



# Inducing Microflocculation Using Mixed-Oxidants

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## Introduction

The intent of this communication is to define conditions under which microflocculation may occur and present a testing protocol that can be used to determine if those conditions are present. In addition, if the microflocculation effect does occur, the results of this testing protocol will provide guidance to the client treatment facility on the optimum dosages of the chemicals to be used in the coagulation/flocculation process in full-scale operations and an assessment of the impact that use of mixed oxidants can have upon the water treatment process.

## Occurrence of Microflocculation

The coagulation/flocculation/settling-clarification/filtration process may be enhanced by pre-treatment with mixed oxidants; the mechanism is known as microflocculation. *Microflocculation* is defined as:

- 1) A reduction in coagulant demand for the same final (filtered water) turbidity, or
- 2) A reduction in final turbidity at the same coagulant demand

*Enhanced Coagulation* is manipulation of the coagulation conditions for the purpose of removing dissolved organic carbon (DOC) from the water in order to lower TTHM formation during final disinfection. *Microflocculation* applies to coagulation for turbidity reduction. To date, MIOX personnel and users have found that where microflocculation has been induced by mixed-oxidant addition in pre-treatment, both the coagulant demand and the final water turbidity have been reduced and, in addition, the formation of TTHMs have also been reduced. In essence, the microflocculation effect accomplished the same objectives as enhanced coagulation. The terminology must be kept separate and distinct because enhanced coagulation is a term with a specific definition under the Disinfectants/Disinfection By-Products (D/DBP) Rule.

The probability of inducing microflocculation by pre-treatment with mixed oxidants can be predicted using the Becker & O'Melia qualitative criteria, originally developed for ozone pretreatment, to evaluate the composition of the raw water (i.e. water prior to coagulant addition). The required data are:

1.  $\text{Ca}^{2+}$  (can be estimated from the hardness)
2. DOC (can be estimated from total organic carbon)
3. Turbidity

The evaluation criteria are:

- In all cases,  $\text{Ca}^{2+} / \text{DOC} \geq 10$  ( $\text{mg/l Ca}^{2+} / \text{mg/l DOC}$ )
- In low turbidity waters ( $< 2$  ntu),  $\text{Turbidity} / \text{DOC} > 0.5$  ( $\text{ntu} / \text{mg/l DOC}$ )
- In moderate turbidity waters, (2 to 10 ntu),  $\text{Turbidity} / \text{DOC} > 1.3$  ( $\text{ntu} / \text{mg/l DOC}$ )
- In high turbidity waters ( $> 10$  ntu),  $\text{Turbidity} / \text{DOC} > 2$  ( $\text{ntu} / \text{mg/l DOC}$ )

In addition, Becker & O'Melia found that a cationic polymer flocculant aid was needed in the coagulation step.

Any site treating already for turbidity reduction can evaluate the possibility of a reduction in coagulant usage and probably a concurrent reduction in final turbidity and DOC (and TTHMs) by comparing a water analysis with the Becker & O'Melia criteria. Those sites that are treating already for DOC reduction due to regulatory requirements can also perform jar tests to determine possible DOC (and TTHM) reductions achieved by the microfloculation effect of mixed oxidants.

### **Coagulation, Flocculation, and Settling-Clarification**

The purpose of coagulation/flocculation/settling-clarification is to remove particulates, especially colloidal-size non-settleable solids, and color (due to naturally-occurring humic and fulvic acids). In the coagulation process, chemicals are added which cause the colloidal-size particles to destabilize and clump together, gradually aggregating into larger and heavier particles that will settle. The primary coagulant chemicals (usually aluminum salts (alum) or iron salts (ferric chloride)), in addition to destabilizing the colloidal-size particles in the water, themselves form precipitates which “sweep” particulates from the water and adsorb larger organic molecules such as the humic and fulvic acids, removing them from the water. The entire collection of aggregated particulates and precipitates of the coagulant chemicals with adsorbed organic materials is termed “floc.”

Cationic, anionic, or non-ionic organic polymers are often added as flocculant aids to increase the density and “toughness” of slow-settling floc. In waters of exceptionally high turbidity due to colloidal clays (as is seen often in the Midwest), some treatment plants are able to destabilize the colloidal clays using flocculant aids alone without the primary coagulant chemicals.

For a specific coagulant (such as alum), the pH of the water determines which chemical compounds predominate. Lower pH values tend to favor positively charged species, which are desirable for destabilizing the negatively charged colloids and particulates. The optimum pH for coagulation by alum generally falls in the range of pH 5 to 7. Residual alkalinity in the water usually is sufficient to buffer the pH during the coagulation process.

The chemistry of the coagulation/flocculation process is very complex; fortunately, once the doses of the chemicals – both primary coagulants and polymer flocculant aids – are optimized,

the process works extremely well, usually requiring fairly minor adjustments as conditions of the raw water vary. However, one needs to realize and deal with the following features:

1. Primary coagulants and polymers can be both underdosed and overdosed with resulting adverse effects on coagulation/flocculation/settling-clarification/filtration efficiency.
2. The size and rate of formation of the floc for optimum treatment performance vary with the treatment plant design; one size/rate does not always suit all treatment plants.
3. Some polymers lose their effectiveness in the presence of a chlorine residual; and
4. Some polymers are dosage limited; the maximum dosage is specified by the manufacturer.

The coagulation/flocculation/settling-clarification process typically is conducted in a 3 step hydraulic environment – rapid mix, slow mix, and settling-clarification. There are many variations, but for this communication we will deal only with the typical. Rapid mixing equally distributes the coagulant chemicals throughout the water in a few seconds, resulting in formation of very small floc particles. The slow mix step, running usually for several minutes, promotes interparticle contacts and consequent agglomeration of the small floc particles into larger particles (flocculation). The settling step allows maximum settling of the floc. The hydraulic conditions of the jar tests model those of the typical treatment plant through use of stirring paddles whose rotational speeds can be varied.

## GENERAL JAR TEST PROCEDURES

### Equipment and Chemicals Needed<sup>1</sup>:

1. Jar testing apparatus (Phipps-Bird 6 1 Liter jars preferred)
2. Pipettes ranging from 100  $\mu$ l to 10 ml (**glass pipettes** – not plastic)
3. Stopwatch
4. Stock aluminum sulfate (alum) solution - used as the primary coagulant
5. Cationic polymer – used as a coagulant aid

**Preparation of 10,000  $\text{mg/l}$  (1.0%) alum solution:** Weigh 10.00 g of aluminum sulfate  $[\text{Al}_2(\text{SO}_4)_3 \cdot 14 \text{H}_2\text{O}]$  and dissolve into 1 liter of de-ionized water.

**Preparation of 1,000  $\text{mg/l}$  (0.1%) cationic polymer:** Weigh 1.00 g of cationic polymer and dissolve into 1 liter of de-ionized water.

### Establish a Range of Doses

Compare the current raw water quality conditions with treatment records to determine a range of suitable dosages of primary coagulant and cationic polymer for the jar tests.

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<sup>1</sup> Fresh mixed oxidant solution for use in the microfloculation evaluation should be collected in clean glass containers.

As an example, let's assume that records indicate that a typical range of dosages employed by the treatment plant are as follows:

Alum:	5 to 30 $\text{mg/l}$
Cationic Polymer:	0.25 to 1.5 $\text{mg/l}$

and that the dosages for current water conditions are about 20  $\text{mg/l}$  alum (as alum) and 1.0  $\text{mg/l}$  cationic polymer. These values will form the basis for design of the jar tests.

### Determine Hydraulic Conditions

The default hydraulic conditions modeled in the jar testing are:

Rapid Mix	80 rpm for 60 seconds (4800 rpm•seconds)
Slow Mix	20 rpm for 20 minutes
Settling	0 rpm (or "dead slow") for 30 minutes

These simulate (model) the hydraulic regimes of a typical 3.0 MGD treatment plant. Some client treatment plants will have determined jar test parameters that model their hydraulic regimes more closely; if so, use theirs.

Small adjustments may be made to the default conditions for rough correspondence to hydraulic conditions at the client plant – for flows < 3.0 MGD, decrease the rpm of the rapid mix and increase the duration; for flows > 3.0 MGD, increase the rpm of the rapid mix and decrease the duration. The product of the rpm and the duration should be about 4800 rpm•seconds.

### Floc Formation Observations

The following observations and descriptions should be made when observing floc formation in the jar tests; these form the basis for evaluation of the results:

1. Rate of floc formation – best done by observing the floc at specific times after rapid mix
2. Floc size – pinpoint, pinhead, larger than pinhead, and snowflake are typical descriptors
3. Settling – none, slight, much
4. Floc vortex formation near the stir paddles – none, slight, much
5. Clarity of supernatant and water between floc particles – very cloudy to very clear

Typically, faster rates of floc formation (particularly to large particles), good settling, good vortex formation, and a high degree of clarity of the supernatant and water between floc particles are favored because they indicate greater turbidity removal and thorough conversion of the coagulant into floc, leaving less to be removed by filtration.

### Evaluation of Test Results

Each treatment plant will have its own criteria for evaluating the jar test results; these are based largely on the treatment process and the hydraulics of the plant. The criteria will include, as a function of time: first appearance of floc; size of floc particles; clarity of water between floc particles; floc settling; and clarity of supernatant. The plant operator will also be interested in the total mass of floc formed (as settled sludge). The lead operator at the client treatment plant should examine the results personally to judge whether the microfloculation effect, if it occurs, will be helpful to the plant's process.

For our purposes, determining whether the microfloculation effect occurs requires that we compare coagulant dosages and appearance of the floc and supernatant as a function of time *at optimum conditions* between a control (without mixed oxidants in pretreatment) and a test (with mixed oxidants in pretreatment). As a result, we have to select optimum conditions according to some criteria – here is what we use:

- Rate of floc formation – faster is better
- Floc Size – bigger is better
- Floc Settling – more settling is better
- Clarity of supernatant and water between floc particles – very clear is best

**The optimum condition is defined by the jar that makes the biggest floc that settles the most, leaving the clearest supernatant, in the shortest time after the rapid mix step.**

### JAR TESTING IN CONTROLS

#### Test Sequence No. 1 – Determine Optimum Coagulant Dosage in a Control

To continue the example, set the jars as illustrated below, with the expected optimum dose being in the middle jar – jar #3 or #4. In the test, the coagulant dose is varied above (to the right or higher # jar) and below (to the left or lower # jar) by some convenient increment – in this example the increment is 5 <sup>mg/l</sup> alum dose (as alum).

TEST SEQUENCE NO. 1 (Alum dosing)						
Jar No.	1	2	3	4	5	6
Alum, <sup>mg/l</sup>	5	10	15	20	25	30

## Perform Tests

Collect a fresh 2 gallon sample of the raw water to be tested from the plant flow when you are ready to perform the jar test. The temperature of the water sample being tested should be approximately the same as the temperature of the water being treated.

## Procedure

1. Record the test sequence and water quality data;
2. Fill test jars or beakers to the 1 liter mark with the raw water to be tested;
3. If a cationic polymer is used by the treatment plant currently (remember that we will use it in the test for microflocculation by mixed oxidants later whether the plant uses it now or not), add an appropriate volume of the cationic polymer reagent to match their typical dose. In this example, the plant uses 1.0 mg/l; 1.0 ml of the reagent contains 1.0 mg of cationic polymer so add 1.0 ml of reagent to each jar.<sup>2</sup>
4. Add measured volumes of stock alum solution into each jar as quickly as possible; thereafter, start stirring as quickly as possible. In Test Sequence No. 1, the following reagent volumes would be added:

TEST SEQUENCE NO. 1 (Reagent Volumes)						
Jar No.	1	2	3	4	5	6
Alum, mg/l	5	10	15	20	25	30
Reagent Volume, ml(1%)	0.5	1.0	1.5	2.0	2.5	3.0

5. Quickly lower the stirring paddles into the jars and start them immediately. Operate the paddles for one minute (default time) at 80 rpm (default value).
6. Reduce mixer speed to 20 rpm (default value) to simulate flocculation basin conditions. If a different speed better simulates actual flocculation basin conditions in the plant, use those conditions.
7. Record the floc formation observations at 5 minute intervals through the slow mix process; the default duration of the slow mix is 20 minutes. If the plant has a different slow mix duration, use that.
8. Stop the stirring mechanism. Allow the floc to settle over a period of 30 minutes (default time) or for a period similar to the plant conditions. At 10 minute intervals, record approximate thickness of the floc layer (as a % of water column height), floc appearance, and clarity of supernatant. Cloudy supernatant indicates poor

<sup>2</sup> In our experience, the floc formation characteristics are relatively insensitive to the polymer dose over a range of 0.25 to 2.0 mg/l. Overdosing and underdosing are possible but *the default for most testing will be 1.0 mg/l*. If the plant DOES NOT use a polymer, this test MUST be repeated with the default dose of polymer as part of the control.

coagulation; proper coagulation makes well-formed floc particles and clear supernatant.

9. Measure the turbidity of the settled water (optional, if a turbidimeter is available).
10. Evaluate the results of the jar test (example below).

TEST SEQUENCE NO. 1 (Turbidity Evaluation)						
Jar No.	1	2	3	4	5	6
Alum, $\text{mg}/\text{l}$	5	10	15	20	25	30
<b>Supernatant Turbidity, NTU</b>	<b>0.8</b>	<b>0.4</b>	<b>0.2</b>	<b>0.3</b>	<b>0.5</b>	<b>0.9</b>

**Note:** Overdosing and underdosing lead to poor coagulation and cloudiness (or turbidity) as in this example in jars 1, 2 (underdosed) and 4, 5 and 6 (overdosed). In this idealized example, the optimum dose is clearly 15  $\text{mg}/\text{l}$  alum. While a turbidity value is used to represent the optimum dose, the optimum can often be determined visually.

### Test Sequence No. 2 – Determine Optimum Cationic Polymer Dose in a Control

Assume that the alum dosage at optimum condition (hereafter, *optimum alum dose*) in the control was 15  $\text{mg}/\text{l}$ . The next step is to evaluate the effect of varying the cationic polymer dosage on the control using the optimum alum dose. You will be varying the cationic polymer dose from 0.25  $\text{mg}/\text{l}$  to 1.5  $\text{mg}/\text{l}$ , with the cationic polymer dose used in Test Sequence #1 (if any) or the default dose (1.0  $\text{mg}/\text{l}$ ) at Jar #4.

TEST SEQUENCE NO. 2 (Cationic Polymer Dosing)						
Jar No.	1	2	3	4	5	6
Alum, $\text{mg}/\text{l}$	15	15	15	15	15	15
<b>Cationic Polymer, <math>\text{mg}/\text{l}</math></b>	<b>0.25</b>	<b>0.5</b>	<b>0.75</b>	<b>1.0</b>	<b>1.25</b>	<b>1.50</b>

### Perform Tests

Collect a fresh 2 gallon sample to be tested from the plant flow when you are ready to perform the jar test. The temperature of the water sample being tested should be approximately the same as the temperature of the water being treated.

### Jar Test Procedure

1. Record the test sequence and water quality data;
2. Fill test jars or beakers to the 1 liter mark with water to be tested;
3. Add measured volumes of stock cationic polymer solution into each jar. In Test Sequence #2, the following reagent volumes would be added:

TEST SEQUENCE NO. 2 (Reagent Volumes)						
Jar No.	1	2	3	4	5	6
Alum, $\text{mg/l}$	15	15	15	15	15	15
Cationic Polymer, $\text{mg/l}$	0.25	0.50	0.75	1.0	1.25	1.50
Reagent Volume, ml(0.1%)	0.25	0.50	0.75	1.0	1.25	1.50

4. Add measured volumes of stock alum solution into each jar and as quickly as possible; thereafter, begin the stirring.
5. Quickly lower the stirring paddles into the jars and start them immediately. Operate the paddles for one minute (default time) at 80 rpm (default value).
6. Reduce mixer speed to 20 rpm (default value) to simulate flocculation basin conditions.
7. Record the floc formation observations at 5 minute intervals through the slow mix process; the default duration of the slow mix is 20 minutes (default time).
8. Stop the stirring mechanism. Allow the floc to settle over a period of 30 minutes (default time) or for a period similar to the plant conditions. At 10 minute intervals, record approximate thickness of the floc layer (as a % of water column height), floc appearance, and clarity of supernatant.
9. Measure the turbidity of the settled water (optional, if a turbidimeter is available).
10. Evaluate the results of the jar test (see discussion on page 5).

## JAR TESTING – TESTS FOR THE MICROFLOCCULATION EFFECT

Once the optimum dosages of alum and cationic polymer have been determined in the control (raw water) in Test Sequences #1 and #2, you are ready to check for the microflocculation effect by pretreatment with mixed-oxidant solution.

### Determine the Immediate Oxidant Demand of the Raw Water

1. Determine the concentration of oxidant produced by the mixed-oxidant generator using established procedures (be sure to use oxidant demand free (ODF) water that you have made yourself for dilutions of neat mixed-oxidant solution; DO NOT TRUST DEIONIZED or DISTILLED WATER TO BE OXIDANT DEMAND FREE). All measurements of the free available chlorine (FAC) concentration are made with an appropriate testing device; i.e., HACH color wheel or colorimeter using the DPD method.
2. For this example, assume the measured FAC concentration in the mixed-oxidant solution is  $3,800 \text{ mg/l}$  and you estimate that the immediate oxidant demand of the raw water is  $4 \text{ mg/l}$ . To confirm the estimate of immediate oxidant demand, add varying

doses of mixed-oxidant solution to each of 4 different 1 liter capped sample bottles containing the raw water. See table below for dosages:

Oxidant dosages	
Volume of oxidant per liter of sample	Dosage
0.95 ml	3.6 mg/l
1.05 ml	4.0 mg/l
1.16 ml	4.4 mg/l
1.26 ml	4.8 mg/l

3. Add the above volumes of mixed-oxidant solution to the respective bottles, cap, and shake vigorously. As quickly as possible, and within 5 minutes of dosing, measure the FAC in each bottle.
4. Take the immediate oxidant demand as  $[\text{Dose (mg/l)} - \text{residual FAC (mg/l)}]$  in the bottle having the lowest detectable FAC<sup>3</sup>.

### Microflocculation Testing

Use the immediate oxidant demand as measured above as the pretreatment dose in all subsequent jar tests.<sup>4</sup>

### Test Sequence No. 3 – Determine the Optimum Alum Dose with Mixed-Oxidant Pretreatment

We will dose the raw water in each jar with mixed-oxidant solution to just satisfy the immediate oxidant demand (assumed in this example to be 4.0 mg/l) and add cationic polymer at the optimum determined in the control in Test Sequence #2 (assumed in this example to be 1.5 mg/l). We will also vary the alum dose.

In this case, for purposes of positioning the jars, we will assume that the microflocculation effect WILL occur and will result in about a 20% decrease in the optimum alum dose (this is not unreasonable – decreases of up to 40% have been observed). And we will vary the alum doses in 20% increments above and below the optimum alum dose in the control (Test Sequence #1).

<sup>3</sup> If the microflocculation effect occurs, pretreatment with mixed-oxidant solution will result in less coagulant being used; however, any FAC residual remaining will produce disinfection by-products. Thus, the logic in determining the immediate oxidant demand is to dose to cause the microflocculation effect but to leave nil FAC residual.

<sup>4</sup> We have recently found that the microflocculation effect, if it occurs at all, is relatively insensitive in magnitude to the mixed-oxidant solution dose in pretreatment over a broad dose range. Thus, a dose needed to just satisfy the immediate oxidant demand is sufficient to demonstrate the effect. If implemented in full-scale operation, actual doses can be varied, higher or lower (to a lower limit where the effect disappears) to accomplish other objectives.

Thus, in this example, Jar #4 will receive an alum dose of 12 mg/l [15 mg/l - 0.2(15 mg/l)], and the doses to the other jars will be  $\pm 3.0$  mg/l [0.2(15 mg/l)] from the Jar #4 dose of 12 mg/l. Note that this strategy enables the optimum alum dose determined in the control to be included in this test also (in Jar #5) so that if the effect does not occur, the optimum alum dose would be the same as in the control (15 mg/l) and be seen in Jar #5.

### Perform Tests

Collect a fresh 2 gallon sample to be tested from the plant flow when you are ready to perform the jar test. The temperature of the water sample being tested should be approximately the same as the temperature of the water being treated. In Test Sequence #3, the following doses would be used.

TEST SEQUENCE NO. 3 (Alum Dosing)						
Jar No.	1	2	3	4	5	6
Oxidant Dosage, mg/l	4.0	4.0	4.0	4.0	4.0	4.0
<b>Alum Dosage, mg/l</b>	<b>3</b>	<b>6</b>	<b>9</b>	<b>12</b>	<b>15</b>	<b>18</b>
Cationic Polymer Dosage, mg/l	1.5	1.5	1.5	1.5	1.5	1.5

### Test Procedure:

1. Record the test sequence and water quality data;
2. Fill test jars or beakers to the 1 liter mark with water to be tested; and
3. Add measured volumes mixed-oxidant solution, followed by cationic polymer stock solution;
4. Add measured volumes of stock alum solution into each jar and as quickly as possible; thereafter, begin the stirring.
5. Quickly lower the stirring paddles into the jars and start them immediately. Operate the paddles for one minute (default time) at 80 rpm (default value).
6. Reduce mixer speed to 20 rpm (default value) to simulate flocculation basin conditions.
7. Record the floc formation observations at 5 minute intervals through the slow mix process; the default duration of the slow mix is 20 minutes (default time). If the plant has a different slow mix duration, use that.
8. Stop the stirring mechanism. Allow the floc to settle over a period of 30 minutes (default time) or for a period similar to the plant conditions. At 10 minute intervals, record approximate thickness of the floc layer (as a % of water column height), floc appearance, and clarity of supernatant.
9. Measure the turbidity of the settled water (optional, if a turbidimeter is available).
10. Evaluate the results of the jar test (see discussion on page 5).

## Interpretation of the Results

The procedure here is to compare and contrast the optimum condition found in Test Sequence #2 (the control with optimum cationic polymer dose) with the optimum condition found in Test Sequence #3. Remember our definition:

**The optimum condition is defined by the jar that makes the biggest floc that settles the most, leaving the clearest supernatant, in the shortest time after the rapid mix step.**

If the microflocculation effect occurs, the primary evidence is that the optimum alum dose (ie., the alum dose at optimum condition) in the mixed-oxidant solution pretreatment test will be lower than the optimum alum dose in the control. If this is the case, continue the evaluation by comparing and contrasting the specific observations in the jars (control and test) at optimum conditions as follows:

- |                           |   |
|---------------------------|---|
| 1. Rate of floc formation | Compare the time required for the floc to reach the maximum size  |
| 2. Floc size              | Compare the descriptions of the maximum sizes of the floc produced  |
| 3. Settling               | Compare the descriptions of the degrees of settling   |
| 4. Vortex formation       | Compare the descriptions of the degrees of vortex formation   |
| 5. Clarity                | Compare the descriptions of clarity of supernatant and water between floc particles, or the turbidity measurements of the supernatant |

If the microflocculation effect occurs, *as signaled primarily by reduction in the optimum alum dose*, it is usually accompanied by a significant change in all the above features of the floc -- the rate of formation is faster; i.e., the time required for the same size particle to be formed is shorter; the size of the final floc is larger and, as a result, the degree of settling is greater; the floc tends to form a vortex around the slowly-rotating paddle; and both the supernatant and the water between the floc particles are quite clear. Also, the turbidity of the supernatant is very low (it is typical for turbidities to be < 0.1 ntu; that is, nearly drinking water quality).

The plant operator will need to judge for himself whether these features are beneficial to his specific operations. For example, at Santa Fe, NM, these features enabled the treatment plant, which uses an upflow clarifier for the settling-clarification step and was designed for 8 MGD, to operate at 10 MGD and to realize many other savings in costs, as well as a decrease in TTHM formation through the distribution system. A treatment plant at Lower Valley, NM, by contrast, uses direct filtration for clarification so the floc particle size was critical to satisfactory operations; the plant operator did not even want

to consider employing mixed-oxidant solution in pretreatment because it would likely change the form of the floc and seriously hamper the efficiency of the direct filtration process.

### **Modifications to Dosing in Actual Operations**

In our experience, the doses of mixed-oxidant solution (in pretreatment), alum, and polymer at optimum condition determined in the jar testing are a very good model of those that will prove to be optimum in actual full-scale operations. However, treatment plant operators often vary doses to obtain best results. Here are some guidelines for the plant operator:

1. Mixed-Oxidant Solution Dose – The occurrence of the microflocculation effect is relatively insensitive to dose so long as some minimum dose is maintained; this minimum is best determined in actual operations. A rough, but very effective, test for the operator is to decrease doses from that needed to just satisfy the immediate oxidant demand until the turbidity at the top of the clarifier increases. At that point, the mixed-oxidant solution dose is below the minimum needed to cause the effect. Doses higher than that needed to satisfy the immediate oxidant demand will still cause the microflocculation effect; thus, higher doses will likely leave a FAC residual in the water and could be used to meet C•T credit requirements. However, an FAC residual will cause formation of TTHMs by reaction with precursors both remaining in the water and those captured in the floc blanket.
2. Cationic Polymer Dose – The condition of the floc is more sensitive to the polymer dose than it is to the mixed-oxidant solution dose. The operator should begin plant operations using the optimum polymer dose determined in Test Sequence #2, find the minimum mixed-oxidant solution dose to achieve best results as discussed in Item 1 above, and then decrease the polymer dose cautiously, again monitoring the turbidity at the top of the clarifier.
3. Alum Dose – The condition of the floc is typically most sensitive to the alum dose. The operator should begin plant operations using the optimum alum dose determined in Test Sequence #3, find the minimum mixed-oxidant solution dose (Item 1 above), then find the optimum cationic polymer dose (Item 2 above), and only then vary the alum dose cautiously, again monitoring the turbidity at the top of the clarifier. At Santa Fe, NM, the final dose of alum at optimum plant operations was within 10% of that determined in the jar testing.

## REFERENCES

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