Jar Testing Made Easy
Achieve meaningful, useful, and transferable jar testing results by applying best practices learned from a recent study of 37 water treatment facilities in California.

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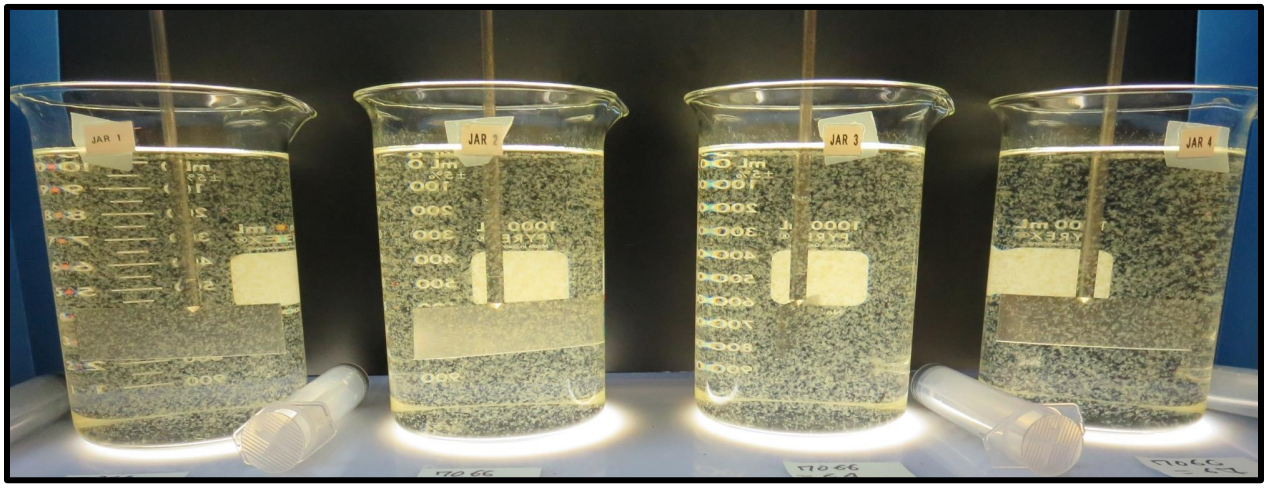
Jar testing and filterability procedures yield useful data to help water treatment plant operators and engineers select the best coagulant and optimum dose. As part of a California State Water Resources Control Board research project, more than 1,400 individual jar tests were conducted from 2018 to 2020 for 37 of the state's public surface water treatment plants using various treatment technologies. Field and laboratory results validated the developed jar test and filterability procedures, accurately predicting full-scale plant filtration performance and indirect organic reductions.



JAR TESTING CONCERNS

Water treatment plant operators add coagulant(s) to neutralize negatively charged particles and combine them into larger particles for removal. Jar testing can be used as a tool to help select the proper coagulant and dose for the reduction of pathogens and disinfection by-product pre-cursors. However, existing jar testing procedures can be involved, time consuming and may not provide the necessary data to make informed decisions on the selected coagulant type and dose for transferable full-scale plant performances.

Treatment plants with flocculation and settling basins are designed to remove as much suspended solids and dissolved organic carbon (DOC) as practical before filtration. To achieve this goal, selected coagulant(s), doses, mixing energies and flow contact times

are adjusted to produce a settleable floc. Plants with pre-roughing filters (nonbuoyant and buoyant medias), are designed (media type, size, depth and contact times) to generate a removable floc through hydraulically produced energy. Any pre-treatment carry-over floc should be robust so it can be removed in the final media filtration process. The same principals are valid for membrane treatment plants with pre-treatment, as reducing suspended solids and dissolved organics are critical parameters in reducing membrane fouling and disinfectant by-products.

It's important to optimize settleability of formed flocs for solids reduction, longer filter runs, and improved overall treatment plant performance. Just as important is the need to optimize the reduction of DOC and media filterability of carryover floc particles that aren't settled or physically removed in the pre-treatment process stage. By working with several water treatment utilities, it was determined that filterability analysis on carry-over floc and indirect measurements of DOC removal generally aren't performed. Utility personnel that do perform filterability testing may use a method and/or analysis that does not generate transferable data to full-scale plant filtration performance. The California State Water Resources Control Board's research resulted in a filterability technique and indirect dissolved organic measurements will be discussed that provides good transferable data to full-scale plant performances.

JAR TEST FIELD STUDY

The 37 surface water treatment plant sources involved in the research were jar tested to develop, improve and validate jar testing and filterability procedures. Many of these plants were visited multiple times during different seasons. The practical procedures developed and described here generated good floc production that allowed the evaluation and analysis of selected coagulants, dose, filterability, indirect dissolved organic reduction and settleability. The jar test results are representative of full-scale plant performances which was confirmed by comparing coagulant dose, filtrate turbidity and indirect organic reduction.

Measurements. Measured jar testing parameters were filtrate turbidities, filtrate %UVT/UVA and settled water turbidities. Source water turbidities and UVT/UVA were also measured. Ultraviolet transmittance (UVT) is a measurement of the amount of ultraviolet light (254 nm wavelength) that passes through a water sample compared to the amount of light that passes through an organic free water sample expressed as a percentage, %UVT. UV absorbance (UVA) is a relative measure of the amount of light absorbed by a water sample compared with the amount of light absorbed by an organic free water sample. These parameters are an indirect measurement of dissolved organic carbon. If one parameter is measured, the other can be calculated (UVA = -log(%UVT/100); $\%UVT = 10^{(-UVA)} \times 100\%$). UVA values have a linear relationship of organic matter in water. For example, if the concentration of organic material in the water were to reduce by half via treatment, then UVA would reduce by half. UVT values do not have a linear relationship to organic concentration.

Humic substances absorb UV light at 254 nm, whereas nonhumic substance are low in UV absorption at 254 nm. Humic substances comprise about 60-80% of soil organic

matter and are removed through the coagulation/filtration process. Nonhumic substances comprise about 5-25% of the humus in soils which are nonamenable to enhanced coagulation. Two source waters with the same UV absorbance value can have very different percent organic properties.

Jar Tester. A four-jar tester using 1-Liter round beakers were used for nearly all field and laboratory studies. Most source waters were collected at the plant and transported back for laboratory jar testing. The benefits in using 1-liter round jars over 2-liter squared jars are (1) 50 percent less water required for a set of jar testing, (2) mathematically easier for preparing stock solutions, (3) ease of drawing samples for analysis, and (4) easy cleaning and storage.

Flash Mixing. Flash mixing at 200 revolutions per minute (RPM) for 30-60 seconds using 1-liter jars to rapidly disburse the coagulant(s) was used for most studied sources. To evaluate the impact flash mixing had on filtrate turbidity, %UVT/UVA and settleability, mixing duration was varied from 60-0 seconds for selected sources (Table 1). In most cases, jar testing with and without flash mixing had no significant impact on filtrate turbidity and %UVT/UVA. For jars tested without initial flash mixing, delay of floc development occurred impacting floc settleability in most sources resulting in higher settled water turbidities. As more jar test studies were conducted, 30 seconds of flash mixing (200 RPM) was determined to be an efficient duration for rapid mixing.

Case Study: Flash Mixing. In a case study, water system (CLO, Table 1) operated for several months without its inline motionless flash mixer pending replacement. There was no measurable decline in plant settle and filterability performances. Jar testing was conducted and showed no significant performance differences with and without flash mixing.

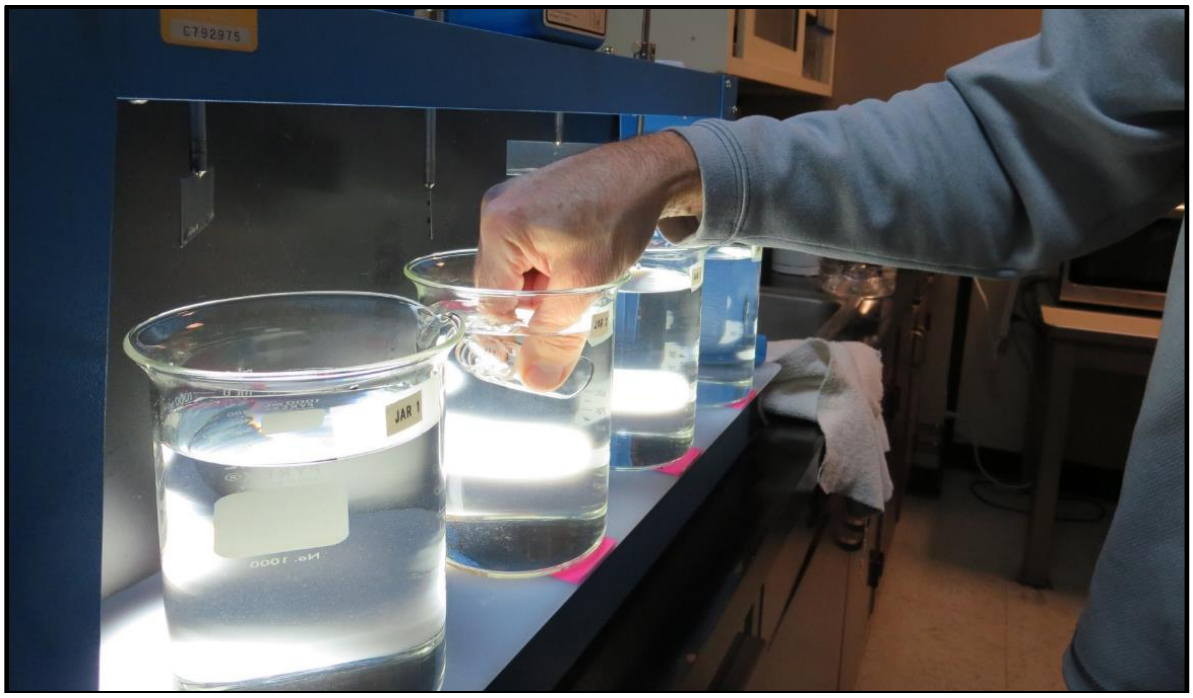
Given the overall jar test results of source waters tested with and without initial rapid mixing, flash mixing at 200 RPM for 20 to 60 seconds is considered adequate to rapidly disperse the applied chemical. For older jar testing equipment with a maximum paddle speed of 100 RPM, limit studies have shown that mixing for 20-60 seconds was adequate.

TABLE 1. Flash and Floc Speed Variations

Plant ID	200 RPM Flash sec	RPM Floc Speed	Floc Mix min	Coag/ Aid mg/L	Filtrate NTU	Filtrate %UVT	Filtrate UVA/cm	Settled NTU 25 min
SW	60	10	5	67	0.09	96.1	0.017	0.82
SW	60	20	5	67	0.09	96.1	0.017	0.63
SW	60	30	5	67	0.11	95.6	0.020	0.49
SW	60	40	5	67	0.11	95.7	0.019	0.51
SW	0	30	5	67	0.06	96.7	0.015	0.84
SW	15	30	5	67	0.06	96.6	0.015	0.78
CLO	60	30	5	23	0.08	94.8	0.023	0.48
CLO	60	30	10	23	0.07	94.5	0.025	0.39

CLO	60	30	20	23	0.07	94.9	0.023	0.30
CLO	60	30	40	23	0.07	94.9	0.023	0.36
CLO	0	30	5	23	0.07	94.4	0.025	0.43
CLO	0	30	10	23	0.07	94.6	0.024	0.30
CLO	0	30	20	23	0.08	94.6	0.024	0.22
CLO	0	30	40	23	0.06	94.7	0.024	0.15
GS	30	30	5	29/2.9	0.08	91.7	0.038	0.38
GS	30	30	10	29/2.9	0.09	91.8	0.037	0.22
GS	30	30	20	29/2.9	0.08	91.8	0.037	0.30
COC	30	30	3	38/37	0.06	94.5	0.024	1.87
COC	30	30	5	38/37	0.07	94.3	0.025	1.07
COC	30	30	10	38/37	0.06	94.4	0.024	0.82
COC	30	30	15	38/37	0.09	94.3	0.025	0.39
COC	0	30	3	38/37	0.07	94.3	0.025	2.51
COC	0	30	5	38/37	0.12	94.0	0.026	1.53
COC	0	30	10	38/37	0.15	93.9	0.027	0.75
COC	0	30	15	38/37	0.10	94.0	0.026	0.43
MID	60	30	5	9.5	0.07	97.4	0.011	5.3
MID	60	30	10	9.5	0.06	97.2	0.012	4.0
MID	60	30	15	9.5	0.05	97.4	0.011	2.8
HM	60	10	5	23	0.08	88.2	0.055	0.42
HM	60	30	5	23	0.08	89.2	0.050	0.35
HM	60	30	5	24	0.07	89.8	0.047	0.28
HM	60	30	10	24	0.07	89.7	0.047	0.22
HM	60	30	15	24	0.07	89.6	0.048	0.22
HM	60	30	20	24	0.07	89.8	0.047	0.21
CW	0	30	5	18	0.06	89.4	0.049	0.28
CW	15	30	5	18	0.06	89.2	0.050	0.34
CW	30	30	5	18	0.07	89.3	0.049	0.36
CW	60	30	5	18	0.07	89.2	0.050	0.26
GTD	0	30	5	1.5	0.11	97.8	0.010	1.8
GTD	60	30	5	1.5	0.08	97.2	0.012	1.4
HH	0	30	5	100	0.05	94.1	0.026	0.31
HH	60	30	5	100	0.06	94.6	0.024	0.21
KsC	0	10	2	14.5	0.08	90.1	0.045	-
KsC	30	10	2	14.5	0.09	90.3	0.044	-
SC41	0	30	5	8.0	0.13	96.8	0.014	7.0
SC41	60	30	5	8.0	0.10	96.6	0.015	4.8

Settleability. Settled water turbidity samples were taken 25 minutes from the end of the flocculation process. A settling duration of 25 minutes was chosen as this was the time period to complete the filterability and %UVT/UVA analysis for a four-jar tester.

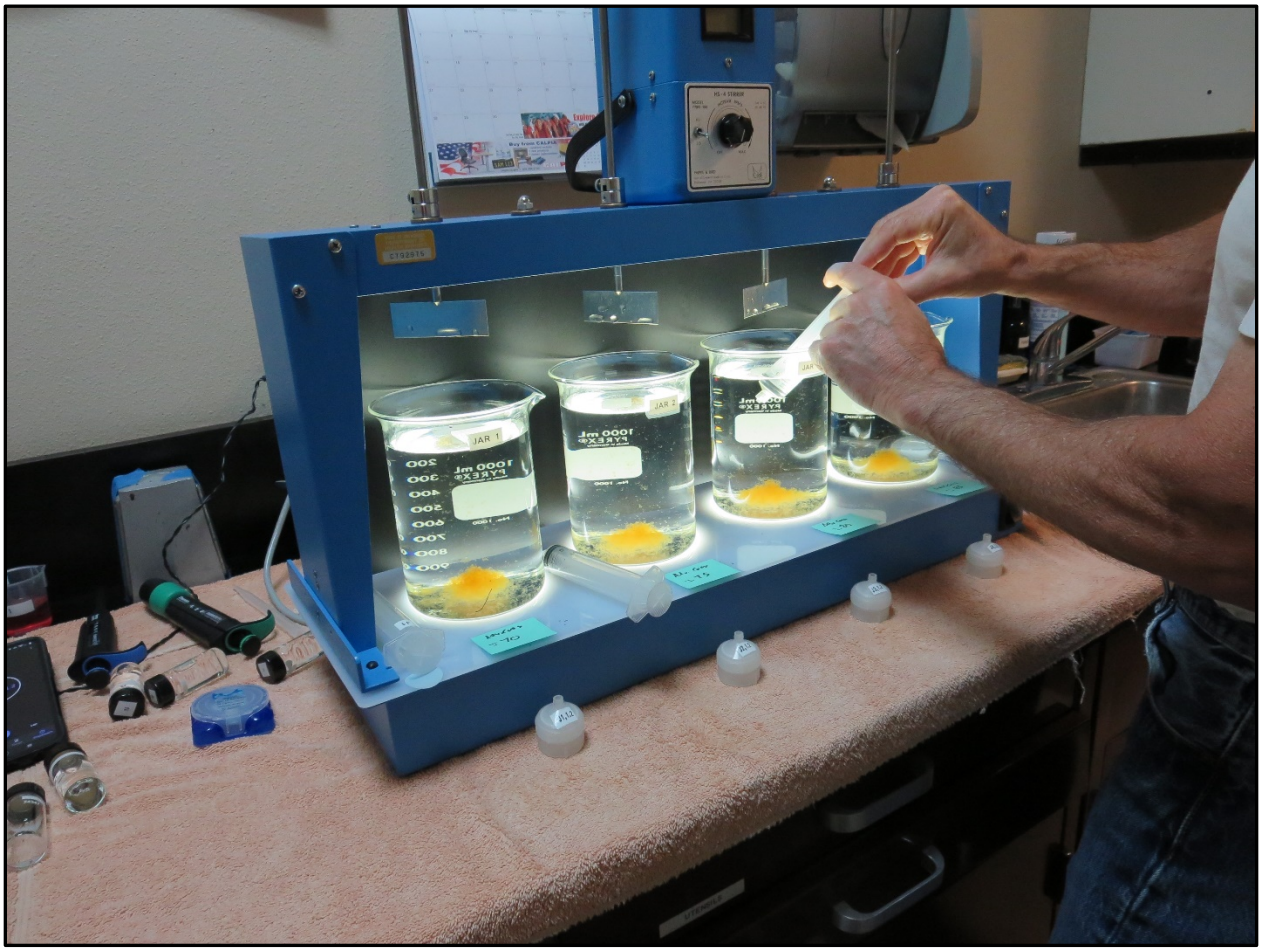


For some tested source waters, shorter and longer settling times were evaluated (Table 2) to determine impact on settleability performance. The settleability performance between each jar and coagulant is relative and therefore is not critical to match those values to full-scale performance values. Extending the flocculation duration provides time for increase in particle collision which improves floc formation producing heavier floc resulting in improved settleability for most jars up to the point of diminishing returns. To improve settleability for a given settling time, the flocculation duration can be extended if the goal is to match full-scale plant performance.

TABLE 2. Settleability

Plant ID	200 RPM Flash Mix sec	30 RPM Floc Mix min	Coag/ Aid mg/L	Filtrate NTU	Filtrate %UVT	Filtrate UVA/cm	Settle NTU 15 min	Settle NTU 25 min	Settle NTU 35 min
CLO	0	5	33	0.12	93.7	0.028	1.6	1.1	0.95
CLO	0	10	33	0.17	93.6	0.029	0.63	0.45	0.55
CLO	0	20	33	0.12	93.6	0.029	0.58	0.36	0.38
CLO	0	40	33	0.46	93.3	0.030	0.31	0.25	0.28
SW	60	5	38	0.09	91.4	0.039	2.3	1.4	1.0
SW	60	5	40	0.39	88.6	0.053	1.8	1.4	1.1
SW	60	5	36/1.8	0.50	86.7	0.062	2.4	1.4	1.0
SW	60	5	38/1.9	0.40	88.3	0.054	1.6	1.4	1.1
GS	30	5	29/2.9	0.08	91.7	0.038	0.60	0.38	0.42
GS	30	10	29/2.9	0.09	91.8	0.037	0.26	0.22	0.23
GS	30	20	29/2.9	0.08	91.4	0.039	0.28	0.27	0.22

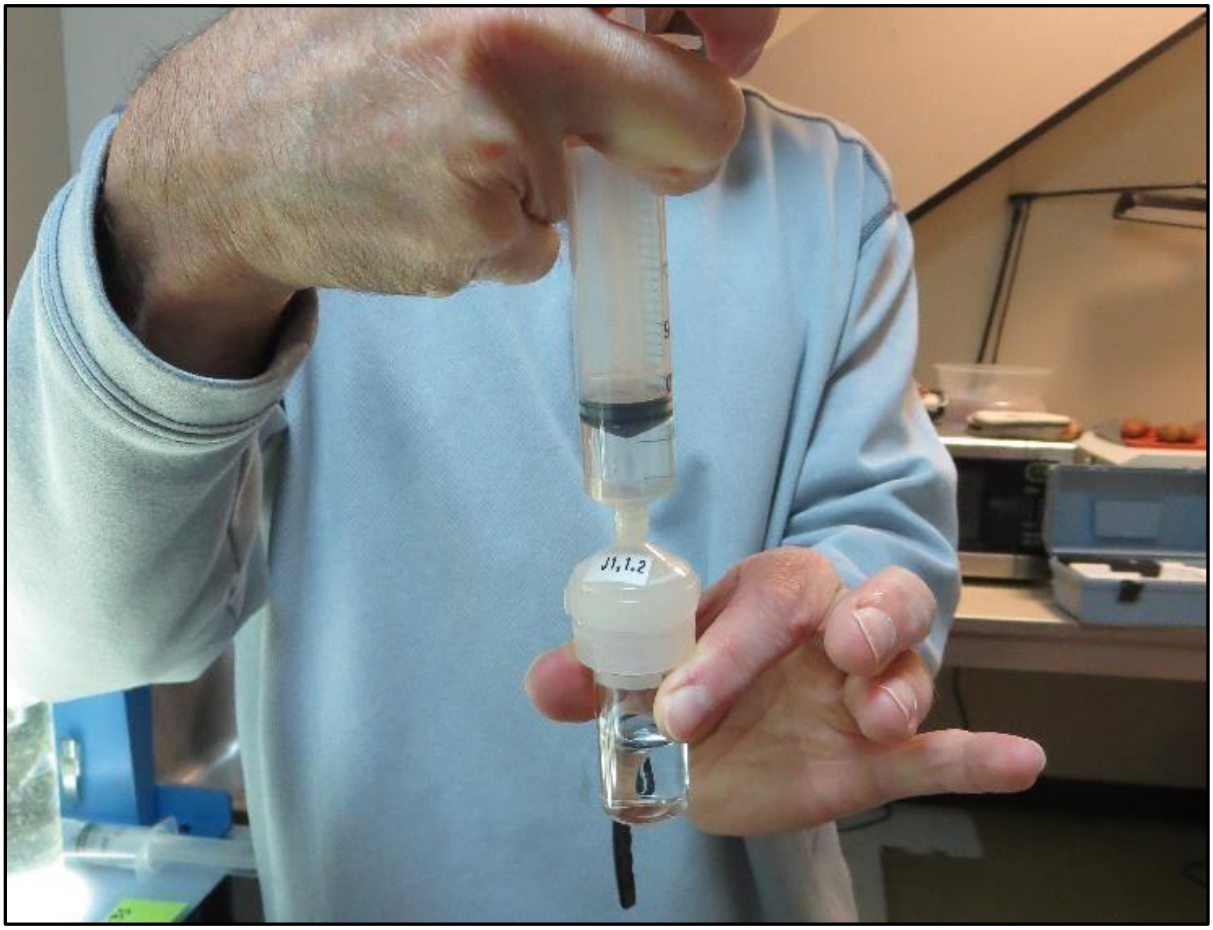
FILTERABILITY TEST



Plant operators should have confidence that the selected coagulant and dose will provide the optimum filtrate turbidity and indirect DOC reduction. The results from evaluating 37 source waters and a number of coagulant products demonstrated that the test jar with the lowest settled water turbidity did not necessarily produce a filtrate water with the lowest turbidity or lowest indirect reduction of DOC. The developed filterability test was used to evaluate the performance of floc particles removal between each tested jar. Jar testing data indicated the filterability results were consistent with full-scale plant performances based on equivalent coagulant doses.

Laboratory supplies and equipment used to conduct the filterability test consisted of a 30 mL syringe, a filter holder with a membrane filter assigned to each tested jar and portable turbidity meter. About 1-inch below the water surface for each jar, coagulated water is drawn with a 30 mL syringe immediately at the end of the flocculation period when evaluating direct filtration plants and plants with roughing filters. For conventional and dissolved air flotation plants, coagulated water is drawn 5 minutes at the end of the flocculation period for the filterability analysis. The purpose of early withdrawal of

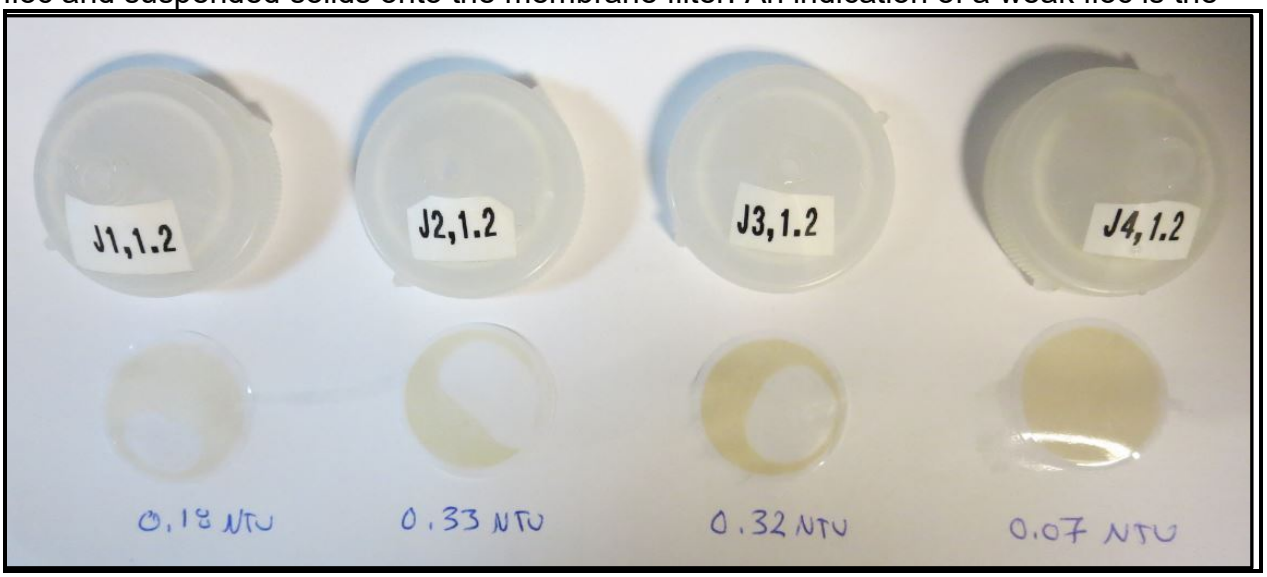
coagulated water before it had time to properly settled is to evaluate the filterability and floc strength of potential carry-over floc for each tested coagulant and dose.



Filter Material and Size. 1.2 µm absolute size Isopore membrane filters were used for the filterability test. Submicron and weak floc particles will pass through the Isopore membrane filter increasing filtrate turbidity. Comparing full-scale data to that of obtained from Isopore membrane filter with a 1.2 µm absolute size shows good filtrate turbidity correlation. An Isopore membrane filter is placed into each filter holder and attached to a 30 mL syringe with luer-lock tip filled with flocculant water from each jar. By hand, the flocculant water is slowly pushed through the 1.2 µm membrane filter directly into a cuvette for filtrate turbidity and %UVT/UVA measurements.

Using a smaller pore-size filter (<1.2 µm absolute) will remove weak flocs and submicron particles that would otherwise breakthrough a 1.2 µm membrane filter resulting in similar filtrate turbidities between optimum and non-optimum coagulant doses. Conversely, using a filter pore-size greater than 1.2 µm will allow most flocs (strong and weak) to breakthrough significantly increasing filtrate turbidities providing useless data to distinguish between optimum and non-optimum filtrate turbidity and coagulant dose.

Floc Strength. In selecting the best coagulant and dose, visual floc strength can provide supporting data. Floc strength is based on the uniform coverage of removed floc and suspended solids onto the membrane filter. An indication of a weak floc is the



rise in filtrate turbidity and nonuniform solids coverage on the membrane filter. In translating the results to full-scale media filtration, observed were shorter filter runs, and higher filtrate turbidities. The laboratory Isopore membranes are inspected by removing them from the filter holder and placing them on a surface for visual comparison.

%UVT/UVA MEASUREMENTS

An important parameter of jar testing are the measurements of %UVT/UVA. In evaluating which coagulant and dose produced the best filtrate turbidity, measurements of %UVT/UVA provided additional supporting data regarding indirect reduction of dissolved organics. Jar testing allowed for the evaluation of different dose and/or coagulants and to compare which jar(s) of similar filtrate turbidity provided optimum indirect dissolved organic reduction via measurements of %UVT/UVA. Each plant's filtrate %UVT/UVA was also measured to compare with jar test results. In most cases, similar results were observed.

Source %UVT/UVA. Source water %UVT/UVA was measured to provide a comparison to filtrate water. Suspended solids can interfere with %UVT/UVA measurements regarding the absorption of indirect dissolved organic carbon. For true %UVT/UVA measurements, source water samples should be filtered directly into a cuvette using a 0.4 µm absolute size Isopore membrane to remove most suspended solids applying the same filterability technique for filtrate water analysis.

Post Chlorination %UVT/UVA. The addition of chlorine to the source and/or filtrate water can rapidly react with natural organic matter (NOM) by oxidation creating disinfection by-products that are not measured by %UVT/UVA. The NOM will be reduced resulting in a lower UVA value. Chlorine is reactive with humic substances creating disinfection by-products not measured by %UVT/UVA. Chlorine is less reactive with nonhumic substances forming less disinfection by-products. A water with little change in %UVT/UVA after disinfection could be an indication of less production of disinfection by-products. Due to the potential change in plant filtrate %UVT/UVA and turbidity taken downstream of the chlorine injection point, plant samples should be taken before chlorine injection when comparing jar test results of filtrate %UVT/UVA and turbidity.

PRE-OXIDATION

Pre-oxidation can improve filtrate turbidity, enhance DOC reduction, improve taste and odors and reduce coagulant dose. Jar testing with and without ozonation, potassium permanganate and chlorine as pre-oxidants were evaluated.

Pre-Ozonation. Two treatment facilities with pre-ozonation were evaluated. Jar testing was conducted on the source waters before and after ozonation to assess the impact to coagulant dose, filtrate turbidity and indirect organic reduction. As shown in Table 3, pre-ozonation at plant HM had a significant impact on coagulant dose and indirect DOC reduction. For plant MID, a fairly pristine source, the pre-ozonation process had a minor impact on coagulant dose and DOC reduction. The average total organic carbon (TOC) for HM was 4.9 mg/L compared to 1.5 mg/L for MID.

TABLE 3. Pre-Ozonation

Plant ID	200 RPM Flash Mix sec	30 RPM Floc Mix min	Pre-Ozone	Coag mg/L	Filtrate NTU	Filtrate %UVT	Filtrate UVA/cm	Settled NTU (25 min)
HM	60	5	No	45	0.09	88.6	0.053	1.0
HM	60	5	Yes	28	0.06	92.5	0.034	1.5
MID	60	5	No	11	0.05	96.2	0.017	9.0
MID	60	5	Yes	10	0.05	97.6	0.011	8.5

Pre-$KMnO_4$. Jar testing was conducted for a water system that injects potassium permanganate ($KMnO_4$) as a pre-oxidant. Water was collected at the source before $KMnO_4$ injection and downstream at the plant before coagulant injection. One of the

evaluations of this study was to compare treatment performances with and without $KMnO_4$ pre-oxidation (Table 4).

There were no significant performance differences between filtrate and settled water turbidities. However, measurements of %UVT/UVA showed improved indirect reduction in dissolved organics with the $KMnO_4$ pre-oxidated water. The $KMnO_4$ hydraulic contact time is at least 30 minutes before coagulant injection. To evaluate a source water with and without $KMnO_4$ in jar testing, slow flocculation and variable detention time is needed followed by coagulation for performance evaluation.

TABLE 4. Potassium Permanganate Pre-Oxidation

Plant ID	200 RPM Flash Mix sec	30 RPM Floc Mix min	Pre-$KMnO_4$	Coag/ Aid mg/L	Filtrate NTU	Filtrate %UVT	Filtrate UVA/cm	Settled NTU 25 min
GS	30	5	No	24/2.4	0.10	90.5	0.043	0.31
GS	30	5	No	26/2.6	0.08	90.6	0.043	0.41
GS	30	5	No	28/2.8	0.08	90.6	0.043	0.32
GS	30	5	No	30/3.0	0.07	90.8	0.042	0.37
GS	30	5	Yes	23/2.3	0.12	91.1	0.040	0.48
GS	30	5	Yes	25/2.5	0.10	91.5	0.039	0.40
GS	30	5	Yes	27/2.7	0.09	91.5	0.039	0.39
GS	30	5	Yes	29/2.8	0.08	91.7	0.038	0.38

TABLE 5. Sodium Hypochlorite Pre-Oxidation

Plant ID	200 RPM Flash Mix sec	30 RPM Floc Mix min	Pre-Cl_2	Coag/ Aid mg/L	Filtrate NTU	Filtrate %UVT	Filtrate UVA/cm	Settled NTU 25 min
HM	60	5	No	45	0.09	88.6	0.053	1.0
HM	60	5	No	50	0.09	88.7	0.052	1.2
HM	60	5	Yes	45	0.07	89.2	0.050	0.9
HM	60	5	Yes	50	0.07	89.4	0.049	0.9
MID	60	5	No	11	0.05	96.2	0.017	9.0
MID	60	5	No	12	0.06	96.4	0.016	10.2
MID	60	5	Yes	11	0.07	95.9	0.018	5.2
MID	60	5	Yes	12	0.05	96.2	0.017	5.8
BHP	60	5	No	37.5	0.07	88.9	0.051	0.4
BHP	60	5	No	42.5	0.06	89.0	0.051	0.6
BHP	60	5	Yes	37.5	0.05	90.1	0.045	0.3
BHP	60	5	Yes	42.5	0.05	89.8	0.047	0.3

Pre-Chlorination. In several jar testing with and without chlorine, pre-chlorination generally improved the filtration performance. A general by-product of pre-chlorination is an increase in %UVT or decrease in UVA. The change in %UVT/UVA is assumed to

result from some of the DOC being converted to disinfection by-products giving a false indication that DOC was reduced through the coagulation process. For this study, there's no supporting data to verify if pre-chlorination has a negative effect on disinfection by-products formation.

CASE STUDY: TTHM/HAA5

Jar testing procedures and analysis were applied to a utility with disinfection by-products (TTHMs/HAA5s) over the maximum contamination level (MCL) (Table 6). Several coagulants were jar tested over a 12-month period to determine which coagulant provided consistent and optimum filtrate turbidity and indirect reduction in DOC on the seasonal water quality characteristics. The treatment facility serves a community of 110 service connections. The treatment plant has two identical trains allowing side-by-side studies to be conducted. Each treatment train consists of a non-buoyant roughing filter followed by multi-media filtration in closed pressurized vessels. The empty-bed-contact-time (EBCT) for the roughing filter is approximately 9 minutes. The first series of testing began with Train 1. Operating with the plant's existing coagulant, a grab sample was taken for measurements of filtrate turbidity and %UVT/UVA. Train 1 was then taken off-line and backwashed. The original coagulant was taken off-line and a new selected coagulant from jar test results was put on-line. Filter-to-waste was initiated for Train 1 until the online filtrate turbidity met compliance performance before placed into service. After in service for one hour, a filtrate grab sample was taken and analyzed for turbidity and %UVT/UVA. The results between the original and new coagulant are depicted in Table 7.

TABLE 6. Trihalomethanes & Haloacetic Acids

Sample Quarter	Total Trihalomethanes (TTHMs, ug/L)	Haloacetic Acids (HAA5s, ug/L)
1st Qtr. 2018	120	140
2nd Qtr. 2018	110	136
3rd Qtr. 2018	76	47.7
4th Qtr. 2018	110	92.4
1st Qtr. 2019	130	140
2nd Qtr. 2019	98	49.8
3rd Qtr. 2019	120	2.8
New Coagulant Online (4th Qtr. 2019)	76	24.6
1st Qtr. 2020	79	0
2nd Qtr. 2020	84	0

Once the plant's filtrate and indirect DOC performance of the new coagulant was confirmed, the next test performed was to compare the disinfection by-products between each train using the plant's original coagulant on one train and the new coagulant on another train. After a few weeks running the new coagulant in Train 1 and the original coagulant in Train 2, samples were taken from each train when each was approximately 50% into their filter run-time. One-liter filtrate samples were taken from each treatment train and analyzed for turbidity and %UVT/UVA. Thereafter, each of the

1-liter samples were spiked with 2.0 mg/L NaOCl and held for 7 days in a dark environment. At the end of 7 days, samples were transferred to sample vials and transported to a certified laboratory for TTHMs/HAA5s analysis (Table 8).

TABLE 7. Treatment Plant Performance

Train #	Coagulant	Filtrate, NTU	%UVT	UVA/cm
1	Original Coagulant	0.10	91.6	0.038
1	New Coagulant	0.05	97.2	0.012

TABLE 8. Treatment Plant Performance and Disinfection By-Products

Train #	Coagulant	Filtrate, NTU	%UVT	UVA/cm	TTHM ug/L	HAA5 ug/L
1	New Coagulant	0.06	97.2	0.012	43	9.9
2	Original Coagulant	0.07	90.8	0.042	110	49

Note: Filtrate 1-liter samples spiked with 2.0 mg/L NaOCl and held for 7 days in dark environment.

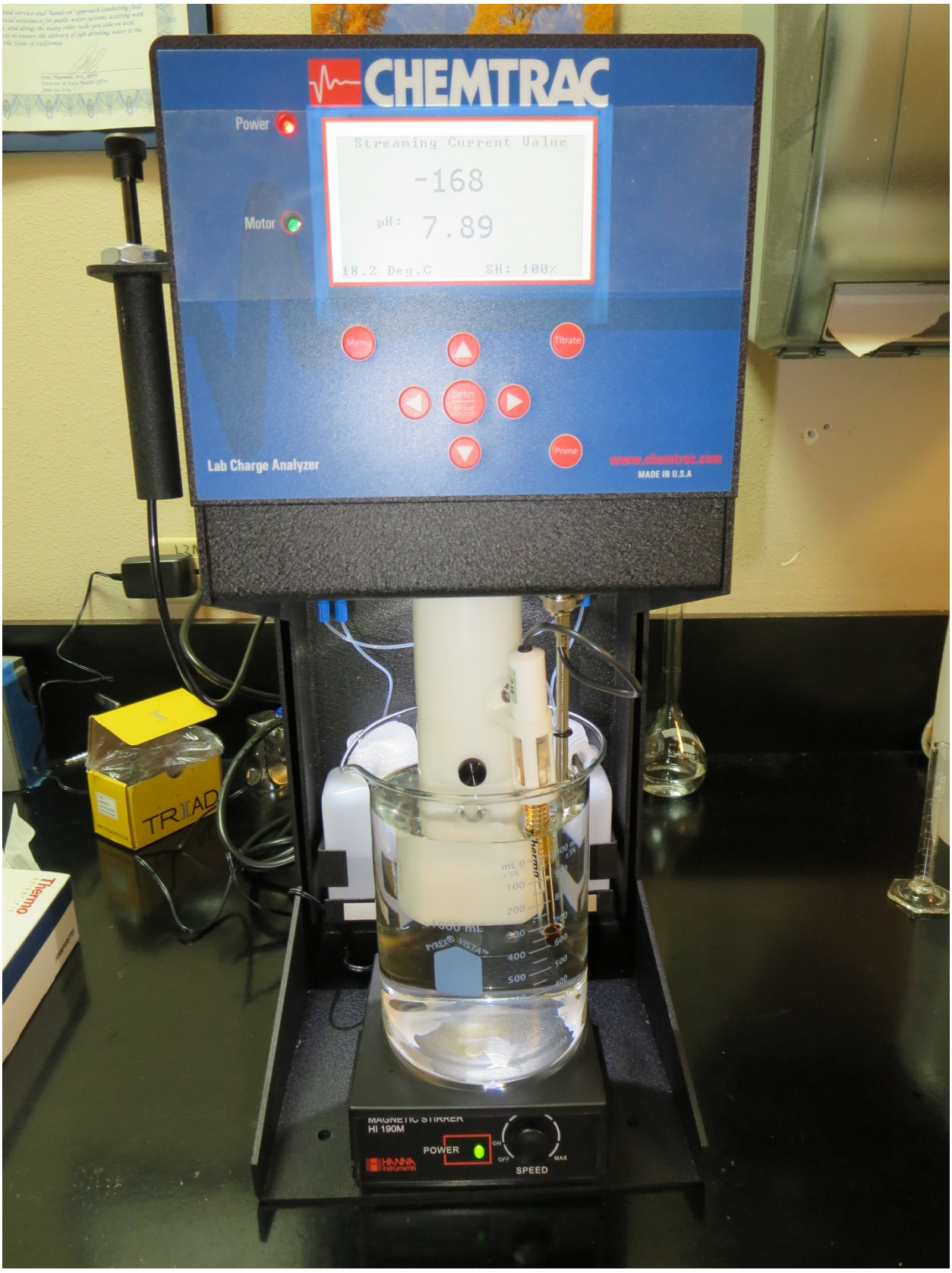
The experimental results (Table 8) showed a significant improvement in the reduction of TTHMs/HAA5s with the new coagulant. With the new coagulant online, an increase in pH depression and shorter filter run-times were observed. To increase filter run times, the operator started dosing a small amount of PolyDADMAC which was already onsite that increased filter run times. Using the on-site available process for potential corrosion control, post-treatment caustic soda was added to raise pH back to normally operations.

In Table 6 shows the 2019 4th quarter to present TTHMs/HAA5s results since the new coagulant went online. More research is ongoing as the water system is not able to determine optimum coagulant dose. The water system is looking into online UVT/UVA monitoring that can be used for coagulant adjustment.

CHARGE NEUTRALIZATION

A laboratory charged analyzer (LCA) was used to determine the coagulant dose needed to neutralize the charged particles in tested source waters. Jar test doses are bracketed around the LCA coagulant dose results. Particles in source waters are generally negatively charged. Using the LCA results reduced the number of jar testing needed to find the best coagulant and dose for optimum performance. For water systems with multiple sources and/or experience seasonal changes in source water characteristics, the LCA is an excellent tool to start with in narrowing down the optimum coagulant dose range.

The LCA used in this study has two feed pumps that automatically inject the test coagulant and acid or base if needed into a 1-liter beaker until the charged particles have been neutralized. At charge neutralization, the LCA coagulant and acid/base doses are displayed.


CHEMTRAC
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-168
pH: 7.89
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Lab Charge Analyzer
www.chemtrac.com
MADE IN U.S.A
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SPEED

TABLE 9. Laboratory Charged Analyzer vs Jar Test Results*

Plant ID	LCA mg/L	Coagulant/ Aid mg/L	Filtrate NTU	Filtrate %UVT	Filtrate UVA/cm	Settled NTU 25 min
MK	27	35	0.05	89.3	0.049	0.3
BHP	31	32.5	0.07	88.7	0.052	0.5
NMW	31.8	30	0.05	-	-	1.2
KCW	38	38	0.07	91.5	0.039	0.2
HMW	23.2	28	0.05	93.2	0.031	0.8
CH	22	21/3	0.07	92.8	0.032	0.33
CLO	31.9	35	0.08	89.7	0.047	1.2
VH	15	16	0.06	95.5	0.020	2.4
HV	29	29	0.07	89.0	0.051	0.40
GS	28	26/2.6	0.08	90.6	0.043	0.32
CW	19	23	0.08	90.0	0.046	0.39
KC	35	35	0.07	91.5	0.039	0.46
CF	76/5	76/5	0.07	89.6	0.048	0.40
LP	90	90	0.13	81.9	0.087	0.77
FNP	0.06/6.3	0.06/16	0.06	96.9	0.014	0.76
GSD	12.3	12	0.08	96.1	0.017	1.7
GTD	1.6	1.5	0.08	97.2	0.012	1.4
FSP	8.7	9.0	0.05	96.9	0.014	1.8
HH	101	105	0.05	94.8	0.023	0.2
COC	36	36	0.07	92.5	0.033	1.08
MID	9.45	9.5	0.07	97.4	0.011	5.3
SW	54	54	0.06	96.2	0.017	0.65
SFG	38.4/4	40/4	0.07	88.9	0.051	0.7
PV	25	30	0.06	89.2	0.050	0.35
KsC	14.5	14.5	0.07	90.5	0.043	-
SH	32	34	0.07	93.2	0.031	3.8
AC	192	190	0.12	81.6	0.088	5.0
SC41	7.5	8.0	0.12	96.5	0.015	5.9
HM	18.8	23	0.08	89.2	0.050	0.35
RV	14	14	0.08	93.1	0.030	0.47

* Flash Mix 30-60 seconds (200 RPM), Floc Mix 5 minutes (30 RPM)

For each source water tested, one or more coagulants were tested to determine coagulant dose at which particle charge neutralization was achieved. Table 9 depicts the LCA charge neutralization dose compared with the dose determined by jar testing source waters for the listed water systems to achieve optimum or near optimum filtrate turbidity and %UVT/UVA values. For water systems implementing enhanced coagulation or improve on DOC reduction, a higher dose was usually required than what is depicted in Table 9 under the LCA and coagulant/aid dose columns.

Note - the LCA coagulant dose at charge neutralization doesn't mean the tested coagulant will jar test well regarding filterability, %UVT/UVA and settleability. A poor performing coagulant produces weak flocs that will penetrate the laboratory 1.2 µm Isopore membrane filter increasing filtrate turbidity and resulting in a negative impact on %UVT/UVA.

PRACTICE

Jar testing should be performed regularly during non-water quality events to develop and maintain the necessary skills and confidence to be able to confront water quality changes. Ideally, performing at least one set of jar testing per week will help keep procedures fresh in memory and to maintain skills and confidence. Maintain database record of coagulant, doses, filtrate and indirect DOC performances for any operator/engineer to review for seasonal water quality. Initial skill and confidence building will require several hours of jar testing and practice.

JAR TESING PROCEUDURES

1. Fill 1-liter beakers with source or pre-oxidized (ozone, potassium permanganate, chlorine) water and place in jar tester.
2. Place a label in front of each jar with coagulant name and dose.
3. Place a labeled 30 mL syringe with luer-lock tip next to each jar.
4. Insert 1.2 µm Isopore membrane filter (polycarbonate, hydrophilic) into each filter holder and place in front of each jar. Wet filter support screen before placement of membrane filter.
5. Prepare 100-200 mL of stock solution and pour sample into 50 mL beaker.
6. Lower paddles into each jar and tighten.
7. Set paddle jar testing speed to 20-30 RPM.
8. Verify each jar is centered with no slippage of paddles.
9. Using the 50 mL beaker, pipette correct amount of coagulant and add to jar #1. Repeat procedure for remaining jars.
    a. Method of delivery - pipette (100-1,000 uL, 0.50-5.0 mL).
    b. If coagulant and/or filter aids are added, inject separately into each jar.
    c. If powder activated carbon (PAC) is added, add it after coagulant addition.
    d. Note: You may use same pipette for adding chemicals to each jar. It is not necessary to add coagulants and pre-oxidants simultaneous to each jar.
10. Flash mix - Increase paddle speed to 200 RPM and hold for 20 – 30 seconds.
11. Flocculation – Reduce paddle speed to 20-30 RPM and hold for 5 minutes.
    a. Increase flocculation time to 10-15 minutes if PAC (powder activated carbon) is added.
12. Turn off mixer and lift paddles from jars and secure.
13. Jar testing is completed (5.5 minutes).

SAMPLING – FILTERABILITY/SETTLEABILITY

1. For direct filtration and plants with pre-roughing filter.

a. Below surface (1-inch), syringe 25-30 mL from each jar at end of the flocculation period.

2. Plants with pre-settling (i.e., conventional treatment or equivalent).
   a. Wait 5 minutes at end of flocculation period then syringe 25-30 mL from each jar 1 inch below surface.
   b. Note: Syringe suction rate is about 30 mL/15 sec. Regardless of suction rate be consistent.
3. After 25 minutes of total settling, dip assigned cuvette into each jar below surface (1.5-2-inches). Suggestion: Move jars forward to edge of base to allow easier dipping of cuvette.

FILTERABILITY & %UVT/UVA ANALYSIS

1. The filterability and %UVT/UVA analysis are conducted during the settling period.
   a. Good laboratory practice is imperative for obtaining meaningful results.
   b. Always hold cuvette sample cell towards top to avoid fingerprints on glass where turbidity is read.
   c. One designated clean cuvette is used for all jars. It is verified by measurement of low turbidity (≤ 0.08 NTU) using bottled water.
2. Start with Jar #1 and complete analysis before going to the next jar.
3. Attached filter holder to syringe and filter-to-waste 3-4 mL.
4. Syringe remaining coagulated water directly into a clean cuvette to appropriate level.
   a. Keep the filtration rate to a slow to fast drip (60 – 90 seconds to dispense 20 mL).
   b. Drip rate should decrease with increase head loss due to solids removal. Do not try to maintain initial drip rate with increase head loss or force floc breakthrough may result. Head loss is felt by the increase thumb pressure on the syringe plunger.
5. Measure and record filtrate turbidity once reading has stabilized.
   a. Wipe dry and clean outer cuvette before measurement.
   b. Tilt cuvette up to 90 degrees to remove any formed micro bubbles before measurement.
   c. Up to 1-2 minutes may be needed for turbidity reading to stabilize.
6. Transfer remaining filtrate water from cuvette to %UVT/UVA cuvette and measure/record.
7. Rinse both cuvettes with clean water and repeat procedures for remaining jars.

SETTLEABILITY (TURBIDITY ANALYSIS)

1. At the end of 25 minutes of settling, dip the assigned cuvette for each jar 1-1.5 inches below surface to fill. Operator may change the flocculation and/or settling durations to closely match plant settled water turbidities.
   a. Only dip cuvette once as floc particles will rise as cuvette is removed from jar.
2. Measure turbidity from each cuvette assigned to jar. Take 3 readings and record midpoint value. For plants without settling, settleability analysis isn't required.

DATA RECORDING

1. Jar number
2. Product/coagulant dose (mg/L) and pre-oxidant/dose if added
3. Filtrate turbidity
4. Filtrate %UVT/UVA
5. Settled turbidity and settle duration time
6. Flash and floc mix durations and RPM

LABORATORY EQUIPMENT, SUPPLIES & CONSUMABLES

1. Jar tester
2. 1-liters beakers used as jars (Pyrex Glass Griffin Beaker)
3. Swinnex Filter Holder (25 mm dia.) or equivalent
4. Isopore Membrane Filter, polycarbonate, Hydrophilic, 1.2 µm, 25 mm dia
5. Syringe with Luer-Lock Tip, 30 cc, w/rubber plunger
6. Benchtop or portable turbidity meter (EPA 180.1 approved or equivalent)
7. Benchtop or portable UVT/UVA analyzer
8. Pipettes (100-1,000 uL, 0.5 – 5 mL) and tips
9. Volumetric flask (100- & 200-mL)
10. 50-mL beakers for pipetting coagulants and/or oxidants
11. Post-it notes or laboratory tape and marker – placed in front of each jar with coagulant name and dose
12. Distilled or deionized water for stock solution preparation
13. Coagulant sample products
14. Disposable Wipes
15. Towels – for under Jar tester; whipping paddles/rods; drying jars
16. Glassware soap and brush for cleaning jars and beakers

SETUP

1. Place large towel on laboratory counter
2. Setup jar testing equipment
3. Setup turbidity meter and calibrate
4. Designate one clean cuvette for the filterability analysis
5. Have a label cuvette prepared for each jar for settleability analysis (i.e., 1, 2, 3, …)
6. Setup UVT/UVA instrument and calibrate with organic free or distilled water
7. Fill jars up with source water
8. Prepare stock solutions
9. Place a post-it notes in front of each jar and write down name of coagulant and dose
10. Prepare filter holders and place one in front of each jar
11. Place a 30 mL Luer-Lock Syringe next to each jar
12. Prepare pipette(s)
13. Prepare notebook for recording results

JAR TEST PROCEDURES (1-LITER JARS) - OVERVEIW

Chemical Application	Flash Mix 200 RPM (20-30 sec)	Flocculation 30 RPM (5 min)	Sampling/ Filterability, %UVT/UVA	*Sampling/ Settleability (25 min)
Set paddle speed to 20-30 RPM and pipette coagulant into each jar one at a time.	Increase paddle speed to 200 RPM and hold for 20 to 30 seconds.	Reduce paddle speed to 30 RPM and hold for 5 minutes. End of period, lift paddles out of water and secure.	Using a 30 mL Luer-lock syringe assigned to each jar, sample at end of flocculation period for plants without settling. Wait 5 minutes for plants with settling.	25 minutes at end of flocculation period, dip assigned cuvette into each jar and measure settled water turbidity.

*Sampling/Analysis are not needed for plants without settling.

STOCK SOLUTION PREPARATION

Most coagulant products are diluted to 0.1 to 1.0% (1-liter jars) or 0.2 to 2.0% (2-liter jars) for jar testing. A volume of 1 mL of water has a mass of 1 gram (1,000 mg). When coagulant products are diluted (<4%), it can be assumed the solution weight is the approximate weight of water. If 1 mL of a 1% stock solution is added to 1-liter of water, the mass dose is 10 mg into 1 liter (10 mg/L). Table 10 provides the dose for percent stock solutions.

TABLE 10. Dose vs. %Stock Solution

1-Liter Jars	2-Liters Jars
1% Solution by Weight: 1 mL = 10 mg Injection into 1-liter jar 0.1 mL = 1 mg/L dose 1.0 mL = 10. mg/L dose 0.1% Solution by Weight: 1 mL = 1 mg Injection into 1-liter jar 0.1 mL = 0.1 mg/L dose 1.0 mL = 1.0 mg/L dose	2% Solution by Weight: 1 mL = 20 mg Injection into 2-liter jar 0.1 mL = 1 mg/L dose 1.0 mL = 10. mg/L dose 0.2% Solution by Weight: 1 mL = 2 mg Injection into 2-liter jar 0.1 mL = 0.1 mg/L dose 1.0 mL = 1.0 mg/L dose

To dilute a coagulant product, calculate the pipette amount (mL) of product that is to be added to a specific amount of water volume for the desired percent stock solution. The following is the general equation:

Stock Solution Equation:

$(\%Product\ Strength1)(SG1)(V1) = (\%Diluted\ Product\ Strength2)(SG2)(V2)$

- %Product Strength$_1$, assume all coagulant products are 100% (exception, Alum/Ferric)
- SG_1 = Product Specific Gravity
- V_1 = mL of product to mix with water (mathematically solved)
- %Diluted Product Strength$_2$ (% stock solution) = 0.1, 1.0, 0.2, 2.0%, etc.
- SG_2 = Diluted Product (Stock Solution) Specific Gravity ≈ 1.0
- V_2 = Stock solution volume, mL (100, 200, 500, etc.)

Except for Alum and Ferric coagulants, use 100% for coagulant product strength when preparing stock solutions. The doses will be based on product and not active ingredient(s).

Example: Coagulant Product, SG = 1.34

- Prepare a 1%, 200 mL Stock Solution
- $(\%Product\ Strength1)(SG1)(V1) = (\%Diluted\ Product\ Strength2)(SG2)(V2)$

$(100\%)(1.34)(V1) = (1\%)(1)(200\ mL), Solve\ for\ V1$

$$V1 = \frac{(1\%)(1)(200\ mL)}{(100\%)(1.34)} = \frac{200}{(100)(1.34)} = 1.49\ mL$$

Pipette 1.49 mL of coagulant product and mixed with water in a 200 mL Flask w/stopper for a 1% stock solution. Invert flask several times to ensure mixing.

Biography

Guy Schott is a Professional Civil Engineer with the California State Water Resources Control Board, Division of Drinking Water. Mr. Schott has a Bachelor and Master of Science degrees in Civil Engineering from California State University of Fresno and holds T5 and D2 licenses in drinking water. He has been a member of the California Water Treatment Committee since 1996. His expertise is in surface and groundwater treatment applications, filter surveillance, membranes, jar testing, lead/copper corrosion control treatment, tracer studies and Excel software application development for the drinking water industry.