higher basicity products consume less alkalinity (i.e., 50% basicity product would consume half the alkalinity of equivalent alum dose).

Polymer Considerations

- Consist of long chain organic molecules.
  - Described by their molecular weight and charge density.
- Minimal effect on alkalinity.
- Product strength typically same as product weight (e.g. assume 100% strength).
- Provide multiple functions:
  - Coagulant (cationic)
  - Flocculant (anionic)
  - Filter aid (cationic, anionic, or non-ionic ⇒ all at very low dosages: < 0.1 mg/L)

Dose and Chemical Feeder Settings

Would you be able to answer the following questions?

What was the coagulant dose when we exceeded 1 NTU?

Did we exceed the maximum recommended dose (NSF-60)?

Which coagulant costs less given the differences in aluminum content?

Will we need new feed pumps if we increase plant capacity?

Dose and Chemical Feeder Settings

You will need…

1) Dosage required for good water quality (jar test, target pH, target chlorine residual, etc.)
2) Chemical pump feed rate required for desired dose.
3) Product strength (density x % concentration).

Approach

1. Establish a desired chemical dose (jar testing results are of little value if they can't be applied in plant!).
2. Calculate the coagulant feed pump setting to achieve the desired dose.
3. Adjust the coagulant feed pump based on a calibration curve or pump flow rate test with graduated cylinder.

Conversion Factors

Good conversion factors to know:

1 lb = 454 grams (2.2 kg)
1% = 10,000 mg/l (Assumes specific gravity = 1)

About water:

Specific gravity of water = 1.0 (varies with temp)
1 gallon of water weighs 8.34 lbs (8.344 lbs at its densest)
1 ml of water weighs 1 gram
1 US gallon = 231 cubic inches = 7.785 liters (3.78541)

About the "pounds formula"

$$Feed\ rate\left(\frac{lbs}{day}\right) = 8.34\ x\ dose\left(\frac{mg}{liter}\right) x\ flow\left(\frac{MG}{day}\right)$$

1. Can be used for liquid products (can be used as is if product has a specific gravity of 1 and is 100% pure – e.g. water. chlorine is generally considered to have a SG of 1. Polymers are generally treated as 100% "pure".)
2. Can be used for dry products (assumes 100% active ingredient).

More about the "pounds formula"

$$Feed\ rate\left(\frac{lbs}{day}\right) = 8.34\ x\ dose\left(\frac{mg}{liter}\right) x\ flow\left(\frac{MG}{day}\right)$$

1. Can be used for liquid products (can be used as is if product has a specific gravity of 1 and is 100% pure)
2. Can be used for dry products (assumes 100% active ingredient).
3. 8.34 is factor resulting from a "simple" conversion of units:

$$\left[\frac{1\ lb}{454\ \cancel{grams}}\right] x \left[\frac{1\ \cancel{gram}}{1{,}000\ mg}\right] x \left[\frac{3.7854\ liters}{\cancel{gallon}}\right] x \left[\frac{1{,}000{,}000\ \cancel{gallons}}{MGD}\right]$$

$$= 8.34\ \frac{lb-liter}{mg-MG} = \frac{8.34\ lbs}{MG\left(\frac{mg}{liter}\right)}$$

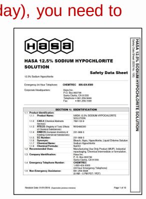
Feed rate in gallons/day (GPD)

$$Feed\ rate\left(\frac{lbs}{day}\right) = \frac{8.34\ lbs}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)} x\ dose\left(\frac{\cancel{mg}}{\cancel{liter}}\right) x\ flow\left(\frac{\cancel{MG}}{day}\right)$$

Convert to gpd – density

If the feed rate needs to be in volume (e.g. gallons/day), you need to factor in the density of the product (weight/volume).

1. A volume (e.g. gallon or ml) of product may be literally weighed to determine this.
2. Or you could use the specific gravity of the product, which is typically available from the product specification sheet.



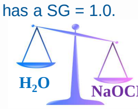
Density

$$Feed\ rate\left(\frac{lbs}{day}\right) = \frac{8.34\ lbs}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)} x\ dose\left(\frac{\cancel{mg}}{\cancel{liter}}\right) x\ flow\left(\frac{\cancel{MG}}{day}\right)$$

Density

1. The density of a substance is the weight for a given unit volume. For example water has a density of 8.34 lbs/gallon (1 g/ml).
2. Specific gravity (Sp. Gravity or SG) is the density of a liquid substance relative to the density of water. Water has a SG = 1.0.

Example: 12.5% sodium hypochlorite (NaOCL) has a SG of around 1.2, therefore, the density of the chlorine = SG of chlorine x density of water.



$$Density\ of\ 12.5\%\ NaOCL = 1.2\ x\ 8.34 = 10\ lbs/gallon$$

Density and GPD

$$Feed\ rate\left(\frac{lbs}{day}\right) = \frac{8.34\ lbs}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)} x\ dose\left(\frac{\cancel{mg}}{\cancel{liter}}\right) x\ flow\left(\frac{\cancel{MG}}{day}\right)$$

Convert to gpd

$$Feed\ rate\ (gpd) = \frac{\left[Feed\ rate\left(\frac{lb}{day}\right)\right]}{\left[SG\ x\ 8.34\ \frac{lb}{gal}\right]}$$

Or combined…

$$Feed\ rate\ (gpd) = \frac{\left[\frac{\cancel{8.34\ lbs}}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)} x\ dose\left(\frac{\cancel{mg}}{\cancel{liter}}\right) x\ flow\left(\frac{\cancel{MG}}{day}\right)\right]}{\left[SG\ x\ 8.34\frac{\cancel{lb}}{gal}\right]}$$

% Concentration

$$Feed\ rate\left(\frac{lbs}{day}\right) = \frac{8.34\ lbs}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)} x\ dose\left(\frac{\cancel{mg}}{\cancel{liter}}\right) x\ flow\left(\frac{\cancel{MG}}{day}\right)$$

How does % concentration factor in?

If the product is diluted in any way, this also needs to be factored in. Generally this is expressed as a % concentration (e.g. 12.5% sodium hypohchlorite, 50% caustic, or 48.5% alum).

Divide the feed rate by the product % concentration (converted to a decimal by dividing by 100%) as shown below:

$$Feed\ rate\ (gpd) = \frac{\left[\frac{\cancel{8.34\ lbs}}{\cancel{MG}\left(\frac{\cancel{mg}}{\cancel{liter}}\right)} x\ dose\left(\frac{\cancel{mg}}{\cancel{liter}}\right) x\ flow\left(\frac{\cancel{MG}}{day}\right)\right]}{\left[SG\ x\ 8.34\frac{\cancel{lb}}{gal}\right] x \left[\frac{\cancel{\%}\ strength}{100\cancel{\%}}\right]}$$

Example – “pounds formula”

Example: What feed rate in (lbs/day, gpd, and ml/min) is needed for 0.5 mg/l dose of 12.5% NaOCL (SG = 1.2) at a flow rate of 1 MGD?

$$1)\ Feed\ rate\ \left(\frac{lbs}{day}\right) = \frac{8.34\ lbs}{MG\left(\frac{mg}{liter}\right)}\ x\ 0.5\ \left(\frac{mg}{liter}\right) x\ 1\ \left(\frac{MG}{day}\right) = \boxed{4.17\ \frac{lbs}{day}}$$

$$2)\ Feed\ rate\ (gpd) = \frac{\left[4.17\left(\frac{lbs}{day}\right)\right]}{\left[12.5\%\ x\ 1.2\ x\ 8.34\frac{lbs}{gal}\right]} = \boxed{3.33\ \text{gpd}}$$

$$3)\ Feed\ rate\ \left(\frac{ml}{min}\right) = \left(\frac{1\ day}{1{,}440\ min}\right) x\ 3.33\ \left(\frac{gallons}{day}\right) x\ 3.7854\ \left(\frac{liters}{gallon}\right) x\ 1{,}000\ \left(\frac{ml}{liter}\right)$$

$$= \boxed{8.75\ \text{ml/min}}$$

Oregon Health Authority

Coagulant Feed Rate - Summary Liquid Products

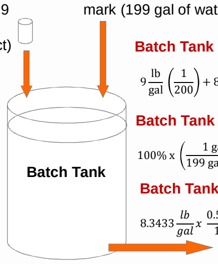
- Convert desired dose to required feed rate:
  - Dose (ppm) x 8.34 lb/gal x flow (MGD) = feed rate (lb/day)
  - Feed rate (lb/day) ÷ product density (lb/gal) ÷ % strength = feed rate (gal/day)
    - Product density = product weight per unit volume (liquid alum ~ 11.1 lb/gal)
    - Sometimes the term “product strength” is used to combine the terms of product density times % strength (liquid alum ~ 11.1 lb/gal x 48% alum = 5.3 lb/gal)

Oregon Health Authority

Example Product Strength Calculation for a Diluted Polymer

Add 1 gallon of polymer weighing 9 lb/gal (density of 100% pure product)

Fill batch tank with water to 200 gallon mark (199 gal of water at 8.34 lb/gal)



Batch Tank Density =

$$9\frac{\text{lb}}{\text{gal}}\left(\frac{1}{200}\right) + 8.34\frac{\text{lb}}{\text{gal}}\left(\frac{199}{200}\right) = 8.3433\ \text{lb/gal}$$

Batch Tank Concentration (%wt/wt) =

$$100\%\ \text{x}\left(\frac{1\ \text{gallon x 9 lb/gal}}{199\ \text{gallons x 8.34 lb/gal}}\right) = 0.5423\%$$

Batch Tank Concentration (lb/gal) =

$$8.3433\frac{lb}{gal}\ x\ \frac{0.5423\%}{100\%} = 0.045\ lbs\ of\ polymer/gallon$$

Oregon Health Authority

Another way to calculate density in this example:

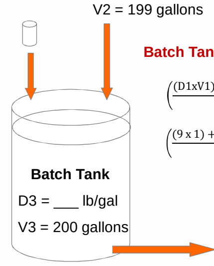
D1·V1 + D2·V2 = D3·V3 ====> D3 = (D1·V1 + D2·V2) / V3

D1 = 9 lb/gal

V1 = 1 gallon

D2 = 8.34 lb/gal

V2 = 199 gallons



Batch Tank Density =

$$\left(\frac{(\text{D1xV1}) + (\text{D2xV2})}{\text{V3}}\right) = \text{D3}$$

$$\left(\frac{(9\ \text{x}\ 1) + (8.34\ \text{x}\ 199)}{200}\right) = 8.3433\ \text{lbs/gallon}$$

Oregon Health Authority

Can you calculate concentration the same way? Yes!

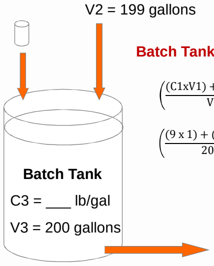
C1·V1 + C2·V2 = C3·V3 ====> C3 = (C1·V1 + C2·V2) / V3

C1 = 9 lb/gal

V1 = 1 gallon

C2 = 0 lb/gal

V2 = 199 gallons



Batch Tank Concentration =

$$\left(\frac{(\text{C1xV1}) + (\text{C2xV2})}{\text{V3}}\right) = \text{C3}$$

$$\left(\frac{(9\ \text{x}\ 1) + (0\ \text{x}\ 199)}{200}\right) = 0.045\ \text{lbs of polymer/gallon}$$

Oregon Health Authority

Another example with chlorine:

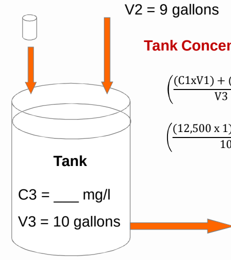
C1·V1 + C2·V2 = C3·V3 ====> C3 = (C1·V1 + C2·V2) / V3

C1 = 12,500 mg/l chlorine (12.5%)

V1 = 1 gallon

C2 = 0 mg/l chlorine

V2 = 9 gallons



Tank Concentration =

$$\left(\frac{(\text{C1xV1}) + (\text{C2xV2})}{\text{V3}}\right) = \text{C3}$$

$$\left(\frac{(12{,}500\ \text{x}\ 1) + (0\ \text{x}\ 9)}{10}\right) = 1{,}250\ \text{mg/l}$$

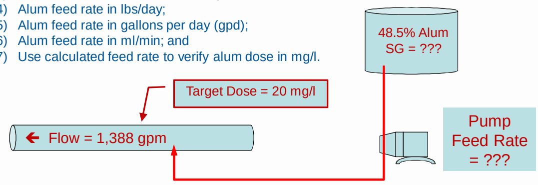
Oregon Health Authority

One more example – Alum (it just got real!)

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight (density) of 10.9 lbs/gal.

Solve for:

1) Plant flow in MGD;
2) Alum specific gravity (SG);
3) Available alum concentration in mg/l;
4) Alum feed rate in lbs/day;
5) Alum feed rate in gallons per day (gpd);
6) Alum feed rate in ml/min; and
7) Use calculated feed rate to verify alum dose in mg/l.



One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow in MGD;
2) Alum specific gravity (SG);

$$1)\ Plant\ flow = 1{,}388\ gpm\ x \left(\frac{1\ MGD}{694\ gpm}\right) = 2\ MGD$$

$$2)\ Alum\ SG = 10.9\left(\frac{lb}{gal}\right)\ x\ \left(\frac{1\ gal\ water}{8.34\ lbs}\right) = 1.30695 \sim 1.31$$

48.5% Alum
SG = 1.31

Flow = 1,388 gpm = 2 MGD

$$100\%\ water\ weighs \left(\frac{1\ gram}{1\ ml}\right) \Rightarrow \left(\frac{1\ gram}{1\ ml}\right) x \left(\frac{1\ lb}{454\ gram}\right) x \left(\frac{3.78541\ l}{1\ gallon}\right) x \left(\frac{1{,}000\ ml}{l}\right) = 8.338\ lbs/gallon$$

One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD
2) Alum SG = 1.31
3) Available alum concentration in mg/l – there are 2 ways to solve for this;

The 1st way uses the relationship of 1% = 10,000 mg/l, which is based on the weight of water (SG=1) where 1 ml weighs 1 gram. This calculation is shown below:

48.5% Alum
SG = 1.31

$$100\%\ water\ weighs \left(\frac{1\ gram}{1\ ml}\right) \Rightarrow \left(\frac{1\ gram}{1\ ml}\right) x \left(\frac{1{,}000\ mg}{1\ gram}\right) x \left(\frac{1{,}000\ ml}{l}\right) = 1{,}000{,}000\ mg/l$$

$$1\%\ of\ the\ weight\ of\ water = 1\%\ x \left(\frac{1{,}000{,}000\ mg}{100\ \%}\right) = 10{,}000\ mg/l$$

One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD
2) Alum SG = 1.31
3) Available alum concentration in mg/l – there are 2 ways to solve for this;

The 1st way uses the relationship of 1% = 10,000 mg/l, which is based on the weight of water (SG=1) where 1 ml weighs 1 gram. This calculation is shown below:

48.5% Alum
SG = 1.31

$$Available\ alum\ concentration\ in\ \frac{mg}{l} = SG\ x\ \%\ concentration\ x \left(\frac{10{,}000\ mg/l}{1\ \%}\right)$$

$$Available\ alum\ concentration = 1.31\ x\ 48.5\%\ x \left(\frac{10{,}000\ mg/l}{1\ \%}\right) = \boxed{635{,}350\ mg/l}$$

Remember, we have to account for liquid alum (which is a dilution containing 48.5% alum in water)

One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD
2) Alum SG = 1.31
3) Available alum concentration in mg/l – there are 2 ways to solve for this;

The 2nd way uses the % concentration, density of the 48.5% alum, and a series of unit conversions…

48.5% Alum
SG = 1.31

$$\left(\frac{48.5\%}{100\%}\right) x \left(\frac{10.9\ lbs}{gallon}\right) x \left(\frac{454\ g}{1\ lb}\right) x \left(\frac{1{,}000\ mg}{1\ g}\right) x \left(\frac{1\ gallon}{3.7854\ l}\right) = \boxed{634{,}032\ mg/l}$$

$$1.31\ x\ 48.5\%\ x \left(\frac{10{,}000\ mg/l}{1\ \%}\right) = 635{,}350\ mg/l$$

One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD
2) Alum SG = 1.31
3) Available alum concentration in mg/l – there are 2 ways to solve for this;

The 2nd way uses the % concentration, density of the 48.5% alum, and a series of unit conversions…

48.5% Alum
SG = 1.31

$$\left(\frac{48.5\%}{100\%}\right) x \left(\frac{10.9\ lbs}{gallon}\right) x \left(\frac{454\ g}{1\ lb}\right) x \left(\frac{1{,}000\ mg}{1\ g}\right) x \left(\frac{1\ gallon}{3.7854\ l}\right) = \boxed{634{,}032\ mg/l}$$

$$1.31\ x\ 48.5\%\ x \left(\frac{10{,}000\ mg/l}{1\ \%}\right) = 635{,}350\ mg/l$$

Why the difference? Rounding errors ☹

One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD;
2) Alum SG = 1.31;
3) Available alum concentration = 634,032 mg/l;
4) Alum feed rate in lbs/day;

$$Feed\ rate\ \left(\frac{lbs}{day}\right) = \frac{8.34\ lbs}{MG\left(\frac{mg}{liter}\right)}\ x\ 20\ \left(\frac{mg}{liter}\right)\ x\ 2\ \left(\frac{MG}{day}\right) = \boxed{333.6\ \frac{lbs}{day}}$$

Pump Feed Rate = 33.6 lbs/day

Health Oregon Authority

One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD;
2) Alum SG = 1.31;
3) Available alum concentration = 634,032 mg/l;
4) Alum feed rate = 333.6 lbs/day;
5) Alum feed rate = 63 gpd;

$$Feed\ rate\ (gpd) = \frac{\left[333.6\left(\frac{lbs}{day}\right)\right]}{\left[\left(\frac{48.5\%}{100\%}\right)x\ 1.31\ x\ 8.34\frac{lbs}{gal}\right]} = \frac{\left[333.6\left(\frac{lbs}{day}\right)\right]}{\left[5.2988\frac{lbs}{gal}\right]} = \boxed{63\ \frac{gal}{day}}$$

Pump Feed Rate = 63 gpd

Health Oregon Authority

One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD;
2) Alum SG = 1.31;
3) Available alum concentration = 634,032 mg/l;
4) Alum feed rate = 333.6 lbs/day;
5) Alum feed rate = 63 gpd;
6) Alum feed rate in ml/min;

$$Feed\ rate\ \left(\frac{ml}{min}\right) = \left(\frac{1\ day}{1{,}440\ min}\right)x\ 63\ \left(\frac{gallons}{day}\right)x\ 3.7854\ \left(\frac{liters}{gallon}\right)x\ 1{,}000\ \left(\frac{ml}{liter}\right)$$

$$Feed\ rate = \boxed{165\ ml/min}$$

Pump Feed Rate = 165 ml/min

Health Oregon Authority

One more example - Alum

Jar testing shows that the most settleable floc is formed at an alum dose of 20 mg/l. The flow rate on the plant effluent meter reads 1,388 gpm and will stay at that rate for the next 24 hours. The coagulant used is 48.5% liquid alum with a weight of 10.9 lb/gal.

Solve for:

1) Plant flow = 2 MGD;
2) Alum SG = 1.31;
3) Available alum concentration = 634,032 mg/l;
4) Alum feed rate = 333.6 lbs/day;
5) Alum feed rate = 63 gpd;
6) Alum feed rate = 165 ml/min;
7) Use calculated feed rate to verify alum dose in mg/l.

$$C1Q1 + C2Q2 = C3Q3$$

$$\left(\frac{C1Q1 + C2Q2}{Q3}\right) = C3$$

48.5% Alum SG = 1.31

Target Dose = 20 mg/l

C3 = ____ mg/l Q3 = 2,000,063 gpd

Flow

C2 = 0 mg/l Q2 = 2,000,000 gpd

Pump Feed Rate = 63 gpd

$$\left(\frac{(634{,}032\ x\ 63) + (0\ x\ 2{,}000{,}000)}{2{,}000{,}063}\right) = \boxed{19.97\ mg/l}$$

C1 = 634,032 mg/l Q1 = 63 gpd

Health Oregon Authority

Determination of Coagulant Feed Rate Dry Products

- Convert dose to feed rate:
  - Dose (mg/l) x 8.34 lb/gal x flow (MGD) = feed rate (lb/day)
- Dry feeders:
  - Calibrate from grab sample(s) over timed period.
    - Weigh sample(s) and express as weight per unit time.
    - Develop calibration curve based on multiple grab samples at different feeder settings.

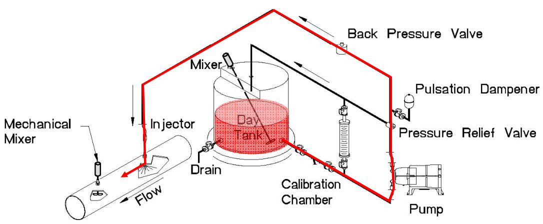
Health Oregon Authority

Approach

1. Establish a desired chemical dose (jar testing results are of little value if they can't be applied in plant!).
2. Calculate the coagulant feed pump setting to achieve the desired dose.
3. Adjust the coagulant feed pump based on a calibration curve or pump flow rate ("drawdown") test with graduated cylinder.

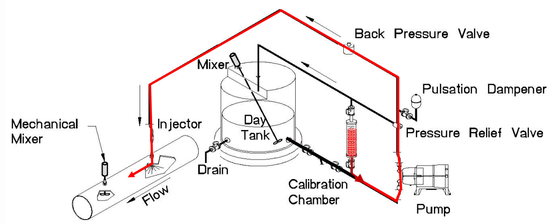
Health Oregon Authority

Pump Flow
Normal coagulant flow path



181

Pump Flow Rate ("Drawdown") Test
Coagulant flow during pump drawdown test



182

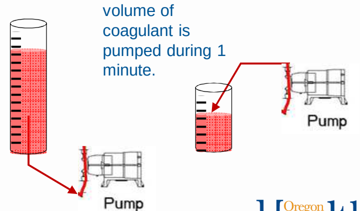
Pump Flow Rate ("Drawdown") Test
Coagulant flow during pump drawdown test

Either:

1. Fill the calibration column and allow pumping coagulant out of column.
2. Measure what volume of coagulant is pumped during 1 minute.

or:

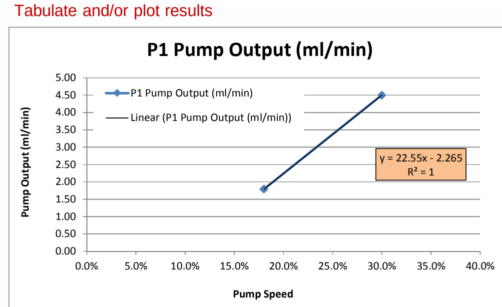
1. Pump into a graduated cylinder.
2. Measure what volume of coagulant is pumped during 1 minute.



183

Pump Flow Rate ("Drawdown") Test
Coagulant flow during pump drawdown test

Tabulate and/or plot results



184

Pump Flow Rate ("Drawdown") Test
Coagulant flow during pump drawdown test

You can have a calibration column for each pump or use the same calibration column for two pumps (a primary pump and a backup for example), provided they pump the same chemical.

City of Corvallis, 2009

185

Example – Does current dose match what you think you are dosing?

Equation 1:

$$\text{Feed Rate, mL/min} = \frac{\text{(Sample Volume) mL}}{\text{(Sample Time) min}}$$

Equation 2:

$$\text{Feed Rate, gal/day} = \frac{\text{(Feed Rate) mL}}{\text{min}} \text{ x } \frac{\text{gal}}{\text{3,785mL}} \text{ x } \frac{\text{1,440min}}{\text{day}}$$

Equation 3:

$$\text{Feed Rate, lb/day} = \frac{\text{(Feed Rate) gal}}{\text{day}} \text{ x } \frac{\text{(Product Strength) lb}}{\text{gal}}$$

Equation 4:

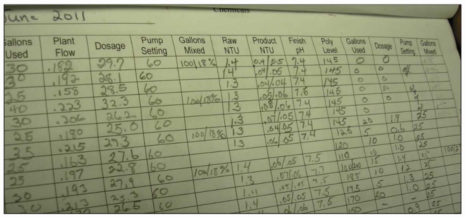
$$\text{Dose, mg/L} = \frac{\text{(Feed Rate) lb}}{\text{day}} \text{ x } \frac{\text{day}}{\text{(Flow) MG}} \text{ x } \frac{\text{gal}}{\text{8.34 lb}}$$

Pump 1 Dosage Check

Variable	Result	Units	Comments
Reported plant flow	57	gpm	
Reported plant flow	0.082	MGD	(57 gpm)
Feed Rate	4.5	ml/min	Drawdown Test (Equation 1)
Feed Rate	1.71	gal/day	(Equation 2)
Product Strength	100	%	
Product Specific Gravity	1.24	SpGr	
Product Density	10.34	lbs/gal	100% PASS C-X, SpGr=1.24
Feed Rate	17.71	lbs/day	(Equation 3)
Calculated plant dosage	25.86	mg/L	(Equation 4)
Reported plant dosage	26	mg/L	

Homework Assignment

- Develop operational guidelines for plant-specific approach to setting coagulant feed.



Coagulation Optimization
Potential Special Studies

- Coagulant type and dose for given water quality (i.e., turbidity, alkalinity, temp., TOC, algae).
- Rapid mix (ideal: high energy & short time).
- Coagulation pH (TOC removal).
- Effect of coagulant aids.
- Addition of alkalinity (e.g., lime, soda ash).
- Effect of pre-oxidants (i.e., chlorine, $KMnO_4$).
- Others?

Flocculation Optimization
Possible Special Studies

- Mixing energy (use jar test calibration studies to assess changes in mixing speed).
- Basin short-circuiting (baffle addition?).
- Floc breakup at transition zones.
- Use of flocculant aids.
- Others?

Jar Testing

- Advantages:
  - Can be used to optimize both coagulation and flocculation
  - Available in most plants
  - Proven process control tool
  - Effective training tool (special studies)
- Disadvantages:
  - Matching jar test performance to plant
  - Jar test procedure intimidating for some plant staff

Jar Testing
Equipment needed

1. 300-RPM jar tester
2. 2-L square jars (x6)
3. 10-ml pipette
4. 1.0, 3.0, 12.0 ml syringes (x6)
5. Plastic cups (x6)
6. 100-ml Volumetric flask
7. Turbidimeter w/6 sample vials
8. Coagulant

Jar Testing
Jar testers come in a variety of forms

<= 4-jar (portable)

Programmable =>

<= 6-jar =>

Jar Testing

Jars can be 2-L square or 1-L round

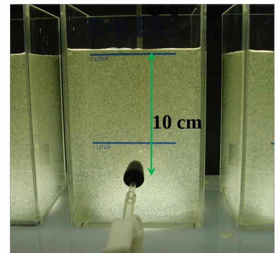
bulkhead fitting
(works better)

cork" stopper
(tends to dislodge)

no good way to sample

Advantages of the 2-Liter Square Jars

- Better mixing
- Mixing curve available
- Better insulating properties (reduces water temperature changes)
- More water for testing (versus 1 L)
- Standard sampling location used to determine settling velocity



Standard Jar Test Procedure

1. Prepare chemical stock solutions or microsyringes.
2. Decide on jar chemical doses and volumes.
3. Collect water sample and fill jars.
4. Start mixer and adjust for rapid mix.
5. Add chemicals in same sequence as plant.
6. Adjust mixer speed to simulate flocculation.
7. Stop mixer after floc time and settle.
8. Sample jars and test.

Jar Test Basics

Preparing Stock Solutions

- Determine the dose range to be tested:
  - Use historical data, vendor recommendations, raw water quality.
- Select the stock solution concentration.
- Make stock solution using a volumetric flask and distilled water.
- Make dilute stock solutions (< 0.1 %) on a daily basis (> 0.1% hold for a week).
- Remember – stock solutions can be made to test polymers, pre-oxidants, and pH adjustment chemicals.

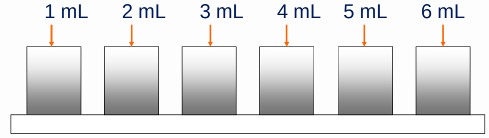
Stock Solution Selection

Dose (mg/L) for each mL of Stock Solution Added to 2-Liter Jar	Stock Solution Concentration	
	% wt	Mg/L
0.10	0.01	100
0.25	0.05	500
0.50	0.10	1,000
1.0	0.20	2,000
2.5	0.50	5,000
5.0	1.0	10,000
10.0	2.0	20,000

Example Jar Test Setup

Stock Solution *

1 mL 2 mL 3 mL 4 mL 5 mL 6 mL



5 mg/L 10 mg/L 15 mg/L 20 mg/L 25 mg/L 30 mg/L

Dose

* 1% stock solution provides 5 mg/L dose in 2 L jar per 1 mL added

Adding Coagulant Directly to Jars Using Micro-syringe

- Some vendors (e.g. DelPac) recommend dosing their coagulant using micro-syringes (versus making a stock solution).
- Coagulant is placed on septum or slide cover and dropped into the jars.

Micro-syringe

Septum

Slide Covers

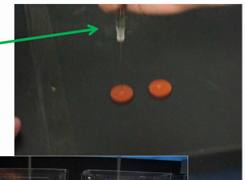
For example:

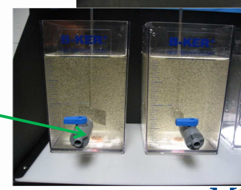
- DelPac product with specific gravity of 1.206 and 20 mg/L dose to 2 L jar.
- Required volume:

20 mg/L x (1 µl/1.206 mg) x 2 L = 33.2 µL

Adding Coagulant Directly to Jars Using Micro-syringe

- Deliver coagulant to septa or slide cover using micro-syringe.
- Drop the septa into the jar at the time when coagulant is to be added.
- Septa stays in jar.





Equipment and Techniques Considerations

- Thoroughly clean jars and mixers to remove chemical residue.
- 2-liter square jars preferred with sample tap at 10 cm:
  - 2-liter beakers acceptable (with baffles)
- Transferring dose:
  - Multiple syringes (1cc = 1mL)
  - Containers with pre-measured volumes (rinse container with distilled water after transfer)
  - Use microsyringe and septa if dosing neat.
- Sampling:
  - Flush sample taps slowly before sampling (displace tube volume).

Initial Jar Test Settings

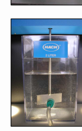
- Based on existing unit process sizes and equipment mixing energy
- Based on current plant flows and basin loadings
- Use as a starting point for making a jar test work at your plant
- Initial settings should be calibrated

Summary

- Gain experience and confidence with jar testing – it can be a powerful tool.
- Paying attention to details makes the difference between a good jar test and a bad one.

Exercise – Jar Test Demonstration

- Use 4-jar mixer
- Use one 2-L square jar and three 1-L round jars
- Make 1% Alum Stock Solution
- Dose Jars



Calibration of Jar Test Settings

- Main criticism of jar testing:

  Jar test results do not predict my plant's performance.
- Possible reasons:
  - Inaccurate dosing of jars
  - Stock solutions are not accurate
  - Water temperature effects
  - Jar testing equipment is not clean (residual chemicals)
  - Out-of-date or damaged jar testing equipment
  - Jar conditions do not match plant conditions (i.e., mixing energy, detention time, sludge addition)
  - Plant conditions are not what they are assumed to be (e.g., inaccurate dosing, plugged chemical feed lines, short-circuiting, mixing energy too low or too high)

What is Jar Test Calibration?

- Jar test calibration is the systematic use of special studies to match plant and jar test conditions so that jar testing can be used as a useful tool to support plant optimization!
- Requires a commitment at the staff level to "make the jar test work"

Jar Test Calibration is Conducted in Four Studies

- Study 1 – Quality Control
- Study 2 – Rapid Mix
- Study 3 – Flocculation
- Study 4 – Sedimentation

Studies will likely need to be repeated to complete the jar test calibration for your plant!!

Equipment Needed

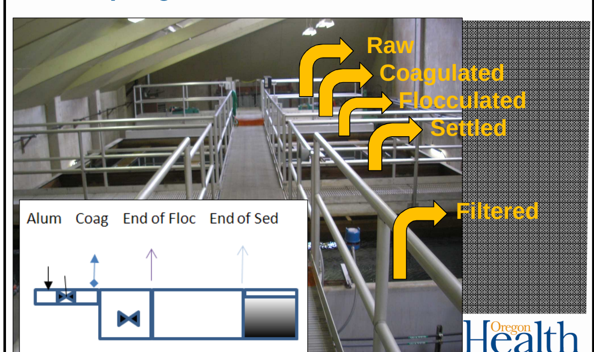
- Jar Tester (6 jars, 300-rpm)
- Six 2-L Square Jars
- Portable or benchtop turbidimeter
- pH analyzer
- Misc. lab ware for making stock solution

(Jar tester located in lab)

Sampling Sites - Lab

Raw water sample line – clearly labeled taps help!

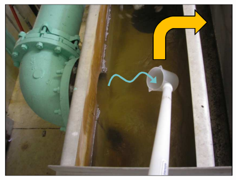
Sampling Sites - Plant



Sampling Sites - Plant

Raw
(pre alum addition)

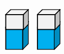
Coagulated
(post rapid mix)



Study 1 - Quality Control

- This special study must be successfully accomplished before proceeding with jar test calibration at your facility.
- Settling curves are used as a primary indicator during jar test calibration to show that similar floc is being formed in the jar as well as in the plant.
- Approach: Treat two jars in an identical manner. Develop settling curves for both jars.

Study 1 – Quality Control (checking sampling technique)

- Use 2 jars filled with raw water 
- Dose both jars equally with the current plant dose
- Place in jar tester and complete jar test sequence for your plant

Time min	Jar 1 NTU	Jar 2 NTU
0	5.14	5.75
1	5.55	5.99
2	5.33	5.3
4	5.03	4.48
6	4.44	5.06
8	4.42	4.35
10	3.67	3.87

Example Jar Speed	Example Mix Time
300 RPM	5 seconds
77 RPM	30 seconds
52 RPM	20 minutes
Turn mixer off and wait 1 minute for jars to stop spinning (the end of this wait period will be considered T = 0 minutes for sampling)	
Settle for 10 minutes, sampling turbidity from each jar at T = 0, 1, 2, 4, 6, 8, and 10 minutes.	

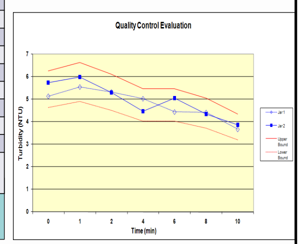
Data will be tabulated and graphed (1 curve for each jar)
If curves match – quality control is good

Study 1 – Compare the Two Settling Curves

Time min	Jar 1 NTU	Jar 2 NTU	Absolute Difference (Diff between Jar 1 and Jar 2) NTU
0	5.14	5.75	0.61
1	5.55	5.99	0.44
2	5.33	5.3	0.03
4	5.03	4.48	0.55
6	4.44	5.06	0.62
8	4.42	4.35	0.07
10	3.67	3.87	0.2
Total ABS difference:			2.52 NTU
Average of all readings			4.88 NTU
Ratio: Total ABS diff ÷ Avg of all readings:			0.52

Ratio ≤ 1.0 indicates lines considered to be similar
2.0 ≥ Ratio > 1.0 indicates room for improvement
Ratio > 2.0 indicates dissimilar lines

If reproducible results are not achieved, technique must be addressed… repeat the study!

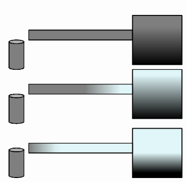


How is quality control study useful?

Study 1 – Quality Control Special Study

- Helps refine sampling technique
- Not flushing sampling line leads to erroneous results

T = 0 min: 2 NTU — 2 NTU
T = 5 min: 2 NTU — 1 NTU
T = 10 min: 2 NTU — 0.5 NTU



Study 2 – Rapid Mix Process Calibration

- Calibration factors (variables):
  - Detention time & mixing energy – Start with theoretical for your plant
  - Definition of rapid mix is often expanded to include multiple mixing zones.
  - Chemical addition – Match chemical addition in plant. Use sample with most chemicals added (dynamic testing).
- Performance indicators:
  - Measure pH following rapid mix in jars and compare to pH following plant rapid mix (works best with alum and ferric).
  - Matched pH indicates accurate stock solutions and jar test dosing.

Study 2 – Rapid Mix
(For alum, match pH to verify dose & stock solution)

- Use 6 jars filled with raw water
- Dose jars to bracket current plant dose
  (jar 1 to have no coagulant, jar 4 to have plant dose)
- Place in jar tester and complete the following mixing/sampling sequence:

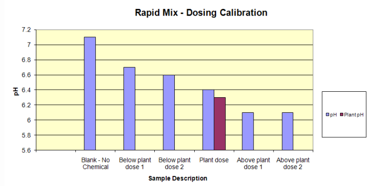
Jar	Dose Mg/l	Jar pH	Plant Grab Sample pH
1	0 (blank)	7.1	
2	10	6.7	
3	12	6.6	
4	16 (plant dose)	6.4	6.3
5	20	6.1	
6	20	6.1	

Example Jar Speed	Example Mix Time
300 RPM	5 seconds
77 RPM	30 seconds
10 RPM	While sampling
Sample pH from each jar	
Sample pH of coagulated water from the plant (grab sample just prior to flocculation)	

Data will be tabulated and graphed (1 curve for each

Study 2 – Rapid Mix Results

Jar	Dose mg/l	Jar pH	Plant pH
1 (Blank)	0	7.1	
2	10	6.7	
3	12	6.6	
4 (plant dose)	16	6.4	6.3
5	20	6.1	
6	20	6.1	



Interpretation of Results:
Some coagulants like alum will lower the pH. The pH in the jar at the plant dose should match the plant pH. If not, then check dosage calculations and/or stock solution preparation.

Note: the rapid mix setting (time and jar mixing speed) is not confirmed by this study.

How is rapid mix study useful?

Study 2 – Rapid Mix/Dosing Control Special Study

- If you are not able to replicate plant dose in the jar, the reverse may also be true – i.e., you may want to replicate results of different coagulant doses you've created in the jars.
- Procedures for making stock solutions may need refining.
- Plant dose calculations may need to be revised.
- Coagulant pump output may not be as predicted, as evidenced by a pump calibration.

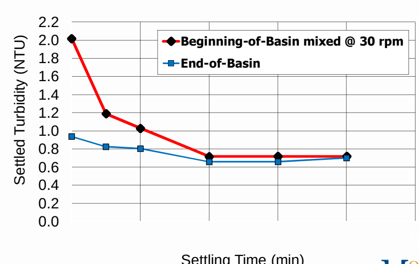
Study 3 – Flocculation Process Calibration

- Calibration factors:
  - Detention time – Start with theoretical for each stage.
  - Chemical addition – If feeding flocculent aid, match dose and feed location.
  - Mixing energy – Start with theoretical mixing energy for each stage
  - Performance indicators:
  - Floc particle settling characteristics
  - Compare jar and plant settling curves following flocculation

Study 3 – Flocculation Process Calibration

- Calibration Steps:
  - 1st – collect water from the beginning of the floc basin, being careful not to break floc apart.
  - Take sample and run the jar test procedure beginning with the flocculation stage and develop a settling curve.
  - Take another sample of water from the end of the floc basin, by carefully dipping into the basin. Then develop a settling curve for this sample.
  - Graph and compare both settling curves.

Study 3 – Compare Settling Curves from Beginning-of-Floc-Basin and End-of-Floc-Basin Sampling.



Flocculation – Studies 3b and 3c (Adjust mixing time and speed – observe impact)

- Study 3b – ½ time
  - Use 2 jars
  - Repeat study 3a with only ½ the mixing time
  - Tabulate and plot the results to see the impact
- Study 3c – ½ mixing speed
  - Use 2 jars
  - Repeat study 3a with only ½ the mixing speed
  - Tabulate and plot the results to see the impact

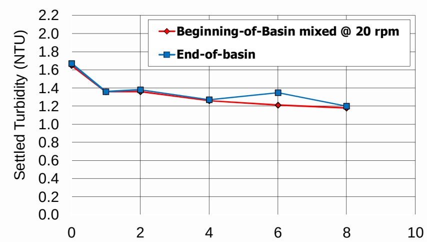
3b. Results for ½ Time

Time min	Jar 1 NTU	Jar 2 NTU
0	1.79	1.87
1	2.01	1.83
2	2.02	1.87
4	1.8	1.95
6	1.83	1.86
8	1.87	1.76
10	1.85	1.86

3c. Results for ½ Speed

Time min	Jar 1 NTU	Jar 2 NTU
0	1.72	2.14
1	1.64	2.21
2	1.65	1.96
4	1.63	2.09
6	1.72	2
8	1.39	1.98
10	1.16	1.96

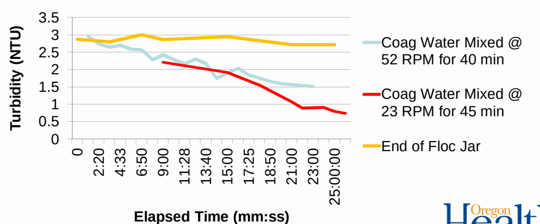
Study 3 – Example Showing Impact on Settling Curve When Jar Mixing Energy Decreased



How is flocculation study useful?

- Study 3 – Flocculation Process Calibration

  You may want to replicate different flocculation speeds in your jars (think of the jars as a pilot plant) before trying the change full-scale.



Study 4 – Sedimentation Process Calibration

- Calibration approach for sedimentation:
  - A theoretical jar sampling time can be calculated by knowing the sedimentation basin loading rate.
    - For example: surface loading rate = 0.5 gpm/ft^2 ~ **2 cm/min**
    - Sampling jar after 5 minutes is equivalent to this loading rate (10 cm settling distance ÷ **2 cm/min**)
    - Add extra time for the water in the jars to stop moving after mixer is stopped (e.g., ½ to 1 minute; maybe settle for 6 min.)
  - Sedimentation calibration is conducted by collecting 2 jars of water from the end of the flocculation basin, simulating a slow mix step in the jar tester, and developing a settling curve over ~ 30 minutes.

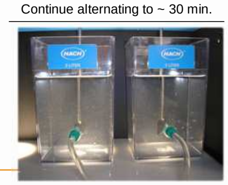
Study 4 – Enhancement to Sedimentation Process Calibration

- Impacts of continued flocculation in sedimentation basin:
  - Continued flocculation typically occurs at the beginning of conventional sedimentation basins.
  - The result is larger, faster settling particles, and plant performance is often better than jar performance.
- To simulate this effect, a short period of time and low energy are applied to the end of floc basin sample to start the test (e.g., 5 minutes @ 7 rpm).

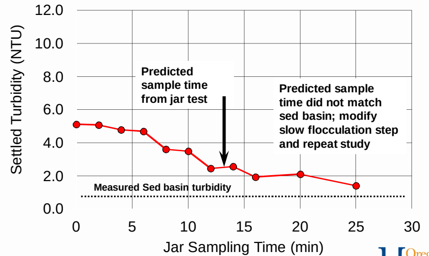
Study 4 – Sedimentation Process Calibration

- Fill 2 jars from end of flocculation process. Two jars are used to minimize drawdown in the jars during sampling.
- Start the test with the slow mix step (e.g., 5 min. @ 10 rpm to keep floc suspended).
- Next, sample jars alternately from Time 0 to ~ 30 minutes.
- While conducting the settling test, also collect samples of the sedimentation basin effluent and measure turbidity.
- Compare jar settling curves with actual sedimentation basin performance.

Time	Jar 1	Jar 2
0	Sample	
2		Sample
4	Sample	
6		Sample
8	Sample	
Continue alternating to ~ 30 min.		



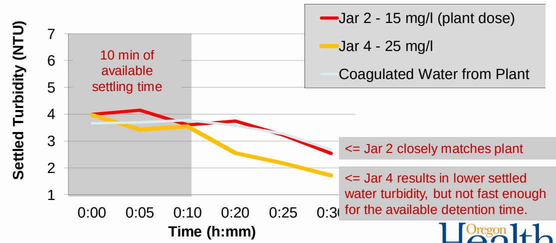
Study 4 – Example Settling Curve to Assess Sedimentation Sampling Time



How is sedimentation study useful?

- Study 4 – Sedimentation Process Calibration

This may influence a decision to switch coagulants or dosages.



Example Calibrated Jar Test Settings

- Rapid Mix:
  - Set jar mixer to 300 rpm (static mixer).
  - Add Alum coagulant and mix @ 300 rpm for 5 seconds.
  - Turn down mixer to 77 rpm for 2 minutes (pipeline mixing).
- Flocculation:
  - Turn down mixer to 40 rpm for 15 minutes (1st stage floc).
  - Turn down mixer to 25 rpm for 15 minutes (2nd stage floc).
  - Turn down mixer to 7 rpm for 10 minutes (floc/sed transition mixing).
- Sedimentation:
  - Stop mixer.
  - Sample jars for turbidity after 10 minutes.

During the Jar Test Calibration Process…

- You may discover things about your plant that you did not know before.
- Initial special studies may point to plant limitations:
  - Flow splitting
  - Chemical feeding
  - Limited range in mixing energy (i.e., rapid mix, flocculation)
  - Others
- Identifying and correcting plant limitations is part of jar test calibration and future special studies.
- Remember "special studies breed more special studies."

Streaming Current

Streaming current

1. A device consisting of a piston within a cylinder that is used to draw the water sample in, induce a current through fluid motion, and measures the streaming current as a constant signal output.
2. A stationary liquid boundary layer lies at the surface of both a piston and a cylinder, which contains negatively charged particles. Since the stationary layers contain negative particles, the fluid between the cylinder wall and the piston becomes positively charged. These two oppositely charged layers glide past each other as the piston moves up and down in the cylinder. This movement of two charged layers, induces a current, which is then measured by an electrode in microamperes.
3. The current is an alternating current (AC) due to the back and forth motion of the piston. This alternating current is then rectified and time-smoothed to provide a "streaming current" or constant signal output (numerical reading).

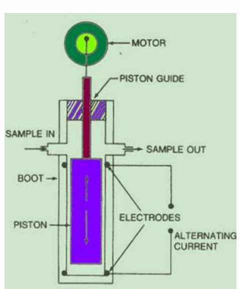


Figure 1. A simple diagram of the SCM sampling cell

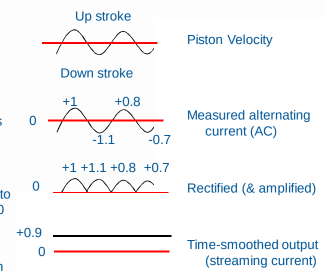
Streaming Current

Output ("zero offset out") is in relative units (does not provide actual current or charge density due to sensitivity in small differences between the cylinder wall).

Measured current is impacted by irregularities in the cylinder wall as well as the motor speed.

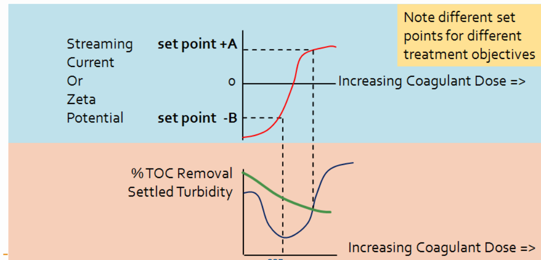
Span/gain adjustment:
Used to vary output by a factor of up to 30 or 50. 10% dose change = +10

Zero adjust/"Zero offset in":
Used to move the reading up or down in value by a selected amount.



Streaming Current - Particle Charge Relationship to Turbidity & TOC

An example of how particle charge can be related to settled water turbidity and TOC removal.

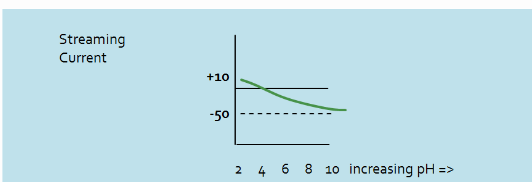


Streaming Current Response

- Streaming current goes more positive caused by:
  - Decrease in: pH, flow, color, turbidity, lime, caustic, and anionic polymers
  - Increase in: Alum, Ferric sulfate, ferrous sulfate, PAC, cationic polymers, and chlorine.
- Potassium permanganate has no appreciable effect (1-2 ppm dose)
- “Set point” determined by optimizing coagulation and turbidity/TOC removal (jar testing) and noting SC reading

Streaming Current - Particle Charge Relationship to pH

An example of how particle charge can be related to a buffered kaolinite suspension of varying pH.



Streaming Current - Rapid Fluctuations

Rapid fluctuations in SCD readings can be caused by:

- Improperly mixed coagulant in the sample line causing the detector to measure alternating doses of coagulated and under-coagulated water
- Extended off and on periods of the coagulant feed system, that provides periods of under dosing and over dosing, even though the dose may be correct when averaged over time.
- SCD sensor in need of cleaning. Be sure to check sample lines as clogging is a commonly reported problem – clear sample lines help identify problems.

Streaming Current – Good Applications

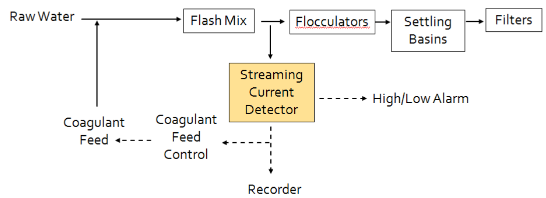
- Streaming current detectors set up to control coagulant dose are good for:
  - When charge neutralization is the main objective
  - Responding to rapid changes in raw water quality (e.g. storm events)
  - Compensating for variations in strengths of similar products or different batches of same product
  - Responding to changes in plant influent flow rates
- Periodic jar testing to verify the optimal set point is strongly recommended.

Streaming Current – Considerations

- Control - Where the coagulant is controlled by the SCD controller, but not the lime addition for pH. The solution is to control both the pH and coagulant feed rates at a constant proportion with the ability to manually fine-tune the proportion.
- PAC - The periodic addition of PAC may require that set points be closely monitored. The PAC may add a coagulant demand due to its negative surface charge, but may also lower the coagulant demand, depending upon the level of organics adsorbed by the PAC
- Maintenance - Fe, Mn and lime can deposit and foul sensor (Clean per Mfr. Recommendations)
- Temperature - Where temperature fluctuations greatly impact coagulation rates. The solution is to determine optimum set points monthly or at least quarterly.

Streaming Current Device Placement

- Placement should be after coagulant addition and rapid mixing.
- Depending on the efficiency of the rapid mix, a delay time of 2-5 minutes should be incorporated (e.g. through a longer sample line) to ensure the coagulant has fully equilibrated. If the coagulant is given enough time to adsorb or precipitate onto particles, less of it will remain in solution to deposit onto surfaces of the SCD's sensor.
- On the other hand, an excessive lag time will cause an excessively delayed coagulant feed control response causing the coagulant feed control to "chase" the SCD set point.



241

Streaming Current – Jar Testing

Jar testing can help identify:

- Sensor malfunction or need for cleaning
- When "sweep floc" coagulation may be needed
- Temperature effects
- Signal delay effects
- Optimum dose for removal of NOM, as indicated by TOC or UV254

242

Exercise

- Form groups of 4 or 5 and…
  1. Share <u>your</u> process for coagulation control with your group.
  2. Share at least 1 experience that helped you better improve your process.
  3. Identify any opportunities to improve your process.
- Identify one person to report to the class:
  1. What was the most common coagulation control tool or method used?
  2. Report on at least 1 experience that the class may be able to benefit from.
  3. Provide an example of at least 1 opportunity for improvement identified among your group.

Class Outline

9 AM	Introduction/Overview
10:15 AM – 15 minute break	
10:30 AM	Coagulation/Flocculation
12 noon – Lunch (on your own)	
1 PM	Clarification/Sedimentation
2 PM	Filtration
2:15 PM – 15 minute break	
2:30 PM	Filtration (continued)
3:30 PM	General Operations
4:30 PM - End	

244

Class Outline

9 AM	Introduction/Overview
10:15 AM – 15 minute break	
10:30 AM	Coagulation/Flocculation
12 noon – Lunch (on your own)	
1 PM	Clarification/Sedimentation
2 PM	Filtration
2:15 PM – 15 minute break	
2:30 PM	Filtration (continued)
3:30 PM	General Operations
4:30 PM - End	

245

Clarification/Sedimentation (Conventional Filtration)

Clarification is generally considered to consist of any process or combination of processes which reduce suspended matter prior to filtration.

Sedimentation is clarification that relies on gravity to settle particles out.

Clarification Objectives (Conventional Filtration)

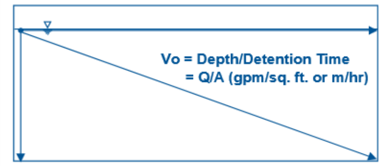
Key objective is to lower the particulate load to the filters
- Accomplished with gravity or other separation processes
- Collected solids need to be physically removed
- Turbidity removal is typically in the 60-80% range (Hudson, 1981)

Oregon Health Authority

Clarification (Conventional Plants)

Sizing is often defined by hydraulic loading rate (gpm/ft² or m/hr)

- 0.5 gpm/ft² = 1.2 m/h = 0.066 ft/min



Oregon Health Authority

Clarification (Conventional Plants)

Forms of clarification include:

- Sedimentation basins (0.5 – 0.7 gpm/ft², depending on depth)
- High rate clarification:
  - Tube (1-2 gpm/ft²) or plate settlers (~ 4 gpm/ft²)
  - Contact adsorption clarifiers or "contact clarifiers" (8 gpm/ft²)
  - Solids contact clarifiers (8-12 gpm/ft² for IDI Densadeg)
  - Sludge blanket clarifiers (2-4 gpm/ft² for IDI Superpulsator)
  - Dissolved air flotation (2-20 gpm/ft² depending on configuration)
  - Sand ballasted (15-30 gpm/ft² for Kruger Actiflo®)

Oregon Health Authority

Sedimentation Basins

(baffled or unbaffled)

- Proper design allows the velocity of water to be reduced so that particles can settle out by gravity.
- The rate at which a particle settles out has to be faster than the rate at which the water flows from the basin's inlet to its outlet.
- Baffles help prevent short circuiting and lower detention times.
- Surface overflow rate $\leq$ 0.5 gpm/ft² with velocities less than 0.5 ft/min

Oregon Health Authority

Sedimentation – Basins (radial flow)

Circular radial-flow clarifies direct coagulated water up through the center and then into a weir trough.

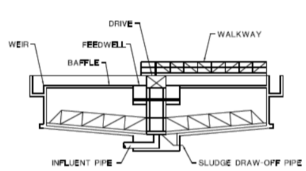


Figure 7-6. Circular Radial-Flow Clarifier

Circular Radial Flow Clarifier

Oregon Health Authority

Tube and Plate Settlers

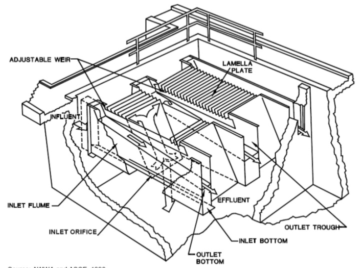
- Same concepts as sedimentation basins, but can be operated at higher loading rates.
- Tubes and plates placed in a basin decrease the distance the particles have to settle out (i.e., particles only need to settle to the surface of the tube or plate below ~ 2 inches)
- Tubes and plates are inclined (typically 60°) to allow collected sludge to slide down to the bottom of the basin for removal.
- Generally, a space of 2 inches is provided between the tube walls or plates to maximize settling efficiency.

Oregon Health Authority

Plate Settlers

Parallel plates set at an incline shorten the distance the particles have to settle out.

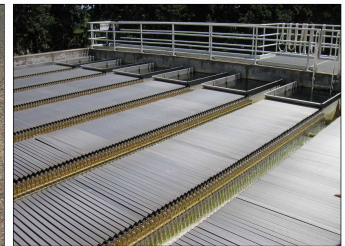
(~ 4 gpm/ft^2 10-ft long @ 55 with 2” spacing)



Source: AWWA and ASCE, 1998.

Figure 7-7. Plate Settlers Used for High-Rate Sedimentation

Plate Settlers – City of Corvallis (2006)



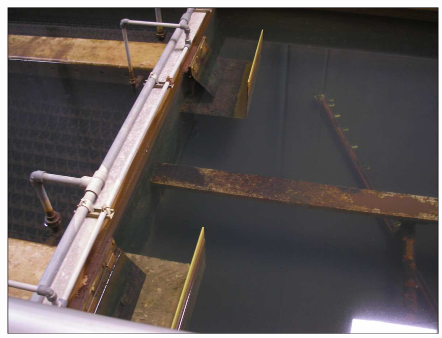
Tube Settlers

Tube settlers are basins filled with tubes set at an incline of generally 60 °. Tube openings are typically around 2” in size.

Loading rate $\leq$ 2 gpm/ft^2 of cross sectional area.

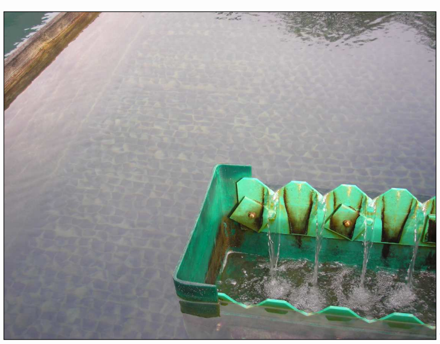
City of Albany (2014)

Tube Settlers



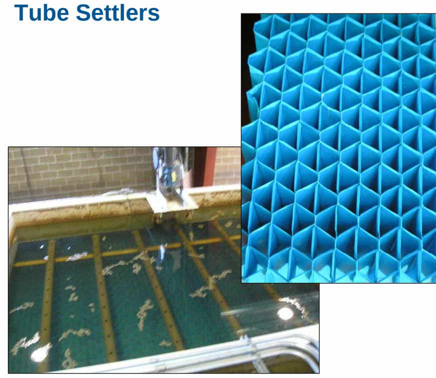
City of Scappoose, 2013

Tube Settlers



City of Corvallis, 2010

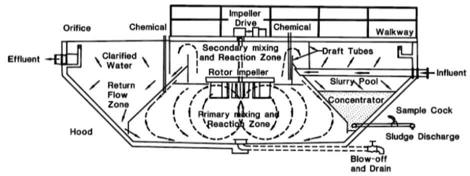
Tube Settlers



City of Sweet Home, 2015

Solids Contact Clarifiers

- Accelator® Solids Contact Unit has two mixing zones.
- Raw or coagulated water enters the primary mixing zone where coagulation and flocculation begin.
- The resulting particles are pumped up into a secondary mixing zone where more gentle mixing allows the completion of the flocculation process.
- Water then flows down a draft tube, where particles settle on the hood to the sludge blanket at the bottom of the basin.
- Clear water flows upward at constantly reducing velocity to allows small particles to settle out.



Source: AWWA and ASCE, 1998.

Solids Contact Clarifiers

Accelator® Solids Contact Unit with tube settlers is shown for the City of Albany (2012)

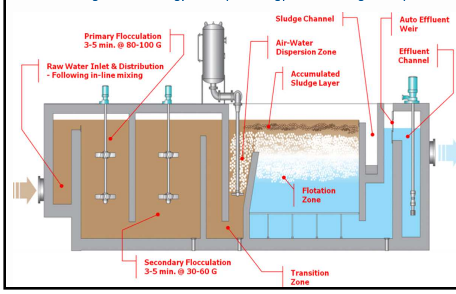
Sludge Blanket Clarifiers

- A variation of solids contact units in which coagulated water flows up through a blanket of previously formed solids.
- The floc grows in size and becomes part of the blanket, which can develop to a depth of several feet for efficient clarification.
- In both sludge and solids contact clarifiers, solids management is key to their efficiency.

Solids analysis for the City of Albany, 2012

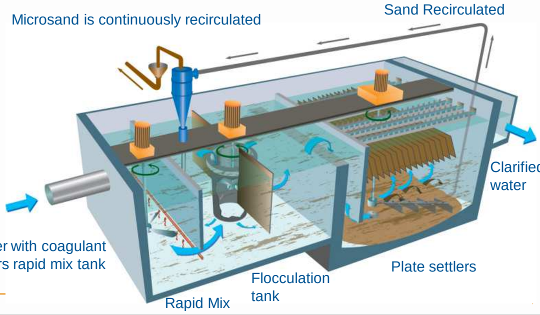
Dissolved Air Floatation

- In use since the late 1960's
- Uses micro air bubbles to attached and float flocculated particles and solids to the surface for removal. Primarily for low solids and algae
- Loading rate is 2-6 gpm/ft^2 (6 – 20 gpm/ft^2 for high rate)



Sand Ballasted Flocculation

- Introduced in 1989, the Actiflo® process from Kruger uses microsand and polymer injected into the floc chamber that allows the flocculated particles to settle out much faster through parallel plates.
- Microsand is continuously recirculated



Contact Adsorption Clarifiers

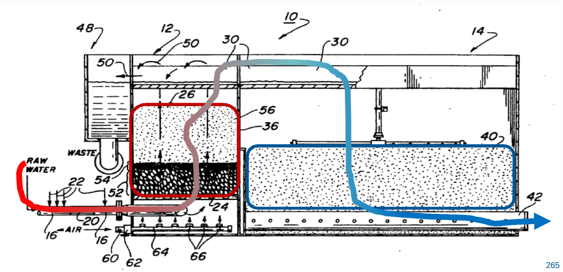
- Coagulated water flows up through clarifier.
- Clarifier media either gravel or plastic beads. Clarifier is periodically "rinsed" of solids.
- Clarified water flows onto filter.
- Configured as a package plant, small footprint, easy to increase the capacity.

Contact Adsorption Clarifier

Roberts Filter Group Pacer II (model P-1400) ContaClarifier™

52 = flocculation layer
54 = transition layer
56 = filtration layer
} Contact Adsorption Clarifier (ContaClarifier™)

40 = Tri-media rapid sand filter (anthracite, sand, garnet) } Polishing Filter



265

Contact Adsorption Clarifier

Units are backwashed or "rinsed" at the same rate and direction that they filter, except rather than the water going to the top of the filter, it is diverted to waste.

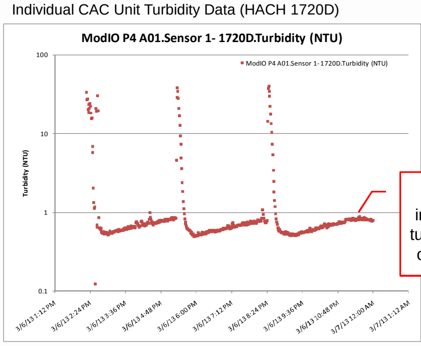
ContaClarifer™ rinse initiated at 5-6 psi (26 – 31 inches head)

1st Stage of Rinse:
- 4.5 min air/water flush
- Air Scour Rate @ 840 cfm (140 ft^2 x 6 cfm/ft^2)
- Water rinse @ 10 gpm/ft^2 (1,400 gpm/140 ft^2)

2nd Stage of Rinse:
- 6 min water rinse only @ 10 gpm/ft^2

Contact Adsorption Clarifier

Individual CAC Unit Turbidity Data (HACH 1720D)



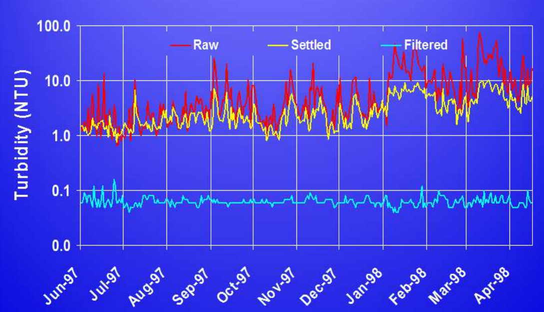
CAC units exhibit similar characteristics as normal filters

Data shows slight increase of clarified turbidity towards end of run prior to rinse

Clarification Optimization Objectives

- Achieve clarified/settled water performance goals.
- Maintain consistent performance during varying source water conditions.

Example Data For Plant With Uncontrolled Settled Water Turbidity



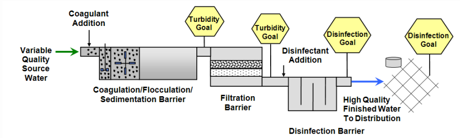
Sedimentation Optimization Possible Special Studies

- Inadequate coagulation/overfeed.
- Unequal loading to multiple units.
- Turbidimeter data integrity (i.e., sample line cleaning issues).
- Mass control in solids contact units (unit start-up and sludge wasting).
- Polymer type and dose impact on contact adsorption clarifiers.
- Impact of "floc-bubble" aggregate characteristics on dissolved air flotation.

Optimization Goals for Settled Water Turbidity

Practice should embrace the multiple barrier approach, meeting optimization goals 95% of the time.

Water Treatment Plant Optimization Goals		
SEDIMENTATION (for conventional systems)	Turbidity Goal	Criteria
Settled water	≤ 2.0 NTU, 95% of the time.	If average annual raw water turbidity is > 10 NTU
Settled water	≤ 1.0 NTU, 95% of the time.	If average annual raw water turbidity is ≤ 10 NTU



271

Class Outline

9 AM	Introduction/Overview
10:15 AM – 15 minute break	
10:30 AM	Coagulation/Flocculation
12 noon – Lunch (on your own)	
1 PM	Clarification/Sedimentation
2 PM	Filtration
2:15 PM – 15 minute break	
2:30 PM	Filtration (continued)
3:30 PM	General Operations
4:30 PM - End	

272

Conventional and direct filtration

- Commonly called "rapid sand" or "rapid rate" filtration (as opposed to slow sand filters at 0.1 gpm/ft^2)
- Filtration rate typically 2-4 gpm/ft^2
- Requires controllable backwash with water and perhaps air scour.
- Mixed media filters: layers of support gravel, sand, anthracite.

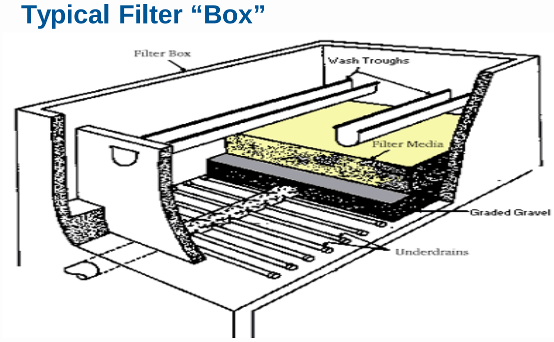
Typical Filtration Loading Rates	
Sand Media	2.0 gpm/ft^2
Dual/Mixed Media	4.0 gpm/ft^2
Deep Bed (Typically anthracite >60 in. in depth)	6.0 gpm/ft^2

"Ten States Standards"

Ten States Standards
http://10statesstandards.com/index.html

Member States and Provinces	
Illinois	New York
Indiana	Ohio
Iowa	Ontario
Michigan	Pennsylvania
Minnesota	Wisconsin
Missouri	

Typical Filter "Box"



Media

Water flows through progressively larger pores as it passes from coal to sand to gravel.

This example shows the following from top to bottom (as the water would flow)

1. Anthracite
2. 2 layers of sand
3. 3 layers of support gravels
4. "Block" underdrain

Media

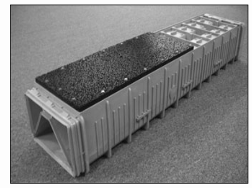
Example shown is from the City of Grants Pass
- Top Layer Anthracite
- Layer 2 Filter sand
  (Silica sand w/ D10 = 0.45 mm- 0.55 mm)
- Layer 3 #50 garnet sand
- Layer 4 #12 garnet gravel
- Layer 5 3/8" x 3/16" gravel
- Layer 6 3/4" x 3/8" gravel
- Bottom layer 1-1/2" x ¾" gravel

Oregon Health Authority

Conventional and direct filtration

Underdrains can be a series of perforated pipe or proprietary underdrain "block", or "folded plate" underdrains.

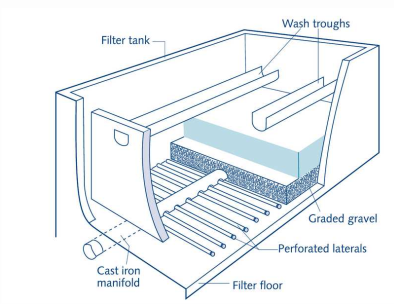
Ovivo Flexscour® "folded plate"



Xylem Leopold® "block"

Oregon Health Authority

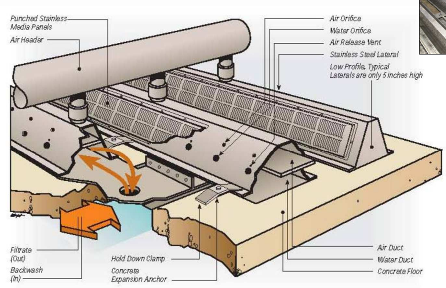
Conventional and direct filtration



Perforated Pipe Underdrains

Oregon Health Authority

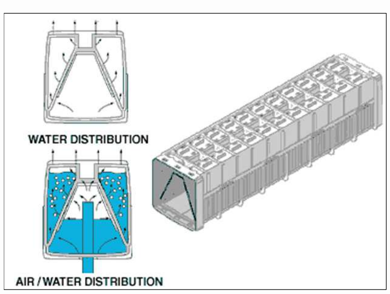
Conventional and direct filtration



Ovivo Flexscour® Folded Plate Underdrains

Oregon Health Authority

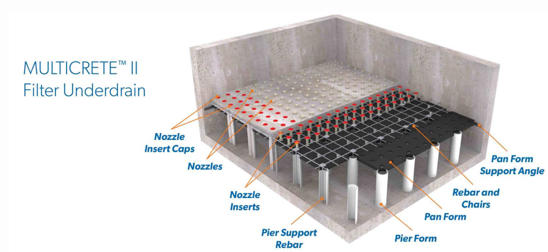
Conventional and direct filtration



Xylem Leopold® "Block" Underdrains

Oregon Health Authority

Conventional and direct filtration



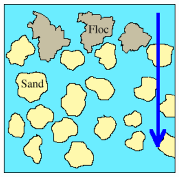
WesTech® Multicrete™ II Filter Underdrain

Oregon Health Authority

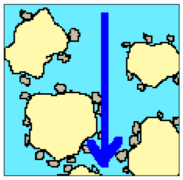
Conventional and direct filtration

Involves adsorption and physical straining of flocculated particles.

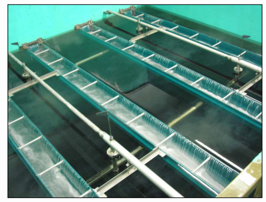
Straining:
Passing the water through a filter in which the pores are smaller than the particles to be removed



Adsorption:
The gathering of gas, liquid, or dissolved solids onto the surface of another material

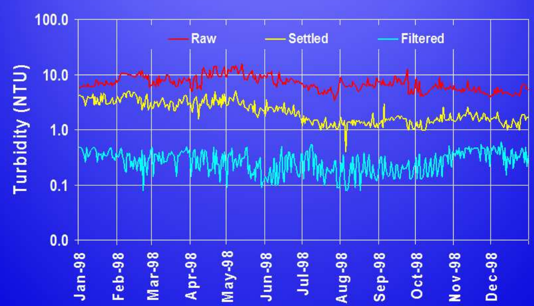


Filtration Optimization Objectives



- Achieve filtration performance goals.
- Minimize turbidity spikes during routine filter operation.
- Minimize turbidity spikes following filter backwash.

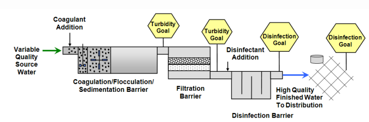
Example Data For Plant With Uncontrolled Filter Effluent Turbidity



Optimization Goals for Filter Effluent Turbidity

Practice should embrace the multiple barrier approach.

FILTRATION (conventional and direct systems)	Turbidity Goal	Criteria
IFE and CFE filtered water	• Turbidity ≤ 0.10 NTU, 95% of the time • Max turbidity ≤ 0.30 NTU.	Based on maximum values recorded during 4-hour increments (excluding the 15 minute period following backwash)
IFE filtered water after backwash	• Turbidity returns to ≤ 0.10 NTU within 15 minutes after backwash. • Max spike ≤ 0.30 NTU. • Turbidity at return to service ≤ 0.10 NTU.	Goals apply to both systems with and without filter-to-waste capability. Goals apply to the backwash recovery period starting immediately after backwash.

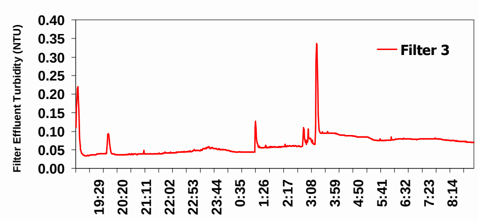


286

Filtration Optimization
Lowering Filter Effluent Turbidity

- Possible Special Studies:
  - Coagulation control (use your calibrated jar test procedure!)
  - High settled water turbidity (solids loading)
  - Initiation of backwash (before breakthrough)
  - Media depth and type of media
  - Impact of manganese removal on filter performance (oxidation of manganese with chlorine or permanganate can result in small MnO_2 particles that are difficult to settle and filter out).

Example Data Showing Turbidity Spike Control Problem



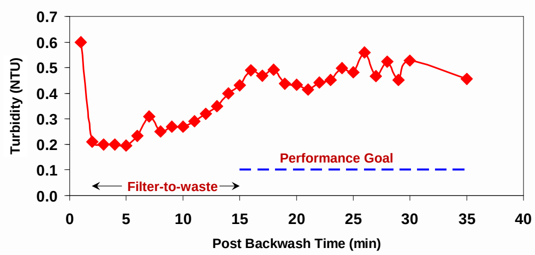
Filtration Optimization
Spike Control During **Routine** Operation

- Possible Special Studies:
  - Raw and settled water quality variations (storm events)
  - Hydraulic surges due to flow rate changes
  - Start-up/stop operation (small plants)
  - Filter backwash effects on loaded filters
  - Turbidimeter data integrity (e.g., sample line, sample flow rate). Long sample lines increase signal delay and can allow particles to settle out causing periodic spikes.

Filtration Optimization
Spike Control **During** Routine Operation (cont.)

- Possible Special Studies (cont.):
  - Unequal flow splitting between unit processes
  - Return of plant recycle flow
  - Malfunctioning filter rate control valves
  - Others?

Example Data For **Post Backwash** Turbidity Spike Control Problem



Filtration Optimization
Spike Control Following Backwash

- Possible Special Studies:
  - Inadequate chemical conditioning of water
  - Backwash procedures:
    - Lack of or inadequate surface wash or air scour
    - Backwash flow rate (media expansion)
    - Backwash duration (too short → dirty filters; too long → too clean)
    - Rapid start-up/shut-down of backwash flow (gradual ramping allows for media to gradually expand and re-stratify)
    - Applying an extended sub-fluidization (not enough to fluidize media) step at end of backwash (~1 bed volume)
    - Length and rate of filter-to-waste
    - Lack of or length of filter resting period

Filtration Optimization
Spike Control Following Backwash (cont.)

- Possible Special Studies (cont.):
  - Use of filter aid
  - Addition of coagulant or polymer to backwash supply water at the end of the backwash cycle to "condition" the water remaining in the filter.
  - Loss of filter integrity:
    - Loss of media
    - Damaged underdrains
    - Mud balls in media
    - Cracks or sidewall channels in media
  - Others?

Class Outline

9 AM	Introduction/Overview
10:15 AM – 15 minute break	
10:30 AM	Coagulation/Flocculation
12 noon – Lunch (on your own)	
1 PM	Clarification/Sedimentation
2 PM	Filtration
2:15 PM – 15 minute break	
2:30 PM	Filtration (continued)
3:30 PM	General Operations
4:30 PM - End	

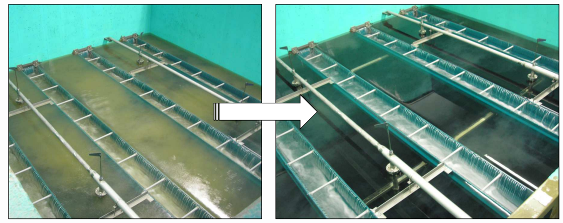
294

Class Outline

9 AM	Introduction/Overview
10:15 AM – 15 minute break	
10:30 AM	Coagulation/Flocculation
12 noon – Lunch (on your own)	
1 PM	Clarification/Sedimentation
2 PM	Filtration
2:15 PM – 15 minute break	
2:30 PM	Filtration (continued)
3:30 PM	General Operations
4:30 PM - End	

Optimizing Backwash

- Backwashing is conducted in order to remove particulates built up in the filter.
- Headloss, time, and turbidity can all be indicators of when to backwash.



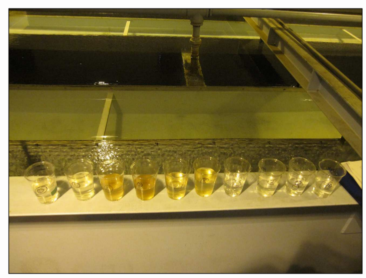
Fort Richardson, AK

Optimizing Backwash

If backwashing is ineffective, mud balls can develop in the filter, which results in plugged portions of the filter and high localized loading rates (due to the plugged portions).

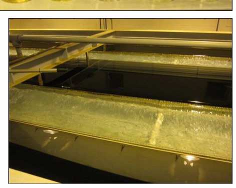
Optimization Studies - Backwash

Backwash trough turbidity can provide a quick evaluation of how well your backwash process is working and where to optimize the process.



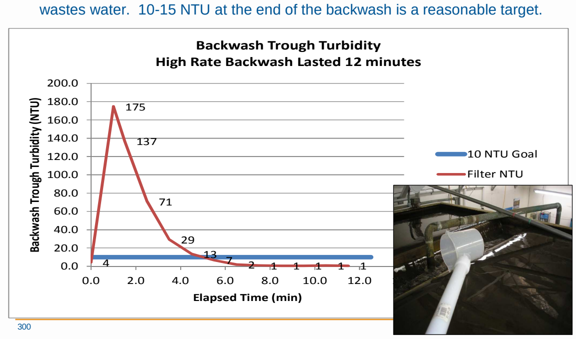
Backwash Trough Turbidity Profile

1. Measure grab samples for turbidity at 1 minute intervals during high rate backwash.
2. Record and plot results to see how fast the filter cleans up.



Backwash Trough Turbidity

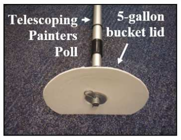
- Develop a graph of your results to help in your evaluation.
- Backwashing to where the trough turbidity is below 10 NTU has little benefit and wastes water. 10-15 NTU at the end of the backwash is a reasonable target.

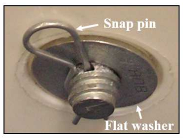


Measuring Bed Expansion During Backwash

Measured bed expansion should be about 20% and such that media is not lost out the backwash trough.

Measurements are easy using a tool you can make yourself.

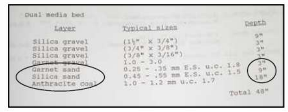




301

Bed Expansion

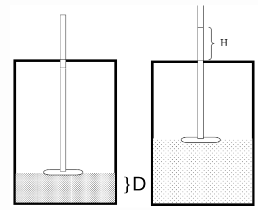
The calculation is simple.


Dual media bed

Layer	Typical sizes	Depth
Silica gravel	(1½" x 3/4")	9"
Silica gravel	(3/4" x 3/8")	3"
Silica gravel	(3/8" x 3/16")	3"
Garnet gravel	1.0 - 3.0	3"
Garnet sand	0.25 - .35 mm E.S. u.c. 1.8	3"
Silica sand	0.45 - .55 mm E.S. u.c. 1.5	9"
Anthracite coal	1.0 - 1.2 mm u.c. 1.7	18"
		Total 48"

H = 7-inches (measured)
D = 30-inches (sand & anthracite depth)
% Expansion = 100% * (H / D)
% Expansion = 100% * (7/30) = 23%
Expansion should be 20% or more

Measure the distance of expansion and divide by the depth of expandable media



302

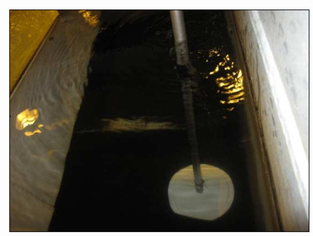
Bed Expansion

1. With the filter at rest, measure media depth to a fixed reference (filter side wall)
2. Move the top zip tie level with the fixed reference

303

Bed Expansion

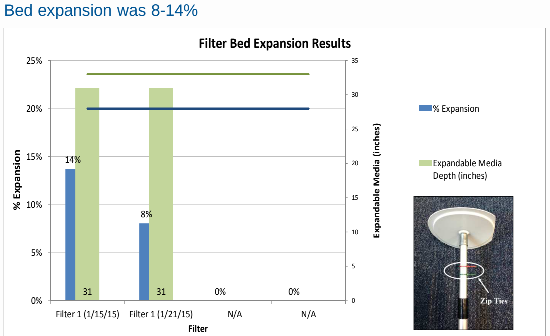
3. During backwash, move bed expansion tool upwards until expanded media is just able to float over the white disk
4. Move the bottom zip tie level with the fixed reference
5. Measure the distance between the zip ties (the expansion) and divide by the depth of expandable media



304

Graph of Bed Expansion Results

Bed expansion was 8-14%

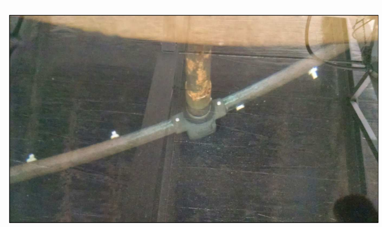


305

Other Observations During Backwash

Check operation and condition of surface wash.

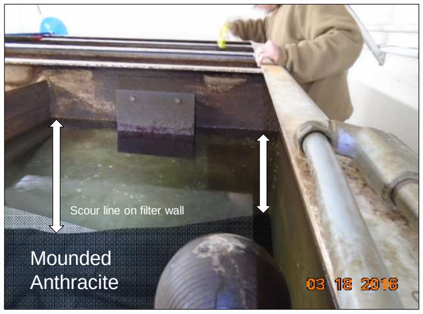
- Surface wash arm should rotate during the first phase of the backwash, but not continue throughout the backwash.
- This system had a surface wash that continued through to the end of the backwash, causing mounding in the filter bed.



306

Other Observations During Backwash

Mounding of media after a backwash due to continuous surface wash.



307

Other Observations During Backwash

Mounding of media after a backwash due to continuous surface wash.

308

Other Observations During Backwash

Check operation and condition of surface wash.

- Surface wash arm should be around 2" above the top of the media
- Corrosion may develop at junctions of dissimilar metals – use dielectric coupling
- Nozzles may be plugged or gasket may be leaking at arm junction causing weak jet as evidenced by slow or lack of arm rotation

309

Other Observations During Backwash

Look for evidence of air binding that may be due to high dissolved oxygen in colder waters being released inside a warmer plant or air binding as a result of vacuum conditions created in a clogged filter.

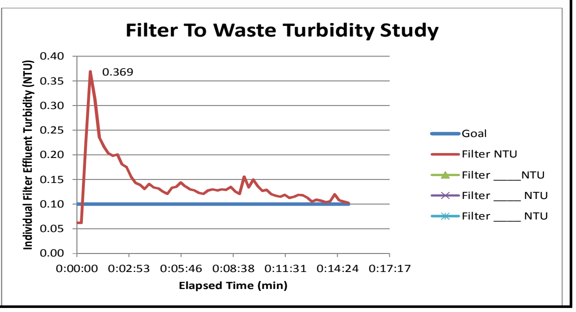
Air binding in a contact adsorption clarifier in California

310

Filter-to-waste Turbidity

Measure filter-to-waste turbidity and plot data

Goal is to minimize post backwash spikes and return filter to service at ≤ 0.10 NTU.



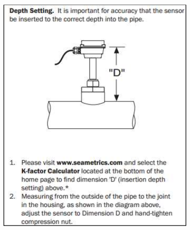
Verify Plant Flows

Verify Plant Flows – 195 gpm or 4,700 gpm???

Math error in converting to gpm:	195 gpm => 4,700 gpm
Wrong calibration factor (K):	4,700 gpm => 243 gpm
Wrong insertion depth (D):	243 gpm => 217 gpm

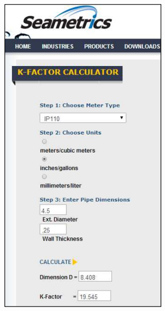
1 ≠ K = 19.545

6.5 ≠ D = 8.408"



Depth Setting. It is important for accuracy that the sensor be inserted to the correct depth into the pipe.

1. Please visit **www.seametrics.com** and select the **K-factor Calculator** located at the bottom of the home page to find dimension 'D' (insertion depth setting) above.*
2. Measuring from the outside of the pipe to the joint in the housing, as shown in the diagram above, adjust the sensor to Dimension D and hand-tighten compression nut.



312

Challenges to optimization

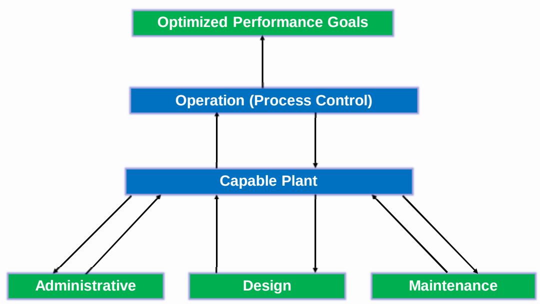
Challenges to optimizing treatment plants include:

- Management and staff buy-in on optimization goals
- Optimization limitations consist of multiple “small” issues
- Duration is multi-year (requires patience and tenacity)
- Lack of optimization “tools”

Process control is in your control

- Process control is any activity required to develop a capable plant and take it to the desired level of performance.
- By applying what you learn at your plant, you can demonstrate that it is capable of meeting optimized performance goals.
- Meeting optimization goals improves public health protection and can often result in cost savings.

Process control is key to a capable plant



Priority-Setting

- Relate activities you do to achieving goals:
  - Always start by initiating operations-based activities (within operators’ control!).
  - Address administration, design, or maintenance limitations to support capable plant, as needed.
- Reassess efforts routinely.

Operational guidelines are an important tool

- Formalize and provide consistency for plant activities.
- Developed by the plant staff (skill development).
- Used as communications/ training tool (field test on other plant personnel).
- Encourage continuous modification and improvement.
- Development of a sampling guideline is suggested as homework from this training.

Sampling Guideline

Example Table from a Plant Sampling Guideline

Sample	Sample Location	Sample Type	Data Recording
Plant Raw Water	Tap by raw water sink	Grab every 4 hours	Maximum daily value
Sedimentation Basin Effluent	Individual basins at exit location	Grab every 4 hours	Maximum daily value
Filter Effluent	Individual filters (membrane trains)	Continuous (max. each 15 minutes logged on SCADA)	Maximum daily value
Combined Filter Effluent	Entrance to clearwell	Continuous (max. each 15 minutes logged on SCADA)	Maximum daily value

- Describes how to do a specific operator activity.
  - Also describes the what, who, where, and when details.
- Don’t make developing guidelines *“hard.”*

Special Studies

- Tool for conducting plant *"research"*
- Powerful tool for teaching problem-solving skills
- Structured approach for assessing and documenting optimization efforts

Oregon Health Authority

Special Study Format
"The Scientific Method"

- Hypothesis
- Approach and resources
- Duration of study
- Expected results
- Summary and conclusions
- Implementation

Oregon Health Authority

Special Study Approach

- Identify topic (look at factors that impact ability to meet water quality goals)
- Gather information/data.
- Don't make the process intimidating.
- Involve plant staff in development.

Oregon Health Authority

Special Study Approach (cont.)

- Hypothesis:
  - Minimize variables to allow determination of a cause/effect relationship.
- Approach and resources:
  - Develop site-specific aspects of conducting the study.
  - Document historical data.

Oregon Health Authority

Special Study Approach (cont.)

- Duration of study:
  - Allow time to collect background performance data (before/after process change).
  - Establish timeframe that will allow development of reliable results.
- Expected results:
  - Define expected results and limitations of the study.

Oregon Health Authority

Special Study Approach (cont.)

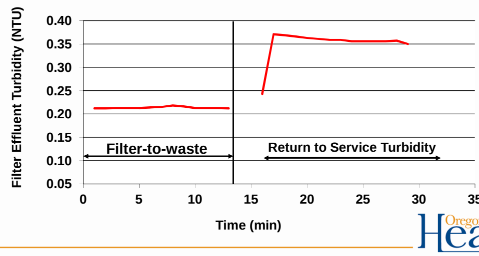
- Summary and Conclusions:
  - Complete after special study activities.
  - Summarize data (tables, charts).
  - List key findings relative to hypothesis.
  - Use as foundation for changing current practices (operations, design, administrative, etc.).
- Implementation:
  - Completed after conclusions have been developed.
  - Basis for full-scale plant operational changes.
  - Demonstrates to staff and administration site-specific problem- solving approach (efforts result in verification or change).

Oregon Health Authority

Special Study Example – Post Backwash Spikes

- Identified Problem:
  - After filter-to-waste, turbidity spikes to more than 0.3 NTU and it takes another 15 minutes to drop below 0.1 NTU.

Profile of Filter Performance Following Backwash

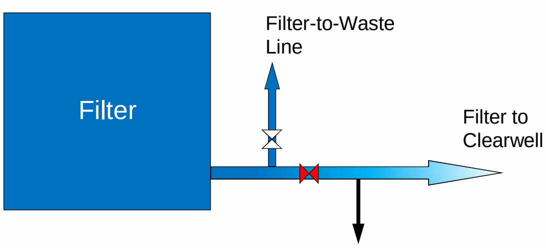


Special Study Example – Post backwash spikes

- Hypothesis:
  - Since filter-to-waste turbidity was always very stable and usually less than 0.1 NTU, the integrity of the turbidity data was suspected.
- Approach:
  - Investigate source and transmission of filter effluent turbidity data.

Special Study Example – Post Backwash Spikes

Sample tap does not reflect filter-to-waste turbidity during filter-to-waste.



Special Study Example – Post backwash spikes

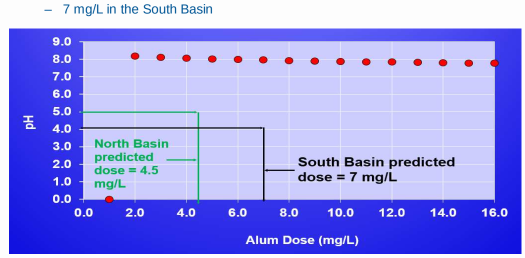
- Conclusions:
  - Optimized filter performance was not demonstrable with current sampling location
- Implementation:
  - Change sample location and modify data handling to be able to account for filter-to-waste turbidity.

Special Study Example – Coagulation

- Identified Problem:
  - Performance differences were observed between the north and south filters in a direct filtration plant.
- Hypothesis:
  - Filter performance discrepancies were caused by different performance from the north and south floc basins.
- Approach:
  - In the floc basins, monitor variables that could cause performance deviations (e.g., mixing energy, pH).
- Conclusions and Implementation:
  - pH measurements were different between the two floc basins.
  - Develop an alum dose versus pH curve to determine alum dose to north and south basins.

Special Study Example – Coagulation

Based on the differences in pH measured in both basins, the dose would have been:
- 4.5 mg/L in the North Basin
- 7 mg/L in the South Basin



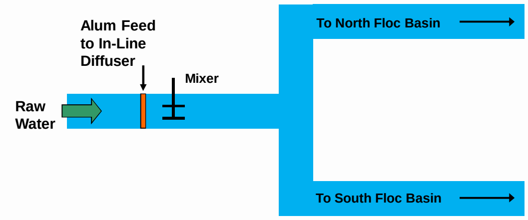
Special Study Example – Coagulation

Special studies breed new special studies….

- Identified problem:
  - Alum dosage was not equal to each floc train
- Hypothesis:
  - The rapid mix unit was not adequately mixing the alum in the raw water
- Approach:
  - Inspect the rapid mix unit and assess potential mechanical or plugging problems

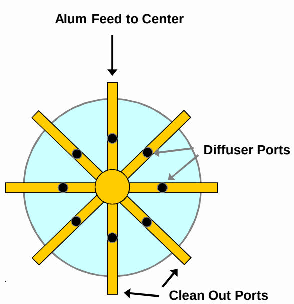
Special Study Example – Coagulation

Coagulant Injection Schematic – 45 inch raw water line



Special Study Example – Coagulation

Coagulant Injection Diffuser



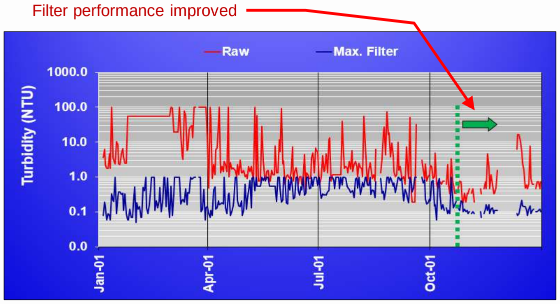
- Conclusions and Implementation:
  - The design was causing plugging in the rapid mix unit.
  - When the diffuser ports were cleaned, the alum feed and pH values in the floc basins were similar.
  - Plugging reoccurred in about a week after cleaning.
  - Diffuser was modified to feed from the center rather than ports.
  - Carrier water for the alum feed was initiated rather than feeding alum in neat form.

Special Study Example – Coagulation

pH Variations in Floc Basins matched

Special Study Example – Coagulation

Filter performance improved



Exercise –

1 MGD Plant in Berry, Alabama

- Develop a special study to evaluate post backwash spikes.

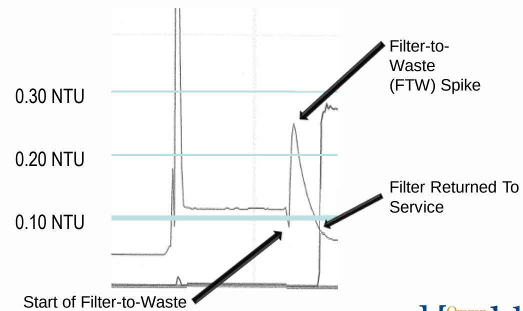
Exercise – Berry, AL

Original backwash sequence:

1. Air Only (2 minutes)
2. Air / low-rate backwash at 5 gpm/sq ft (45 seconds)
3. High-rate backwash at 18.5 gpm/sq ft (160 seconds)
4. Second low-rate wash to fill filter (165 seconds)

Exercise – Berry, AL

Original backwash profile



Total FTW Time of 60 Minutes

Exercise – ETSW at 1 MGD Plant in Berry, Alabama

- Post backwash spikes lead operators to want to try an extended terminal subfluidization wash (ETSW)
- Develop a special study to evaluate the impact of ETSW.

ETSW Background & Concepts

- ETSW is a filter backwash technique that involves extending the normal backwash duration at a subfluidization flow rate for an amount of time sufficient to move one theoretical filter-volume of water through the filter box.

  (reported by Amburgey, 12/03 AWWA Journal)

- The intent of ETSW is to remove the backwash remnant particles normally left within and above the media following backwash, preventing their passage into the finished water supply.

ETSW Mechanisms

- Incremental decrease in backwash allows the bed to settle more slowly (dislodges fewer remnant particles).
- Media restratification moves more small grains to top of the bed, creating a lower porosity layer.
- Most of the dislodged remnant particles are removed from filter box at low flow rate.

Exercise - ETSW

How would you complete the table below?

ETSW Special Study	October 2015
Hypothesis:	
Approach and resources:	
Duration of study:	
Expected results:	
Summary and conclusions:	
Implementation:	

Exercise - ETSW

How would you complete the table below?

ETSW Special Study	October 2015
Hypothesis:	Remnant particles left within and above the media following backwash are reaching their way into the finished water. Implementing ETSW should solve this problem.

Exercise - ETSW

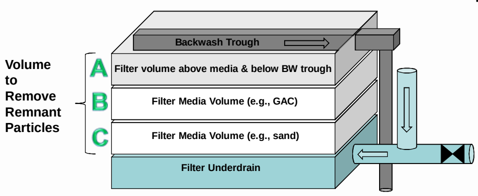
How would you complete the table below?

ETSW Special Study	October 2015
Approach and resources:	1. Determine if low rate backwash rate of 3 to 6 gpm/ft^2 can be achieved (be cautious of throttling pumps) 2. Can the flow rate be controlled and measured? If not flow measurement can be a challenge, but it's not a deal killer. 3. If 1. and 2. are feasible, estimate low-rate wash duration: • Determine bed volume to be displaced • Based on low-rate wash rate, calculate duration 4. Filter 1 was selected to be the test filter while maintaining Filters 2 and 3 the same (control filters).

ETSW Technique Measurements and Calculations

At what flow rate?

~ 3 to 6 gpm/ft^2 – minimal media expansion



How long?

Time to replace ~ 1 bed volume

= A + B + C (assume 100% of volume in A+B+C)

Example ETSW Calculations

- Calculate Bed Volume:
  - Surface area of filter = 320 ft^2
  - Media depth = 30 inches (sand & anthracite)
  - Water depth between media and top of BW trough = 54 inches
  - Total bed depth = 30 + 54 = 84 inches = 7 ft.
  - Total bed volume = 320 ft^2 x 7 ft = 2,240 ft^3
  - 2,240 ft3 x 7.48 gal/ft3 = 16,755 gallons
- ETSW wash rate = 5 gpm/ft^2 x 320 ft^2 = 1,600 gpm
- ETSW time = 16,755 gal. ÷ 1,600 gpm = 10.5 minutes

Exercise - ETSW

How would you complete the table below?

ETSW Special Study	October 2015
Hypothesis:	
Approach and resources:	
Duration of study:	Try ETSW on three backwashes on filter #2
Expected results:	ETSW will reduce post backwash turbidity spikes
Summary and conclusions:	
Implementation:	

Exercise - ETSW

How would you complete the table below?

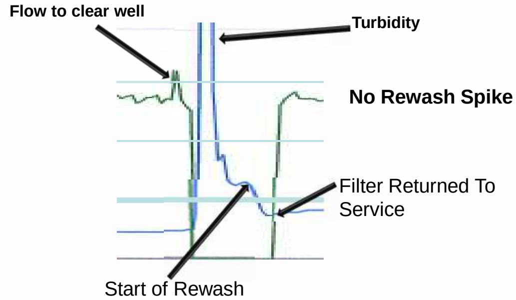
ETSW Special Study	October 2015
Hypothesis:	
Approach and resources:	
Duration of study:	
Expected results:	
Summary and conclusions:	ETSW not only reduced post backwash turbidity spikes, it also decreased the amount of water consumed during the backwash process.
Implementation:	

Exercise – Berry, AL

Original backwash sequence:

1. Air Only (2 minutes)
2. Air / Low Wash at 5 gpm/sq ft (45 seconds)
3. High wash at 18.5 gpm/sq ft (160 seconds)
4. Second low wash to fill filter (~~165 seconds~~) – extended to 465 seconds

Exercise – Berry, AL – results with second low wash extended to 465 s



Total Rewash Time of ~~20~~ 60 Minutes

350

Example – Berry, AL

Before ETSW

- Backwash:
  - 10,800 Gallons Used
  - 9 Minutes
- Rewash:
  - 22,680 Gallons Used
  - 60 Minutes
- Turbidity Spike:
  - 0.25 NTU
- Total:
  - 33,500 Gallons Used
  - 75 Minutes

After ETSW for 465 seconds

- Backwash:
  - 15,750 Gallons Used
  - 18 Minutes
- Rewash:
  - 11,340 Gallons Used
  - 30 Minutes
- Turbidity Spike:
  - Spike was reduced to a few minutes, all during rewash. No post rewash spike.
- Total:
  - 27,000 Gallons Used
  - 60 Minutes

351

Exercise – Berry, AL

Modified original backwash sequence:

1. Air Only (2 minutes)
2. Air / Low Wash at 5 gpm/sq ft (45 seconds)
3. High wash at 18.5 gpm/sq ft (160 seconds)
4. Second low wash to fill filter (~~165 seconds~~) – extended to 465 seconds

Example – Berry, AL

- Berry WTP is saving approximately 15,000 gallons per backwash.
- Filters returned to service in less than 15 minutes.

353

Example – Berry, AL

Feedback from a water plant manager:

"If my operators gave me a formal study like this with documented results and recommendations, it would provide a strong basis for making a change to my plant. I could not ignore it".

354

ETSW Benefits

- Lowers filter-to-waste time (rewash).
- Reduces or eliminates rewash spike.
- Filters return to service quicker.
- Less water wasted.
- No degradation of filter performance.

ETSW Benefits

- Successful ETSW results assume that previous backwash steps result in adequately cleaned media.
- Refinements to existing backwash procedure may be part of ETSW evaluation (e.g., changes to initial low wash and high wash duration).

ETSW Benefits

- ETSW can be fairly simple to implement, but filter backwash controllability needs to be assessed first.
- Potential ETSW benefits include improved filter performance, shorter filter-to-waste time, and water savings.
- ETWS will be one special study conducted during the Day 2 plant training.

Impacts of Special Study Approach

- Provides data-based reasons for change.
- Powerful site-specific training tool:
  - Teaches problem-solving skills
  - Addresses limitations
- Convincing to management and outside technical resources.
- Basis for future special studies (i.e., special studies *"breed"* more special studies).

Optimization Summary

- Develop onsite priority-setting capability:
  - Set priorities based on impact to water quality.
  - Routinely assess optimization status through formal communication and training.
- Develop onsite problem-solving capability:
  - Develop and utilize operational guidelines.
  - Develop and utilize special studies.
- Key to success:
  - systematic and ongoing pursuit of optimization goals.

Homework!

- Study 1 – Chemical feed pump evaluation
- Study 2 – Filter bed expansion and backwash duration
- Study 3 – Post backwash performance assessment
- Study 4 – Performance of adjacent filters during backwash and turbidimeter signal verification
- Study 5 – Comparison of sedimentation basin performance
- Study 6 – Turbidimeter calibration check

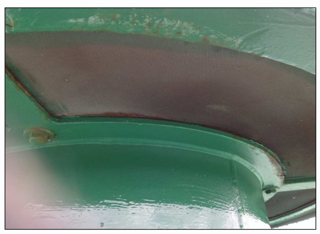
Don't ignore reservoirs!

City of Sheridan, 2008

Screened Vent

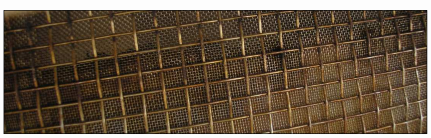
Clatskanie, 2014

Screened Vent



Clatskanie, 2014

Sheridan, 2011



Protected Overflow

"Duck Bill"
Sheridan, 2011

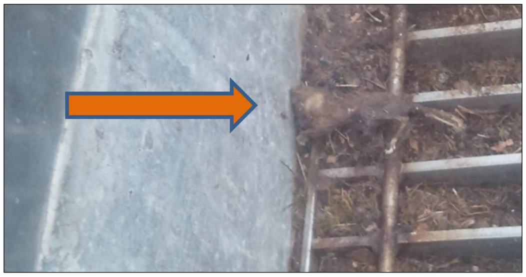
Flap valve
Warrenton, 2014

Watertight Hatch
(keep gutter drains clear of debris)

What happens when gutter drains clog?

Hatch should be rodent proof

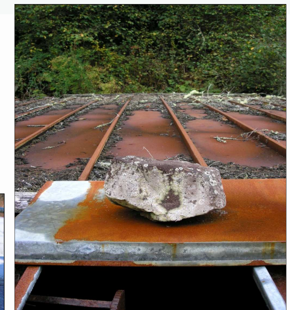
(keep gutter drains screened)



Hatch should be locked…

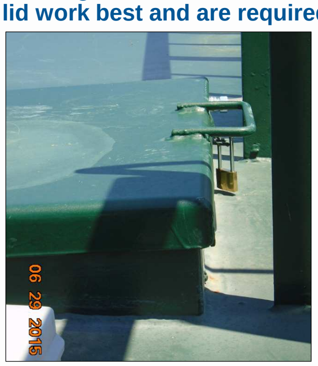
unlike these!

Rock lock =>



<= Tire lock

Curbing, lock, and "shoebox" style overlapping lid work best and are required for new tanks



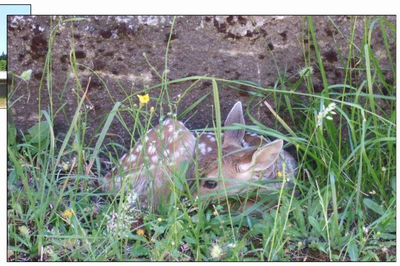
Don't forget about security

How many think this tank was secure?

Don't forget about security

How many think this tank was secure?

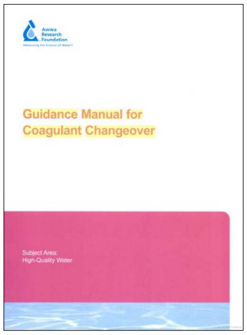
Animal trail found under the fence



Don't forget about safety

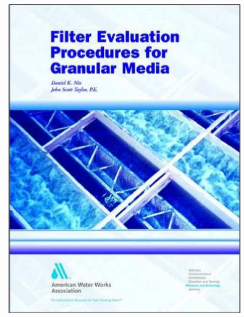
Great for safety – not sure how secure though??

For more information…



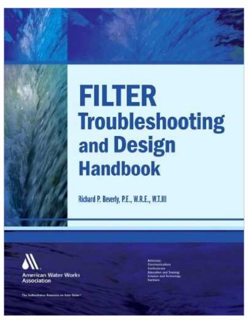
Guidance Manual for Coagulant Changeover (AWWARF, 2003)

For more information…



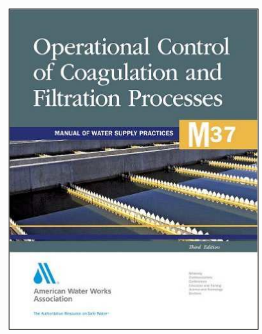
Filter Evaluation Procedures for Granular Media (AWWA 2003)

For more information…



Filter Troubleshooting and Design Handbook (AWWA 2005)

For more information…

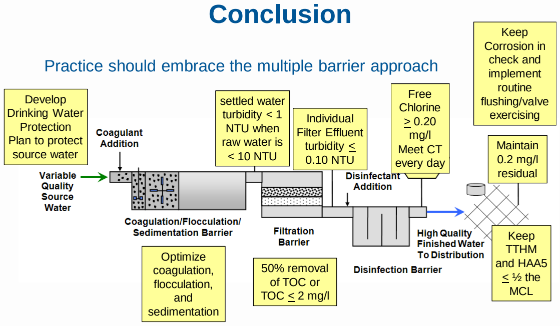


M37 Operational Control of Coagulation and Filtration Prcoesses (AWWA, 2011)

Chapter 1: Particle and NOM Removal
Chapter 2: Jar Testing
Chapter 3: Online Sensors
Chapter 4: Flocculation and Clarification
Chapter 5: Filtration
Chapter 6: Pilot Testing and Pilot Filters
Chapter 7: Case Studies

Conclusion

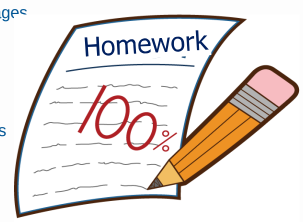
Practice should embrace the multiple barrier approach



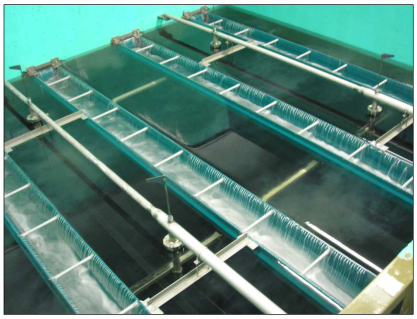
Homework Reminder

Create Standard Operating Procedures (SOPs) for…

1) Determining chemical dosages
2) Verifying flow rates
3) Calculating CT
4) Calibrating turbidimeters
5) Conducting a backwash
6) Data collection and analysis
7) Regulatory reporting



Thank You!!



379