TCEQ REGULATORY GUIDANCE
Water Supply Division
RG-379 • Revised January 2022

Total Organic Carbon (TOC) Guide

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY • PO BOX 13087 • AUSTIN, TX 78711-3087

Contents

Glossary

Alkalinity: a measure of a water's buffering capacity or its ability to resist changes in pH upon the addition of acids or bases.

Alternative compliance criteria (ACC): The eight alternative compliance criteria are part of the TOC removal requirements of the DBP1R. A plant that meets one of the ACC is not required to remove TOC for the time period covered by the ACC.

Alternative percent TOC removal requirement: The percentage TOC removal achieved at the PODR in the Step 2 jar test.

Community water system (CWS): System with a potential to serve at least 15 residential service connections on a year-round basis or serves at least 25 residents on a year-round basis.

Disinfectant: A chemical or a treatment which is intended to kill or inactivate pathogenic microorganisms in water.

Disinfection: A process which inactivates pathogenic organisms in the water by chemical oxidants or equivalent agents.

Distribution system: System of pipes that carries potable water from a treatment plant to consumers. The term includes pump stations, ground and elevated storage tanks, potable water mains, and potable water service lines and all associated valves, fittings, and meters, but excludes potable water customer service lines.

Disinfection byproduct precursor : Molecules present in natural water that tend to form disinfection byproducts when water is disinfected. EPA uses total organic carbon (TOC) and specific ultraviolet absorbance (SUVA) as surrogates for DBP precursors.

Dissolved organic carbon (DOC): The portion of organic matter that can pass through a filter ranging in size from 0.7 and 0.22 micrometers.

Drinking water: Public and private water distributed by any entity or individual for human consumption.

Groundwater system under the influence of surface water (GUI): A PWS that uses groundwater with some contact with surface water. These systems may have significant occurrence of micro and macro organisms. They may also exhibit fluctuations in water quality conditions such as turbidity and temperature.

Total Haloacetic Acids (HAA5): A carbon with a carboxyl group and one to three halogens. There are five regulated HAAs out of nine total: Dibromoacetic Acid, Dichloroacetic Acid, Monobromoacetic Acid, Monochloroacetic acids, Trichloroacetic Acid

Monitoring plan: All PWSs are required to develop a monitoring plan, including all community, transient and non-transient water systems. Monitoring plans are a system-specific document that specifies water quality monitoring performed by the system is representative of water distributed to consumers and is consistent with regulatory requirements.

Point of diminishing returns (PODR): Pertains to the DBP1R TOC removal requirements. In a Step 2 Jar Test, the PODR is the point at which an additional 10 mg/L of alum results in the removal of no more than 0.3 mg/L of TOC.

Public water system (PWS): A PWS provides potable water for the public's use through at least 15 service connections or serves at least 25 individuals for at least 60 days out of the year. The complete definition is found in rule at 30 TAC §290.38 (71).

Raw water: Water prior to any treatment including disinfection that is intended to be used after treatment as drinking water.

Specific ultra violet absorbance (SUVA): provides a general characterization of the nature of natural organic mattter (NOM) in a water sample. Used to determine DBP formation potential. Measured using UV254.

Total organic carbon (TOC): A group parameter measuring the total amount of carbon in water present as organic molecules. EPA uses TOC as a surrogate for DBPPs in the DBP1R.

Treatment train: Individual treatment methods used in sequence.

Total Trihalomethanes (TTHM): Three halogens and one hydrogen all bonded to a carbon. Four Trihalomethanes are regulated: Chloroform, dibromochloromethane, bromodichloromethane, and bromoform.

Ultraviolet light of wavelength 254 nanometers (UV254): A water quality test that provides a quick measurement of organic matter in water. Related to SUVA.

Abbreviations

ACC	alternative compliance criteria
ASTM	American Society for Testing Materials (ASTM)
$CaCO_3$	calcium carbonate
ClO_2	chlorine dioxide
CNX	cyanogen halides
EDR	electrodialysis reversal
DBP	disinfection byproduct
DBPR	Disinfection Byproduct Rule
DBP1R	Stage 1 Disinfection Byproduct Rule
DBP2R	Stage 2 Disinfection Byproduct Rule
DWW	Texas Drinking Water Watch
EPA	United States Environmental Protection Agency
$FeCl_3$	ferric chloride
$Fe_2(SO_4)_3$	ferric sulfate
g/L	grams per liter
GUI	ground water under the influence of surface water
HDT	hydraulic detention time
L	liter
LT2 Rule	Long-Term 2 Enhanced Surface Water Treatment Rule
µg/L	microgram per liter
mg/L	milligram per liter
mg/mL	milligram per milliliter
ppm	parts per million
PACl	polyaluminum chloride
PN	public notice
PWS	public water system
RG	regulatory guidance
rpm	revolutions per minute
RAA	running annual average
SWMOR	Surface Water Monthly Operating Report
SWTP	surface water treatment plant (also referred to as plant)

SWTR	Surface Water Treatment Rule
SOC	synthetic organic chemical
SOP	standard operating procedure
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TOC	total organic carbon
TOCMOR	Total Organic Carbon Monthly Operating Report
UV	ultraviolet

Introduction

Disinfection is a crucial way to protect the public from pathogens. Unfortunately, while disinfectants inactivate pathogens, they also react with naturally occurring disinfection byproduct (DBP) precursors to form DBPs. Some of the DBPs, such as trihalomethanes (TTHMs) and haloacetic acids (HAA5), are health concerns. The TCEQ Disinfection Byproducts[1] webpage has information related to DBPs including how they form and how to control them.

Total organic carbon (TOC) is used as a surrogate measurement for DBP precursors. The treatment technique for TOC removal lessens DBP precursors available to form DBPs during disinfection.

To address this, surface water treatment plants (SWTP) must comply with TOC removal requirements under the Stage 1 Disinfectants and Disinfection Byproducts Rule. The TOC removal requirements apply only to SWTPs that treat surface water or groundwater under the direct influence of surface water (GUI) using coagulation and sedimentation for treatment, unless certain other conditions exist. These conditions are described in the TOC Requirements section.

This guidance addresses basic TOC removal requirements. This **guidance is not a substitute for the rules.** If there appears to be a discrepancy between this guidance and the rules, follow the rules.

The rules related to this guidance are located in Title 30 of the Texas Administrative Code (30 TAC), Chapter 290, Subchapter F: Drinking Water Standards Governing Drinking Water Quality and Reporting Requirements for PWSs, Section 290.112: Total Organic Carbon.[2]

Information in this document is adapted from the EPA's *Enhanced Coagulation and Precipitative Guidance Manual* (EPA 815-R-99-012, May 1999). This guidance document is available on EPA's Guidance Manuals for the Surface Water Treatment Rules[3] webpage.

For information regarding the effects changing disinefectants has on the production of DBPs see table 3-2 of the EPA's *Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual* (EPA 815-R-99-015, August 1999).

TOC Requirements

All PWS SWTPs that use conventional treatment to treat surface water or GUI must comply with TOC requirements. Conventional systems use coagulation, flocculation, sedimentation, and filtration to treat the water. Each PWS using an open-air clarification or a sedimentation step during treatment must collect a TOC sample set.

Requirements include monthly monitoring and reporting, and quarterly compliance determinations.

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[1] www.tceq.texas.gov/drinkingwater/chemicals/dbp

[2] www.tceq.texas.gov/goto/290-toc

[3] www.epa.gov/dwreginfo/guidance-manuals-surface-water-treatment-rules

The following are exceptions to this requirement, based on the type of treatment technology used.

- Transient, non-community systems are not required to comply with TOC regulations.
- Systems without open-air sedimentation or clarification steps are not required to comply with TOC regulations.
- Systems that use unconventional filtration (reverse osmosis (RO), membrane, electrodialysis reversal (EDR)) may be required to collect a TOC sample set but are not required to meet TOC removal requirements.
- If sedimentation or clarification has elevated hydraulic detention times (HDT), the facility must collect TOC samples, but are not required to meet TOC removal requirements. Examples include Trident filters, Roberts filters, or Actiflow clarifier.

TCEQ Contact Information

For questions about rules, additional reporting requirements, and/or this guidance call 512-239-4691 and ask for a Surface Water Treatment Rule (SWTR) Coordinator. You can also contact a SWTR Coordinator by emailing SWTR@tceq.texas.gov.

Monitoring and Reporting

Monitoring Locations

PWS must collect their TOC samples at locations consistent with monitoring requirements in 30 TAC Section 290.112(c)[4] and listed in the system's monitoring plan. Information on monitoring plans, along with the monitoring plan template is located at [Public Water System Monitoring Plans](www.tceq.texas.gov/goto/pws/monitoringplan)[5] webpage.

For information regarding TOC sample storage and preservation see section 5.3 of the EPA's *Enhanced Coagulation and Pricipitative Softening Guidance Manual* (EPA 815-R-99-012, May 1999).

Raw Water Sampling Location

Raw water must be sampled before any chemicals are added. Raw water TOC and alkalinity samples should be taken at the same location. The samples may be taken from the any of the following:

- lake
- the raw water pump station
- an influent trough or head tank before the rapid mix
- any place accurately representing raw water quality before chemical addition

Any of the locations labeled **(1)** in Figure 1 are valid locations for taking raw water samples.

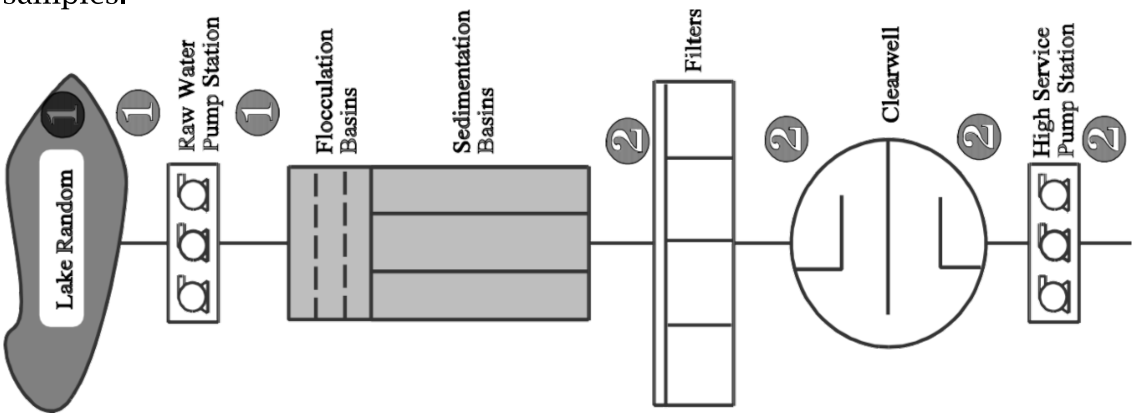

Figure 1. TOC Sample Set Locations

Treated Water Sampling Location

Treated water samples for TOC analysis are taken after sedimentation but alternatively, can be taken after filtration. Any sampling point after the sedimentation basin effluent up to the point of combined effluent filter turbidity sampling is

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[4] www.tceq.texas.gov/goto/290-toc

[5] www.tceq.texas.gov/goto/pws/monitoringplan

acceptable. From a regulatory standpoint, the treated water sample point in relation to any in-plant chemical injection points does not matter.

Any of the locations labeled **(2)** in Figure 1 are okay for taking treated water samples.

Monitoring Frequency

Every plant must collect raw water TOC, raw water alkalinity, and treated water TOC samples at least once a month. This group of samples is called a *TOC sample set*. While raw water alkalinity and raw water TOC samples must be collected at the same time, treated water samples should be collected no sooner than one hour after collecting raw water samples.The one hour wait time is a minimum, but it normally takes water more than one hour to flow through a SWTP and your goal is to collect samples from the same water before and after it is treated. If you wish to discuss the timing of your sampling collection, contact TCEQ to speak with a TOC compliance specialist at SWTR@tceq.texas.gov or by calling 512-239-4691. You can find the exact rule language for the TOC monitoring requirements in 30 TAC Section 290.112(c).[6]

Note: If samples are sent to a laboratory, consider the time it takes to get results back when scheduling sample collection. Laboratory turnaround time for TOC samples can range from two to four weeks and it is your responsibility to report the results to TCEQ. Consider collecting the TOC sample set early in the month, so results are back with enough time to complete and submit reports to TCEQ.

A plant may choose to collect more than one TOC sample set in a month. If so, the results of all TOC sample sets collected at the locations designated in system's monitoring plan must be reported on the TOCMOR. Multiple TOC sample sets may be needed if a plant treats water with a highly variable TOC concentration. For example, if your plant treats water from two reservoirs in one month, consider taking a TOC sample set before and after changing between water sources. Or, if heavy rains change the treatability of the source water, consider taking a TOC sample set before and after the rain.

Raw Water Sampling for Systems that Blend

Some PWSs use more than one raw water source on a continuous or seasonal basis. These sources—which may involve surface waters or a combination of surface and groundwater—are blended to create the plant influent. PWSs may also introduce groundwater directly into a treatment train unit process. There are numerous ways to blend different raw waters and to introduce them to the treatment train. Only general guidelines are provided here. For more assistance, contact the TCEQ Drinking Water Quality Team at 512-239-4691.

TOC samples must be taken from untreated raw water before any disinfectant, oxidant, or other treatment is applied. Compliance sampling is complicated by this requirement because PWSs frequently apply disinfectant at the source-to-plant transmission lines. This may make it impossible to sample the plant influent immediately after the raw waters are blended, because disinfectant is present.

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[6] www.tceq.texas.gov/goto/290-toc

Blending of Ground and Surface Waters

Ground and surface waters that are blended before the application of disinfectant can be sampled after blending. Groundwater introduced to the treatment train after rapid mix should not be included in the raw water TOC sample.

Systems that blend ground and surface water should consider blending the water after treatment, so that low-turbidity groundwater does not make it harder to treat the surface water.

Blending One or More Surface Water Sources Before Oxidation

When one or more surface water sources is oxidized before blending, do not sample the blended raw water, because disinfectant or oxidant is present. Use one of the following procedures to collect raw water samples. Example 1 shows how to determine raw water TOC for blended sources.

Composite Sample: Collect a raw water sample from each source and create a composite sample by mixing the raw water samples based on the percentage each source contributes to the influent. For example, if a source is 30% of the plant influent, it would be 30% of the composite sample's volume. Once the composite sample is created, a single TOC or alkalinity analysis can be performed. Composite sampling is less expensive than weighted calculation.

Weighted Calculation: Sample each raw water source and perform a TOC analysis. Calculate the blended water's TOC, based on the flow from each source. Equation 1 is for blended TOC and Equation 2 is for blended alkalinity.

Equation 1. Blended TOC = Sum of (% source) x (TOC of source)

Equation 2. Blended Alkalinity = Sum of (% source) x (alkalinity of source)

Determining Raw Water TOC for Blended Sources

A plant uses water from three sources. They contribute 50, 20, and 30 percent of the plant influent. The TOC results are 6.0, 4.0, and 3.0 milligrams per liter (mg/L), respectively. The alkalinity results are 70, 90, and 85 mg/L, respectively. What is the blended TOC and alkalinity?

Solutions: The plant operator can either calculate the results mathematically or make a composite sample and measure it.

(1) **Composite Sample**: Collect undisinfected (unoxidized) water from each raw water source. Mix the sample water together in the proportion it contributes to flow. That is, blend 50 milliliters (mL) from Source 1, plus 20 mL from Source 2, plus 30 mL from Source 3. Measure the alkalinity and TOC.

(2) **Calculated Solution**: The calculated concentrations will be:

Blended TOC = [(0.5 x 6.0) + (0.2 x 4.0) + (0.3 x 3.0)] = 4.7 mg/L

Blended alkalinity = [(0.5 x 70) + (0.2 x 90) + (0.3 x 85)] = 78.5 mg/L

Example 1. Determining Raw Water TOC for Blended Sources

Required Analytes

All systems subject to TOC reporting requirements must measure and report TOC and alkalinity data for compliance purposes. Additional analytes, depending on the compliance strategy used include pH, TTHM, HAA5, ultraviolet light absorbance at 254 nm (UV254), dissolved organic carbon (DOC), and magnesium hardness. Table 1 shows the analytes and methods a system must test for based on the compliance strategy. The approved analytical methods are listed on the Drinking Water Laboratory Approval Form. Table 1 shows the analytes and methods a system must test for based on the compliance strategy and alternative compliance critieria (ACC) sampling being used.

Table 1. Required Analytes Tested by Compliance Strategy

Compliance Strategy	Analyses
Step 1	TOC, alkalinity
Step 2	TOC, alkalinity, pH
ACC 1	TOC, alkalinity
ACC 2	TOC, alkalinity
ACC 3	TOC, alkalinity, TTHM, HAA5
ACC 4	TOC, alkalinity, TTHM, HAA5
ACC 5	TOC, alkalinity, DOC, UV254 (SUVA)
ACC 6	TOC, alkalinity, DOC, UV254 (SUVA)
ACC 7	TOC, alkalinity
ACC 8	TOC, alkalinity, magnesium

Laboratory Approval

Laboratories must get TCEQ laboratory approval before operators can analyze and report data for TOC compliance. This applies to PWS laboratories that analyze one or more of the approved laboratory analytes to determine compliance with treatment technique requirements.

To be approved, the laboratory must complete the Drinking Water Laboratory Approval Form and Instructions (TCEQ-10450) available on the Public Water System Monitoring Plans[7] webpage, indicating the methods and quality control procedures used to anylize each analyte. The laboratory must meet all laboratory approval requirements and the form must be signed by the individual responsible for laboratory operations. TCEQ reviews the form upon receipt and contacts the laboratory if the form is approved or disapproved, if the form has errors, or if the form is incomplete.

The Drinking Water Laboratory Approval Form is submitted as part of a PWS's monitoring plan. Monitoring plan information is located on the Public Water System Monitoring Plans[8] webpage. For specific questions about laboratory approval, contact the TCEQ Laboratory Approval Coordinator at 512-239-4691.

PWSs have the option to have their TOC samples analyzed by a TCEQ approved commercial laboratory or other approved PWS laboratory. Lists of TCEQ approved PWS

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[7] www.tceq.texas.gov/goto/pws/monitoringplan

[8] www.tceq.texas.gov/goto/pws/monitoringplan

and commercial laboratories are available on the Public Drinking Water System Monitoring Plans[8] webpage.

Texas Drinking Water Watch

The public has access to TCEQ PWS data through the Texas Drinking Water Watch[9] (DWW) database. This website offers access to PWS information and water quality data including but not limited to the following:

- water system detail such as county served, population, system type, and source
- violations
- enforcement actions
- compliance sample schedules
- chemical sample results
- lead and copper sample results
- coliform and *E. coli* sample results

Use the DWW Instructions[10] webpage for help accessing DWW.

Standard Operating Procedures

Each PWS needs to create standard operating procedures (SOPs) based on their system requirements. SOPs are important for any task that requires detailed, consistent, and repeatable results. Regular updating and review of SOPs is important in keeping processes and procedures current. Training for PWS staff on methods outlined in SOPs is also key to producing consistent and quality results.

Example SOPs Chemical Feed Rates and Process Control Jar Testing are provided in Appendices 2 and 3. These examples can be used as a starting point for your PWS. Remember to make changes so the SOPs are specific to the processes used at your plant(s).

TOC Reporting Requirements

If your systems are subject to the TOC requirements described in this document, you must report data monthly using the approriate version of the Surface Water Monthly Operating Report (SWMOR). The SWMOR forms can be downloaded from the Forms, Instructions, and Guidance for SWMORs[11] webpage. Up to four separate worksheets could be used for TOC reporting.

Depending on specific treatment processes, you enter TOC information and data on one or more pages (worksheets). Every SWTP with at least one sedimentation or clarification basin must submit a P.6 TOCMOR worksheet each month. Use of the other worksheets depends on individual circumstances described below.

Instructions for completing and submitting the worksheets are included in the TCEQ regulatory guidance (RG) Surface Water Treatment Plant Requirements for Monthly

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[9] dww2.tceq.texas.gov/DWW/

[10] www.tceq.texas.gov/goto/dww-inst

[11] www.tceq.texas.gov/goto/swmor-forms

Reporting and Public Notification[12] (RG-211); Chapter 3-Entering Data in a Customized SWMOR Workbook[13]. The following describes each worksheet.

- **P.6 TOCMOR Worksheet**—Every SWTP with at least one sedimentation or clarification basin must submit a P.6 TOCMOR worksheet each month. The Worksheet contains cells reporting both information about the type of treatment, and TOC data.
- **P.7 TOC ACC Worksheet**—If your SWTP uses one of the ACCs to meet TOC removal requirements, you need to complete and submit the P.7 TOC ACC worksheet.
- **P.8 TOC Step2 Worksheet**—Only required if you run a Step 2 Jar Test and want to use the results to help meet your TOC treatment technique requirement.
- **SUVA Jar Test Worksheet**—Provided for your convenience. Use this worksheet to record your jar test results and SWTP conditions at the time of testing. It is not used for compliance.

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[12] www.tceq.texas.gov/drinkingwater/swmor/swmor/rg-211.html

[13] www.tceq.texas.gov/downloads/drinking-water/operating-reports/rg-211-chapter-3.pdf

Compliance Strategy

TOC removal requirements are dependant on the source water's natural alkalinity and TOC content before any treatment chemicals are added. There are three ways to remain in compliance with the TOC removal requirements:

- Meet the Step 1 TOC removal requirement through coagulation and filtration, or
- Meet any of the alternative compliance criteria (ACCs) also classified as Step 1.
- Meet the Step 2 Alternative Minimum TOC removal goal.

Most systems will meet the Step 1 TOC removal requirements. The order in which to consider the plant's compliance strategy is shown in Figure 2.

First, collect your TOC sample set and have the samples analyzed. Enter the results into the TOCMOR and determine if the Step 1, in-plant removal requirements were met. Reference the Step 1 TOC Removal Requirements section. If not, review the Alternative Compliance Criteria (ACC) section. If the SWTP can meet one of these criteria, you do not need to meet a specific TOC removal requirement.

If you determine that the plant cannot meet the Step 1 removal requirements through in-plant removal or through the application of an ACC, you must run a Step 2 jar test. The Step 2 jar test will give you a Step 2 alternative TOC removal goal, as described in the Step 2 Alternative TOC Removal section.

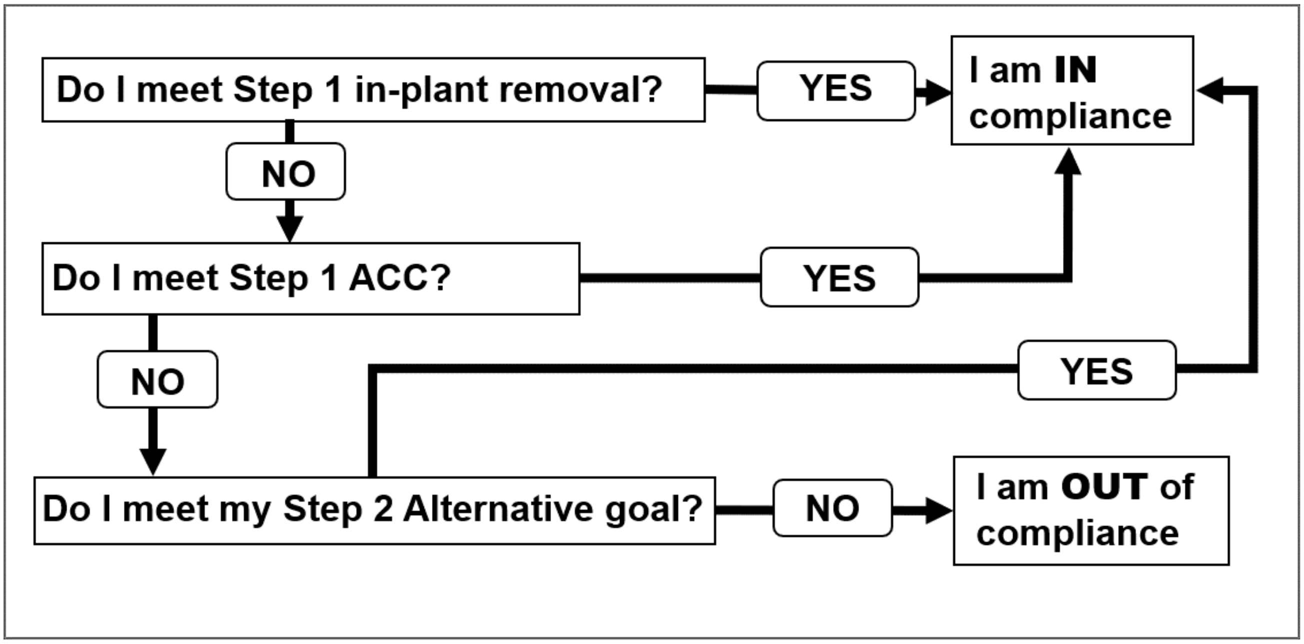

Figure 2. Compliance Determination Flowchart

Step 1 TOC Removal Requirements

Once TOC sample results have been returned to you from the lab, you must determine if the plant meets the Step 1, in-plant removal requirement, as shown in Table 2.

To use Table 2,

- measure raw water TOC in milligrams per liter (mg/L),
- measure raw water alkalinity in mg/L as calcium carbonate ($CaCo_3$), and
- find the box on the table that applies to your raw water ranges.

The percent shown in the box is your plant's Step 1 required removal percent. If the plant cannot meet the Step 1 TOC removal requirement in Table 2, you must decide if your plant can apply a Step 1 ACC. If not, you must perform a Step 2 jar test. The exact language for the TOC removal requirements can be found in 30 TAC Section 290.112(b).[14]

Note: Softening plants must meet TOC removal requirements for raw water alkalinity > 120 mg/L (as $CaCO_3$).

Table 2. Step 1 Metric of Required TOC Removal Percentage

Raw Water TOC Ranges	Raw Water Alkalinity Ranges (mg/L as $CaCO_3$)		
(mg/L)	*0 to 60*	*> 60 to 120*	*> 120*
2.0 ≤ TOC ≤ 4.0	**35.0%**	**25.0%**	**15.0%**
4.0 ≤ TOC ≤ 8.0	**45.0%**	**35.0%**	**25.0%**
TOC ≥ 8.0	**50.0%**	**40.0%**	**30.0%**

The percent removal requirements specified in Table 2 were developed based on the "treatability" of different waters. TOC removal is generally more difficult as alkalinity increases and TOC decreases. When alkalinity is high, more acid must be added to force the pH down, so just adding coagulant may not do the job. The best (optimal) pH range for coagulation with alum is 5.5 to 6.5. In more alkaline waters, TOC removal cannot be achieved easily through the addition of coagulant alone. TOC removal is also generally more difficult as the TOC level decreases because there are fewer opportunities for particles to contact each other and form floc. See Example 2.

Month-to-month changes in raw water TOC and/or alkalinity levels will cause some plants to move from one cell of Table 2 to another. Therefore, the plant's required Step Step1 TOC removal percentage may change, based on the TOC and alkalinity levels of the monthly raw water compliance sample.

Step 1 Removal Requirement

A plant in southeast Texas is treating water that has an alkalinity of 7 mg/L (as $CaCO_3$) and a TOC of 8.3 mg/L. What is the plant's Step 1 required removal percentage?

Solution: The operator uses the Table 2 column for alkalinity between 0 to 60 mg/L (as $CaCO_3$). Move down the column to the row for raw water "TOC ≥ 8.0 mg/L." The Step 1 required removal rate for the plant is 50%.

Example 2. Step 1 Determining Required Removal Percentage

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[14] www.tceq.texas.gov/goto/290-toc

Step 2 Alternative TOC Removal

If a plant fails to meet the Step 1 removal requirement in any month, the plant's *alternative minimum TOC removal goal* (Step 2 removal requirement) must be determined.

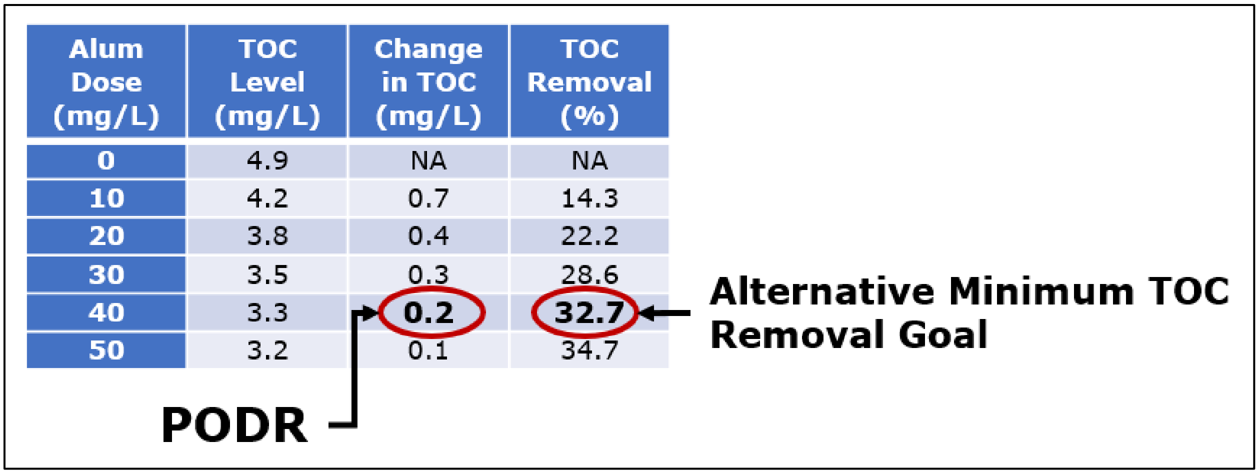
PWSs that choose to use jar testing (not pilot testing) to determine their Step 2 removal requirements should follow the procedures described in this guidance manual. A system that chooses to use pilot-scale Step 2 testing should follow the procedures described in the EPA guidance document (EPA 815-R-99-012).

A Step 2 jar test establishes the plant's required percent removal rate for up to six months. See the Compliance Determination section.

The purpose of the jar test is to establish an alternative minimum TOC removal goal, not to determine full-scale operating conditions.

In a Step 2 jar test, 10 mg/L increments of alum (or an equivalent amount of metal-based coagulant) are added to a series of jars to determine the incremental impact to TOC removal. Coagulant must be added in required increments until a target pH is achieved. The point where adding another 10 mg/L dose of alum does not remove at least 0.3 mg/L of TOC is defined as the *point of diminishing return* (PODR). Figure 3 provides an example of how data is used to determine the PODR.

The percentage TOC removal achieved at the PODR in the Step 2 jar test is defined as the plant's *alternative minimum TOC removal goal*, subject to approval by TCEQ's Public Drinking Water Program. For a discussion of how to define the PODR see the Determine the PODR section.



Alum Dose (mg/L)	TOC Level (mg/L)	Change in TOC (mg/L)	TOC Removal (%)
0	4.9	NA	NA
10	4.2	0.7	14.3
20	3.8	0.4	22.2
30	3.5	0.3	28.6
40	3.3	0.2	32.7
50	3.2	0.1	34.7

Alternative Minimum TOC Removal Goal

PODR

Figure 3. Example of PODR Calculation

The goal of the Step 2 procedure is to determine the amount of TOC that can be removed with reasonable amounts of coagulant and to define an alternative TOC removal goal. The procedure is neither designed nor intended to be used to establish a full-scale coagulant dose requirement. Once a plant's alternative TOC removal goal is approved by TCEQ, a plant may aim to achieve this removal at full scale by using any appropriate combination of treatment chemicals.

Frequency of Step 2 Jar Testing

You must perform a Step 2 jar test if the monthly TOC sampling shows the plant will not meet Step 1 removal requirements. After TCEQ approval, the plant may use that *alternative minimum TOC removal goal* for each month in both the quarter when the Step 2 test was performed and the following quarter (six months total).

For example, if TCEQ approves the results of a Step 2 jar test you conducted in February, you can use the results for the months of January through June. Once you have an approved Step 2 removal requirement, you may use any combination of coagulant, coagulant aid, filter aid, and pH adjustment to achieve that removal in the full-scale plant.

After you start Step 2 jar testing, you may do the jar testing once and use those results for six months. However, you may wish to redo the Step 2 jar testing if your raw water changes due to rain or blending. There is no upper limit to the frequency at which Step 2 jar tests are performed, as long as the results are submitted to the TCEQ for approval at least 15 days before the end of the quarter in which you wish to apply the new alternative minimum TOC removal goal.

Step 2 Jar Test Method

The Step 2 procedure is based on the incremental addition of a metal-based coagulant to define an alternative TOC removal percentage. Only aluminum- or iron-based coagulants may be used for the Step 2 procedure. **The addition of acid, polymers, or other treatment chemicals to the test jars is not permitted.** It is important to determine the proper amount of coagulant needed as enhanced coagulation can affect treatment. Side effects of enhanced coagulation can be found in Appendix 1.

Step 2 jar test results are not used to set full-scale operating conditions.

Note: Use the SWMOR P.8-TOC Step2 Worksheet to record your Step 2 jar test data.

Regular grade alum must be used in 10 mg/L increments. The equivalent increments for all coagulants are provided in Table 3.

- regular grade alum – aluminum sulfate, $Al_2(SO_4)_3 \cdot 14H_2O$ in aqueous solution
- reagent grade alum – aluminum sulfate, $Al_2(SO_4)_3 \cdot 18H_2O$ in aqueous solution
- ferric chloride, $FeCl_3 \cdot 6H_2O$ in aqueous solution
- ferric chloride, $FeCl_3$ in aqueous solution
- ferric sulfate, $Fe_2(SO_4)_3 \cdot 9H_2O$ in aqueous solution
- ferrous sulfate $FeSO_4 \cdot 7H_2O$ in aqueous solution

Plants not using metal coagulant: Some plants use a proprietary polymer blend for coagulation. If your plant does not use a metal coagulant mentioned in Table 3, you should perform Step 2 jar testing using alum.

Plants using metal coagulants with additives: Some plants use coagulants that contain other chemicals, such as polymers or copper sulfate. If your plant uses a liquid coagulant with additives, you may not use that solution in Step 2 jar tests. You must obtain and use one of the chemicals identified in Table 3 to conduct a Step 2 jar test.

Table 3. Coagulant Dosage Equivalents in mg/L

Jar No.	Regular Grade Alum	Reagent Grade Alum	Ferric Chloride ($FeCl_3 \bullet 6H_2O$	Ferric Chloride ($FeCl_3$)	Ferric Sulfate	Ferrous Sulfate
1	10	11.2	9.1	5.5	9.5	9.4
2	20	22.4	18.2	11.0	19.0	18.8
3	30	33.6	27.3	16.5	28.5	28.2
4	40	44.8	36.4	22.0	38.0	37.6
5	50	56.0	45.5	27.5	47.5	47.0
6	60	37.2	54.6	33.0	57.0	56.4
7	70	78.4	63.7	38.5	66.5	65.8
8	80	89.6	72.8	44.0	76.0	75.2
9	90	100.8	81.9	49.5	85.5	84.6
10	100	112.0	91.0	55.0	95.0	94.0

The Step 2 procedure requires that coagulant be added in increments until the pH of the test sample is at or below the target pH (Table 4). The target pH values depend on the raw water alkalinity to account for the higher coagulant dosages needed to reduce pH in higher alkalinity waters.

Table 4. Step 2 Target pH

Alkalinity (mg/L as $CaCO_3$)	Target pH
0-60	5.5
> 60-120	6.3
> 120-240	7.0

For water with alkalinity of less than 60 mg/L (as $CaCO_3$)—for which addition of small amounts of coagulant drives the pH below the target pH before significant TOC removal is achieved—add base to maintain the pH between 5.3 and 5.7 until the PODR criterion is met. The chemical used to adjust the pH should be the same chemical used in the full-scale plant unless that chemical does not perform adequately in jar tests. Substitute chemicals should be used in this case.

Step 2 Jar Testing Procedure

The following procedure should be used to conduct Step 2 jar testing. This procedure relies on the addition of coagulant only. Acid and polymers must not be used in the jar test, even if they are used in full-scale treatment. Base must be added if the pH of the water drops too low (see Table 4). The following list summarizes the Step 2 jar test procedure sequence:

1. Gather testing supplies.
2. Prepare coagulant dosing solution.
3. Determine the initial coagulant dose.
4. Determine the number of jars (and pH adjustment, if applicable) required.
5. Record starting conditions, coagulant dose, pH, alkalinity.
6. Collect raw water for testing.

7. Set up the jars.
8. Rapid mix the jars and add coagulant.
9. Slow mix and settle the jars.
10. Take samples to measure TOC, pH.
11. Determine PODR.

Step 2 Jar Testing Supplies

The following supplies are needed to complete a Step 2 jar test.

- Jar test apparatus with 1- or 2-L beakers or square mixing jars.
- Dosing solution of alum or other coagulant.
- The dosing solution must be freshly prepared the day of the test. See the Determine the Initial Coagulant Dose section for information on preparing an alum or ferric dosing solution. The dosing solution must be made from straight coagulant that is **not** blended with polymer or other chemicals.
- Base (if needed to adjust pH).
- Hydrometer or other equipment to measure the specific gravity of the coagulant, if using liquid coagulant.
- pH meter calibrated according to *Standard Methods* (American Public Health Association, latest edition).
- Sample bottles for alkalinity and pH analysis of coagulated water. Sample bottles for TOC analysis.
- 25- and 50-mL pipettes, with bulbs used to accurately measure volumes when preparing dosing solutions. Volumetric pipettes may be used for more precise dosages. Plastic disposable syringes (without needles) may be used to measure coagulant doses to be applied during the jar tests, but not to prepare the dosing solution.
- 1-L graduated cylinders.
- Large carboys for collecting raw water (preferably with siphons or taps for dispensing water). A suitable laboratory tap may also be used.
- Magnetic stirrer with stirring bars.
- Miscellaneous beakers and glassware.
- SWMOR P.8 TOC Step2 Worksheet for recording Step 2 jar testing data.

Dosing Solutions for a Step 2 Jar Test

You must prepare the Step 2 dosing (stock) solution using a metal-based coagulant. If you use alum in the plant, make an alum dosing solution. If you use ferric coagulant in the plant, make a ferric dosing solution. If you use only polymer or polyaluminum chloride (PACl), get some alum to use in Step 2 jar testing.

When you prepare the dosing solution, make it strong enough so that adding 1 mL to the test jar, yields a 10 mg/L alum dose (or an equivalent amount of iron). For example, if you use alum and 1-L test jars, make a 10,000 mg/L (10 g/L, 10 mg/mL) solution. That way, adding 1 mL of dosing solution to the 1-L test jar, yields a dose of 10 mg/L. However, if you use alum and 2-L test jars, make the dosing solution twice as strong. So that adding 1 mL of solution to the larger jar still yields a 10 mg/L dose.

pH of Dosing Solution

The pH of the coagulant dosing solution should generally be below 3.0. If the pH of the coagulant dosing solution increases significantly above 3.0, some metal hydroxide precipitation may occur, resulting in the loss of active coagulant. If this happens make a fresh dosing solution.

Dry Coagulant Dosing Solution for a Step 2 Jar Test

To prepare a dosing solution using one of the dry chemicals listed in Table 5, follow the steps below:

1. Add 400 mL of distilled or deionized (DI) water to a 1000-mL volumetric flask.
2. Add the proper amount of dry coagulant to the flask and swirl it until the chemical dissolves.
3. Finish filling the flask to the 1000-mL mark with distilled or deionized water.
4. Stopper the flask and completely mix the dosing solution by inverting the flask several times.

Table 5. Step 2 Dosing Solution Recipes for Dry (Solid) Chemicals

Coagulant Chemical	Desired Increment in Step 2 Jars (mg/L)	1-Liter Jars Dosing Solution Recipe (grams)	2-Liter Jars Dosing Solution Recipe (grams)
Regular Grade Alum (dry) $Al_2(SO_4)_3 \bullet 14\ H_2O$	10.0	10.0	20.0
Regent Grade Alum (dry) $Al_2(SO_4) \bullet 18H_2O$	11.2	11.2	22.4
Ferric Chloride (dry) $FeCl_3$	5.5	5.5	11.0
Ferric Chloride (dry) $FeCl_3 \bullet 6H_2O$	9.1	9.1	18.2
Ferric Sulfate (dry) $Fe_2(SO_4)_3 \bullet 9H_2O$	9.5	9.5	19.0
Ferrous Sulfate (dry) $FeSO_4 \bullet 7H_2O$	9.4	9.4	18.8

Liquid Coagulant Dosing Solution for a Step 2 Jar Test

You may use liquid coagulant to prepare the dosing solution only if your plant meets **all** of the following conditions:

1. You are feeding solutions of ferric chloride, liquid alum, liquid ferric sulfate, or liquid ferrous sulfate.
2. Your liquid coagulant does not contain any other chemicals, such as polymer, copper sulfate, etc.
3. You know the exact amount (concentration) of active chemical in the liquid coagulant.

4. You are able to measure the specific gravity of the liquid coagulant.

If you cannot meet all four conditions, prepare the dosing solution using the procedure outlined in Dry Coagulant Dosing Solution for a Step 2 Jar Test section. You must use one of the dry coagulants listed in Table 5.

Plants Using Liquid Ferric or Liquid Ferrous Coagulants: Vendors frequently fail to provide the percent ferric (active iron) of the iron solutions they sell. If you do not know the amount of iron in your solution, you must obtain dry ferric (or ferrous) coagulant.

The most convenient way to measure liquid coagulants is to use volumetric measurements like milliliters (mL). However, each mL of the dosing solution must create an applied dose equal to 10 mg/L of regular grade dry alum. So, you must prepare the dosing solution on a **dry weight** basis, even if you use a liquid coagulant. To do this, first determine how much **dry** coagulant is contained in each mL of the liquid, and then figure out how much of the liquid coagulant is needed to make the dosing solution.

Determining How Much Dry Coagulant in Each Milliliter of Liquid Coagulant

The strength of a liquid iron or alum coagulant is typically reported on a **percent** basis. For example, each pound of a 30 % liquid alum solution contains 0.30 pounds of reactive (dry) alum. However, to prepare a dosing solution, you must know the amount of reactive (dry) chemical, in each milliliter of the liquid solution. Therefore, the first step in preparing a dosing solution is to convert the concentration of the liquid coagulant from **percent** to **milligrams per milliliter (**mg/mL) using Equation 3.

Equation 3. Concentration (mg/L) = (% alum) x (specific gravity) x (conversion factor)

For Equation 3.

- Percent alum = grams of dry alum per 100 grams of liquid coagulant solution
- Conversion Factor = 1000 milligrams per gram (mg/g)

Note About Specific Gravity: If the specific gravity of your liquid alum is between 1.32 and 1.35, you can assume that it contains 48% dry alum. You can use the calculations from Example 3. If not, use Equation 3 and the information in Appendix 5 to determine your alum solution concentration.

Converting from percent to mg/L

An operator uses liquid alum with a specific gravity of 1.33. The liquid alum contains about 48% regular grade alum [$Al_2(SO_4)3$]•$14H_2O$] on a dry weight basis. What is the concentration of the coagulant in milligrams of dry alum/milliliter of coagulant (mg/mL)?

Solution: The concentration can be converted to mg/mL using Equation 3.

alum concentration (mg/mL) =

0.48 [mg alum/100g solution] x 1.33 [g solution/1 mL solution] x 1000 [mL/L] =

638 mg alum/mL

Example 3. Converting from Percent to mg/L

Figuring out how much liquid coagulant to use when making a dosing solution

After determining how much **dry** coagulant each milliliter of liquid coagulant contains, you can figure out how much liquid coagulant is needed to make a liter (L) of dosing solution. To make a liter of dosing solution, use Equation 4. To determine grams of dry coagulant use Equation 3. See Example 4.

$$\mathbf{4}\ .\ \text{Volume of liquid coagulant (mL)} = \left(\frac{\text{dry coagulant}}{\text{coagulant content of liquid}}\right) \text{x conversion factor}$$

For Equation 4,

- Dry coagulant = grams
- Coagulant content of liquid = mL
- Conversion Factor = 1000 mg/g

Calculations for how much liquid alum to use when making a Step 2 jar test dosing solution.

Example for preparing a 20 g/L dosing solution.

The operator from Example 3 wants to make a dosing solution with the liquid alum in use at the plant. The liquid alum contains no additional chemicals, and the jar test apparatus has 2-Liter jars. <u>How much of the liquid alum should be used to make his dosing solution?</u>

Solution: Liquid alum contains no additional chemicals, so the operator knows it can be used to prepare the dosing solution. The operator is using 2-L jars and alum. Use Table 5 to determine you need 20 grams of alum to prepare 1-L of dosing solution. From the calculations described in Example 3, the operator knows that each mL of liquid coagulant contains 638 mg of dry alum. Plug all this information into Equation 4 to find the amount of liquid alum needed for the dosing solution.

<u>volume of liquid coagulant (mL)</u> =

20 [g of alum] x 1000 [mg alum/g alum] / 638 [mg alum/mL liquid alum] =

31.3 [mL liquid alum]

Example 4. Calculating Liquid Alum

Preparing the Dosing Solution

To prepare a dosing solution using a liquid coagulant, use the following procedure:

- Add about 400 mL of distilled or deionized water to a 1000-mL volumetric flask.
- Add the proper amount of liquid coagulant to the flask and swirl it until the chemical dissolves.
- Finish filling the flask to the 1000-mL mark with distilled or deionized water.
- Stopper the flask and completely mix the dosing solution by inverting the flask several times.

Determining the Initial Coagulant Dose

If using alum, ferric, or ferrous coagulants, you can start dosing jars one increment below the concentration of coagulant you use full scale. For instance, if you add 55 mg/L of alum at full scale, start your jar test at a dose of 50 mg alum/L, so your jars would be 50, 60, 70, 80, 90, 100 mg/L, and so on.

However, if you are using other coagulants, such as polymer, PACl, or aluminum chlorohydrate, begin your Step 2 jar test with a dose of 10 mg/L alum dose.

Determining the Number of Jars Required and pH Adjustment

You need enough jars to reach both the PODR and the target pH. If the alkalinity level of your raw water is at least 60 mg/L, this is a straightforward process. Just continue until the target pH is reached. If the alkalinity level of your raw water is lower than 60 mg/L, the process may be a little more complex. You may need to add a base to keep the pH from dropping to the target pH before reaching the PODR.

The first time you do a Step 2 jar test, start with one full set of jars. If you meet the PODR after three or four jars, TCEQ may allow you to run fewer jars in future tests.

Determining Number of Jars when Alkalinity is ≥ 60mg/L

If your raw water alkalinity level is at least 60 mg/L, you can use the following procedure to determine the number of jars needed to run the first Step 2 jar test.

1. Collect a sample of raw water and fill one of the jar test jars to the full mark.
2. Measure the pH and alkalinity of the raw water.
3. Place the jar on a magnetic stirrer.
4. Add alum to this sample in 10-mg/L increments (or equivalent ferric dose). Use Example 3 to determine appropriate incremental doses for each type of coagulant.
5. Measure and record the pH after each incremental coagulant dose.
6. Determine the alum or ferric dose required to reach the target pH. Use Table 4 to determine the target pH.
7. Use Equation 5 to determine the equivalent alum doses.

$$\textbf{Equation 5}.\ \text{Equivalent alum dose (mg/L)} = \frac{\text{(ferric dose in mg/L)}}{\text{(mg/L ferric)/(mg/L alum)}} \text{ x (mg/L alum)}$$

The number of increments of alum added to hit the target pH is the number of jars dosed with alum (or iron coagulant) during the jar test.

Example 5 shows the process of determining the number of jars needed for a Step 2 jar test when the alkalinity is relatively high.

Determining the number of jars needed for a Step 2 jar test when the raw water alkalinity level is at least 60 mg/L.

An operator at a treatment plant that uses ferric chloride has a raw water with an alkalinity level of 84 mg/L and a pH of 7.6. The plant is currently applying a ferric dose of 19 mg/L.

Solution: Since the plant is using ferric chloride, the operator uses Table 3 to determine that a dose of 5.5 mg/L is equivalent to a 10 mg/L alum dose. Since the plant is currently applying 19 mg/L of ferric, the operator can determine the plant's equivalent alum dose using **Equation 5**:

$$Equivalent\ alum\ dose\ at\ plant\ (mg/L) = \frac{19}{(5.5/10)}\ x\ 10 = 34.5\ mg/L$$

Using this result, the operator determines the Step 2 jar test can begin with an equivalent alum dose of 30 mg/L at Jar 3. Refer to Example 3 to determine the appropriate incremental $FeCl_3$ dose. Since the jar test apparatus has 2-L jars and the plant uses a dry coagulant, the operator refers to Table 5 and uses 11 grams of $FeCl_3$ to prepare 1 L of dosing solution. Using one of the 2-L jars the operator gets the following results.

Jar No.	Equivalent Alum Dose	Ferric Dose (mL of dosing solution)	Alkalinity	pH
0	0	**0** (raw water)	84	7.6
3	30	16.5	▨	7.1
4	40	22	▨	7.0
5	50	27.5	▨	6.8
6	60	33	▨	6.5
7	70	38.5	▨	6.4
8	80	44	▨	6.3
9	90	49.5	▨	6.1

Based on these results and Table 3, the operator correctly concludes that a Step 2 jar test needs to be run out to an equivalent alum dose of at least 80 mg/L.

Example 5. Determining Number of Jars When Alkalinity ≥ 60 mg/L

Determining Number of Jars When Alkalinity is < 60 mg/L

When the raw water alkalinity level is below 60 mg/L, small increases in coagulant doses can produce rapid decreases in pH. Consequently, you can reach the target pH long before reaching the PODR. This problem is particularly severe when the raw water alkalinity level is below 20 to 30 mg/L.

TCEQ is concerned that the Step 2 jar test may be concluded before the PODR is reached. Consequently, we require that you raise the coagulant dose by at least five increments before concluding the test. Basically, you must run at least five jars above your current coagulant dose. For example, if you currently apply a 26-mg/L dose of alum, TCEQ might not approve the results of the jar test unless doses of 20, 30, 40, 50, 60, and 70 mg/L are included in the test.

If your raw water alkalinity level is below 60 mg/L, you may find that the pH of your jar falls below the target pH before reaching the maximum dose needed. In this case, add a base to one or more of the jars to keep the pH within the target pH range. When you have a raw water with relatively low alkalinity, you should use the following procedure to determine the number of jars needed during your first Step 2 jar test.

1. Collect a sample of raw water and fill one of the jar test jars to the full mark.
2. Place the jar test jar on a magnetic stirrer.
3. Measure the pH and alkalinity of the raw water.
4. Add alum to this sample in 10 mg/L increments (or equivalent ferric dose). Use Table 2 to determine appropriate incremental doses for each type of coagulant.
5. Measure and record the pH after each incremental coagulant dose.
6. If the pH of the jar falls below 5.3, add enough base to raise the pH level to between 5.3 and 5.7.
7. 50 mg/L of alum or an equivalent amount of iron), keep going until you have.

The number of increments of alum needed to hit the target pH will be the number of jars dosed with alum (or iron coagulant) during the jar test.

Example 6 shows how an operator goes through the process of determining the number of jars needed for a Step 2 jar test when the alkalinity is below 60 mg/L (as $CaCO_3$).

Recording Starting Conditions and Chemical Doses

Record the starting conditions and chemical doses. Enter the type of coagulant and the concentration of the dosing solution. If a base is going to be used during the test, also record the type and concentration of the base solution. Note the mixing and settling conditions that will be used in the jar test. Record the desired chemical doses for each of the jars and the volume of dosing solution to be added to each. Alum should be dosed at increments of 10 mg/L (or iron coagulant at an equivalent dose from Table 3) up to the maximum increment.

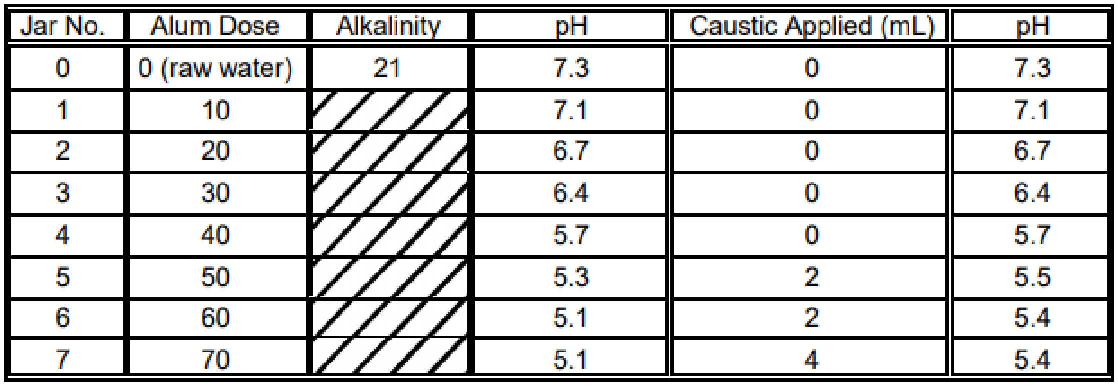
Determining the number of jars needed for a Step 2 jar test when the raw water alkalinity level is less than 60 mg/L.

An operator at a treatment plant that uses a pure polymer coagulant has a raw water with an alkalinity level of 21 mg/L and a pH of 7.3. The plant is currently applying a polymer dose of 6.3 mg/L and uses liquid caustic to adjust the pH of its finished water.

Solution: Because the plant uses polymer as its primary coagulant, the operator must prepare the dosing solution using dry alum. Since the jar test apparatus has 2-L jars, the operator refers to Table 5 and uses 20 grams of regular grade dry alum to prepare 1 L of dosing solution.

The operator is required to begin the Step 2 jar test at an incremental alum dose of 10 mg/L, because the plant uses polymer as its primary coagulant (see Determine the Initial Coagulant Dose section). In addition, TCEQ will probably require an alum dose of at least 50 mg/L (i.e., 5 incremental doses) before they approve the results.

Each 10 mg/L alum dose will consume about 5 mg/L of alkalinity. Consequently, the operator needs to adjust the pH for the last couple of doses. To address this problem, the operator prepares a 10% dilution of the liquid caustic to use in the test. Then, using one of the 2-L jars and the procedure described above, the operator obtains the following results.



Jar No.	Alum Dose	Alkalinity	pH	Caustic Applied (mL)	pH
0	0 (raw water)	21	7.3	0	7.3
1	10	▨	7.1	0	7.1
2	20	▨	6.7	0	6.7
3	30	▨	6.4	0	6.4
4	40	▨	5.7	0	5.7
5	50	▨	5.3	2	5.5
6	60	▨	5.1	2	5.4
7	70	▨	5.1	4	5.4

Based on these results, the operator concludes that he must run the Step 2 jar test out to an equivalent alum dose of at least 50 mg/L. However, since the last three increments gave some unclear results, the operator decides to run the jar test out to a dose of 70 mg/L, just to be safe. Finally, the operator needs to add some of the dilute caustic to the last couple of jars to keep the pH of the settled water between 5.3 and 5.7.

Example 6. Determining Number of Jars When Alkalinity < 60 mg/L

Collecting Raw Water for Testing

It is important to conduct the jar test with freshly collected water, if possible. Collect as much raw water for the jar test as you need (10 to 30 L, depending on number and size of jars).

Temperature

It may be difficult to maintain ambient water temperatures during jar testing. Jar testing may take up to two hours. This includes time for mixing and settling. During this time, the water temperature will gradually change until it reaches room temperature. Temperature change during jar testing may interfere with floc settling because of convection currents or release of dissolved air from the water.

Make every effort to minimize temperature change during jar testing. This can be accomplished by conducting jar tests in a room which is not climate controlled (e.g., filter gallery), or by immersing the jars in a water bath through which plant water is circulated.

Storage

It is best to collect fresh raw water for a jar test. However, if you have to store raw water for addtional testing, the sample should be refrigerated at approximately 4°C. Before starting any testing on the refrigerated water, adjust the sample temperature back to the ambient raw water temperature at collection. Bring the temperature up gradually using a method such as immersing jars or bottles in a water bath through which plant water is circulated. Samples that have been stored should be inverted to resuspend any solids that have settled to the bottom of the container during storage.

Setting up the Jars and Preparing Dosing Syringes

Fill the jar test jars with the proper amount (1 or 2 L) of raw water and place the jars on the jar test apparatus. Lower the stirrer paddles, turn on the mixer, and set the speed just high enough to prevent settling of any suspended materials.

Label the syringes and fill the coagulant dosing solution syringe for each jar with the appropriate amount of dosing solution. If pH adjustment is needed for one or more jars, fill the base syringe with the appropriate type and amount of base. Lay the labeled syringes next to the respective jars.

Adding Chemicals

Increase the mixing speed to achieve rapid mix conditions, and quickly inject the chemicals into each jar. If possible, you should inject both the coagulant dosing solution and the base at the same time. However, if it is impractical to inject the two chemicals simultaneously, add the base first and then add the coagulant.

Regardless of whether the chemicals are injected simultaneously, be sure to inject all chemicals injected into all the jars within 5 or 6 seconds. Start timing the rapid mix period as soon as the chemicals are added to the last jar.

Mixing and Settling

Rapid mix, flocculate, and settle, using the times recorded on the SWMOR P.8-TOC Step2 Worksheet.

Jar test mixing conditions should reflect full-scale mixing conditions and detention times at the plant’s maximum daily flow for the quarter being tested. However, for rapid mixing, a detention time of at least one minute should be used. If the plant mixing intensities and durations are not known, use a rapid mix at 100 revolutions per minute (rpm) for one minute, flocculate at 30 rpm for 20 minutes, and settle (0 rpm) for 30 minutes before sampling.

Taking Sample to Measure TOC and pH

After settling, sample the supernatant for TOC analysis. Use 25- or 50-mL wide- bore pipettes, a siphon apparatus, or sampling ports located on the side of the mixing jars. During sampling, the tip of the pipette should be approximately 10 cm (4 in.) below the water surface. In a typical 2 L square jar, the sampling port is also located approximately 10 cm below the 2 L mark on the side of the jar. While sampling, be careful not to disturb the settled floc and to avoid suspended floc.

Note on Sample Preservation: Preserve and/or refrigerate the samples for subsequent TOC analysis. TOC samples must be acidified with sulfuric or phosphoric acid if they are not going to be analyzed within 24 hours. Provide a unique sample ID for each sample and note the ID numbers. If you are sending out your samples for analysis, follow the laboratory's instructions.

After settling, measure the pH of the jars and record the values. Take samples for alkalinity, if desired, and analyze within appropriate holding times.

Determining the PODR

When you have the TOC laboratory results, enter the values and determine the PODR. See Example 7.

How to Determine the PODR and Alternative Removal Requirement

The PODR is defined at the point where addition of a 10 mg/L alum dose (or equivalent) results in less than 0.3 mg/L of TOC removal. This can be easily determined by looking at the data you collect for the Step 2 jar test. See Example 7.

Two PODRs

Sometimes, a Step 2 jar test has two places where the PODR is reached. In this case, official PODR is the second point at which the TOC removal drops below 0.3 mg/L (Figure 4).

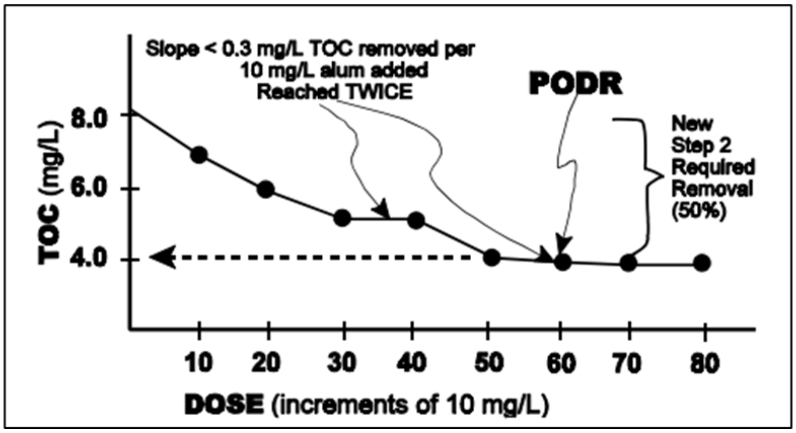
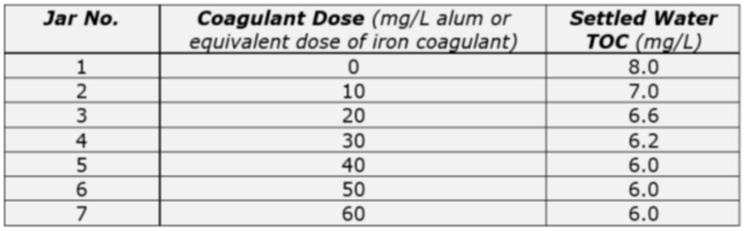


Figure 4. Example of PODR Determination When the PODR Occurs Twice

Determining the PODR

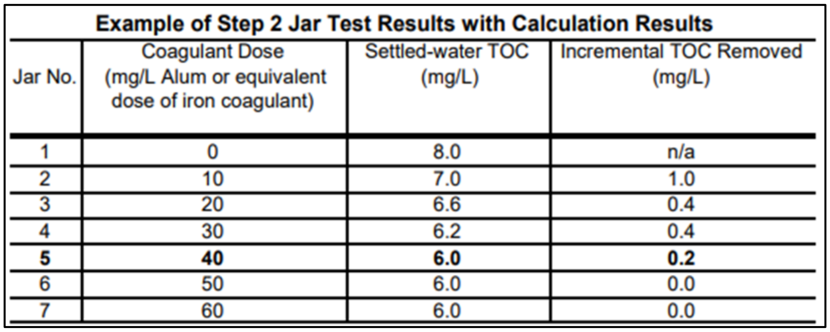
A SWTP runs a Step 2 jar test with these results:



Jar No.	**Coagulant Dose** *(mg/L alum or equivalent dose of iron coagulant)*	**Settled Water TOC** *(mg/L)*
1	0	8.0
2	10	7.0
3	20	6.6
4	30	6.2
5	40	6.0
6	50	6.0
7	60	6.0

1. What is the PODR for this jar test?

Solution: The PODR is the point at which 10 mg/L of additional alum removes less than 0.3 mg/L of TOC. Calculate how much TOC each increment of additional alum achieved.



Example of Step 2 Jar Test Results with Calculation Results

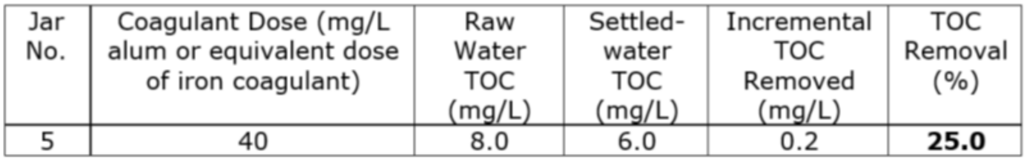
Jar No.	Coagulant Dose (mg/L Alum or equivalent dose of iron coagulant)	Settled-water TOC (mg/L)	Incremental TOC Removed (mg/L)
1	0	8.0	n/a
2	10	7.0	1.0
3	20	6.6	0.4
4	30	6.2	0.4
5	**40**	**6.0**	**0.2**
6	50	6.0	0.0
7	60	6.0	0.0

The PODR is at Jar 5, 40 mg/L of alum added, where addition of a 10 mg/L increment of alum results in removal of 0.2 mg/L of TOC, which is less than 0.3.

2. What is the alternative removal requirement for this plant?

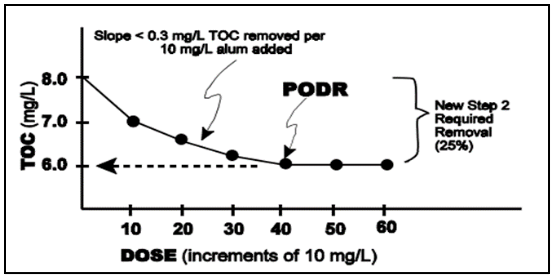
Solution: The *alternative removal requirement* is the percent removal achieved in the Step 2 jar test at the PODR. The TOC removal in Jar 5 is the new required removal for this plant. For Jar 5:

% TOC removal = (1-6.0/8.0) x 100 = 25%



Jar No.	Coagulant Dose (mg/L alum or equivalent dose of iron coagulant)	Raw Water TOC (mg/L)	Settled-water TOC (mg/L)	Incremental TOC Removed (mg/L)	TOC Removal (%)
5	40	8.0	6.0	0.2	**25.0**

The removal at the PODR is 25%. The plant must now achieve 25% TOC removal from raw water unless the alternative removal requirement is above the Step 1 requirement. Graphing your results can help understand the Step 2 jar test.



Example 7. Determining the PODR

Water "Not Amenable to Treatment"

Sometimes, a Step 2 jar test shows that no additional TOC removal is possible, no matter how much coagulant is added. Plants may apply to the state for a waiver from the enhanced coagulation requirements if they consistently fail to achieve the PODR.

These plants have a raw water where enhanced coagulation will not work. An example of the graph of the Step 2 jar test for water not amenable to treatment is shown in Figure 5. The plant should send TCEQ the Step 2 MOR jar test results showing that PODR cannot be achieved.

Note: TOC removal is never greater than 0.3 mg TOC removed/L per 10mg/L alum or equivalent dose of ferric salt added to all coagulant dosages during the Step 2 jar test procedure.

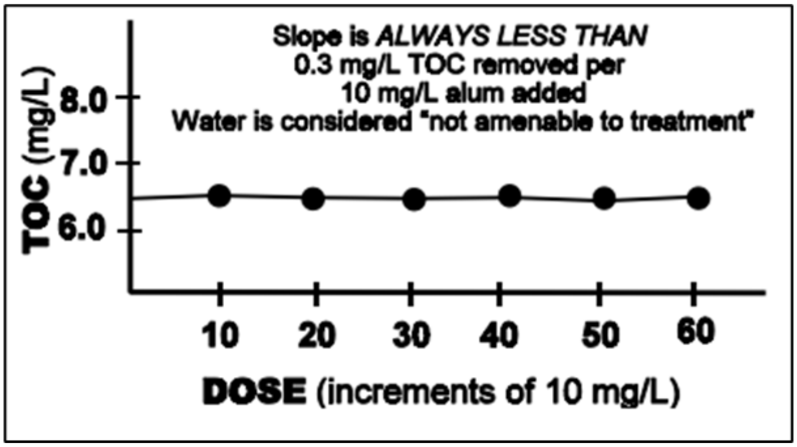


Figure 5. Example of Jar Test Results for Water "Not Amenable to Treatment"

Alternative Compliance Criteria (ACCs)

The TOC in some waters is not very easy to remove by coagulation or precipitative softening. For this reason, alternative compliance criteria (ACCs) were developed to allow plants flexibility for establishing compliance with the treatment technique requirements. These criteria recognize the low potential of certain waters to produce DBPs, and account for those waters with TOC that is very difficult to remove.

A plant can establish compliance with the enhanced coagulation or enhanced softening TOC removal requirement by meeting any one of eight ACCs. The ACCs are summarized in Table 6.

Table 6. Summary of ACCs

ACC	Description	Additional Analysis
1	raw water TOC < 2.0 mg/L	none*
2	treated water TOC < 2.0 mg/L	none*
3	TTHM < 40 µg/L; HAA5 < 30 µg/L; raw water TOC < 4.0 mg/L; and raw water alkalinity > 60 mg/L ($CaCO_3$)	none*
4	TTHM < 40 µg/L; HAA5 < 30 µg/L, and the system uses only chlorine	none*
5	raw water specific ultraviolet absorbance (SUVA) < 2.0 L/mg-m	raw water SUVA
6	treated water SUVA < 2.0 L/mg-m	treated water SUVA (jar test)
7	softening; and treated water alkalinity less than 60 mg/L (as $CaCO_3$)	treated water alkalinity
8	Softening; and magnesium hardness removal ≥ 10 mg/L (as $CaCO_3$)	raw and treated water magnesium

* Raw water TOC and alkalinity and treated water TOC must be measured and reported in the TOCMOR every month.

ACC 1: Raw Water TOC < 2.0 mg/L

If the raw water contains less than 2.0 mg/L of TOC, by either the current months sample result OR as a running annual average (RAA) of quarterly averages, a utility is in compliance with the TOC treatment technique requirement.

Monitoring and Reporting: There are no extra monitoring and reporting requirements for this ACC.

ACC 2: Treated Water TOC < 2.0 mg/L

If a treated water contains less than 2.0 mg/L , by either the current months sample result OR as a RAA of quarterly averages, a utility is in compliance with the TOC treatment technique requirement.

Monitoring and Reporting: There are no extra monitoring and reporting requirements for this ACC.

ACC 3: Raw Water TOC < 4.0 mg/L, Raw Alkalinity > 60 mg/L (as $CaCO_3$), TTHM $\leq$ 40 µg/L, and HAA5 $\leq$ 30 µg/L

It is more difficult to remove TOC from waters with higher alkalinity and lower TOC. Therefore, PWSs that meet the criteria for ACC 3 can establish compliance with the treatment technique requirements. All the parameters— TOC, alkalinity, total trihalomethanes (TTHM), and haloacetic acids (HAA5)— are computed quarterly and determined based on a RAA.

If the RAA of each parameter listed above satisfies the respective values, the plant is in compliance for at least three months, or until the next calendar quarter ends and value is recalculated.

Monitoring and Reporting: Systems that meet ACC 3 do not have to do extra monitoring, but they must locate and report their average TTHM and HAA5 compliance values on the TOCMOR. Contact the TCEQ if you need assistance with this step.

ACC 4: TTHM ≤ 40 µg/L, HAA5 ≤ 30 µg/L, and Chlorine Only

Plants that use only free chlorine in the plant and for maintenance of a residual in the distribution system and that achieve the stated TTHM and HAA5 levels are in compliance with the treatment technique. The TTHM and HAA5 levels are based on RAAs, computed quarterly.

If the RAA of TTHM is less than 40 µg/L and the RAA of HAA5 is less than 30 µg/L and the plant uses only chlorine in the plant and distribution system, the plant is in compliance for at least three months, or until the next calendar quarter ends and the value is recalculated.

Monitoring and Reporting: Systems that meet ACC 4 are not required to do extra monitoring, but they must locate and report their average TTHM and HAA5 compliance values and certify that only chlorine was used as a disinfectant in the plant and distribution system.

ACC 5: Raw Water SUVA ≤ 2.0 L/mg-m

If the raw water specific ultraviolet absorption (SUVA) is less than or equal to 2.0 liters per milligram-meter (L/mg-m), by either the current months sample result OR calculated quarterly as a RAA, the utility is in compliance with treatment technique requirements. Until the utility has a complete 4 quarters of SUVA data from previous monitoring periods, the utitliy cannot take advantage of a RAA calculation. This means that if a utiltiy plans to use this ACC in the future, raw water SUVA should be measured and documented every month so that a complete data set is availabe. The EPA guidance document includes a more thorough discussion of SUVA.

If the system uses a RAA SUVA calculation, the system is in compliance for at least three months or until the next quarter ends and the value is recalculated. This data must be resubmitted on a monthly basis.

Monitoring and Reporting: Systems that meet ACC 5 must measure and report raw water SUVA. Raw water SUVA samples must be taken before any oxidant is added to the water. If the plant purchases and treats water that has already been disinfected, the plant must obtain samples from the source water before the initial disinfection point.

ACC 6: Treated Water SUVA ≤ 2.0 L/mg-m

If the treated water SUVA is less than or equal to 2.0 L/mg-m, by either the current months sample result OR calculated quarterly as a RAA, the PWS is in compliance with the treatment technique requirements. Until the utility has a complete 4 quarters of SUVA data from previous monitoring periods, the utitliy cannot take advantage of a RAA calculation. This means that if a utiltiy plans to use this ACC in the future, raw water SUVA should be measured and documented every month so that a complete data set is availabe.

Monitoring and Reporting: Systems that meet ACC 6 must measure and report treated water SUVA. Treated water SUVA sampling is to be conducted before any oxidant or disinfectant is added and no later than the combined filter effluent. If an oxidant or disinfectant is added upstream of the treated water SUVA collection point, the system may perform a jar test to mimic plant conditions (except for the addition of the oxidant) and sample the jar test water for SUVA analysis.

ACC 7: Treated Water Alkalinity < 60 mg/L (as $CaCO_3$) (Softening Systems)

Softening plants meet ACC 7 if their treated water alkalinity is less than 60 mg/L (as $CaCO_3$), by either the current months sample result OR calculated quarterly as a RAA. Until the utility has a complete 4 quarters of treated water alkalinity data from previous monitoring periods, the utitliy cannot take advantage of a RAA calculation. This means that if a utiltiy plans to use this ACC in the future, treated water alkalinty should be measured and documented every month so that a complete data set is availabe.

Softening plants that currently practice lime softening are not required to change to lime-soda ash softening.

Monitoring and Reporting: Plants that meet this ACC must measure and report treated water alkalinity, as well as raw water alkalinity.

ACC 8: Magnesium Removal ≥ 10 mg/L (as $CaCO_3$) (Softening Systems)

Softening plants meet ACC 8 if they remove at least 10 mg/L of magnesium hardness (as $CaCO_3$), calculated by either the current months sample results OR quarterly as a RAA. Until the utility has a complete 4 quarters of magnesium hardness data, from previous monitoring periods, the utitliy cannot take advantage of a RAA calculation. This means that if a utiltiy plans to use this ACC in the future, magnesium hardness (as $CaCO_3$) should be measured and documented in both the raw and treated water every month so that a complete data set is availabe.

Softening plants that currently practice lime softening are not required to change to lime-soda ash softening.

Monitoring and Reporting: Plants that want to meet this ACC must measure and report raw and treated water magnesium hardness. The TOCMOR is programmed to calculate the amount of magnesium hardness removed.

Compliance Determination

TCEQ calculates compliance and notifies you if a treatment technique violation occurs. The compliance calculation method is included here to assist in determining whether you are likely to have a violation. If you collect more than one TOC sample set in a month, the results of each sample set should be reported on the TOCMOR. The TOCMOR is programmed to average multiple results. Process control sample sets do not have to be reported.

Compliance is calculated at the end of each calendar quarter and is based on the running annual average of quarterly averages. You will find the exact rule language for the TOC compliance determination in 30 TAC Section 290.112(f).

Monthly

Actual Removal: Every month, at least one TOC sample set must be collected. Calculate the *actual TOC removal* by first dividing the treated water TOC result by the raw TOC result, then subtracting that value from 1 (see Equation 6).

$$\textbf{Equation 6.}\ \text{Actual Removal} = 1 - \frac{\text{treated water TOC}}{\text{raw water TOC}}$$

Actual Removal Percent: The *actual removal percent* is just the Actual Removal times 100 (see Equation 7).

$$\textbf{Equation 7.}\ \text{Actual Removal \%} = \text{actual removal x 100}$$

Required Removal Percent: The next step is to determine the *required removal percent* for the month. Required removal percent is from either the Step 1 Table (Table 2 in this RG) or the Step 2 jar test alternative minimum TOC removal goal.

> **Step 1:** If you are using Step 1, the *required removal percent* is in the Step 1 Matrix. See Table 2 in Step 1 TOC Removal Requirements section.
>
> **Step 2:** The Step 2 *alternative minimum TOC removal goal* is determined by doing a Step 2 jar test. A plant that fails to meet Step 1 is required to perform a Step 2 jar test and can apply the Step 2 alternative removal goal to both the quarter the jar test is performed during and the following quarter. The Step 2 alternative removal goal can be applied to that six-month period, even if the plant meets the Step 1 required removal percentage.

Removal Ratio: The *removal ratio* for a sample set is the actual removal percent divided by the required removal percent (see Equation 8). If actual removal is greater than required removal then the ratio is greater than 1.0 and the plant meets requirements for Step 1.

$$\textbf{Equation 8.}\ \text{Removal Ratio} = \frac{\text{actual removal \%}}{\text{required removal \%}}$$

Alternative Compliance Criteria: In any month that the plant qualifies for one of the eight ACCs, the plant will automatically be assigned a removal ratio of 1.0 and the plant meets requirements for Step 1.

Multiple Sample Sets in a Month: If a plant collects multiple samples in a month, calculate the removal ratio for each sample set and average the results. Compliance is then determined as normal.

Quarterly

Quarterly Average Removal Ratio: The *quarterly average removal ratio* is the average of removal ratios for the three months that make up a calendar quarter.

Example: Quarter 1 is January, February and March. Quarter 2 is April, May and June. Quarter 3 is July, August and September. Quarter 4 is October, November and December.

$$\textbf{Quarterly Average (QA) Removal Ratio} = \frac{\text{Month 1 Removal Ratio} + \text{Month 2 Removal Ratio} + \text{Month 3 Removal Ratio}}{3}$$

Running Annual Average Removal Ratio: The *running annual average removal ratio* is the average of removal ratios for the four previous complete calander quarters.

Example: To calculate the RAA Removal Ratio at the end of Q2 2021 (June 2021), assuming the June 2021 data has been collected and documented, use the quarterly removal ratios for calandar quarters Q3 2020, Q4 2020, Q1 2021 and Q2 2021.

$$\textbf{Running Annual Average Removal Ratio} = \frac{\text{QA1 Removal Ratio} + \text{QA2 Removal Ratio} + \text{QA3 Removal Ratio} + \text{QA4 Removal Ratio}}{4}$$

Treatment Technique Compliance: If the running annual average removal ratio is greater than or equal to 1.0, the system is in compliance.

Public Notification

A PWS that incurs a TOC monitoring/reporting violation must notify its customers as specified in 30 TAC 290.122: *Public Notification*. The format and posting of public notification (PN) vary depending on the severity of the health threat involved. Each PN must include the items specified in 30 TAC 290.122(d).

Information and resources related to PNs is located at Public Notice Language for Drinking Water Compliance.[15]

The webpage includes step-by-step instructions for notifying customers of specific violations. The page also includes links to templates for completing mandatory language forms and certificates of delivery.

TCEQ will notify you of any noncompliance. We will also tell you if you need to notify your customers. We strongly recommend that you do not issue a PN for a TOC violation unless you have discussed the potential violation with TCEQ's Surface Water Treatment Rule team at swtr@tceq.texas.gov or 512-239-4691.

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[15] www.tceq.texas.gov/goto/pws/notices

Appendix 1: Side Effects of Enhanced Coagulation

This appendix summarizes some of the possible side effects for systems that do not soften water. In pursuing the goal of additional TOC removal, systems should be aware of potential side effects that may impact their plant. The EPA guidance manual, Enhanced Coagulation and Precipitative Softening Guidance Manual (EPA 815-R-99-012), is available on the EPA's website.[16] It provides additional information on the secondary effects of enhanced coagulation and enhanced softening.

Coagulant Dose

Generally, it is necessary to add more coagulant to remove TOC than is needed to remove turbidity. Therefore, the problems that arise are those you would expect from increasing coagulant dose and decreasing pH.

pH of Coagulation

Besides adding extra coagulant, it may be necessary to lower the pH in some waters, to ensure that coagulation occurs at the best pH. For alum, the best pH range is from 6.8 to 7.5, depending on the water constituents and whether the plant is operating in the charge neutralization or sweep floc mode. Therefore, the problems that arise are those you would expect from increasing coagulant dose and decreasing pH.

Floc Quality

Adding coagulant beyond that needed to optimize turbidity removal and lowering the pH of coagulation may adversely impact floc formation. Floc may tend to be larger, fluffier, and more difficult to settle. This is true especially if the plant is operating in the range of charge neutralization.

Turbidity

Adding additional coagulant, beyond the dose needed to optimize turbidity removal may increase settled-water turbidity. This is especially true if the plant is operating in the charge neutralization range. This phenomenon is illustrated in Figure A1.1. Increased settled-water turbidity may make it more difficult for filters to remove the turbidity and may shorten filter runs.

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[16] www.epa.gov/dwreginfo/guidance-manuals-surface-water-treatment-rules

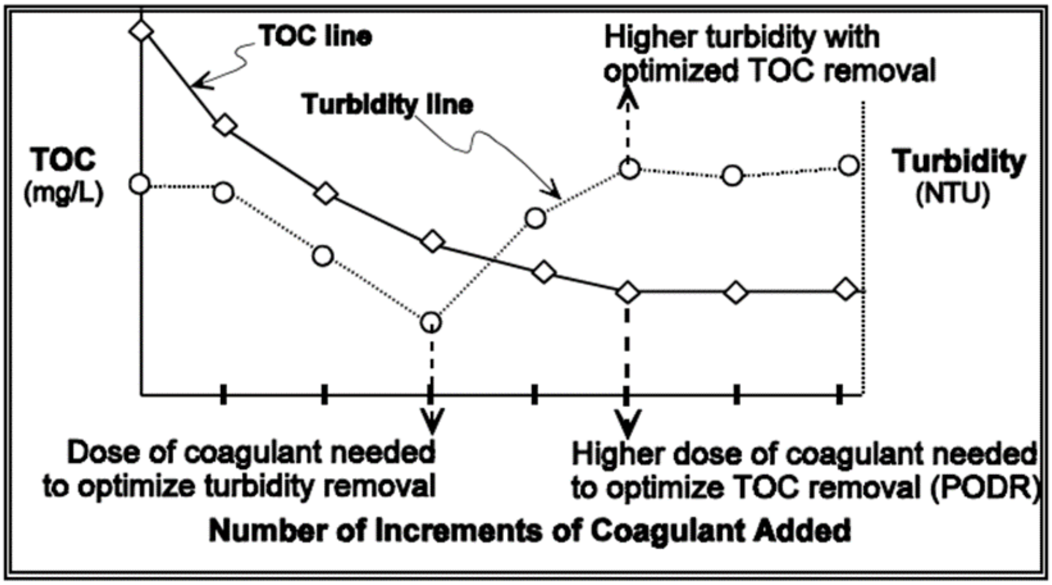

Figure A1.1. Impact of increased coagulant addition to TOC and turbidity removal.

Sludge Quantity

Adding coagulant beyond the dose needed to optimize turbidity removal will likely increase sludge production and may adversely impact the quality of sludge. In order to estimate the cost associated with this, you should do jar, pilot, or full-scale tests. Full-scale tests will provide the best information.

Predictive equations are provided below for sludge production from alum or ferric coagulation, but the equations are only an estimate. These equations are from the *EPA Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual*.

Sludge Production Equations

Alum

$S = Q \text{ x } 8.34 \text{ x } [(AD \text{ x } 0.36) + X + TOC \text{ rem}]$

Ferric

$S = Q \text{ x } 8.34 \text{ x } [(FD \text{ x } 0.5 + X + TOC \text{ rem}]$

Sludge Production Equations Variables

- S = sludge generated in pounds per day
- Q = flow in million gallons per day (MGD)
- AD = alum dose in mg/L or
- FD = ferric dose in mg/L
- X = other chemical doses, such as polymer or PACl, in mg/L
- TOC_{rem} = TOC removed in mg/L

Sludge Quality

Enhanced coagulation usually results in an increased coagulant dose, so clarifier sludge may contain more metals and be more difficult to dewater.

Aluminum

If you are using alum or lime that has aluminum in it, the concentration of dissolved aluminum may increase if the pH is decreased. Aluminum is very soluble from pH 6.2 to 6.5 and over pH 8.0.

Manganese

For systems that need to remove manganese, if the manganese is not entirely oxidized before the settling tank, manganese may break through. Chlorine or potassium permanganate need to be in contact with the water for a period of 15 minutes to 4 hours to get complete oxidation of manganese. Chlorine dioxide will oxidize manganese in 5 minutes. If greensand filters are used to remove manganese, letting the pH get below 6.2 will make the filters work poorly. Also, manganese may be found in some ferric coagulant products. If one of these products is used, it may add dissolved manganese to the water.

Corrosion

Lowering the pH and increasing the dissolved metal salts in the water may result in more corrosive water. Corrosion in a distribution system is always in a state of change. It is recommended that you use the Langelier Saturation Index and Baylis Curve to check the water entering the distribution system after changing your TOC removal process.

Disinfectant

The disinfectant demand may decrease because TOC is part of the disinfectant demand. Therefore, reducing the TOC level will reduce chlorine (or other disinfectant) demand.

Appendix 2: Chemical Feed Rates—Example SOP

The following is an example standard operating procedure (SOP) for chemical feed rates. Each PWS needs to create their own SOPs based on their system requirements.

Example Standard Operating Procedure (SOP) for Measuring and Adjusting Chemical Feed Rates

Summary

To treat water effectively, chemicals must be dosed accurately. This SOP contains procedures for measuring and adjusting the alum and polymer feed rates. Adjusting the coagulant feed involves:

1. measuring the current alum and polymer feed rates,
2. calculating the current dosages using the results of the first step,
3. comparing the results of the second step with the target values set using jar tests or the plant superintendent's recommendation,
4. making necessary adjustments to the alum and polymer feed rates, and
5. verifying that the new feed rate produces the desired doses.

Equipment Needed

The equipment needed for this process includes:

- 500-mL and 250-mL graduated cylinder
- bowl to collect lime sample
- stopwatch or wristwatch with a second hand
- calculator
- waste bucket (old milk jug)
- triple-beam balance

Procedure

a. Measuring Feed Rates

I. *Alum*

   A. Take the stopwatch and the appropriately sized graduated cylinder to the rapid mix (if there are no calibration cylinders on the feed stream that you can use).

   B. Measure and record the volume of alum pumped into the rapid mix for 60 seconds.

      1. If you are not going to conduct a jar test, empty the cylinder into the rapid mix.

2. If you are going to conduct a jar test, pour most of the alum into the rapid mix, but keep enough to prepare the dosing solution.

II. *Polymer*

A. Take the stopwatch and the appropriately sized graduated cylinder to the chemical room (if there are no calibration cylinders on the feed stream that you can use)

B. Get the waste bucket (old milk jug)

C. Valve off the polymer injection line

D. Open the valve on the polymer pump sampling tap and flush the injection line into the waste bucket for 60 seconds

E. Using the graduated cylinder, measure and record the volume of polymer pumped for 60 seconds.

   i. If you are not going to conduct a jar test, empty the cylinder back into the polymer drum

   ii. If you are going to conduct a jar test pour most of the polymer back into the polymer barrel, but keep a little to prepare the dosing solution

F. Close the sampling tap valve and open the valve to the feed (water) line

III. *Lime*

A. Take the bowl and the stopwatch to the lime feeder

B. Place the bowl under the point where the lime drops into the dilution water, and measure and record the amount of lime that is fed in 60 seconds.

C. Take the bowl containing the lime to the laboratory

D. Set up the balance, transfer the lime to the weighing paper, and weigh the sample.

b. Calculating the Current Chemical Dosage

I. *Alum*

Because the alum dosing solution for the jar tests is based on a dry weight, the actual chemical dosages should be calculated on a similar basis, so that the results can be compared. To calculate the current alum dosage, use Equation A2-1.

$$\textbf{Equation A2}-\textbf{1}.\ \text{Alum dose (ppm)}$$
$$= \frac{\text{alum feed rate}^{*}\text{x(1 gal alum/3,785 mL)x(5.34 lbs dry alum/1 gal alum)}}{\text{raw water flow rate}^{**}\text{x(8.34 lbs water/1 gal water)x(1 lbs dry alum/1,000,000 lbs water)}}$$
$$= \frac{\text{alum feed rate}^{*}}{\text{raw water flow rate}^{**}}\ \text{x 169}$$

*expressed in mL/min

**expressed in gal/min

In Equation A2-1, it is assumed that the equivalent dry weight of the liquid alum solution is 5.34 lbs. of dry alum per gallon of alum. If the specific gravity of your alum solution is not close to 1.33, this assumption may lead to slightly inaccurate results. For better accuracy, measure the specific gravity of each batch of alum delivered by the vendor and then read the corresponding equivalent dry weight from the dry weight equivalency chart supplied by that vendor.

Note: When comparing the current alum dose with a target dose obtained from the jar test (see Appendix 3), you must use the same value for the equivalent dry weight in both procedures.

II. *Polymer*

Because the polymer dosing solution for the jar tests is based on a purely volumetric basis, the actual chemical dosages should be calculated on a similar basis, so that the results can be compared. To calculate the current polymer dose, use Equation A2-2.

$$\textbf{Equation A2}-\textbf{2}.\ \text{Polymer dose (ppm)} = \frac{\text{polymer feed rate}^{*}\text{x}((1\text{ gal polymer})/(3785\text{ mL polymer}))}{\text{raw water flow rate}^{**}\text{x}((1\text{ gal polymer})/(1{,}000{,}000\text{ gal water}))} = \frac{\text{polymer feed rate}^{*}}{\text{raw water flow rate}^{**}}\text{ x }264$$

*expressed in mL/min

**expressed in gal/min

III. *Lime*

Because the lime dosing solution for the jar tests is based on a dry weight, the actual chemical dosages should be calculated on a similar basis, so that the results can be compared. To calculate the current lime dose, use equation A2-3.

$$\textbf{Equation A2}-\textbf{3}.\ \text{Lime dose (ppm)}$$

$$= \frac{\text{lime feed rate}^{*}\text{x}((1\text{ lb. lime})/(454\text{ g lime}))}{\text{raw water flow rate}^{**}\text{x}((8.34\text{ lb water})/(1\text{ gal water}))\text{x}((1\text{ lb. lime})/(1{,}000{,}000\text{ lbs water}))}$$

$$= \frac{\text{lime feed rate}^{*}\text{x}1{,}000{,}000}{\text{raw water flow rate}^{**}\text{x}8.34\text{x}454} = \frac{\text{lime feed rate}^{*}}{\text{raw water flow rate}^{**}}\text{x}264$$

*expressed in mL/min

**expressed in gal/min

c. Adjusting the Chemical Feed Rate

I. *Alum*

Adjustments to the alum feed rate should be based on the results of jar tests or recommendations of the plant superintendent. Because the alum dosing (stock) solution for the jar tests is prepared on a dry weight basis. Equation A2-4 applies.

Equation A2 − 4. Required alum feed rate

$$= \text{dosage}^{*}\text{x} \left(\frac{1 \text{ gal alum}}{5.34 \text{ lbs alum}} \right) \text{x} \left(\frac{3{,}785 \text{ mL alum}}{1 \text{ gal alum}} \right) \text{x raw water flow rate}^{*}\text{x} \left(\frac{8.34 \text{ lbs water}}{1 \text{ gal water}} \right)$$

$$= \frac{\text{dosage}^{*}\text{xraw water flow rate}^{*}}{169}$$

*expressed in mL/min

Explanation of units in Equation A2-4

- Required alum feed rate should be in milliliters per minute (mL/min)
- Dosage should be in pounds of alum per 1,000,000 pounds of water (ppm)
- Raw water flow rate should be in gallons per minute (gpm)

Note: When adjusting the alum dose, you must use the same dry weight equivalent value in this calculation as was used to prepare the dosing solution for the jar test. In this equation, it is assumed that the equivalent dry weight of the concentrated alum solution is 5.34 lbs of dry alum per gallon of alum. If the specific gravity of the alum solution differs substantially from 1.33, this assumption may be slightly inaccurate. For better accuracy, measure the specific gravity of each batch of alum delivered by the vendor and then read the corresponding equivalent dry weight from the dry weight equivalency chart supplied by that vendor.

II. Polymer

Adjustments to the polymer feed rate should be based on the results of jar tests or recommendations of the plant superintendent. Because the polymer dosing solution for the jar tests is based on a purely volumetric basis, Equation A2-5 applies:

Equation A2 − 5. Required polymer feed rate

$$= \text{dosage}^{**} \text{ x} \left(\frac{3{,}785 \text{ mL polymer}}{1 \text{ gal polymer}} \right) \text{x raw water flow rate}^{***}$$

$$= \frac{\text{dosage x raw water flow rate}}{264}$$

**expressed in gallons of polymer per 1,000,000 gallons of water (ppm)

***expressed in gallons of water per minute (gpm)

III. Lime

Adjustments to the lime feed rate should be based on either the results of jar tests or the recommendations of the plant superintendent. Because the lime dosing solution for the jar test is on a dry weight basis, Equation A2-6 applies:

Equation A2 − 6. Required lime feed rate

$$= \text{dosage}^{**} \text{ x} \left(\frac{454 \text{ g lime}}{1 \text{ lbs lime}} \right) \text{x raw water flow rate}^{***}\text{x} \left(\frac{8.34 \text{ lbs water}}{1 \text{ gal water}} \right)$$

$$= \frac{\text{dosage x raw water flow rate}}{264}$$

**expressed in pounds of lime per 1,000,000 pounds of water (ppm)

***expressed in gallons per minute (gpm)

IV. Adjusting Feed Rates

Any time that the alum or polymer feed rates are adjusted, you must verify the impact of the adjustments by repeating the feed rate measurement and dosage calculations from Steps 1 and 2.

Appendix 3: Process Control Jar Testing—Example SOP

This example SOP provides instructions on the preparation of dosing solutions and procedures for a process control jar test. It should be used in conjunction with Appendix 2, which discusses chemical feed-rate measurement and adjustment. This example is for a plant that uses alum, polymer, and lime (or caustic) and has 2-L jars.

Note about Personalizing the SOP: You need to modify this example to work for other chemicals or operating conditions. SOP must be written for use with chemicals you use.

Example Standard Operating Procedure (SOP) for Process Control Jar Test

Summary

Jar testing can be a useful way to determine desired coagulant feed rate and the effect of different coagulants or coagulant aids, such as polymers. Process control jar testing is very different from the Step 2 jar testing described in this guidance. For process control jar testing, you can choose what chemicals to feed and what doses to feed. When the process control jar test is finished, you will have useful information to run the plant better. A Step 2 jar test is much more limited, and its only product is a regulatory compliance number. However, after running a Step 2 jar test and determining the plant's new required TOC removal, doing a process control jar test may help you set full scale operating conditions to meet that new required removal.

Note about Mixing Times: Generally, jar tests result in better coagulation and settling than occurs full scale. Mixing in jar tests is almost perfect, but mixing full scale is not. Obviously, the hydraulics in a 2-L jar are more controlled than in a large flow-through plant, where short circuiting and dead zones are present. It may be necessary for the operator to modify the mixing times for jar testing to better match full-scale results. One way to start is to determine the HDT and baffling factor in each process unit and compare the resulting mixing times with the mixing times recommended in this SOP and the Step 2 process. Then, the operator can change the mixing times, compare the results to full scale and repeat the process until the results correlate better.

Equipment Needed

The equipment needed for your plant to go through this process may be different. For this example, the operator would need:

- the logbook for jar test results
- two 2-gallon raw water containers
- jar test apparatus with six 2-L jars (this example uses 2-L jars)
- three 1000-mL volumetric flasks
- 10-mL TenSette (automatic pipettor)
- several 5-mL, 10-mL, and 25-mL syringes
- equipment to conduct pH, turbidity, and alkalinity tests
- triple-beam balance

Procedure

I. *Preparation of a Dosing (stock) Solution*

Dosing solutions must be prepared in concentrations that allow accurate dosing of the amount of raw water being tested in a jar test. Dosing solutions tend to lose their strength over time and should be used withing 24 hours of preparation.

A. Polymer dosing solution (0.2% solution on a volumetric basis).

   A dosage of 1.0 mL of this solution to 2 L raw water is a dosage rate of 1.0 ppm on a volumetric basis.

   1. Using a TenSette pipette, measure 2 mL of polymer solution.
   2. Place the 2 mL of polymer into a 1000-mL volumetric flask.
   3. Add enough demineralized water to bring the volume in the flask to the 1000-mL mark.
   4. Stopper the flask and mix the solution.
   5. Use the dosing solution within 24 hours of preparation.

B. Alum Dosing Solution (2.0% solution on a dry weight basis).

   A dosage of 1 mL of this solution to 2 L of raw water is a dosage rate of 10 ppm on a dry weight basis.

   1. Using the TenSette pipette, measure 31 mL of liquid alum solution. $(ml\ (liquid)\ alum\ per\ liter\ of\ stock\ solution = \%\ dry\ weight * 15.66)$
   2. Place the 31 mL of liquid alum into a 1000-mL volumetric flask.
   3. Add enough demineralized water to bring the volume in the flask to the 1000-mL mark.
   4. Stopper the flask and mix the solution.
   5. Use the dosage solution. Discard it when it is 24 hours old.

C. Lime Dosing Solution (2.0% solution on a *dry weight* basis).

   A dosage of 1 mL of this solution to 2 L of raw water is a dosage rate of 10 ppm on a dry weight basis.

   1. Add about 20 mL of distilled water to a 1000-mL volumetric flask.
   2. Using the balance and weighing paper, measure 2 grams of lime.
   3. Carefully add the lime to the volumetric flask.
   4. Add enough demineralized water to bring the volume in the flask to the 1000-mL mark.
   5. Stopper the flask and mix the solution.
   6. The dosing solution should be used within 24 hours of preparation.

D. Caustic Dosing Solution (alternative pH adjustment) (0.2% solution on a volumetric basis).

   A dosage of 1 mL of this solution to 2 L of raw water is a dosage rate of 1 ppm on a purely volumetric basis.

   1. Using the TenSette pipette, measure 2 mL of caustic solution.

2. Place the 2 mL of liquid alum into a 1000-mL volumetric flask.
3. Add demineralized water to bring the volume in the flask to the 1000-mL mark.
4. Stopper the flask and mix the solution.
5. The dosing solution should be used within 24 hours of preparation.

II. *Conducting the Jar Test*

A. Record the test conditions

In the jar test logbook, record combinations of polymer and alum dosages to test. These will be the dosages. Generally, you will hold one of the dosages constant and vary the other to make your combinations.

B. Collect Raw Water

Fill the two 2-gallon raw water jugs with raw water from the raw water sample point. When you reach the laboratory, invert the raw water jugs three times to ensure that settling has not occurred.

C. Fill the Test Jars

Fill 5 jar test jars halfway full of the raw water from one of the jugs. Finish filling the 5 jars to the 2-L mark with water from the other jug.

D. Measure Raw Water Turbidity, pH, and Alkalinity

Fill 250-mL raw water beaker with raw water. Use this water to run raw water turbidity, pH, and alkalinity.

E. Set Up the Jars

Place 5 jars on the jar test apparatus, lower stirring paddles into the beakers, lock paddle shafts, start stirring the raw water samples at a rate of 100 rpm.

F. Prepare the Dosing Syringes

Fill polymer, alum, and lime syringes with appropriate volume of dosing solution to reach dosage you are testing. Mix flask of lime dosing solution before filling each syringe. Place each syringe next to appropriate jar.

- Use 1 cc of alum dosing solution for each 10 ppm of alum dosage
- Use 1 cc of lime dosing solution for each 10 ppm of lime dosage
- Use 1 cc of polymer dosing solution for every ppm of polymer dosage

G. Dose the Jars

As quickly as possible, inject each sample of raw water with the required alum and polymer dose.

H. Flash Mix

Let the samples stir at 100 rpm for 30 seconds to simulate the flash mix (use the time and speed that best represents your plant, if known).

I. Flocculate

Reduce the stirring rate of the jar test apparatus to 30 rpm, inject each sample of coagulated water with the required lime dose, and let samples mix for 15 minutes to simulate the flocculator (use the time and speed that best represents your plant, if known).

J. Settle

Turn the stirrers off and let samples sit for 30 minutes to simulate sedimentation process (use the time and speed that best represents your plant, if known).

K. Evaluate the Flocculation and Settling Process

During the jar test, the following evaluations should be made:

1. Which combination of dosages formed a floc first?
2. What is the appearance of the floc in each sample?
3. After flash mix and flocculation, which sample had the best settling floc?
4. What is the appearance of the settled water in each sample?

L. Collect Supernatant Samples

At the end of the settling time, lush the jar test sample spigots and collect a sample of settled water from each jar.

M. Measure the Turbidity and pH

Measure the turbidity and pH of each sample to determine the effect of coagulation on the raw water samples.

N. Record the Data

Record the dosages for each sample of raw water, and the observations and results of the jar test on the jar test work sheet.

O. Choose the Best Chemical Combination

Based on observations made during the jar test, record your conclusions of which combination of coagulant and coagulant aid dosages gave the best results for raw water tested.

P. Make changes, as appropriate

If appropriate, contact the supervisor, make necessary adjustments to the coagulant feed rate, and then verify and document the new feed rate on the jar test result log and the daily operational log.

Note on Dynamic Jar Testing: This SOP, and most jar testing, disinfectants are not added. Disinfectants may act as a coagulant aid, leaving them out may prevent the jar test from matching full-scale results. One way that you may be able to make the jar test match full-scale results is to pull samples for jar testing from the plant after disinfectant is added. If coagulant is added concurrently with disinfectant, this can be tricky. You will need to consider where samples can be taken to best represent the water entering the settling basins. Or, possibly, you could add disinfectant to the jars, but this is less likely to represent full-scale conditions.

Appendix 4: Formulas and Conversions

Table A5.1. Percent Solution Values

Percent	lb./gal	oz/gal	mg/L
1	0.084	1.3	10,000
2	0.170	2.7	
3	0.258	4.1	
4	0.348	5.6	
5	0.440	7.0	
6	0.533	8.5	
7	0.629	10.1	
8	0.726	11.6	
9	0.825	14.9	90,000

Table A5.2. Conversions

ounces (fluid) x 29.57	mL
ounces (dry) x 28.35	grams
cubic feet x 7.48	gallons
cubic feet x 62.4	pounds
gal x 8.34	pounds
gal x 3.785	liters
gal x 3785	mL
gal/hour x 63	mL/min
grains/gal x 17.1	ppm (parts per million)
grams x 15.43	grains
MGD x 694	gpm (gallons per million)
10,000 ppm (mg/L)	1%
pounds x 453	grams
pounds x 7000	grains
ppm x 8.33	lb./million gallons
quarts x 948	mL
1 mile	5280 ft
2.31 ft of water	1 pounds per square inch (psi)
0.433 psi	1 ft of water

Feed Rate Formulas

$$\frac{\text{ppm (mg/L) x gpm}}{2000} = \text{lb/hr}$$

$$\frac{\text{ppm (mg/L)x gpm x 0.06}}{\text{\% solution}} = \text{gal/hr}$$

$$\frac{(\text{lb/6minutes}) \times 20{,}000}{2000} = \text{ppm (mg/L)}$$

$$\frac{(\text{grams/6minutes}) \times 44}{\text{gpm}} = \text{ppm (mg/L)}$$

Note:

gpm = gallons per minute

6-minute collection for dry feeder

Equations

In the following calculations:

Π (Pi) = 3.14

L = length

W= width

D = diameter

r = radius

H = height

Area = A (square feet):

Rectangle: $A = L \times W$

Circle: $A = \Pi r^2$

Volume = V (cubic feet)

- Rectangular tanks: $V = L \times W \times H$
- Circular tanks: $V = \Pi r^2 H$

  OR

  $= r \times r \times \Pi \times H$
- Pipes: $V = \Pi(D^2/4)L$

  OR

  $= D \times D \div 4 \times \Pi \times L$

  (Make sure diameter of the pipe and pipe length are in the same units. Divide pipe diameter by 12 to convert from inches to feet)

Appendix 5: Densities and Equivalent Weights of Commercial Alum Solutions[1]

Specific Gravity	Pound per Gallon	% Al_2O_3	Equivalent % Dry Alum[2]	Pound Dry Alum per Gal Solution	Gram Dry Alum per Liter Solution
1.0069	8.40	0.19	1.12	0.09	11.277
1.0140	8.46	0.39	2.29	0.19	23.221
1.0211	8.52	0.59	3.47	0.30	35.432
1.0284	8.58	0.80	4.71	0.40	48.438
1.0357	8.64	1.01	5.94	0.51	61.521
1.0432	8.70	1.22	7.18	0.62	74.902
1.0507	8.76	1.43	8.41	0.74	88.364
1.0584	8.83	1.64	9.65	0.85	102.136
1.0662	8.89	1.85	10.88	0.97	116.003
1.0741	8.96	2.07	12.18	1.09	130.825
1.0821	9.02	2.28	13.41	1.21	145.110
1.0902	9.09	2.50	14.71	1.34	160.368
1.0985	9.16	2.72	16.00	1.47	175.760
1.1069	9.23	2.93	17.24	1.59	190.830
1.1154	9.30	3.15	18.53	1.72	206.684
1.1240	9.37	3.38	19.88	1.86	223.451
1.1328	9.45	3.60	21.18	2.00	239.927
1.1417	9.52	3.82	22.47	2.14	256.540
1.1508	9.60	4.04	23.76	2.28	273.430
1.1600	9.67	4.27	25.12	2.43	291.392
1.1694	9.75	4.50	26.47	2.58	309.540
1.1789	9.83	4.73	27.82	2.74	327.970
1.1885	9.91	4.96	29.18	2.89	346.804
1.1983	9.99	5.19	30.53	3.05	365.841
1.2083	10.08	5.43	31.94	3.22	385.931
1.2185	10.16	5.67	33.35	3.39	406.370
1.2288	10.25	5.91	34.76	3.56	427.131
1.2393	10.34	6.16	36.24	3.74	449.122
1.2500	10.43	6.42	37.76	3.93	472.000
1.2609	10.52	6.67	39.24	4.12	494.777
1.2719	10.61	6.91	40.65	4.31	517.027
1.2832	10.70	7.16	42.12	4.51	540.484
1.2946	10.80	7.40	43.53	4.71	563.539
1.3063	10.89	7.66	45.06	4.91	588.619
1.3182	10.99	7.92	46.59	5.12	614.149
1.3303	11.09	8.19	48.18	5.34	640.938
1.3426	11.20	8.46	49.76	5.57	668.078
1.3551	11.30	8.74	51.41	5.81	696.657
1.3679	11.41	9.01	53.00	6.05	724.987

[1] from Optimizing Water Treatment Plant Performance Using the Composite Correction Program, 1998 Edition, page 239

[2] 17% Al_2O_3 in Dry Alum + 0.03% Free Al_2O_3