

APPENDIX E

JAR TEST PROCEDURES FOR CHEMICAL CLARIFICATION

E-1. General.

a. Laboratory Jar Tests. Jar tests have been used to evaluate the effectiveness of various coagulants and flocculants under a variety of operating conditions for water treatment. The procedures and evaluation process (item 4) and (item 20) have been adapted to dredged material (item 29). However, conducting jar tests and interpreting the results to determine design parameters are not simple tasks because there are many variables that can affect the tests. Only experience can assist in applying the following jar test procedures to a specific project. Additional information (item 22) is available on equipment requirements and the importance of flocculent type, flocculent concentration, flocculent addition methods, temperature, mixing and test equipment, and intensity and duration of mixing on the jar tests results.

b. Jar Test Uses. Jar tests are used in these procedures to provide information on the most effective flocculant, optimum dosage, optimum feed concentration, effects of dosage on removal efficiencies, effects of concentration of influent suspension on removal efficiencies, effects of mixing conditions, and effects of settling time.

(1) The general approach used in these procedures is as follows:

(a) Using site-specific information on the sediment, dredging operation, containment areas, and effluent requirement, select mixing conditions, suspension concentration, settling time, and polymers for testing.

(b) Prepare stock suspension of sediment.

(c) Test a small number (four to six) of polymers that have performed well on similar dredged material. The tests should be run on 2-grams-per-litre suspensions, which is a typical concentration for effluent from a well-designed containment area for freshwater sediments containing clays. If good removals are obtained at low dosages (10 milligrams per litre or less), then select the most cost-effective polymer. If good removals are not obtained, examine the polymer under improved mixing and settling conditions and test the performance of other flocculants.

(d) After selecting a polymer and its optimum dosage, examine the effect of polymer feed concentration over the range of 1 to 30 grams per litre, typical concentrations used in the field, at the optimum dosage.

(e) Determine dosage requirements for the expected range of turbidity and suspended solids concentration to be treated at the primary weir.

(f) Examine the effects of the range of possible mixing conditions on the required dosage of flocculant for a typical suspension.

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(g) Examine the effects of settling time on the removal of suspended solids and turbidity from a suspension of average concentration, using the selected dosage and likely mixing conditions.

(2) The purpose of the approach described is to select an effective polymer for a suspension of a standard concentration, 2 grams per litre, which is a typical effluent solids concentration. In this manner, the effectiveness and dosage requirements of various polymers are easy to compare. The other test variables are set to simulate anticipated field conditions. After a polymer is selected, other variables are examined: polymer feed concentration, solids concentration of suspension to be treated, mixing, and settling time. The approach may be changed to fit the needs and conditions of the specific study.

(3) The details of each test typically are modified to satisfy the constraints and conditions of the project and test. This procedure generally requires judgment from experience with jar tests and chemical treatment. Detailed procedures are found in the following paragraphs.

#### E-2. Selection of Test Conditions.

a. Mixing Intensity and Duration. Prior to testing, the mixing intensity and duration for the jar tests should be selected based on project conditions. Assuming that mechanical mixing will not be used in the treatment system, the amount of mixing should be based on the available head between the two containment areas, i. e., the difference between the water surfaces of the two areas that can be maintained throughout the project (see Figure E-1). The depth of the secondary area must be sufficient to provide 2 to 3 feet of storage and 2 to 3 feet of ponding for good settling. Preferably, 2 to 3 feet of head should be available for mixing. The object is to convert the head into mixing energy in the culvert(s) joining the two containment areas. The amount of head loss is a function of flow rate, culvert diameter, and length.

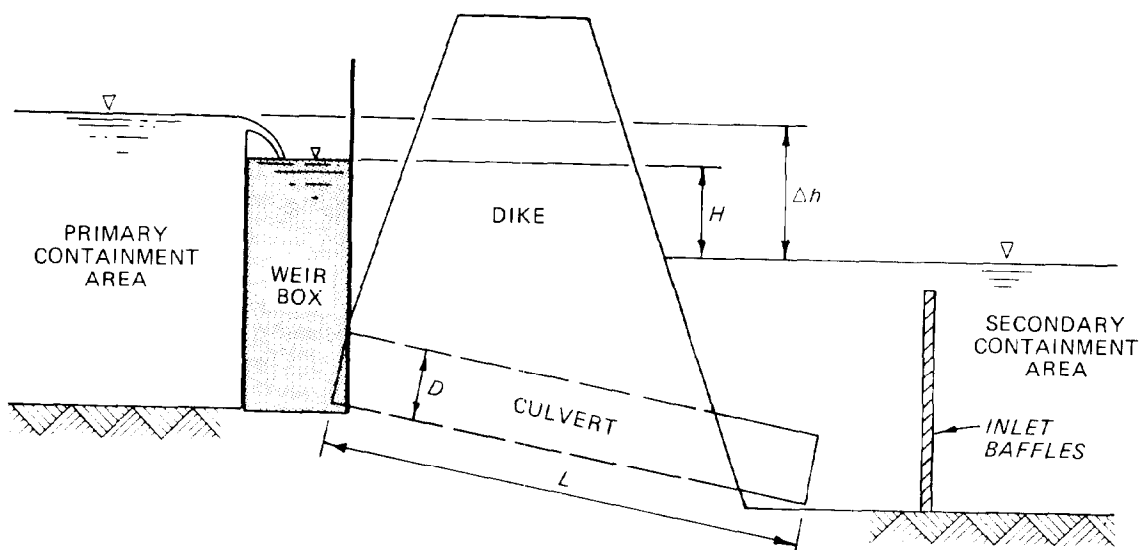


Figure E-1. Example weir mixing system

Table E-I presents typical mixing values for good culvert mixing designs under a variety of conditions assuming a maximum of five culverts and a maximum culvert length of 100 feet. The net mixing  $Gt$  is the product of the mean velocity gradient (intensity) and the duration. The mixing intensity in terms of the mean velocity gradient  $G_1$  for the design conditions in Table E-1 varied from about 250 to 500 set . The effectiveness of polymers increased as the mixing  $Gt$  increased to about 30,000.

(1) The designer may select a  $Gt$  value from Table E-1 for an example with similar flow and mixing head, but preferably the designer should calculate the head loss, mixing intensity, and duration for the existing or designed culvert according to the following procedure for pipe flow (item 31). Assuming a submerged inlet and outlet and corrugated metal pipe,

$$H = \left(1.5 + \frac{Lf}{D}\right) \frac{v^2}{2g} \quad (E-1)$$

where

- H = head loss, feet
- L = culvert length, feet
- f = friction factor
- =  $185 n^2/D^{1/3}$  (n = Manning's coefficient, 0.024 for corrugated metal pipes)
- D = culvert diameter, feet
- v = maximum velocity through culvert, feet per second
- =  $4 Q_{\max}/\pi D^2$
- $Q_{\max}$  = maximum flow rate, cubic feet per second
- g = gravity, 32.2 feet per second<sup>2</sup>

Alternate methods and sources for friction factor and Manning's coefficient are available in Hydraulics Design Criteria 224-1/2 to 224/1/4. The mean velocity gradient  $G$  can be calculated as follows:

$$G = \sqrt{\frac{\gamma_s f \bar{v}^3}{2gD\mu_s}} \quad (E-2)$$

where

- G = mean velocity gradient, second<sup>-1</sup>
- $\gamma_s$  = specific weight, 62.4 pounds per cubic foot
- $\bar{v}$  = average velocity, feet per second
- $\mu_s$  = absolute viscosity,  $2.36 \times 10^{-5}$  pounds per second per square foot at 60° F

The duration  $t$  of the mixing in seconds is determined by

$$t = \frac{L}{\bar{v}} \quad (E-3)$$

Table E-1  
Design Mixing Values (Gt)

Flow cfs	Available Head, ft				
	2	3	4	5	6
5	8,200	9,800	11,300	12,200	12,900
8	7,800	9,300	10,800	11,600	12,300
12	7,500	9,000	10,400	11,200	11,900
16	7,200	8,700	10,000	10,800	11,500
21	7,000	8,400	9,700	10,500	11,100
27	6,800	8,200	9,500	10,200	10,800
36	6,600	7,900	9,100	9,800	10,400
47	6,400	7,600	8,800	9,500	10,100
60	6,200	7,400	8,500	9,200	9,800
74	6,000	7,200	8,300	8,900	9,500
106	5,700	6,800	7,900	8,500	9,000

The mixing increases with increases in head loss, culvert length, and duration and with decreases in culvert diameter. Long, multiple, small-diameter, corrugated culverts provide the best mixing conditions. Good mixing requires a Gt of about 30,000, though a Gt of about 8,000 provides adequate mixing.

(2) An alternative to using long, small-diameter, corrugated culverts to effectively convert the available head into mixing would be to install static mixers in the culvert. Static mixers are fixed obstructions that, when placed in a culvert, efficiently increase the turbulence produced by the flow. The mixers increase the head loss without using smaller diameter or longer culverts. When using these devices, care must be taken to accurately determine the head loss to ensure that good mixing is provided while not exceeding the available head.

(3) After determining G and t for field conditions, use the same G and t for rapid mixing conditions in the laboratory jar test. If the G is greater than the G available on the jar test apparatus, mix at maximum speed and increase the duration to obtain the same Gt. The relationship between G and revolutions per minute of a jar test apparatus is shown in Figure E-2. For slow mixing, mix at 20 revolutions per minute ( $G = 10 \text{ seconds}^{-1}$ ) for

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300 seconds to simulate the exit loss conditions as the water dissipates its kinetic energy upon entering the secondary cell.

b. Suspension Concentration. The next step is to predict the average solids concentrations and turbidity of the suspension to be treated at the primary weir. This can be estimated from past records of dredging at the site or flocculent settling tests. Procedures for containment area design considering both flocculent and zone settling are found herein. The results of flocculent settling tests, when available, should be used to determine the suspension concentration.

c. Settling Time for Flocculated Material. The next variable to establish is settling time. Flocculated (chemically treated) material settles at a rate of about 0.25 feet per minute. The required ponding depth for good settling is about 2 to 3 feet; therefore, a minimum of 10 minutes is needed for settling. Also, due to basin inefficiencies, some of the water will reach the secondary weir in 10 to 20 percent of the theoretical residence time. For secondary containment areas, this may be as short as 10 to 20 minutes, though the mean residence time may be about 50 minutes. Based on this information, the settling time in the jar test should be set at 10 minutes. The effect of settling time on suspended solids removal can be evaluated in the jar test procedures.

d. Selection of Polymers for Testing. The final consideration before starting the jar tests is the selection of polymers to be tested. To simplify the operation of feeding and dispersing the polymer at the project, a low viscosity liquid polymer should be used. Some polymers effective on dredged material are:

Betz	1180 1190
<b>Calgon</b>	<b>M-503</b>
Hercofloc	815 849 863 876
Magnifloc	573c 577c
Nalco	7103 7132

Polymer manufacturers may be able to suggest others. The manufacturers can also recommend maximum polymer feed concentrations. Polymer selected for testing should be nontoxic, nonhazardous, and unreactive. Polymer manufacturers can provide detailed information on the properties of their products. Also, the US Environmental Protection Agency has approved many polymers for use on potable water at the desired dosages. Very little of an applied dosage is expected to be discharged from the containment area since the polymer adsorbs on the solids and settles in the containment area. Therefore,

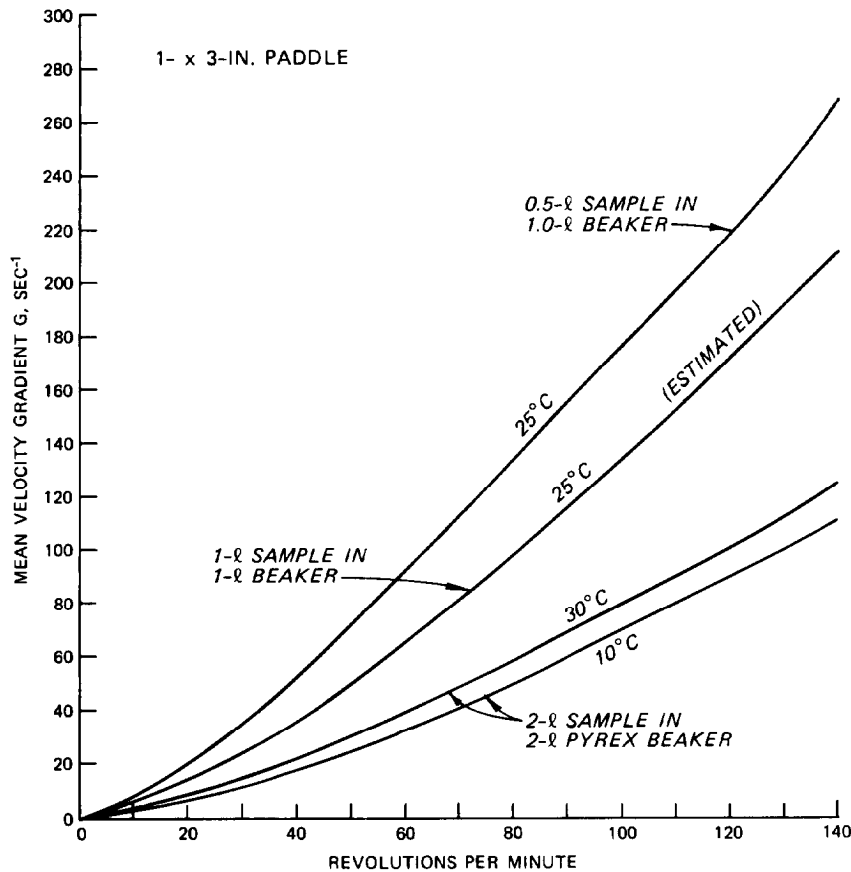


Figure E-2. Velocity gradient  $G$  calibration curves for jar test apparatus

polymers should not be detrimental to the quality of the receiving waters. Polymers do not increase the long-term release of contaminants or nutrients from treated dredged material (item 35).

E-3. Suspension Preparation. Dredged material that is discharged over the weir is composed of only the finest fraction of the sediment. In many cases, this material has been suspended and mixed in the primary containment area for several days while the coarser material settled. Therefore, to obtain representative suspensions for testing, the following procedure is recommended:

a. Thoroughly mix each sediment sample to ensure homogeneity. Then, blend equal portions of each sample to form a representative composite of the sediment. Grain size analysis and soil classification may be performed on this material to characterize the mixture and to compare it with previous characterizations of the sediment.

b. If the sediment mixture contains more than 10 percent (dry weight basis) coarse-grained (>No. 200 sieve) material, the material should be sieved through a standard US series No. 200 sieve. The fines can be washed through

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the sieve using water from the bottom of the water column at the dredging site. If this water is unavailable, tap water may be used in its place, but the salinity of the suspension of fines (<No. 200 sieve) must be adjusted to naturally occurring salinity of the bottom waters at the project site.

c. Prepare a supply of 2.0-grams-per-litre suspensions by diluting a well-mixed portion of the slurry of fines with water from the dredging site or with tap water adjusted with salt to the same salinity. Suspensions at other concentrations would be prepared in the same manner.

E-4. Jar Test Procedures. Having established the test variables, the designer is ready to start the laboratory jar test procedures. Care must be exercised in the tests to ensure that each sample is handled uniformly. The tests must be performed in a standard manner to evaluate the results. The following variables must be controlled: identical test equipment and setup, suspension preparation, sample temperature, polymer feed concentration and age, polymer dosage, sample premix time and intensity, polymer addition method, duration and intensity of rapid mixing, duration and intensity of slow mixing, settling time, sampling method, and laboratory analyses of samples. All of the following procedures described in this section are not necessary for every project. The required tests are dependent on the purpose of the study, and some tests can be eliminated based on past experience of treating dredged material under similar circumstances,

a. Selection of polymer. The laboratory jar test procedures are as follows:

(1) Fill a 1- or 2-litre beaker with a 2.0 grams-per-litre suspension of fine-grained dredged material.

(2) Mix at 100 revolutions per minute and incrementally add polymer at a dosing of 2 milligrams per litre until flocs appear. Note the total dosage applied. (Use a polymer feed concentration of 2 grams per litre or 2 milligrams per millilitre.)

(3) Fill six 1- or 2-litre beakers with a 2.0-grams-per-litre suspension of dredged material and measure the suspended solids concentration and turbidity of the suspension.

(4) Mix at 100 revolutions per minute for 1 minute and then rapidly add the desired polymer dosage to each beaker. Use a range of polymer dosages from 0 milligram per litre to about twice the dosage determined in step (2).

(5) Immediately adjust the mixing to the desired G for rapid mixing as determined earlier. Mix for the desired duration t also determined earlier.

(6) Reduce the mixer speed to a G of 10 seconds<sup>-1</sup> and slow mix for 300 seconds.

(7) Turn off the mixer and settle for 10 minutes.

(8) Withdraw the samples from the 700-millilitre level of 1-litre beakers and from the 1,400-millilitre level of 2-litre beakers.

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(9) Measure the suspended solids concentration and turbidity of the samples. The test data should be recorded on a report form similar to the one shown in Figure E-3. Also record any significant observations such as nature, size, and settling characteristics of the flocs, time of floc formation, and any peculiarities.

(10) Repeat steps (3) through (9) as needed to adequately define the effects of dosage on clarification.

(11) Repeat steps (1) through (10) for the other polymers. A dosage of 10 milligrams per litre should reduce the solids concentrations by 95 percent if the polymer is effective. Examine enough polymers to find at least two effective ones.

(12) Select the most cost-effective polymer that can be easily fed and dispersed.

b. Selection of Polymer Feed Concentration. After selecting the best polymer, the effects of polymer feed concentration and polymer solution age on the removals can be evaluated. Some polymers require great dilution and aging following dilution to maximize their effectiveness. This test is not required if adequate dilution water and solution aging are provided in the design to meet the manufacturer's recommendations. Often, to simplify the treatment system design, these recommendations are not met. The test is performed as follows:

(1) Prepare six fresh solutions of the selected polymer ranging in concentration from about 1 to 40 grams per litre.

(2) Fill six beakers as in step (3) of E-4.a.

(3) Mix at 100 revolutions per minute for 1 minute and then rapidly add the polymer solutions at the effective dosage established earlier and in the same manner.

(4) Continue to follow the procedures outlined in steps (5) through (9) of paragraph E-4.b.

(5) Allow two solutions to age as desired (between 1 hour and 1 day) and repeat steps (2) through (4).

c. Determination of Required Dosage. The dosage requirements of the selected polymer for the anticipated average solids concentration of the primary effluent suspension to be treated at the primary weir should be evaluated. This concentration was determined previously from past records or flocculent settling tests. The procedure is as follows:

(1) Fill six beakers with suspensions at the desired concentration of the fine-grained fraction of dredged material. Measure the suspended solids concentration and turbidity of the suspension.



JAR TEST REPORT FORM

TEST NO. \_\_\_\_\_ DATE \_\_\_\_\_ SAMPLE SOURCE \_\_\_\_\_

COAGULANT \_\_\_\_\_ DOSING METHOD \_\_\_\_\_ TURBIDITY \_\_\_\_\_ pH \_\_\_\_\_

CONC. \_\_\_\_\_ SALINITY \_\_\_\_\_ SS \_\_\_\_\_ TEMP \_\_\_\_\_

JAR NO.	1	2	3	4	5	6
RAPID MIX	RPM					
	TIME, SEC					
SLOW MIX	RPM					
	TIME, SEC					
POLYMER DOSE	mg/l					
	ml					
SAMPLE VOLUME	ml					
SETTLING TIME	MIN					
SUSPENDED SOLIDS AFTER SETTLING	mg/l					
TURBIDITY AFTER SETTLING	NTU'S					

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Figure E-3. Jar test report form

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(2) Mix at 100 revolutions per minute for 1 minute and then rapidly add the desired polymer dosage to each beaker. The range of dosages should be proportional to the solids concentration.

(3) Continue to follow the procedures outlined in steps (5) through (10) of E-4.a. Other suspensions with different solids concentrations may be examined in the same manner to determine the possible range of dosages required for the project and the possible range of effluent quality obtainable under conditions of variable primary effluent solids concentration to be treated.

d. Effects of Mixing. Other mixing conditions can be examined to determine the impact of low flow conditions and to evaluate whether the mixing is adequate. The effects of increasing the mixing by a Gt of 5,000 and 10,000 and of decreasing flow rate by 50, 75, and 90 percent on the polymer dosage requirements can be evaluated as follows:

(1) Calculate the new mixing intensity and duration.

(2) Fill six beakers with a suspension at the anticipated average solids concentration.

(3) Mix at 100 revolutions per minute for 1 minute and then rapidly add the desired polymer dosage to each beaker. Select a range of dosages surrounding the optimum dosage determined in the last set of experiments on the same suspension.

(4) Immediately adjust the mixing to the G value calculated in step E-2.a. for rapid mixing and mix for the calculated duration t .

(5) Follow the procedures outlined in steps (6) through (9) of E-4.a.

e. Effects of Settling Time. The effects of settling time on effluent quality can be examined as follows:

(1) Determine the range of settling time of interest, bearing in mind that the secondary basin will be hydraulically inefficient and the settling conditions will not be quiescent.

(2) Follow the procedures outlined in steps (3) through (9) of paragraph E-4.a., but adjust the settling time and sampling schedule to cover the range determined above.