

# DREDGED MATERIAL RESEARCH PROGRAM



TECHNICAL REPORT D-78-54

## DEVELOPMENT AND APPLICATION OF DESIGN AND OPERATION PROCEDURES FOR COAGULATION OF DREDGED MATERIAL SLURRY AND CONTAINMENT AREA EFFLUENT

by

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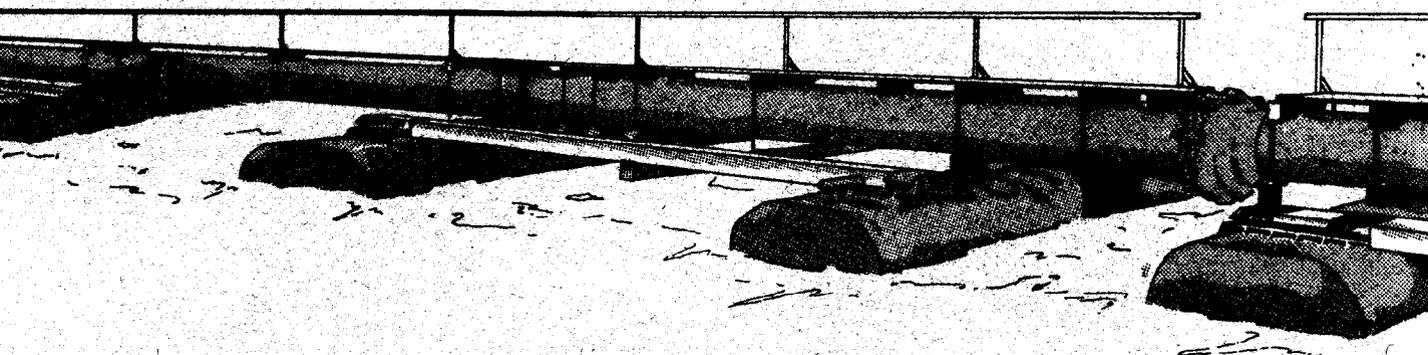
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SUBJECT: Transmittal of Technical Report D-78-54

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1. The technical report transmitted herewith represents the results of one research effort initiated in Task 6B (Treatment of Contaminated Dredged Material) of the Corps of Engineers' Dredged Material Research Program (DMRP). This task, included as part of the Disposal Operations Project of the DMRP, was concerned with evaluating physical, chemical, and/or biological methods for treating contaminated dredged material.
2. In recent years, there has been continued concern about the potential for adverse environmental impact of dredging and disposal operations on water quality and aquatic organisms. It became apparent during the planning phases of the DMRP that there could be situations where it might be necessary to treat contaminated dredged material or the effluent discharged from confined containment areas before it could be returned to open water. Therefore, Task 6B was initiated to meet this possible need.
3. Initial studies within Task 6B and other DMRP tasks indicated that most contaminants in effluents are associated with the solid phase of dredged material. Therefore, if solids could be effectively removed from the effluent, most water quality standards could be met. Laboratory studies within Task 6B indicated that the use of chemical flocculants was potentially a viable method for improving the solids removal from the effluents of containment areas. The study reported on herein was designed to determine the effectiveness of flocculants under field conditions, to develop guidelines for using flocculants in conjunction with a hydraulic pipeline dredge or in confined containment area operations, and to develop a laboratory testing procedure for evaluating the effectiveness of selected flocculants on a particular dredged material slurry.
4. The field work performed for this study indicated that flocculants can be used to increase the effective settling rate of solids suspended in dredged material slurry or effluent from confined containment areas.

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Although the application of flocculants at the effluent weir appears to provide a more effective means of treating the solids in dredged material, under certain circumstances it may be possible to inject flocculants directly into the pipeline to increase the degree of solids retention in the containment area, thereby producing an acceptable level of suspended solids in the effluent. Since the vast majority of potentially toxic chemical constituents are closely associated with the suspended solids, solids removal will also decrease the levels of heavy metals and petroleum and chlorinated hydrocarbons that may be present. Unfortunately, chemical coagulation usually requires a great deal of auxiliary equipment for mixing and storing the flocculants as well as additional settling basins when the effluent is treated at the weir.

5. This report is one of six technical reports addressing the treatment of contaminated dredged material. Other reports deal with laboratory treatability studies, oxygenation of dredged material slurry, oil and grease contamination, and the use of vegetation for treating discharged effluent. The results of all six studies are synthesized in Technical Report DS-78-14 entitled "Treatment of Contaminated Dredged Material."



JOHN L. CANNON  
Colonel, Corps of Engineers  
Commander and Director

Unclassified

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>The purpose of this study was to develop guidelines for the design of facilities to coagulate the overflow from a dredged material containment area. Pilot plant studies were conducted to study the efficiency of polyelectrolyte coagulation of overflow from a dredged material containment area at an active freshwater dredging site. Full-scale studies were conducted at the same site on the feasibility of coagulating dredged material by injecting polyelectrolytes into a hydraulic dredge pipeline.<br>Results of the pilot plant studies showed that, under the conditions tested, polyelectrolytes could be highly effective for coagulation of dredged material. Laboratory procedures were developed that can lead to the selection of the most effective coagulant, the optimum coagulant dosage, and the design parameters for a coagulation system. Examples are provided to illustrate procedures required to design<br>(Continued) |  |   |

20. ABSTRACT. (Continued).

a coagulation system for a containment area overflow.

Results of full-scale tests on the injection of polyelectrolytes into a hydraulic dredge pipeline were highly variable. The high mixing rates and variability of composition of dredged material and flow rates caused a wide variation in treatment efficiency. Design examples are provided for the design of polyelectrolyte feed systems to inject polymer into a hydraulic dredge pipeline.

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## PREFACE

This report presents the results of an investigation entitled "Development and Application of Design and Operational Procedures for Coagulation of Dredged Material Slurry and Containment Area Effluent." The report presents the results of experimental evaluation of the effectiveness of polyelectrolytes for increasing the settleability of the solids suspended in dredged material slurry and the effluent from upland containment areas. This report forms part of the Dredged Material Research Program (DMRP) conducted by the Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

The investigation was initiated by the Environmental Engineering Division (EED) of WES. The resulting data were analyzed and the final report prepared by Dr. Richard H. Jones (Jones, Edmunds and Associates, Inc., of Gainesville, Florida), and some input was provided by Mr. Randall R. Williams (EED of WES). The study was undertaken as part of Task 6B, Treatment of Contaminated Dredged Material, of the Disposal Operations Project (DOP) of the DMRP. The DOP manager was Mr. Charles C. Calhoun, Jr. The Task 6B manager, Mr. Thomas K. Moore, designed the study. The study was under the general supervision of Dr. John Harrison, Chief, EL.

Commanders and Directors of WES during the study and the preparation of the report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

## CONTENTS

|   | <u>Page</u> |
|---|-------------|
| PREFACE . . . . .   | 2           |
| LIST OF TABLES . . . . .  | 5           |
| LIST OF FIGURES . . . . .   | 6           |
| CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)<br>UNITS OF MEASUREMENT . . . . .    | 7           |
| PART I: INTRODUCTION . . . . .  | 8           |
| Background . . . . .  | 8           |
| Concepts of Dredged Material Coagulation Treatment.                                     | 9           |
| PART II: COAGULATION . . . . .  | 10          |
| Theory . . . . .  | 10          |
| Chemical Coagulants . . . . .   | 12          |
| Selection of a Coagulant . . . . .  | 14          |
| PART III: JAR TEST PROCEDURES . . . . .   | 16          |
| Need for Jar Tests . . . . .  | 16          |
| Equipment and Materials Needed . . . . .  | 16          |
| Procedures . . . . .  | 23          |
| PART IV: RESULTS OF A PILOT PLANT STUDY AT A FRESHWATER<br>DREDGE SITE . . . . .        | 42          |
| Procedure . . . . .   | 42          |
| Results . . . . .   | 44          |
| Conclusions . . . . .   | 54          |
| PART V: PIPELINE INJECTION OF POLYELECTROLYTES AT A<br>FRESHWATER DREDGE SITE . . . . . | 55          |
| Introduction . . . . .  | 55          |
| Procedure . . . . .   | 58          |
| Discussion of Results . . . . .   | 59          |
| PART VI: DESIGN OF POLYMER COAGULATION SYSTEMS . . . . .                                | 71          |
| Purpose . . . . .   | 71          |
| Polyelectrolyte Injection into a Hydraulic Dredge<br>Pipeline . . . . .                 | 71          |
| Polyelectrolyte Coagulation of Effluent from a<br>Confined Area . . . . .               | 83          |
| Design of Slow Mix Facilities . . . . .   | 88          |
| Design of Sedimentation Units . . . . .   | 90          |
| PART VII: CONCLUSIONS AND RECOMMENDATIONS . . . . .                                     | 93          |
| Conclusions . . . . .   | 93          |
| Recommendations . . . . .   | 93          |

CONTENTS  
(Continued)

|  | <u>Page</u> |
|--|-------------|
| REFERENCES . . . . .   | 95          |
| APPENDIX A: COAGULATION OF A DREDGED MATERIAL SUSPENSION<br>WITHIN A PIPELINE . . . . .            | A1          |
| APPENDIX B: REVIEW OF EQUIPMENT AVAILABLE FOR COAGULATION<br>AND SEDIMENTATION OF DREDGED MATERIAL | B1          |

LIST OF TABLES

| <u>No.</u> |   | <u>Page</u> |
|------------|---|-------------|
| 1          | Jar Test No. 1.....   | 27          |
| 2          | Jar Test No. 2.....   | 29          |
| 3          | Jar Test No. 3.....   | 29          |
| 4          | Potential Variation for Rapid Mix Conditions.....                           | 31          |
| 5          | Potential Variation for Slow Mix Conditions.....                            | 31          |
| 6          | Potential Variations in Coagulant Feed Concentration.....                   | 33          |
| 7          | Example Jar Test Results on Pipeline Slurry.....                            | 33          |
| 8          | Effect of Mixing Intensity on Clarification of a Pipeline<br>Slurry.....    | 36          |
| 9          | Effect of Time of Mixing on Clarification of a Pipeline<br>Slurry.....      | 36          |
| 10         | Chemical Analyses of Pilot Plant -- Test Run No. 1.....                     | 45          |
| 11         | Chemical Analyses of Pilot Plant -- Test Run No. 2.....                     | 47          |
| 12         | Chemical Analyses of Pilot Plant -- Test Run No. 3.....                     | 50          |
| 13         | Chemical Analyses of Pilot Plant -- Test Run No. 4.....                     | 52          |
| 14         | Run No. 2, Injection Port No. 2, Magnafloc 581-C.....                       | 61          |
| 15         | Run No. 3, Injection Port No. 1, Magnafloc 581-C.....                       | 64          |
| 16         | Run No. 4, Injection Port No. 6, Magnafloc 581-C.....                       | 67          |
| 17         | Run No. 6, Injection at Effluent, Upper Diked Area,<br>Magnafloc 581-C..... | 69          |

## LIST OF FIGURES

| No. |   | Page |
|-----|---|------|
| 1   | Two-Litre Beakers with Mixing Devices.....                                      | 18   |
| 2   | Sampling Devices.....   | 19   |
| 3   | Velocity Gradient Calibration Curves for Water.....                             | 21   |
| 4   | Jar Test Report Form.....   | 28   |
| 5   | Settling Zones.....   | 38   |
| 6   | Interface Height vs. Time.....  | 39   |
| 7   | Settling Curve Test No. 1.....  | 46   |
| 8   | Settling Curve Test No. 2.....  | 48   |
| 9   | Settling Curve Test No. 3.....  | 51   |
| 10  | Settling Curve Test No. 4.....  | 53   |
| 11  | Schematic Diagram of Dredging System and Sampling Points..                      | 57   |
| 12  | Dredged Material Settling Rates, Run No. 2, Sampling<br>Point No. 9.....        | 63   |
| 13  | Dredged Material Settling Rates, Run No. 3, Sampling<br>Point No. 9.....        | 66   |
| 14  | Dredged Material settling Rates, Run No. 4, Sampling<br>Point No. 9.....        | 68   |
| 15  | Dredged Material Settling Rates, Run No. 6, Sampling<br>Point No. 11.....       | 70   |
| 16  | Schematic Diagram of a Simple Liquid Polymer Feed System..                      | 75   |
| 17  | Schematic Diagram of a Single Tank Liquid Polymer Feed<br>System.....           | 76   |
| 18  | Schematic Diagram of a Two-Tank Liquid Polymer Feed System                      | 78   |
| 19  | Schematic Diagram of Liquid and Dry Polymer Feed System<br>Using Two Tanks..... | 79   |

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)  
UNITS OF MEASUREMENT

U. S. Customary units of measurement used in this report can be converted to metric (SI) units as follows:

| <u>Multiply</u>                 | <u>By</u>  | <u>To Obtain</u>                          |
|---------------------------------|------------|---|
| feet                            | 0.3048     | metres                                    |
| pound weight                    | 0.0020886  | poise                                     |
| second per square foot          |            |   |
| cubic feet                      | 0.02831685 | cubic metres                              |
| inches                          | 0.0254     | metres                                    |
| pounds                          | 453.5924   | grams                                     |
| gallons                         | 3.785412   | cubic decimetres                          |
| feet per second                 | 0.3048     | metres per second                         |
| square feet                     | 0.0929030  | square metres                             |
| cubic feet per second           | 0.02831685 | cubic metres per second                   |
| gallons per minute              | 3.785412   | cubic decimetres per minute               |
| gallons per square foot per day | 0.351676   | cubic decimetres per square metre per day |
| feet per minute                 | 0.02831685 | cubic metres per second                   |
| slug per cubic foot             | 0.5154     | grams per cubic centimetre                |

DEVELOPMENT AND APPLICATION OF DESIGN AND OPERATION PROCEDURES  
FOR COAGULATION OF DREDGED MATERIAL SLURRY  
AND CONTAINMENT AREA EFFLUENT

PART I: INTRODUCTION

Background

1. The purpose of this report is to provide guidelines for the design of facilities to coagulate the overflow from a dredged material containment area. Guidelines are also provided for the design of facilities to inject coagulant into a hydraulic dredge pipeline. The guidelines presented are applicable to the design of coagulation facilities to be installed at new or existing containment areas. Guidelines are presented for data collection and sampling requirements, description of testing procedures, design procedures, and operation and management procedures.

2. A general discussion is provided on the theory of coagulation, the various types of coagulants available, and consideration for selection of coagulants which might be tested on a particular dredged material. Laboratory procedures are described for selection of an optimum coagulant and for determining design criteria for coagulation facilities. Results of a pilot plant study on the coagulation of a dredged material confined area effluent are described. Results of a full-scale test of injection of a coagulant into an 18-in.-diameter hydraulic dredge pipeline are also described.

3. Design examples are provided for both coagulation of a dredged material confined area effluent and facilities for injecting a coagulant into a hydraulic dredge pipeline. Design examples include the application of laboratory data for developing design criteria for coagulant storage and feeding equipment, mixing equipment, and clarification facilities. This report does not contain information concerning the design of dredged material containment

areas, design of containment areas for storage of coagulated material, design of containment area dikes, or disposal area reuse management practices. Information concerning these subjects is available in other Dredged Material Research Program (DMRP) reports.

#### Concepts of Dredged Material Coagulation Treatment

4. Diked containment areas are used to store dredged material solids while allowing the water to overflow to the body of water from which the material was dredged. Palermo et al.<sup>1</sup> state that a well designed containment area for fine-grained material may have an effluent suspended solids concentration of from 1000 to 2000 mg/l. In many cases the effluent suspended solids may be many times higher than that from a well designed containment area. Effluent concentrations of these magnitudes may violate State or Federal Water Quality Regulations; therefore, further treatment may be required.

5. The suspended solids in the effluent from a confined area are usually the fine particles which do not readily settle out by gravity. These fine particles may be coagulated by a number of different chemicals which bring them together into a dense mass that will settle. Wang and Chen<sup>2</sup> have evaluated a number of coagulants and determined some of them to be effective for clarification of dredged material. Coagulants may be added directly to a hydraulic dredge pipeline to increase the settling rate within the containment area or added to the effluent from the containment area after the majority of solids have settled out. Efficient coagulation requires optimum chemical concentrations and mixing conditions for floc formation. This report describes procedures required to develop optimum design criteria for full-scale coagulation facilities.

## PART II: COAGULATION

### Theory

6. Dredged material may be composed of any number of different inorganic or organic materials. The portion of dredged material which will not readily settle is usually composed of small colloidal particles which do not settle easily because of their small size or because of the presence of particles with a specific gravity very close to that of the carrying water. The coagulation process is one that causes small particles to agglomerate into larger particles or floc which are of a sufficient size and density to settle. The terms "coagulation" and "flocculation" are to be found in the chemical and engineering literature with different interpretations associated with them. LaMer<sup>3</sup> has defined coagulation as destabilization produced by reduction of the electric charge on a colloidal particle, while flocculation refers to destabilization by the absorption of a portion of a large organic polymer and the subsequent formation of particle-polymer-particle bridges. In this report the terms will be used interchangeably.

7. Colloidal particles in an aqueous system may not come together naturally because of two phenomena, electrical charge and hydration. It has been found that colloidal particles in an aqueous system almost always carry a negative charge. To maintain a net electrical charge of zero, the primary charge of the particle is surrounded by a diffused layer of ions of opposite charge. When two particles having the same charge approach each other they are repelled by their like charge. This is the primary reason for particle stabilization in an aqueous system.

8. A secondary reason for particle stabilization is hydration. Due to the unique properties of water, a charged colloidal particle changes the orientation of water dipoles in its electric field. In such a "solvation shell," the degree of orientation of the dipoles will gradually decrease with increasing distance from the charged surface. It is theorized that the oppositely oriented water dipoles

surrounding a colloidal particle repel each other as particles approach one another. The theory of colloidal particles stabilization is complex and discussed in more detail by Hill<sup>4</sup>, Jones<sup>5</sup>, and Weber<sup>6</sup>.

9. Colloidal particles can be made unstable and to agglomerate into larger particles or floc by several methods as discussed by Weber<sup>6</sup>. These are:

- a. Compression of the diffused layer surrounding a colloid.
- b. Adsorption onto the colloid to produce charge neutralization.
- c. Enmeshment in a precipitate.
- d. Adsorption to permit interparticle bridging.

10. The first method, compression of the diffuse layer surrounding a colloid, occurs when concentrations of ions of opposite charge concentrate around the charged particle, reducing the size of the diffuse layer. All particles have attractive forces, called van der Waal's forces, which cause particles to agglomerate once they are able to come close to one another after the reduction of the diffuse layer. Reduction of the diffuse layer may be caused by monovalent, divalent, or trivalent ions such as  $\text{Na}^+$ ,  $\text{Ca}^{++}$ , or  $\text{Al}^{+++}$ .

11. During the late 1800's and early 1900's, Schulze and Hardy conducted quantitative studies of this destabilization process. Their work led to what is now called the Schulze-Hardy Rule which states that coagulation is caused by ions having an opposite charge to that of the colloidal particles and that the coagulating power of an ion significantly increases with its valence. Quantitatively, the Schulze-Hardy Rule states that a bivalent ion is approximately 30 to 60 times more effective than a monovalent ion and a trivalent ion is 700 to 1000 times more effective than a monovalent. Compression of the diffuse layer by an electrolyte explains why brackish water or estuary systems are nutrient sinks because the small particles in fresh water tend to be coagulated in the more saline system and settle out.

12. The second method of particle destabilization, adsorption to produce charge neutralization, is caused by the actual adsorption of an oppositely charged ion or particle. Although it would appear that aluminum and iron compounds would cause destabilization by reduction of the diffuse layer by  $\text{Al}^{+++}$  and  $\text{Fe}^{+++}$  ions, the fact is that such simple species as  $\text{Al}^{+++}$  and  $\text{Fe}^{+++}$  do not exist in a natural aqueous environment<sup>6</sup>. Rather, these ions react with water to form complexes such as  $\text{Al}(\text{H}_2\text{O})_6^{+++}$  and  $\text{Fe}(\text{H}_2\text{O})_6^{+++}$ . These complexes are adsorbed on colloidal particles causing destabilization and coagulation. The same method of destabilization may be caused by natural or synthetic polymers, which will be discussed later in this section.

13. The third method of destabilization, enmeshment in a precipitate, occurs when a metal salt such as  $\text{Al}_2(\text{SO}_4)_3$ ,  $\text{FeCl}_3$ ,  $\text{CaO}$ , or  $\text{Ca}(\text{OH})_2$  is used in sufficient concentrations to cause the precipitation of a metal hydroxide. Colloidal particles can be enmeshed in the resulting metal hydroxides and removed by settling.

14. Adsorption to permit interparticle bridging is the fourth method of particle destabilization. Interparticle bridging results when one end of a polymer adsorbs onto a colloidal particle and another portion of the polymer adsorbs onto another particle in effect bridging between the two particles. Polymers will be discussed in a later section of this report.

## Chemical Coagulants

### Inorganic Coagulants

15. The effectiveness of trivalent ions has led to the use of iron and aluminum salts as the primary inorganic chemicals used as coagulants. Aluminum sulfate, ferric chloride, and ferric sulfate are the primary coagulants used for the treatment of surface water for public drinking water supplies. These chemicals are potentially useful for coagulation of dredged material.

16. Inorganic coagulants have a pH range for optimum coagulation. The pH of a dredged material may have to be adjusted for optimum efficiency; therefore, the cost involved may necessitate the selection of another type of coagulant.

17. This optimum pH for a particular inorganic coagulant is dependent upon the chemical composition of the dredged material and the concentration of colloids to be removed. Jar test procedures are described in Part III of this report which defines the procedure required for selecting the most effective coagulant.

18. Wang and Chen<sup>2</sup> have conducted laboratory studies on various coagulants to determine which are effective for coagulating dredged material. Although most of their studies were conducted on brackish water, Wang and Chen concluded that, due to the necessity for pH control and the high dosage requirements for inorganic chemicals, only polymers should be considered for coagulating dredged material. Because of the study by Wang and Chen, the Corps of Engineers eliminated inorganic chemicals from consideration in this investigation and all of the data reported are based on the use of polyelectrolytes.

19. Inorganic chemicals, such as aluminum or iron salts, should not be eliminated from consideration, but should be considered along with the many polyelectrolytes available for coagulation of dredged material from freshwater systems.

#### Polymers

20. A polymer is made up of small subunits or monomers linked into a chain. Many polymers occur naturally, such as starch; however, synthetic polymers are finding the widest use in coagulation processes. Synthetic polymers may be of a simple structure containing only one kind of monomer, while others are more complex containing two or more recurring monomer units. The total number of subunits can be varied, producing material of different molecular weight. Polymer chains may be linear or may be branched to varying degrees. If a monomeric unit in a polymer contains ionizable groups (i.e. carboxyl, amino or sulfonic groups) the polymer is termed a polyelectrolyte. A polyelectrolyte may be termed cationic, anionic, or ampholytic

(containing both positive and negative groups) depending upon the type of ionizable groups on the monomeric unit. Polymers without ionizable groups are termed nonionic.

21. All of the monomers in a polyelectrolyte do not necessarily ionize. For example, a polymer comprised of a number of acrylamide groups may have only a small portion of the groups hydrolyzed to an acrylic acid group. Therefore, the negative charge depends upon the degree of hydrolysis.

22. The ability of an anionic polymer to flocculate a negatively charged colloid can be explained by its ability to form a bond between the functional group of the polymer and a specific site on the colloid. This is in spite of the fact that the polymer and colloid have like negative charges and repel each other.

23. Positively charged (cationic) polymers can function as destabilizing agents by charge neutralization of negatively charged colloids, by bonding between the polymer and colloid, or both. Cationic polyelectrolytes appear to hold the best potential for coagulation of dredged material in freshwater systems. In brackish or seawater systems the presence of monovalent or divalent cations can reduce the negative charges on colloids making anionic as well as cationic polyelectrolytes potentially effective.

#### Selection of a Coagulant

24. Theories of colloid destabilization are not sufficiently developed to allow the selection of the optimum coagulant or coagulant dosage without experimentation. This experimentation is in the form of jar tests, which are described in detail in the next section of this report. Because of the large number of available coagulants, it would be impossible to conduct jar tests on all of them.

25. A small number of coagulants should be selected as potentially effective and jar tests conducted to select the most effective from those tested. There are no guidelines available on

how to select coagulants that may be effective on a particular dredged material. It is recommended that a chemical analysis of the material to be coagulated be obtained. This information should be supplied to coagulant manufacturers and experts in the field of coagulation. They will be able to assist in the selection of potentially effective coagulants to be evaluated by jar tests.

26. One point that should not be overlooked is that although some coagulants are approved for use in the treatment of drinking water, certain polymers may be eliminated from consideration for dredged material coagulation because of a potentially harmful effect on the environment. The manufacturer of a coagulant should be requested to supply data on any potential problems that might arise from the use of a product.

## PART III: JAR TEST PROCEDURES

### Need for Jar Tests

27. Jar tests have been used for a number of years to evaluate the efficiency of various chemicals for coagulation of surface water for public and industrial use. However, the procedures for conducting jar tests and evaluating the results have been more an art than a science. Hudson and Scigley<sup>7</sup> and Black et al.<sup>8</sup> have outlined procedures for conducting jar tests; yet after reviewing these references on jar test procedures, it would be very difficult for one not having past experience to effectively conduct jar tests on dredged material.

28. The following discussion of jar test procedures is meant to be only a guide for the investigator. Each site will require the investigator to modify the jar test procedure to take into consideration certain conditions that are site specific. It is recommended that if the investigator is not familiar with jar test procedures assistance should be obtained.

29. When properly conducted, jar tests can provide many of the major parameters necessary for the design of full-scale treatment facilities. These parameters include the following:

- a. Most effective coagulant.
- b. Optimum dosage of coagulant.
- c. Optimum feed concentration of coagulant to be utilized.
- d. Optimum G value (mixing intensity) for each mixing basin.
- e. Optimum detention time in each mixing basin.
- f. Chemical cost.

### Equipment and Materials Needed

30. There is a minimum amount of laboratory equipment required to properly conduct jar tests. The following list of equipment is a generalized list giving the major equipment required.

- a. Two-litre beakers as shown in Figure 1.
- b. Phipps and Bird jar test machine or equivalent.
- c. Variable-speed laboratory mixer (0 to 500 rpm).
- d. Mechanism for injecting coagulant and removing samples (Figure 2).
- e. Equipment used for testing turbidity and other analyses as desired.
- f. Coagulants to be tested.
- g. Laboratory glassware, timer, etc.

### Mixing Equipment

31. The intensity of agitation required in the coagulation process is expressed in terms of a measured mean velocity gradient  $G$  defined by Camp<sup>9</sup> as

$$G = \sqrt{\frac{W}{\mu}}$$

where  $W$  is the rate of power dissipation per unit volume and  $\mu$  is the absolute viscosity of the fluid. To illustrate the meaning of the term "velocity gradient"; if two particles of fluid in a tank are 0.1 ft apart ( $d$ ), and one is moving with a speed of one fps ( $\Delta v$ ) relative to the other, the velocity gradient between them is  $\frac{\Delta v}{d} = 10$ . Velocity gradients can be calculated from the following equations. For baffled basins,

$$G = \sqrt{\frac{62.4 H}{\mu t}}$$

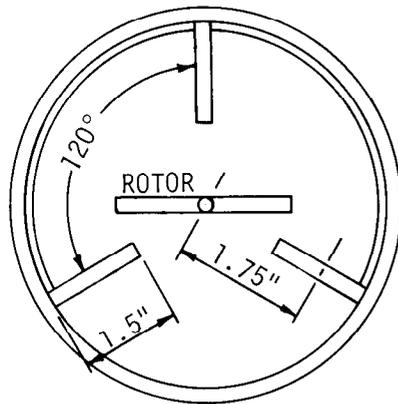
and for mechanical agitation,

$$G = \sqrt{\frac{550 P}{V \mu}}$$

in which  $G$  = the velocity gradient in fps per ft;  $H$  = head loss due to friction (in ft);  $\mu$  = viscosity ( $0.273 \times 10^{-4}$  lb-sec/SF @ 50°F);  $t$  = detention time (in sec);  $V$  = volume of basin in ft<sup>3</sup>; and  $P$  = mixing horsepower.

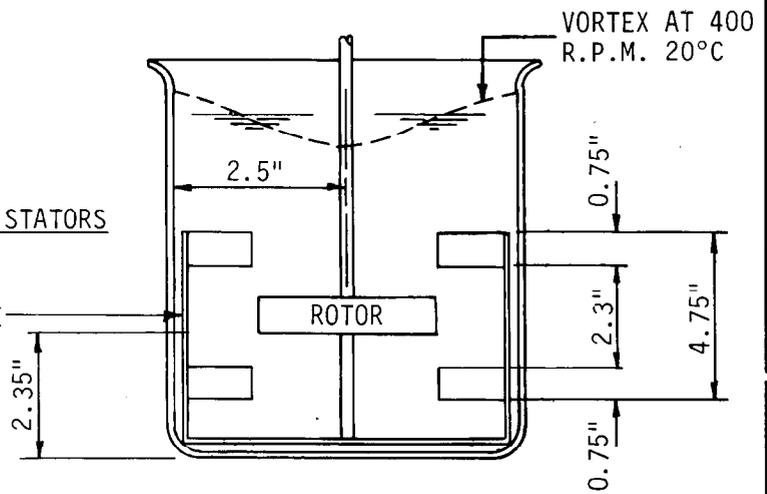
32. Accurate value of  $W$  in jar tests can be determined by measuring the torque input to the liquid at various speeds. The value of  $W$  will vary with temperature because of the change in the

PLAN VIEW  
TWO-LITRE BEAKER WITH STATORS



FRONT VIEW  
TWO-LITRE BEAKER WITH STATORS

STATORS ON WIRE FRAME



FRONT VIEW  
TWO-LITRE BEAKER WITHOUT STATORS

MAXIMUM VORTEX  
AT ABOUT 320 R.P.M.

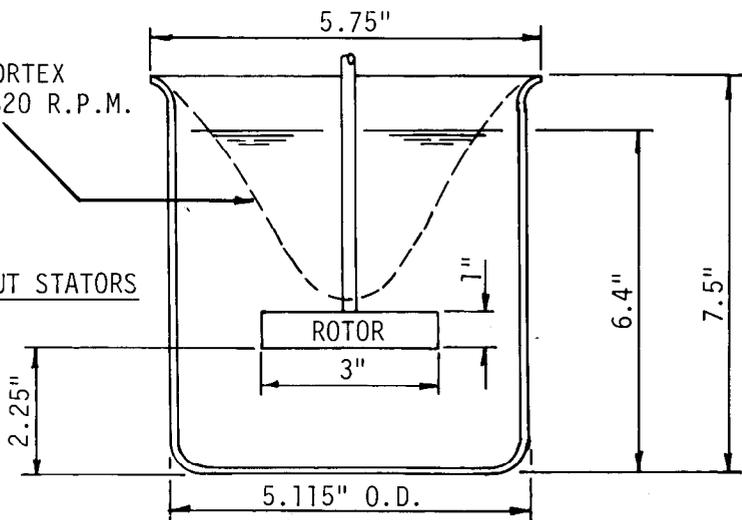
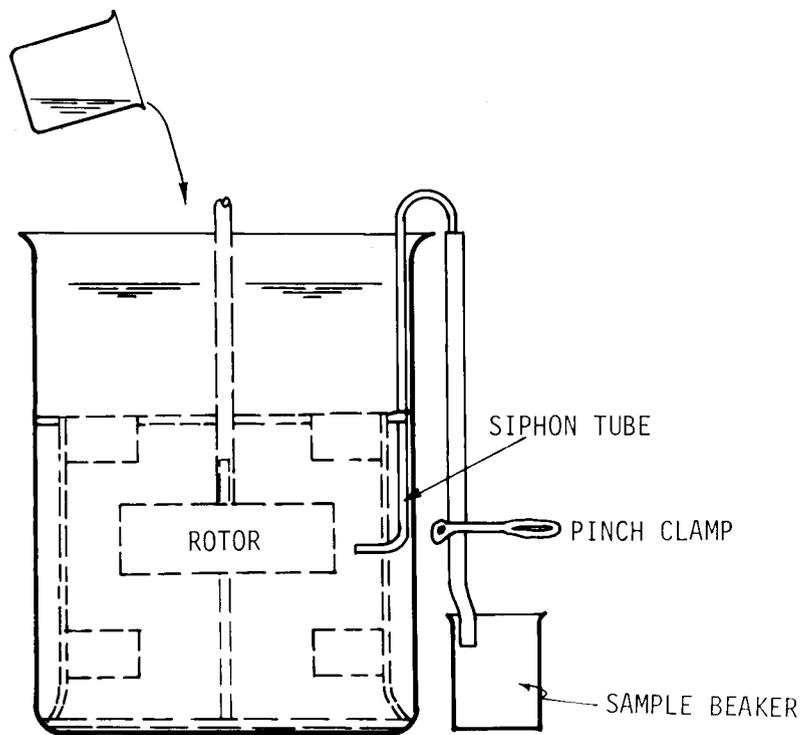
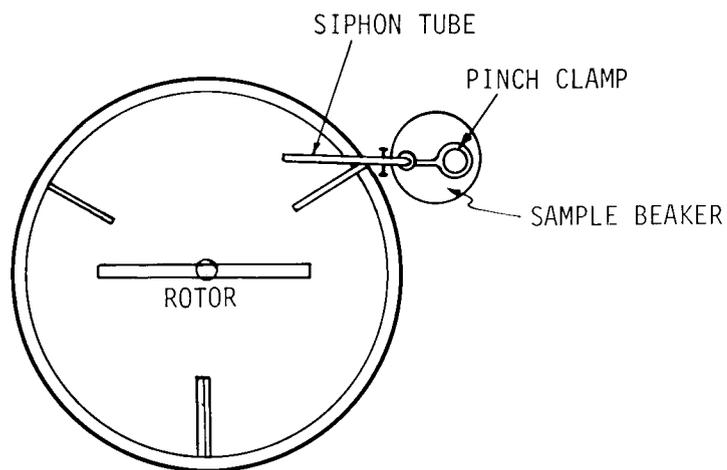


FIGURE 1. TWO-LITRE BEAKERS WITH MIXING DEVICES



FRONT VIEW



TOP VIEW

FIGURE 2. SAMPLING DEVICES

viscosity of the fluid with varying temperature. The formula for calculating  $W$  is:

$$W = \frac{2\pi ST}{V}$$

in which  $S$  is the measured rotor speed in rps;  $T$  is the measured torque input in ft-lbs; and  $V$  is the liquid volume. The viscosity of a fluid at various temperatures may be found in a publication by Vernard<sup>10</sup>.

33. Camp<sup>9</sup> has prepared calibration curves (see Figure 3) plotting  $G$  versus agitator rpm at different liquid temperatures for the mixing equipment shown in Figure 1. The benefit of the stators is to produce higher velocity gradients with lower mixer speeds relative to a beaker where no stators are used. The stators also reduce the rotation of the liquid in the beakers after mixing is completed and settling has begun. Similar calibration curves, as shown in Figure 3, for other mixing equipment may be found in a paper by Lai et al.<sup>11</sup>

#### Coagulants

34. Coagulants have been discussed briefly in Part II of this report. The major chemicals utilized for water treatment have been aluminum or iron salts. Polyelectrolytes have come into use in the last several years and are being used in a number of installations. The jar test procedure described herein is suitable for inorganic coagulants as well as the hundreds of different types of polyelectrolytes. Because most of the research on coagulation of dredged material has been conducted using polyelectrolytes, the emphasis in this section is on these types of coagulants.

#### Temperature

35. Temperature affects several variables in jar testing, including viscosity, and should be controlled in precise work. If possible, jar tests should be conducted on dredged material that has the same temperature or range of temperatures as will be experienced during the operation of full-scale facilities. In many cases this will not be possible; however, the design engineer should consider the effects of temperature in the design of treatment facilities.

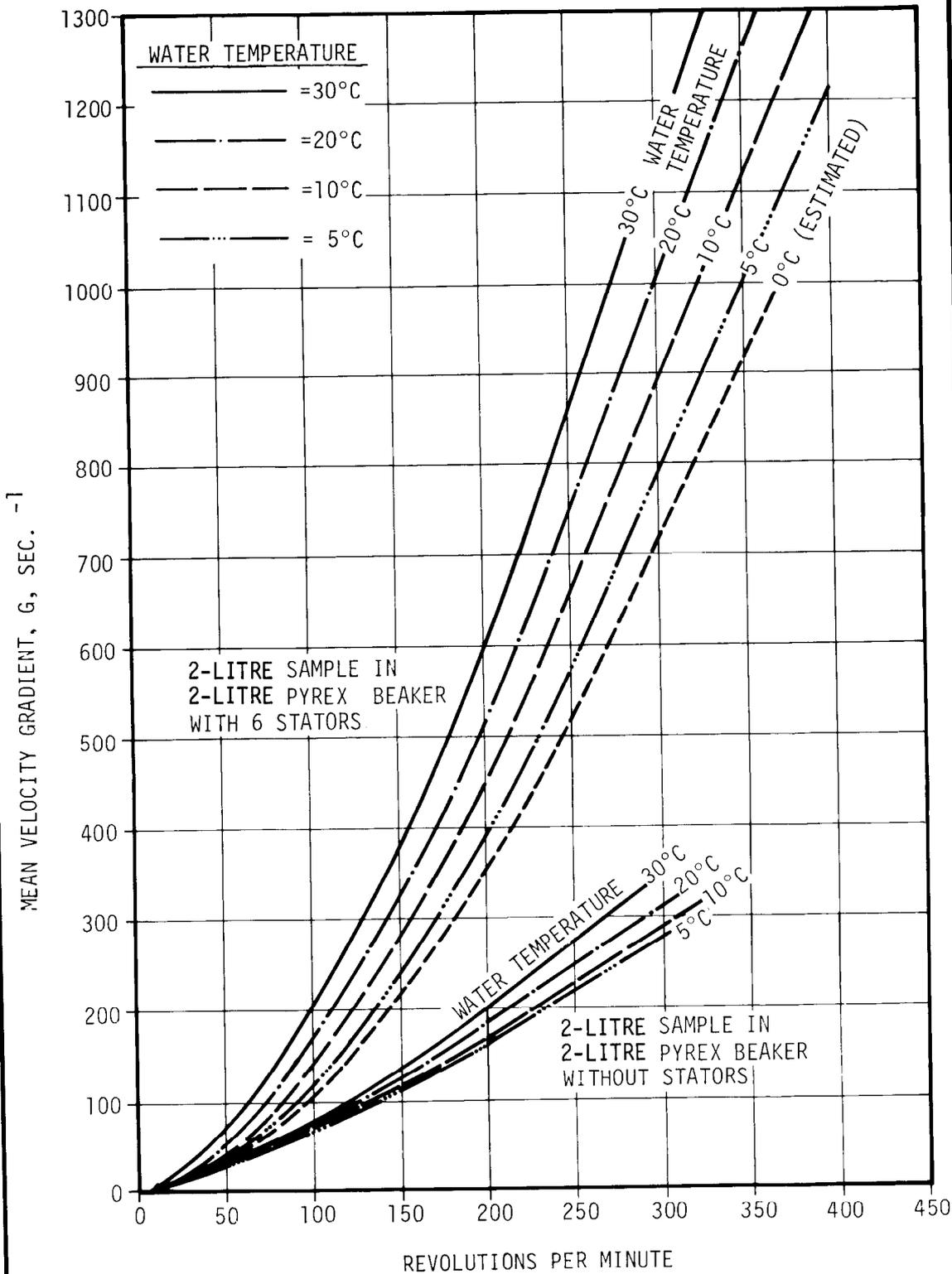


FIGURE 3. VELOCITY GRADIENT CALIBRATION CURVES FOR WATER

### Coagulant Concentration

36. Manufacturers often recommend a polyelectrolyte concentration that is normally most effective. However, in addition to the recommended polyelectrolyte concentration, both higher and lower concentrations should be tested to determine the effects of polymer concentrations on treatment efficiency. There is little information available on the effect of polyelectrolyte concentration on treatment efficiency, partially because of the lack of data on polyelectrolyte treatment of dredged material. Field experience has shown that when the concentration of a polyelectrolyte is excessive, the polymer dosage required may be increased significantly.

### Coagulant Addition

37. The coagulant concentration to be tested should be prepared. The exact dosage of polymer to be added should be measured out in 50-ml or 100-ml beakers or graduated cylinders for addition to all 2000-ml beakers simultaneously. The polymer dose should be added at a controlled rate over a period of two or three seconds rather than being poured in at one time. The small beakers or cylinders will make it much easier to add polymer to all of the 2000-ml beakers at one time.

### Intensity and Duration of Mixing

38. The optimum intensity and duration of mixing, whether in a rapid mix or slow mix basin, depends upon a wide range of factors. These include the type of polymer (cationic, anionic, or nonionic), the characteristics of the dredged material to be treated, and the ionic concentration of the water being treated. Almost all of the information in the literature concerning the effect of intensity and duration of mixing has been developed through research on surface waters coagulated with iron or aluminum salts. The addition of iron or aluminum salts requires an initial flash mixing process because they react almost instantly with water to form complex ions. Polyelectrolytes, however, do not react with water in the same manner, but do require sufficient initial mixing to be rapidly dispersed throughout the solution.

39. The intensity and duration of mixing required for the design of full-scale facilities must be determined from jar tests and/or pilot plant tests. Once polymer has been adsorbed onto a colloidal particle the growth of floc particles depends upon the rate of particles colliding. The rate that particles collide is a function of the mean velocity gradient  $G$ , the number of particles in suspension, and the size of the particles. It would appear from initial examination that by increasing the mean velocity gradient, the detention time for adequate floc formation could be reduced. However, as floc particles increase in size they become more susceptible to shear and breakup. If the mean velocity gradient is too high, the floc will be unable to increase beyond a limiting size. If the floc is not of a size and density to settle at a sufficiently rapid rate, the efficiency of the process will be reduced.

40. Normally, the mixing process required prior to clarification is divided into at least two stages, a period of rapid mixing and a period of slow mixing. The period of rapid mixing is utilized to quickly disperse the polymer throughout the solution and build up small floc particles as rapidly as possible. A period of slow mixing follows rapid mixing and completes the process of floc formation. In the use of polymer injection into a hydraulic dredge pipeline, only one rate of mixing will be considered. The  $G$  and  $t$  of any pipeline can be calculated (Appendix A) from the pipe diameter and length, velocity, Reynold's number, friction head loss, density, and absolute viscosity. In the jar test procedure for confined area overflow, once the polymer dose has been determined, it is then necessary to vary the intensity and duration of mixing to determine the most effective mixing conditions to be used, as well as the effects on the polymer dose previously determined.

## Procedures

### Jar Test Procedure

41. The preceding general discussion indicates the large number of combinations of parameters which could be evaluated. By

proceeding in a step-by-step manner, the investigator should be able to narrow the variables of running jar tests and begin to develop the required design parameters. Individual investigators may vary the procedures as necessary to simulate the particular field conditions encountered.

42. Jar tests should be run using samples from an existing operation or from samples prepared from sediment collected from a new construction or future maintenance dredging site. If samples can be collected from an existing containment area discharge, then a sufficient number of samples must be collected and jar tests run to cover the complete range of dredged material expected to be handled. If jar tests are to be conducted on material from a future maintenance dredging or construction site, then sediment samples must be collected of each representative material to be dredged.

43. Two separate types of jar test procedures will be discussed in this section: (1) jar tests required for coagulation of effluent from upland containment areas; and (2) jar tests required to determine design parameters for coagulant injection into a hydraulic dredge pipeline. The quantity of material which is required to conduct a complete series of jar tests to evaluate just one coagulant on one type of dredged material is significant. For example, as much as 50 lbs of each type of dredged material expressed on a dry weight basis may be required to conduct jar tests where a coagulant will be injected into a dredge pipeline. As much as 50 lbs may be required of each type of dredged material to conduct jar tests where a coagulant will be used to treat the overflow from a proposed confined area.

44. Once a sufficient quantity of material has been collected, then a sufficient volume of material must be prepared for conducting jar tests. For jar tests to be conducted on a pipeline slurry, it is recommended that slurry be prepared in three separate solids concentrations of 5, 10, and 20 percent by weight by diluting with water from the dredge site. The use of 55-gallon drums with mixers

is recommended for preparing the required suspensions and maintaining a homogeneous sample throughout the jar test series.

45. Suspensions representing effluent from a confined area can also be made in 55-gallon drums. Sufficient dredged material should be placed into each drum and diluted with site water so that the completely mixed samples have a solids concentration of approximately 10.0 to 15.0 percent by weight. The mixer should be turned off and the slurry allowed to settle until the supernatant suspended solids concentration is approximately that expected in the effluent of the confined area. Guidelines for estimating suspended solids levels in the effluent from containment areas are given by Palermo et al.<sup>1</sup> The suspended solids in the effluent of a well designed confined area can generally be expected to be from 1000 to 2000 mg/l. Once the material has settled, the supernatant should be decanted and stored for further use. After a sufficient volume of sample has been prepared, it is then necessary to determine if a particular coagulant is effective and if so, at what dosage.

#### Procedure for Confined Area Overflow

46. The first procedure to be discussed is the procedure for confined area overflow. For overflow from a confined area the jar test machine is set up with six two-litre beakers. Each beaker should be baffled as shown in Figure 1. Each of the beakers should be filled with two litres of sample. The selected coagulant is diluted to the recommended concentration according to the manufacturer's specifications and the doses to be tested are added to each of five beakers. The jar test machine has six stirrers, one of which will be used as a blank with no coagulant added. The varying dosages of coagulant are added to the beakers simultaneously as previously discussed. The coagulant is added over a two to three second time period and the small beakers rinsed with a small amount of water. The jar test machine should be mixing throughout this period and the initial rpm should be at least 100. For cationic polyelectrolytes, it is recommended that an initial rapid mixing of 100 rpm for 10 minutes be used, followed by 20 minutes of slow mixing at 20 rpm and finally 30 minutes of quiescent settling. For anionic polyelectrolytes, a rapid mix time of five minutes and

a slow mix time of 20 minutes followed by 30 minutes settling may be more appropriate. These mixing rates should only be considered as a starting point as different coagulants may require more or less agitation (both intensity and duration) to perform most effectively.

47. While the jar tests are being conducted, visual observations should be made to note the rate of floc formation, the strength of the floc, and the relative clarification within each jar. At the completion of the jar test a visual examination and turbidity analyses should be made to determine which particular coagulant dosage appears to be most effective. As an example, the coagulant dosages and the results shown in the abbreviated Table 1 may be used. Complete data should be recorded for each jar test in a table similar to that shown in Figure 4.

48. An examination of the data in Table 2 indicates the most effective polymer dosage to be 22 mg/l. However, another series of jar tests should be run using polymer dosages between 19 and 25 mg/l. The results of the third jar test could be as shown in Table 3.

49. The results of the third jar test show that excellent clarification can be achieved under the mixing conditions tested with a polymer dosage of approximately 21.5 mg/l. Keep in mind, however, that the most effective polymer dosage may not be the most economical. A dosage sufficient to meet the effluent limitations is sufficient.

50. Each of the coagulants to be tested must be evaluated in this same manner to determine if they are effective and at what dosage. The coagulants should then be evaluated further to determine the effect of varying mixing time and intensity on their efficiency. Keep in mind that the use of only one set of mixing conditions may appear to eliminate a coagulant which might be effective under a completely different set of conditions. Therefore, when evaluating coagulants, the effect of both mixing and dosage must be evaluated to determine efficiency.

51. Assume that the jar tests proceed utilizing the same coagulant dosages as shown in jar test No. 3 to determine the effect of intensity and duration of mixing. There are an infinite number

Table 1

Jar Test No. 1: Rapid Mix, 100 rpm for 10 Minutes;  
Slow Mix, 20 rpm for 20 Minutes; Settling  
Quiescent for 30 Minutes

| <u>Jar Number</u> | <u>Coagulant Dosage<br/>(mg/l)</u> | <u>Residual Turbidity<br/>(NTU)</u> |
|-------------------|------------------------------------|-------------------------------------|
| 1                 | 0                                  | 3000                                |
| 2                 | 5                                  | 2500                                |
| 3                 | 10                                 | 2000                                |
| 4                 | 15                                 | 900                                 |
| 5                 | 20                                 | 200                                 |
| 6                 | 25                                 | 1000                                |

JAR TEST REPORT FORM

TEST NO. \_\_\_\_\_ JAR TEST EQPT. \_\_\_\_\_ SAMPLE SOURCE \_\_\_\_\_  
 DATE \_\_\_\_\_ DOSING METHOD \_\_\_\_\_ TURBIDITY \_\_\_\_\_ pH \_\_\_\_\_  
 COAGULANT \_\_\_\_\_ CONC. \_\_\_\_\_ SAMPLING METHOD \_\_\_\_\_ SS \_\_\_\_\_ TEMP. \_\_\_\_\_

| JAR NO.                   | 1          | 2 | 3 | 4 | 5 | 6 |
|---------------------------|------------|---|---|---|---|---|
| RAPID MIX                 | RPM        |   |   |   |   |   |
|                           | TIME, MIN. |   |   |   |   |   |
| SLOW MIX                  | RPM        |   |   |   |   |   |
|                           | TIME, MIN. |   |   |   |   |   |
| POLYMER DOSE              | mg/L       |   |   |   |   |   |
|                           | ml         |   |   |   |   |   |
| RESIDUAL TURBIDITY        | NTU        |   |   |   |   |   |
|                           | %          |   |   |   |   |   |
| FLOC FORMATION            |            |   |   |   |   |   |
| RELATIVE CLARIFICATION    |            |   |   |   |   |   |
| RELATIVE SETTLING RATE    |            |   |   |   |   |   |
| RESIDUAL SUSPENDED SOLIDS | mg/L       |   |   |   |   |   |
|                           | %          |   |   |   |   |   |

COMMENTS \_\_\_\_\_

FIGURE 4. JAR TEST REPORT FORM

Table 2

Jar Test No. 2: Rapid Mix, 100 rpm for 10 Minutes;  
Slow Mix, 20 rpm for 20 Minutes; Settling,  
Quiescent for 30 Minutes

| <u>Jar Number</u> | <u>Coagulant Dosage<br/>(mg/l)</u> | <u>Residual Turbidity<br/>(NTU)</u> |
|-------------------|------------------------------------|-------------------------------------|
| 1                 | 10                                 | 2000                                |
| 2                 | 13                                 | 1200                                |
| 3                 | 16                                 | 800                                 |
| 4                 | 19                                 | 250                                 |
| 5                 | 22                                 | 30                                  |
| 6                 | 25                                 | 1000                                |

Table 3

Jar Test No. 3: Rapid Mix, 100 rpm for 10 Minutes;  
Slow Mix, 20 rpm for 20 Minutes; Settling,  
Quiescent for 30 Minutes

| <u>Jar Number</u> | <u>Coagulant Dosage<br/>(mg/l)</u> | <u>Residual Turbidity<br/>(NTU)</u> |
|-------------------|------------------------------------|-------------------------------------|
| 1                 | 20                                 | 200                                 |
| 2                 | 21                                 | 75                                  |
| 3                 | 21.5                               | 8                                   |
| 4                 | 22                                 | 30                                  |
| 5                 | 22.5                               | 75                                  |
| 6                 | 23                                 | 150                                 |

of variations in mixing time and intensity which could be evaluated. To reduce the variables to a realistic number, it is assumed in this example that two-stage mixing will be utilized in the full-scale system; i.e. a rapid mix stage and a slow mix stage. It is further assumed: (1) the total mixing time for both rapid and slow mixing will be a maximum of 60 minutes; (2) the maximum rapid mix time will be 15 minutes; (3) the approximate maximum mixing intensity will be a G of  $400 \text{ sec}^{-1}$ ; and (4) the approximate minimum slow mix intensity will be a G of  $30 \text{ sec}^{-1}$ .

52. The above assumptions may not apply to all situations as the investigator must make judgment decisions as the jar tests proceed. However, based on the above assumptions, jar tests could be conducted under the conditions of mixing intensity and duration as shown in Table 4. With experience the investigator can significantly reduce the amount of time required to conduct jar tests if the variables are understood. For instance, the required duration of rapid mix may become obvious if a strong floc which has adsorbed all of the colloidal particles is formed within a few minutes, but will not increase in size because of the mixing intensity. The rate and duration of the slow mix may also become obvious when large floc are formed and begin to settle leaving a clear supernatant.

53. Assume that jar test Nos. 4 through 9 were conducted and it was determined by evaluation of the data collected that a coagulant dosage of 22 mg/l and rapid mixing at 100 rpm for 10 minutes gave the best results. Further jar tests must be conducted with the same polymer dose and rapid mixing rates while varying the slow time and rate as shown in Table 5.

54. Each of the coagulants must be evaluated in the same manner as described above. When all of these jar tests are completed, the coagulant can be selected which is most effective, has a relatively low cost, produces a strong floc, and settles well under a range of mixing conditions.

55. Having selected the most effective coagulant and optimum dose, the effect of the polymer feed concentration on its efficiency

Table 4  
Potential Variation for Rapid Mix Conditions

| Jar Test No.<br>(Coagulant Dose Varied<br>from 20 to 23 mg/l) | Rapid Mix          |                       | Slow Mix           |                       |
|---|--------------------|-----------------------|--------------------|-----------------------|
|   | Intensity<br>(rpm) | Duration<br>(minutes) | Intensity<br>(rpm) | Duration<br>(minutes) |
| 4*  | 160                | 5                     | 20                 | 30                    |
| 5   | 160                | 10                    | 20                 | 30                    |
| 6   | 160                | 15                    | 20                 | 30                    |
| 7   | 100                | 5                     | 20                 | 30                    |
| 8   | 100                | 10                    | 20                 | 30                    |
| 9   | 100                | 15                    | 20                 | 30                    |

\* Each jar test to be conducted using six jars.

Table 5  
Potential Variations for Slow Mix Conditions

| Jar Test No.<br>(Coagulant Dose Equal<br>to 22 mg/l) | Rapid Mix          |                       | Slow Mix           |                       |
|--|--------------------|-----------------------|--------------------|-----------------------|
|  | Intensity<br>(rpm) | Duration<br>(minutes) | Intensity<br>(rpm) | Duration<br>(minutes) |
| 10*  | 100                | 10                    | 30                 | 10                    |
| 11   | 100                | 10                    | 30                 | 20                    |
| 12   | 100                | 10                    | 30                 | 30                    |
| 13   | 100                | 10                    | 40                 | 10                    |
| 14   | 100                | 10                    | 40                 | 20                    |
| 15   | 100                | 10                    | 40                 | 30                    |

\* Since all jars will have same coagulant dosage, six jars are not required.

needs to be determined. Further jar tests which should be conducted could have the following conditions: holding the rapid mix at 100 rpm for 10 minutes, and slow mixture at 20 rpm for 20 minutes. The coagulant dosage would be varied from 20 to 23 mg/l in each test as shown in Table 6.

56. Results of these tests will determine if there is any effect of coagulant feed concentration on the dosage of coagulant required and efficiency. Throughout the jar test procedure, when a significant effect is noted it may be necessary to conduct the previous jar tests again taking into consideration a variable which has produced a significant effect.

57. Based on the preceding discussion for confined area overflow, the following design criteria for a particular type dredged material have been determined:

- a. Most effective and economical coagulant.
- b. Mixing time and intensity for rapid and slow mixing basins assuming constant flow system.
- c. Most effective coagulant feed concentration to be fed.

The determination of settling rates and volume of settled dredged material to be handled are the only significant design parameters which have not been discussed. These design parameters will be discussed later in this chapter.

#### Procedure for Pipeline Injection

58. There are only four major variables other than coagulant dosage involved in determining if a polymer is effective for injection into a pipeline. These are: (1) type of dredged material; (2) percent solids; (3) mixing intensity; and (4) mixing time.

59. Conducting jar tests to determine the efficiency of coagulant injection into a pipeline requires modifications to the general procedure previously described. The G value in most pipelines is several times higher than that achievable with a standard Phipps and Bird jar test machine mixing in a two-litre beaker. G values in a pipeline varying from 700 to 1600  $\text{sec}^{-1}$  correspond to mixer speeds of from 300 to 500 rpm in the apparatus shown in Figure 1. The maximum

Table 6  
Potential Variations in Coagulant Feed Concentration

| <u>Jar Test No.</u> | <u>Coagulant Feed Concentration (%)</u> |
|---------------------|---|
| 16*                 | 0.1                                     |
| 17                  | 0.3                                     |
| 18                  | 0.5                                     |
| 19                  | 1.0                                     |

\* Each jar test to be conducted using six jars.

Table 7  
Example Jar Test Results on Pipeline Slurry

| <u>Jar No.</u> | <u>Polymer Dosage<br/>(mg/l)</u> | <u>rpm</u> | <u>t<br/>(min)</u> | <u>Turbidity<br/>(NTU)</u> |
|----------------|----------------------------------|------------|--------------------|----------------------------|
| 1              | 0                                | 300        | 5                  | 1800                       |
| 2              | 3                                | 300        | 5                  | 1500                       |
| 3              | 5                                | 300        | 5                  | 700                        |
| 4              | 10                               | 300        | 5                  | 200                        |
| 5              | 15                               | 300        | 5                  | 40                         |
| 6              | 20                               | 300        | 5                  | 90                         |

rpm of a Phipps and Bird jar test machine is approximately 160. Therefore, a variable-speed laboratory mixer (0 to 500 rpm) is required which will accept the standard mixing blade as shown in Figure 1. The standard two-litre beaker sidewall depth must be extended because the vortex created at a high rpm will cause liquid to spill over the side.

60. The G values produced within a pipeline should be calculated (see Appendix A). Once the range of G values for a particular pipeline has been calculated, the required mixing rate for a standard stirring blade can be determined from Figure 3. If the G value exceeds  $1300 \text{ sec}^{-1}$ , then the graph must be extrapolated. The precise G value in a two-litre beaker with extended sidewall depth and mixing rate determined by extrapolation is unknown; however, considering the variations within the pipeline, the error should have a minor effect on the results of the jar tests.

61. The initial objective of the jar tests is to determine if a particular coagulant is an effective coagulant when injected into a hydraulic dredge pipeline. Two litres of 5.0 percent solids (by wt) dredged material should be poured into each of several two-litre beakers. The rpm of the mixer should be set to give a G value corresponding to the average G value expected in the pipeline. The time of mixing should be the detention time in the pipeline calculated by dividing the length of the pipeline by the average velocity of the fluid in the pipe. Various coagulant dosages should be added to the beakers as previously described. The conditions of the initial set of jar tests might possibly be as shown in Table 7. Turbidity analyses should be conducted on the supernatant of the samples after 30 minutes of settling.

62. Since a 5.0 percent solids concentration was initially chosen, the only other variables are mixing intensity and time of mixing. The mixing intensity may change because of a change in the pumping rate of the dredge. The mixing time will be dependent upon the flow rate in the pipeline, the pipe diameter, and the point selected for coagulant injection. To determine the effect of mixing

intensity and time on the efficiency of a coagulant, at least two more series of jar tests must be conducted. The results of the next jar test could possibly result in the data shown in Table 8.

63. The results of these jar tests indicate that at high G values the effectiveness of the coagulant is reduced. However, since the G value of the pipeline corresponds to 300 rpm, the coagulant will be effective even though the mixing intensity may vary somewhat.

64. The mixing time of five minutes was determined by assuming that the polymer would be injected 4500 ft from the pipe discharge and that the velocity in the pipe was 15 ft/sec. At times it may be desirable to inject polymer nearer the pipe discharge thereby reducing the mixing time in the pipe. A jar test should be conducted to determine the effect of reducing the detention time in the pipeline. The results of this jar test could possibly result in the data shown in Table 9.

65. The results of the preceding example jar test indicate that a reduction in mixing time can significantly reduce the efficiency of polymer injection into a pipeline.

66. Further jar tests should be conducted on dredged material of higher concentrations of solids such as 10 and 20 percent to determine the effects of solids concentration on the efficiency of a particular polymer.

#### Settling Tests

67. Jar test procedures provide a methodology for determining the most effective coagulant, the coagulant dosage, the optimum mixing rates, and the optimum detention times in the mixing basins. Once the dredged material has been coagulated, facilities must be designed to clarify the material. Dredged material coagulated within a hydraulic dredge pipeline will most likely be clarified in the disposal area used to retain the dredged material. Palermo et al.<sup>1</sup> have stated that the area required for concentration of the dredged material is usually larger than that required for clarification and, therefore, controls the area requirements. Palermo et al.<sup>1</sup> have also developed procedures for obtaining the information required to design containment areas for dredged material.

Table 8

Effect of Mixing Intensity on Clarification of a Pipeline Slurry

| <u>Jar No.</u> | <u>Coagulant Dosage<br/>(mg/l)</u> | <u>rpm</u> | <u>t<br/>(min)</u> | <u>Turbidity<br/>(NTU)</u> |
|----------------|------------------------------------|------------|--------------------|----------------------------|
| 1              | 15                                 | 100        | 5                  | 15                         |
| 2              | 15                                 | 150        | 5                  | 20                         |
| 3              | 15                                 | 200        | 5                  | 30                         |
| 4              | 15                                 | 300        | 5                  | 40                         |
| 5              | 15                                 | 400        | 5                  | 100                        |
| 6              | 15                                 | 450        | 5                  | 300                        |

Table 9

Effect of Time of Mixing on Clarification of a Pipeline Slurry

| <u>Jar No.</u> | <u>Coagulant Dosage<br/>(mg/l)</u> | <u>rpm</u> | <u>t<br/>(min)</u> | <u>Turbidity<br/>(NTU)</u> |
|----------------|------------------------------------|------------|--------------------|----------------------------|
| 1              | 15                                 | 300        | 0.5                | 1200                       |
| 2              | 15                                 | 300        | 1.0                | 500                        |
| 3              | 15                                 | 300        | 2.0                | 390                        |
| 4              | 15                                 | 300        | 3.0                | 300                        |
| 5              | 15                                 | 300        | 4.0                | 210                        |
| 6              | 15                                 | 300        | 5.0                | 160                        |

68. Coagulation of the effluent from a containment area usually involves solids concentrations of less than 1.0 percent by weight. Standard procedures have not been developed for conducting settling tests in recommended settling columns because of the inability to transfer the coagulated material to a settling column without breaking up the floc. A standard procedure which coagulates the dredged material within a settling column would solve the problem; however, one is not presently available.

69. An estimate of the settling rate can be made by settling within a two-litre beaker used for jar tests. If zone settling is assumed, the settling rate may be estimated by measuring the liquid-solids interface versus time.

70. Zone settling occurs when high solids concentrations cause particles to lock into a floc structure which subsides through the suspended liquid without pressing on layers of floc below. The floc settles as a blanket with a distinct interface between the settling solids and the clarified supernatant. Figure 5 shows the various zones which are formed when this type of settling occurs. The quantity of solids which can pass down through any stratum of liquid of a unit cross-sectional area is equal to the product of the settling rate and the solids concentration. The settling rate of a flocculated dredged material varies with concentration as well as detention time. The solids quantity which can pass through a given stratum of liquid may be governed by the solids concentration. As settling particles descend in the basin, they must pass through all concentrations between the starting concentration and that of the deposited solids. If, at any intermediate concentration, the solids passing capacity of the stratum is less than at the starting concentration, this zone of intermediate concentration will begin to build up with a resulting barrier zone of the concentration which most limits the flow of the solids down through the basin. The capacity of the basin is thus limited by the area necessary to pass the solids through the limiting zone. Interface height versus time settling tests can be performed on test suspensions with results similar to that presented in Figure 6. The area required for clarification can be estimated by dividing the

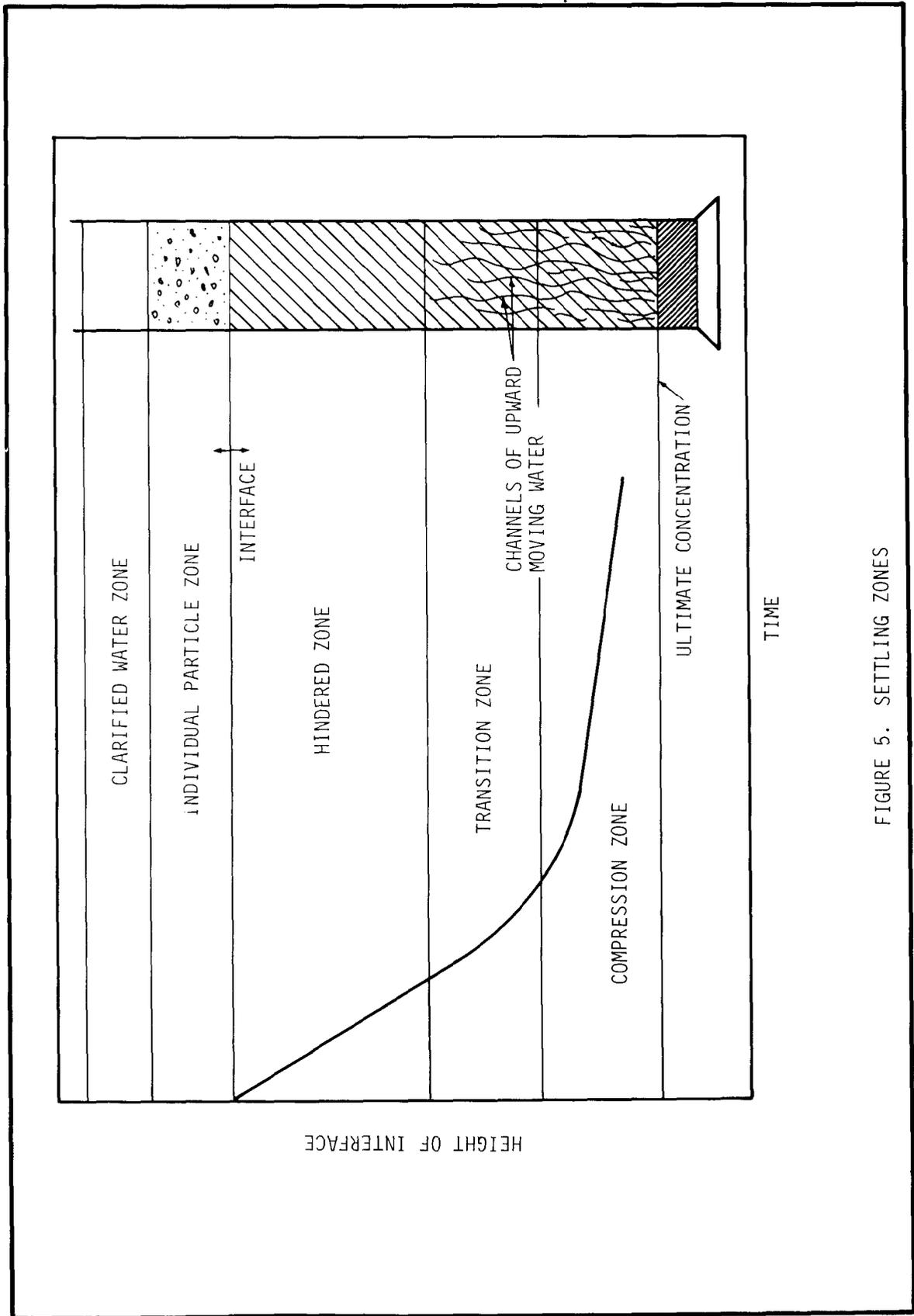


FIGURE 5. SETTLING ZONES

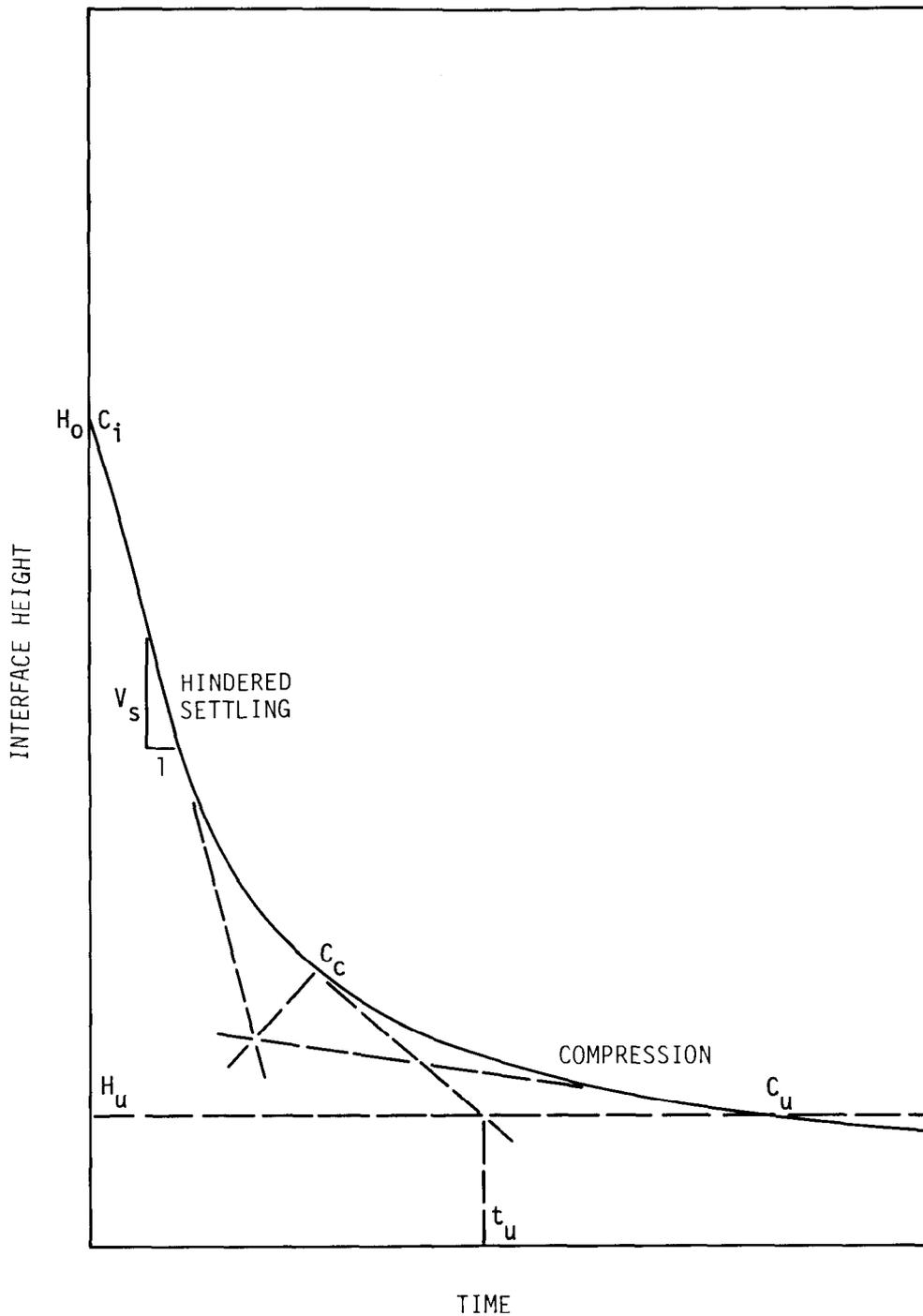


FIGURE 6. INTERFACE HEIGHT VS. TIME

flow rate by the hindered settling velocity shown ( $V_s$ ). Since there exists a critical concentration ( $C_c$ ) which results in the maximum basin area requirement, this concentration must also be used as a basis for design. Talmadge and Fitch<sup>12</sup> have shown that the critical concentration ( $C_c$ ) can be estimated by bisecting the tangents to the hindered settling and compression portion of the interface height-versus-time curve as shown. Knowing the desired underflow concentration for a clarifier,  $C_u$ , a horizontal line is passed through  $C_u$ . The time ( $t_u$ ) required to reach the desired dredge material concentration ( $C_u$ ) is obtained by construction of a line tangent to the curve at  $C_c$  and reading the resultant  $t_u$  on the horizontal axis below the intersection of this line and the horizontal constructed through  $C_u$ . The required surface area is obtained from the formula:

$$A = \frac{Q \times t_u}{H_o}$$

where  $A$  = cross sectional area,  $ft^2$

$Q$  = volumetric flow rate,  $ft^3/sec$

$H_o$  = the initial height of the interface in settling test,  $ft$

$t_u$  = time required to obtain underflow concentration  $C_u$ ,  $sec.$

When the suspended solids concentration is so great that part of the weight of subsiding particles is supported by the structure of the compacting mass below, the suspension has reached the zone of compression. Consolidation within this zone is slower than in upper zones, as seen in Figure 6. The settling rate in this zone has been found to be a function of the initial dredged material depth when the compression zone is entered, ultimate dredged material depth, etc. An estimate of the dredged material volume to be handled can be calculated by the following formula assuming zero solids in the effluent:

$$Q C_i = Q_s C_u$$

where  $Q$  = flow into clarifier

$C_i$  = initial solids concentrations

$Q_s$  = solids underflow from clarifier

$C_u$  = solids concentration of underflow.

71. The above analysis provides information that will assist in the design of a clarifier or settling basin where removal of the

settled material is essentially continuous. The procedure cannot be used for the design of the containment area which will be used for sedimentation combined with consolidation and storage.

## PART IV: RESULTS OF A PILOT PLANT STUDY AT A FRESHWATER DREDGE SITE

### Procedure

72. A pilot plant study was conducted to demonstrate with a flow-through system the efficiency of polyelectrolytes to coagulate suspended material in a containment area effluent. The site was selected for the pilot plant study because of the operation of a hydraulic dredge for ongoing construction.

73. The pilot plant used for the coagulation experiments was a modified physical-chemical pilot plant designed for lime or alum coagulation, sedimentation, and filtration of the effluent from an activated sludge process. The pilot plant was modified by the installation of baffles and piping to achieve the desired configuration. The rapid mix basin was 21.75 inches long, 30 inches wide, and 11.5 inches deep, which provided a volume of 32.5 gallons. Mixing was provided by a 12-inch by 2-inch turbine mixer driven by a variable-speed DC motor. The slow mix or flocculation basin was 21.75 inches wide, 64.5 inches long, and 11 inches deep which provided a volume of 67 gallons. Mixing was provided by a horizontal reel flocculator which was belt-driven by a variable-speed DC motor. The clarifier had an effective surface area of 29 square feet and was approximately 12 feet deep. Modifications were made to the clarifier to prevent excessive currents and to reduce weir overflow rates. The pilot plant filter was not used in the experiments.

74. During the pilot plant tests dredged material at the site was discharged into two containment areas in series. The upper containment area was designed for sand removal for construction purposes with the majority of fines overflowing to the lower containment area. Overflow from the upper containment area was collected in tank trucks for the pilot plant tests. The material in the tank trucks was allowed to settle approximately 12 hours before use because of the significant quantities of sand and heavy silt in the material collected.

75. The supernatant in the tank trucks was utilized for the pilot plant tests. Samples were collected from each tank truck prior to each test for chemical analyses. Jar tests were also conducted to determine the optimum polymer dosage and mixing conditions required. Supernatant from a tank truck and polymer were fed into the rapid mix basin with variable-speed pumps. Each test was conducted over a period of several hours to allow the system to stabilize. After the system had stabilized, samples were collected from the pilot plant effluent for chemical analyses. Settled dredged material was drained from the clarifier after each test run; however, because of its large volume, the clarifier was not totally drained.

76. As previously mentioned, jar tests were conducted on the settled dredged material prior to each test run to obtain the optimum polyelectrolyte dosage. These tests were performed prior to the development of a recommended jar test procedure as defined in Part III of this report. The jar tests were performed with a standard Phipps and Bird jar test machine using 2.0-litre beakers without baffles. The initial mixing rates used were a rapid mix time of 60 seconds at 100 rpm and a slow mix time of five minutes at 20 rpm. A settling time of 30 minutes was used. The relatively short period of rapid and slow mix proved to be inadequate as the resulting turbidity at the optimum polymer dose was greater than 50 NTU.

77. The mixing rates in the jar tests were increased to a rapid mix time of 10 minutes at 100 rpm and a slow mix time of 10 minutes at 20 rpm. A settling time of 30 minutes was used. Results of the jar tests were significantly improved with residual turbidities of less than five NTU resulting. Without baffles in the 2.0-litre beakers, the resulting mean velocity gradient  $G$  was quite low,  $75 \text{ sec}^{-1}$  and  $10 \text{ sec}^{-1}$  for rapid mix and slow mix, respectively. There were no provisions made for calculating the mean velocity gradient in the mixing basins of the pilot plant. The mixing rates were controlled visually as each test continued by observing floc formation in the rapid mix and slow mix basins.

## Results

78. The first pilot plant test was conducted using Hercofloc 863, a cationic polyelectrolyte previously selected by WES. Hercofloc 863 was prepared in a 0.1 percent solution and fed at the dosage rate of 28 mg/l. The total flow rate to the pilot plant was 6.7 gpm, which resulted in a theoretical rapid mix detention time of 4.85 minutes, a flocculation detention time of 10 minutes, and a clarifier surface loading rate of 332 gal/ft<sup>2</sup>/day. Table 10 shows the results of chemical analyses of the pilot plant influent and effluent during test No. 1. The influent turbidity was reduced from 2950 to 37 NTU and the suspended solids from 3276 to 24 ppm. A review of the data shows reduction in all parameters with the exception of ammonia nitrogen, nitrate, calcium, and pH. The increase in calcium concentrations was probably a result of the well water used to dilute the polymer. Figure 7 shows a settling curve for the flocculated material in test No. 1. The zone settling rate of this material was calculated to be 0.22 ft/min, which is equivalent to a surface loading rate of 2360 ft<sup>2</sup>. The settling tests were conducted in a one-litre graduated cylinder. This procedure is sufficient for comparative purposes, but not for obtaining design data<sup>1</sup>.

79. Pilot plant test No. 2 was conducted using Magnafloc 581-C, a cationic polyelectrolyte. Magnafloc 581-C was prepared in a 0.1 percent solution and fed at a dosage rate of 28 mg/l. The flow rate to the pilot plant during the test was 5.0 gpm, which resulted in a theoretical rapid mix detention time of 6.5 minutes, a flocculation detention time of 13.4 minutes, and a clarifier surface loading rate of 248 gal/ft<sup>2</sup>/day. Table 11 shows the results of chemical analyses of the pilot plant influent and effluent during test No. 2. The influent turbidity was reduced from 3500 to 12 NTU and the suspended solids from 2630 to 9 mg/l. A review of the data shows reductions in all parameters with the exception of calcium and pH. Figure 8 shows a settling curve for the flocculated material

Table 10  
Chemical Analyses of Pilot Plant--Test Run No. 1

| <u>Parameter*</u>                | <u>Influent</u> | <u>Effluent</u> |
|----------------------------------|-----------------|-----------------|
| Turbidity (NTU)                  | 2950            | 37              |
| pH                               | 7.1             | 7.8             |
| Alkalinity                       | 24.2            | 32.3            |
| SS                               | 3276            | 24              |
| COD                              | 99              | 12              |
| TOC                              | 3.5             | 2.0             |
| TOT P                            | 1.68            | 0.12            |
| NH <sub>3</sub> -N               | 0.2             | 0.64            |
| ORG-N                            | 2.41            | 0.16            |
| NO <sub>3</sub> -N               | 0.28            | 0.29            |
| Cl <sup>-</sup>                  | 4.75            | 3.80            |
| SO <sub>4</sub> <sup>2-</sup> ** | 5.35            | 2.72            |
| Ca                               | 0.52            | 4.20            |
| K                                | 9.0             | 0.9             |
| Mg                               | 4.3             | 3.5             |
| Na                               | 7.4             | 5.2             |
| Cd                               | 0.004           | 0.0007          |
| Cr                               | 0.23            | 0.02            |
| Cr                               | 0.18            | 0.02            |
| Fe                               | 85              | 3               |
| Hg                               | 0.006           | 0.001           |
| Mn                               | 1.1             | 0.1             |
| Ni                               | 0.7             | 0.04            |
| Pb                               | 0.08            | 0.005           |
| Zn                               | 0.31            | 0.21            |
| op' DDE                          | 0.015           | 0.002           |
| op' DDD                          | ---             | ---             |
| op' DDT                          | ---             | ---             |
| pp' DDE                          | 0.05            | 0.008           |
| pp' DDD                          | ---             | ---             |
| pp' DDT                          | ---             | ---             |
| TOT DDT                          | 0.065           | 0.01            |
| PCB 1242                         | 0.5             | 0.3             |
| PCB 1254                         | 0.22            | 0.1             |
| PCB 1260                         | 0.022           | 0.01            |
| TOT PCB                          | 0.742           | 0.41            |

\* All analyses in ppm unless otherwise shown.

\*\* (0.45-μ filtrate).

Notes: Polyelectrolyte = Hercofloc 863. Dosing Rate = 28 mg/l.  
Pilot Plant Flow Rate = 6.7 gpm.

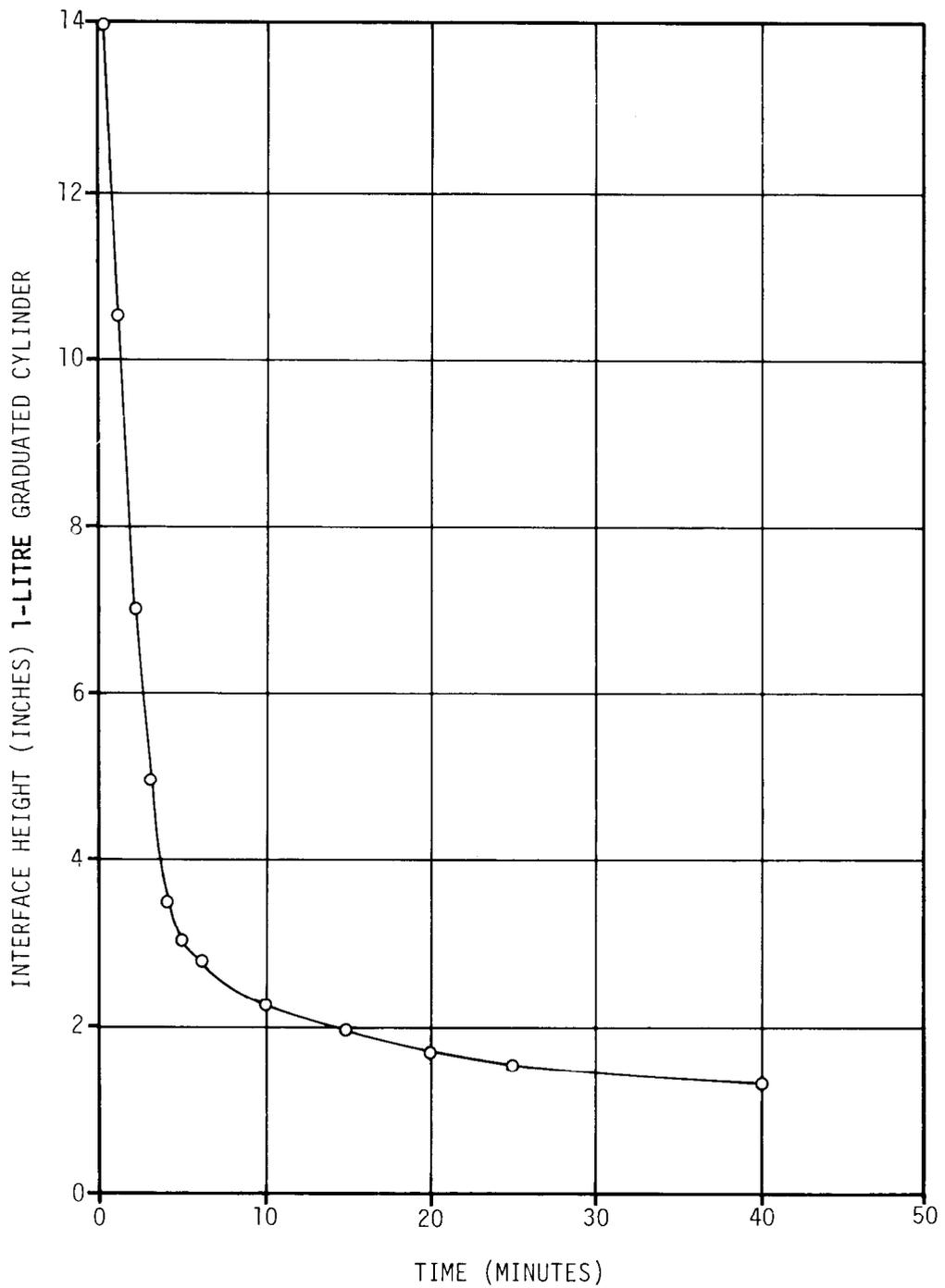


FIGURE 7. SETTLING CURVE TEST NO. 1 (POLYELECTROLYTE-HERCOFLOC 863; DOSING RATE-28 mg/l)

Table 11  
Chemical Analyses of Pilot Plant--Test Run No. 2

| <u>Parameter*</u>             | <u>Influent</u> | <u>Effluent</u> |
|-------------------------------|-----------------|-----------------|
| Turbidity (NTU)               | 3500            | 12              |
| pH                            | 7.2             | 7.9             |
| Alkalinity                    | 30.3            | 34.3            |
| SS                            | 2630            | 9               |
| COD                           | 197             | 8               |
| TOC                           | 11              | 3               |
| TOT P                         | 3.24            | 0.12            |
| NH <sub>3</sub> -N            | 1.19            | 0.85            |
| ORG-N                         | 3.24            | 0.91            |
| NO <sub>3</sub> -N            | 0.37            | 0.29            |
| Cl <sup>-</sup>               | 3.55            | 3.60            |
| SO <sub>4</sub> <sup>**</sup> | 3.15            | 1.36            |
| Ca                            | 1.00            | 4.09            |
| K                             | 17.8            | 0.6             |
| Mg                            | 7.9             | 3.8             |
| Na                            | 11.7            | 4.6             |
| Cd                            | 0.005           | 0.0002          |
| Cr                            | 0.34            | 0.03            |
| Cu                            | 0.27            | 0.01            |
| Fe                            | 210             | 2               |
| Hg                            | 0.002           | 0.001           |
| Mn                            | 2.2             | 0.3             |
| Ni                            | 1.1             | 0.06            |
| Pb                            | 0.08            | 0.006           |
| Zn                            | 0.43            | 0.08            |
| op' DDE                       | 0.014           | 0.001           |
| op' DDD                       | ---             | ---             |
| op' DDT                       | 0.036           | ---             |
| pp' DDE                       | 0.036           | 0.004           |
| pp' DDD                       | ---             | ---             |
| pp' DDT                       | 0.036           | ---             |
| TOT DDT                       | 0.122           | 0.005           |
| PCB 1242                      | 0.81            | 0.21            |
| PCB 1254                      | 0.3             | 0.13            |
| PCB 1260                      | 0.03            | 0.013           |
| TOT PCB                       | 1.14            | 0.343           |

\* All analyses in ppm unless otherwise shown.

\*\* (0.45-μ filtrate)

Notes: Polyelectrolyte = Magnafloc 581-C. Dosing Rate = 28 mg/l.  
Pilot Plant Flow Rate = 5 gpm.

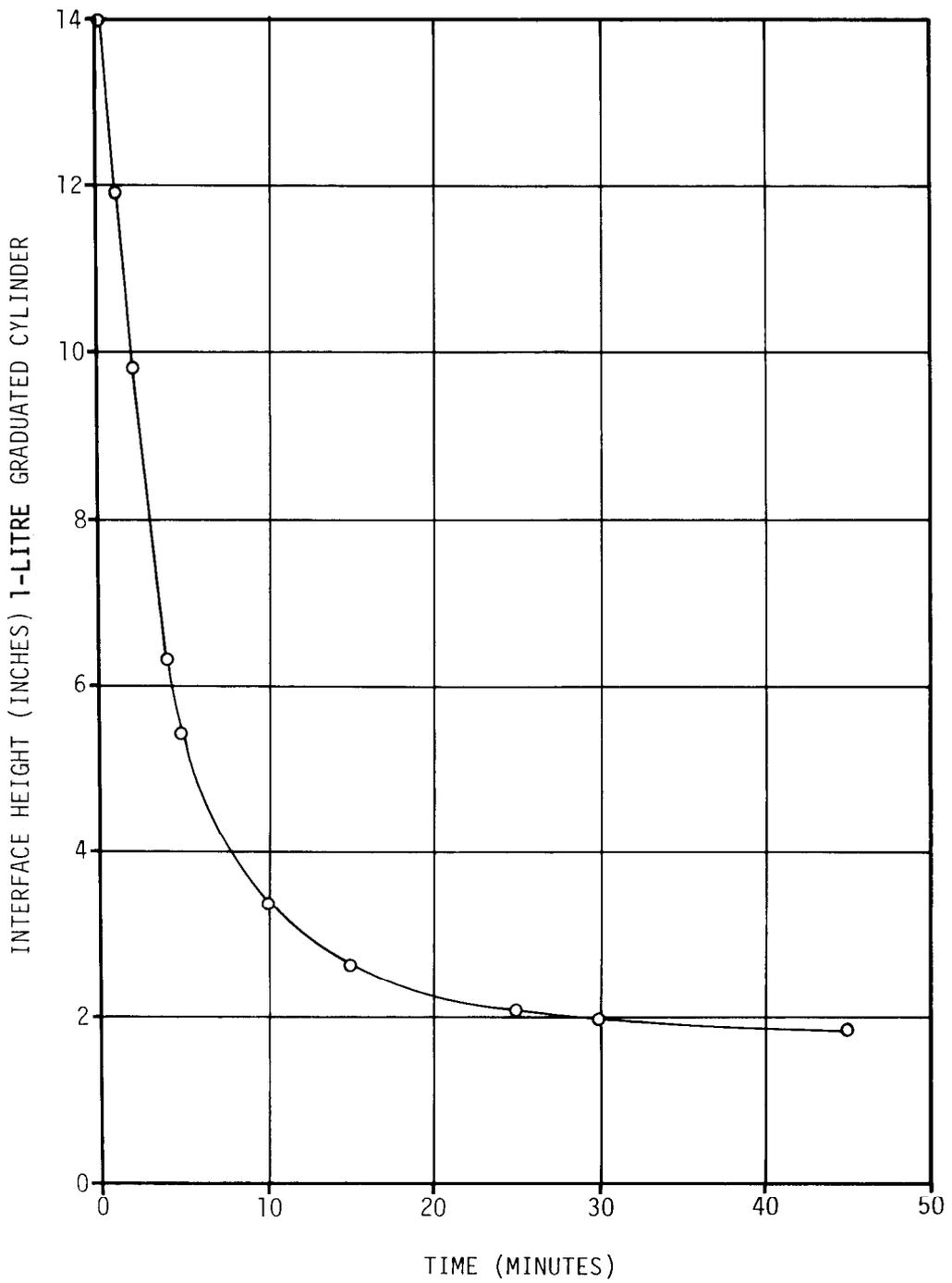


FIGURE 8. SETTLING CURVE TEST NO. 2 (POLYELECTROLYTE-MAGNAFLOC 581-C; DOSING RATE-28 mg/l)

in test No. 2. The zone settling rate of this material is calculated to be 0.16 ft/min, which is equivalent to a surface loading rate of 1720 gal/ft<sup>2</sup>/day.

80. Pilot plant test No. 3 was conducted using Chitosan, a cationic polyelectrolyte. Chitosan was prepared in a 0.25 percent solution and fed at a dosage rate of 4.0 mg/l. The flow rate to the pilot plant was 5.0 gpm, which gave a detention time the same as that in test No. 2. Table 12 shows the results of chemical analyses of the pilot plant influent and effluent during test No. 3. The influent turbidity was reduced from 2800 to <5 NTU and the suspended solids from 5010 to nine mg/l. A review of the data shows a decrease in all parameters with the exception of ammonia nitrogen, organic nitrogen, and pH. Figure 9 shows a settling curve for the flocculated material in test No. 3. The zone settling rate of this material was calculated to be 0.24 ft/min, which is equivalent to a surface loading rate of 2570 gal/ft<sup>2</sup>/day.

81. Pilot plant test No. 4 was conducted using Magnafloc 581-C as previously used in test No. 2. Magnafloc 581-C was prepared in a 0.1 percent solution and fed at a dosage rate of 24 mg/l. The flow rate to the pilot plant was 5.0 gpm, which was the same flow rate as in test Nos. 2 and 3. Table 13 shows the results of chemical analyses of the pilot plant influent and effluent during test No. 4. The influent turbidity was reduced from 2700 to 10 NTU and the suspended solids from 3460 to 32 mg/l. A review of the data in Table 15 shows that all parameters were reduced with the exception of alkalinity, ammonia nitrogen, calcium, pH, PCB 1254, and PCB 1260. Figure 11 shows a settling curve for the flocculated material in test No. 4. The zone settling rate of the material is calculated to be 0.29 ft/min, which is equivalent to a surface loading rate of 3140 gal/ft<sup>2</sup>/day.

90. The results of the pilot plant tests showed that a continuous flow-through process could successfully coagulate the suspended solids in effluent from a confined area with suspended solids concentrations greater than 5000 mg/l and turbidities

Table 12  
Chemical Analyses of Pilot Plant--Test Run No. 3

| <u>Parameter*</u>               | <u>Influent</u> | <u>Effluent</u> |
|---------------------------------|-----------------|-----------------|
| Turbidity (NTU)                 | 2800            | <5.0            |
| Ph                              | 7.1             | 7.4             |
| Alkalinity                      | 34.3            | 20.3            |
| SS                              | 5010            | 9.0             |
| COD                             | 218.0           | 10.3            |
| TOC                             | 9.0             | 7.8             |
| TOT P                           | 2.76            | 0.12            |
| NH <sub>3</sub> -N              | 1.81            | 1.89            |
| ORG-N                           | 0.08            | 0.35            |
| NO <sub>3</sub> -N              | 0.36            | 0.27            |
| Cl <sup>-</sup>                 | 3.5             | 1.5             |
| SO <sub>4</sub> <sup>-</sup> ** | 7.74            | 2.03            |
| Ca                              | 0.92            | 0.52            |
| K                               | 45.4            | 1.1             |
| Mg                              | 15.6            | 2.6             |
| Na                              | 15.2            | 2.6             |
| Cd                              | 0.004           | 0.0004          |
| Cr                              | 0.55            | 0.02            |
| Cu                              | 0.39            | 0.02            |
| Fe                              | 381             | 2               |
| Hg                              | 0.005           | 0.001           |
| Mn                              | 6.0             | 0.3             |
| Ni                              | 1.3             | 0.02            |
| Pb                              | 0.21            | 0.005           |
| Zn                              | 0.66            | 0.07            |
| op' DDE                         | 0.015           | 0.011           |
| op' DDD                         | ---             | ---             |
| op' DDT                         | ---             | ---             |
| pp' DDE                         | 0.028           | 0.014           |
| pp' DDD                         | ---             | ---             |
| pp' DDT                         | ---             | ---             |
| TOT DDT                         | 0.043           | 0.025           |
| PCB 1242                        | 0.58            | 0.36            |
| PCB 1254                        | 0.19            | 0.14            |
| PCB 1260                        | 0.019           | 0.014           |
| TOT PCB                         | 0.789           | 0.514           |

\*All analyses in ppm unless otherwise shown.

\*\* (0.45- $\mu$  filtrate)

Notes: Polyelectrolyte = Chitosan. Dosing Rate = 4 mg/l. Pilot Plant Flow Rate = 5 gpm.

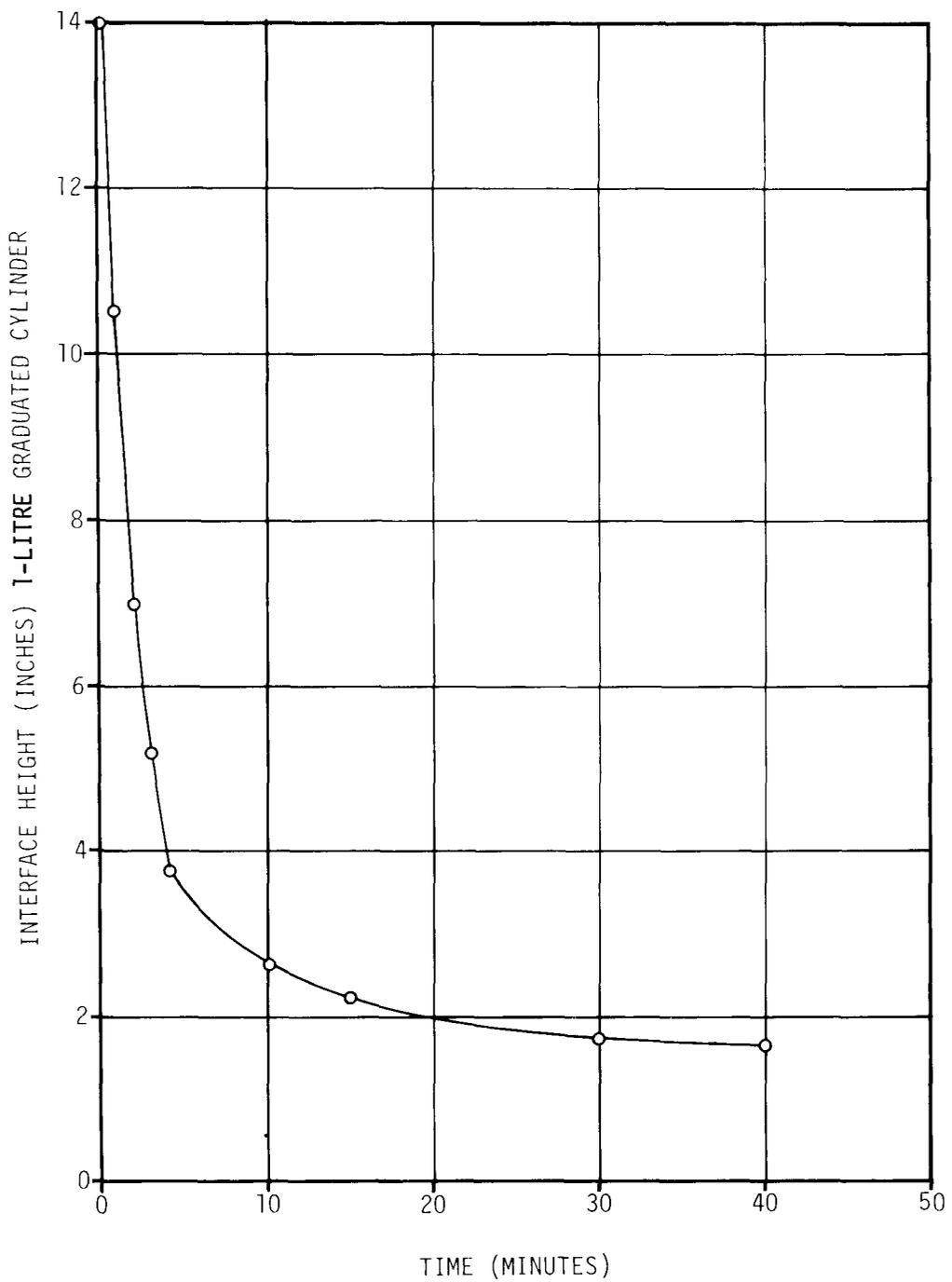


FIGURE 9. SETTLING CURVE TEST NO. 3 (POLYELECTROLYTE-CHITOSAN; DOSING RATE-4.0 mg/l)

Table 13  
Chemical Analyses of Pilot Plant--Test Run No. 4

| <u>Parameter*</u>             | <u>Influent</u> | <u>Effluent</u> |
|-------------------------------|-----------------|-----------------|
| Turbidity (NTU)               | 2700            | 10              |
| pH                            | 7.0             | 7.9             |
| Alkalinity                    | 20.2            | 32.3            |
| SS                            | 3460            | 32              |
| COD                           | 181             | 8               |
| TOC                           | 8.0             | 1.0             |
| TOT P                         | 1.4             | 0.08            |
| NH <sub>3</sub> -N            | 0.20            | 0.71            |
| ORG-N                         | 3.37            | 0.08            |
| NO <sub>3</sub> -N            | 0.41            | 0.23            |
| Cl <sup>-</sup>               | 3.25            | 1.9             |
| SO <sub>4</sub> <sup>**</sup> | 8.4             | 2.3             |
| Ca                            | 0.64            | 3.67            |
| K                             | 30.0            | 1.6             |
| Mg                            | 12.0            | 4.5             |
| Na                            | 15.9            | 4.7             |
| Cd                            | 0.007           | 0.0001          |
| Cr                            | 0.41            | 0.02            |
| Cu                            | 0.36            | 0.02            |
| Fe                            | 273             | 4               |
| Hg                            | 0.009           | 0.001           |
| Mn                            | 3.5             | 0.2             |
| Ni                            | 1.3             | 0.3             |
| Pb                            | 0.16            | 0.04            |
| Zn                            | 0.62            | 0.16            |
| op' DDE                       | 0.05            | 0.001           |
| op' DDD                       | ---             | ---             |
| op' DDT                       | ---             | ---             |
| pp' DDE                       | 0.38            | 0.005           |
| pp' DDD                       | ---             | ---             |
| pp' DDT                       | ---             | ---             |
| TOT DDT                       | 0.43            | 0.006           |
| PCB 1242                      | 1.2             | 0.23            |
| PCB 1254                      | 0.12            | 0.14            |
| PCB 1260                      | 0.012           | 0.014           |
| TOT PCB                       | 1.332           | 0.384           |

\* All analyses in ppm unless otherwise shown.

\*\* (0.45- $\mu$  filtrate)

Notes: Polyelectrolyte - Magnafloc 581-C. Dosing Rate = 24 mg/l.  
Pilot Plant Flow Rate = 5.0 gpm.

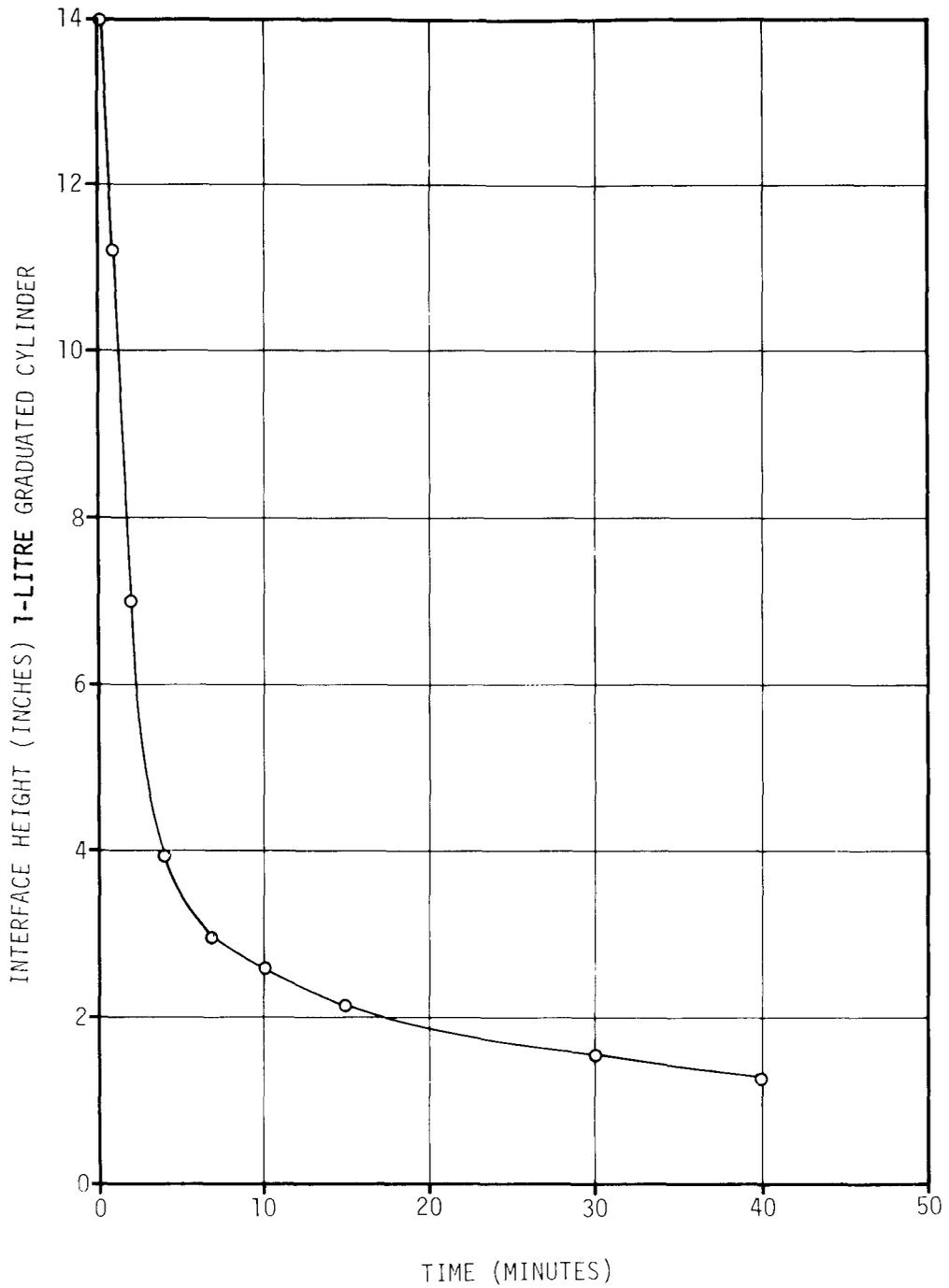


FIGURE 10. SETTLING CURVE TEST NO. 4 (POLYELECTROLYTE-MAGNAFLOC 581-C; DOSING RATE-24 mg/l)

greater than 3500 NTU. The results of the pilot plant study followed closely that of laboratory jar tests.

91. Major significance should not be placed on the results of the influent and effluent chemical analyses for the various test runs other than for turbidity and suspended solids. The data show that the major contaminants are associated with the suspended solids; however, accurate removal efficiencies cannot be calculated for several reasons. First, approximately 3.0 percent of the influent flow to the pilot plant was due to the polymer and its dilution water. Chemical analyses of this flow stream are not available. Second, each test run lasted only four to six hours; therefore, the data represent only short-term tests. Third, because of the large volume of the settling tank, it was not completely drained between test runs; therefore, mixing of the material in the clarifier did occur.

#### Conclusions

92. Several significant conclusions were made based on the results of the pilot plant study:

- a. If properly designed, a coagulation treatment system can be highly effective for treatment of containment area effluent.
- b. The treatment system is easiest to control when the effluent composition and flow rate from the containment area are constant.
- c. Contaminants apparently are associated with solids which settle out after coagulation.

PART V: PIPELINE INJECTION OF  
POLYELECTROLYTES AT A FRESHWATER DREDGE SITE

Introduction

93. There are several benefits which could result from increasing the settling rates of dredged material disposed of in confined areas. These include:

- a. Increased efficiency for suspended solids removal.
- b. Increased settling rates of dredged material thereby reducing the surface area required to meet effluent limitations (sludge volume would be increased however).
- c. Increased compaction of the stored dredged material.

Available Information

94. There is limited information available concerning the effectiveness of injection of polyelectrolytes into hydraulic dredge pipelines. Although several studies of pipeline injection of polyelectrolytes are reported, the results are generally reported in qualitative rather than quantitative terms. One study conducted during maintenance dredging of a ship channel at the Alameda Naval Air Station, California, reported that the injection of eight to 10 ppm of XNP170-T18, a product of Bioquad, Inc., into the suction sides of the dredge pump reduced the settleable solids from the containment area from 10 ml/l to 1.0 ml/l.<sup>4</sup>

Purpose of Field Study

95. The excellent results of the previous pilot plant study discussed in Part IV led to a plan to conduct a full-scale study of polyelectrolyte injection into a hydraulic dredge pipeline at the same site. The purpose of the study was to define some of the problems which would be encountered and to determine the efficiency of polyelectrolyte injection into a hydraulic dredge pipeline under actual field conditions.

Equipment

96. Magnafloc 581-C was used for the field tests because of the excellent results achieved in the previous pilot plant study.

Polymer was diluted with drinking water from a nearby town and transported in a 1000-gallon tank truck to the test site. Polymer was fed into the pipeline by a positive displacement pump. The pump was a Moyno, Type CR, with a 2L6 frame. The pump was driven by a Reliance 3.0 HP variable-speed DC motor through a Reliance 3.4:1 ratio gear reducer. Power was supplied by a Kohler 7.5-kw, single-phase generator. A 1.5-inch diameter high pressure hose with brass Seal Fast Quick Couplers was used to connect the pump discharge to the pipeline injection port. The same type hose was used to connect the suction side of the pump with the polymer storage tank.

#### Description of Pipeline

97. The hydraulic dredge pipeline consisted of an 18-inch steel pipe approximately 6060 feet long. A booster pump was installed 3900 feet from the pipe discharge. Eight ports for injection of polymer or collection of sample were welded into the pipeline. See Figure 11 for location of the injection/sampling ports. Injection ports were installed approximately every 600 feet where possible so that the effect of varying mixing time could be evaluated.

#### Initial Jar Tests

98. Samples were collected from the hydraulic dredge pipeline and jar tests conducted to determine the approximate Magnafloc 581-C dosage required. The jar test procedure used was not the recommended procedure as defined in Section III because the procedure had not been developed at the time. A Phipps and Bird jar test machine was used along with 2.0-litre beakers with no baffles installed. A rapid mix rate of 100 rpm for three minutes, a slow mix rate of 20 rpm for five minutes, and a settling time of 10 minutes were found to be effective for the jar tests. The results of a typical jar test are as follows:

| <u>Jar No.</u> | <u>Polymer Dosage (mg/l)</u> | <u>Final Turbidity (NTU)</u> |
|----------------|------------------------------|------------------------------|
| 1              | 0                            | 1500*                        |
| 2              | 2.5                          | 125                          |
| 3              | 3.5                          | 17                           |
| 4              | 5.0                          | 10                           |
| 5              | 6.0                          | 25                           |
| 6              | 7.5                          | 50                           |

\* After one hour settling.

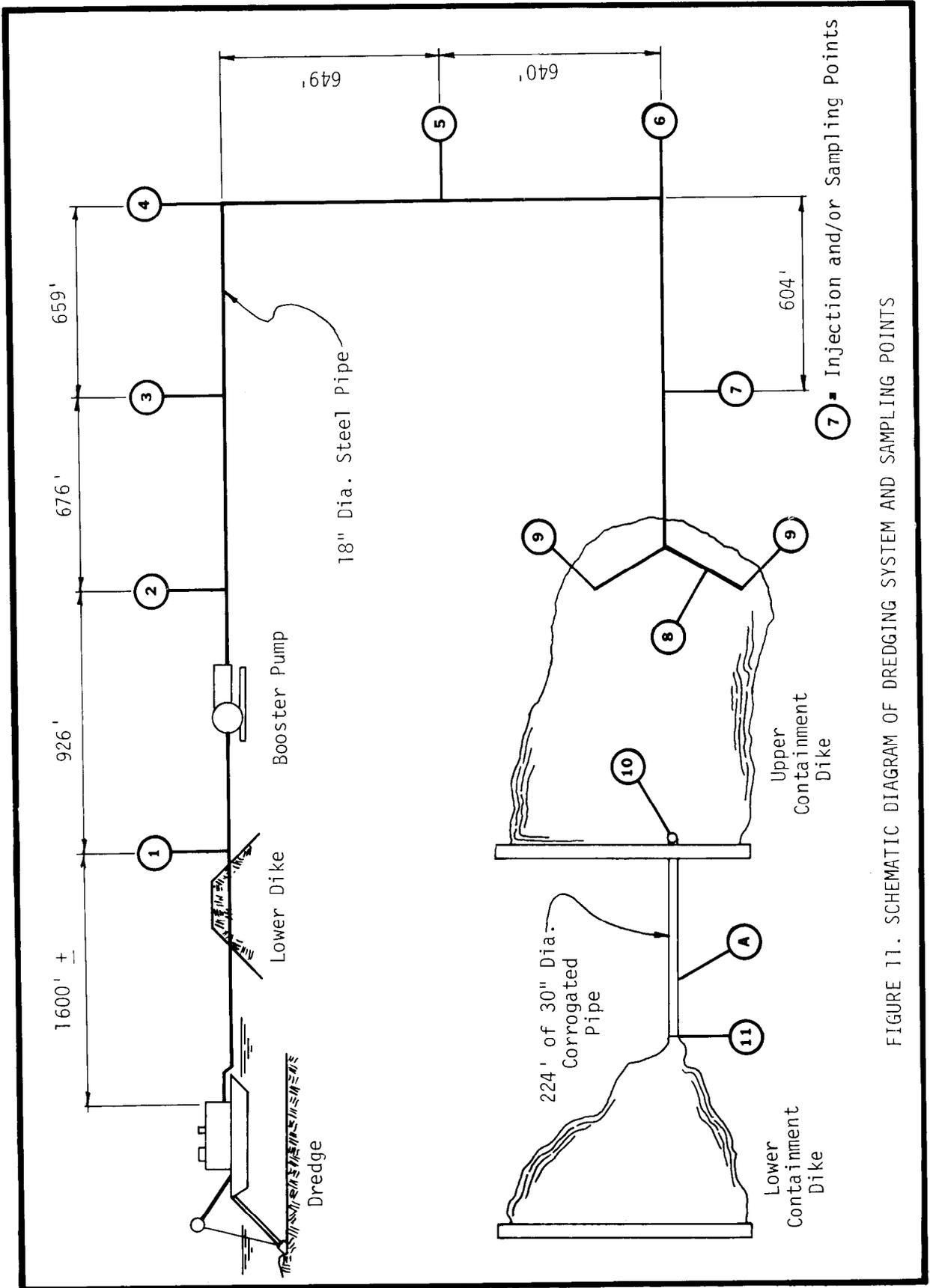


FIGURE 11. SCHEMATIC DIAGRAM OF DREDGING SYSTEM AND SAMPLING POINTS

99. The results of several jar tests showed that for a particular sample, 5.0 mg/l of Magnafloc 581-C produced excellent results with a minimum of mixing. Other samples with higher or lower suspended solids concentrations were coagulated with equal efficiency but required higher or lower polymer dosages, respectively, depending upon the suspended solids concentrations in the sample. Because it was necessary to inject 5.0 percent polymer solutions (limited by available dilution water) instead of a recommended 0.1 percent solution, jar tests were conducted to determine the effect of initial polymer concentration on treatment efficiency. The mixing rates were the same as discussed above; however, a new sample from the pipeline was used. Results of a typical jar test are shown below:

| <u>Jar No.</u> | <u>Polymer Dosage<br/>(mg/l)</u> | <u>Polymer Concentration<br/>(%)</u> | <u>Turbidity<br/>(NTU)</u> |
|----------------|----------------------------------|--------------------------------------|----------------------------|
| 1              | 0                                | ---                                  | 1500*                      |
| 2              | 5                                | 0.1                                  | 150                        |
| 3              | 5                                | 1.0                                  | 500                        |
| 4              | 5                                | 5.0                                  | 600                        |
| 5              | 5                                | 10.0                                 | 700                        |

\*Settled 1.0 hour.

100. The results of the jar tests indicated that high polymer feed concentrations should not be utilized because of the reduced treatment efficiency. However, the size of the tank truck limited the polymer concentration to 5.0 percent to facilitate several hours of polymer injection into the pipeline

#### Procedure

101. A 5.0 percent polymer solution was mixed in a 1000-gallon tank for injection into the pipeline. Assuming a flow of 20.0 mgd in the pipeline the polymer would be used up in six hours at a dosage rate of 10 mg/l. A more dilute solution would have been desirable such as the manufacturer's recommendation of a 0.1 percent solution. However, if a 0.1 percent solution had been used, 50,000 gallons of 0.1 percent solution would have to be injected in six hours as compared with only 1000 gallons of a 5.0 percent polymer solution. Facilities were not available for injecting a

0.1 percent solution; therefore, the tests were limited to injection of a 5.0 percent polymer solution.

102. Polymer was injected at several different points during the field study. Samples were collected at 15 minute intervals at downstream sampling points (see Figure 11). For comparative purposes, one-litre graduated cylinders were filled with the sample collected at each point and a 10-minute settling test conducted by recording the solids interface height vs. time. At the end of the settling test a sample was collected of the supernatant for a turbidity analysis. This type of settling test was chosen because of its simplicity and can be used only as an indication of the efficiency of polymer coagulation.

### Discussion of Results

103. The initial plan was to determine the feed rate of the polymer by measuring the gauge pressure at the injection point and using the pump curve as a rough indication of the polymer feed rate. This proved unsuccessful as the pump curve for the Moyno pump did not provide the actual discharge rate of the pump; therefore, the discharge rate was determined by measuring the volume of polymer pumped from the tank truck vs. time. The water truck was equipped with a calibrated sight gauge.

104. The initial test, Run No. 1, was conducted to perfect the polymer injection and sampling technique and to define problems which might be encountered. It quickly became apparent that there were many problems associated with injection of polymer into a hydraulic dredge pipeline. The polymer feed rate is a function of the type material being dredged, the optimum polymer dosage, the concentration of solids in the pipeline, and the flow rate in the pipeline. All three of these variables were constantly changing while the hydraulic dredge was operating. The type of material being dredged varied from minute to minute depending upon the location of the dredge cutter head at any particular moment. The solids concentration varied from close to zero to over 40 percent solids depending

upon the operation of the dredge. The flow in the pipeline varied from essentially zero when the pipeline becomes plugged to a velocity of 20 fps or greater. Because of these variables, it was impossible to inject an optimum polymer dosage much less determine the dosage required. A polymer dosage of 20.5 mg/l was determined by trial and error to provide significant results in the samples collected. The dosage was obviously too high at times of either very low flow or low suspended solids concentrations or too low under conditions of high flow or high suspended solids concentrations.

105. Consideration was given to collecting samples from the sampling points on a staggered time basis in an attempt to collect a sample of a particular material as it flowed in a slug through the pipe. This idea was abandoned because of the lack of a suitable method to measure flow in the pipeline and the highly variable nature of the flow rate. The problems which were defined in Run No. 1 led to the procedure utilized in the following test runs, which have previously been described. Run No. 2 consisted of injection of Magnafloc 581-C at Port No. 2. The polymer dosage throughout the test was at a constant rate of 20.5 mg/l assuming a flow rate of 20 mgd in the pipeline. Samples were collected at sampling points 3, 4, 6 and 9 in the pipeline. Table 14 shows the results of the turbidity analyses on the supernatant from samples collected at each of the sampling points.

109. It is extremely difficult to interpret the data in Table 14 and infer from it the effectiveness of the polyelectrolyte. A general observation can be made that Magnafloc 581-C did coagulate the dredged material during the tests and produced a strong floc. Floc size was limited in the dredge pipeline because of the high mixing intensity; however, large flocs formed in a matter of seconds after the samples were collected in a sample bucket. There is a possibility that turbidity levels in the sample supernatants could have been decreased if samples from the pipeline had not been taken through a cracked two-inch gate valve located at each sampling point, with the exception of the pipe discharge.

Table 14

Run No. 2, Injection Port No. 2, Magnafloc 581-C\*

| Time<br>(hr) | Average<br>Polymer<br>Dose<br>(mg/l) | Port                        |                             | Port                        |                             | Port |  |
|--------------|--------------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|------|--|
|              |                                      | No. 3<br>Turbidity<br>(NTU) | No. 4<br>Turbidity<br>(NTU) | No. 6<br>Turbidity<br>(NTU) | No. 9<br>Turbidity<br>(NTU) |      |  |
| 1115         | 20.5                                 | 155                         | 250                         | 200                         | 50                          |      |  |
| 1130         | 20.5                                 | 70                          | 275                         | 110                         | 12                          |      |  |
| 1145         | 20.5                                 | 183                         | 170                         | 105                         | 17                          |      |  |
| 1200         | 20.5                                 | 80                          | 15                          | 140                         | 21                          |      |  |
| 1215         | 20.5                                 | 170                         | 250                         | 55                          | 25                          |      |  |
| 1230         | 20.5                                 | 1150                        | 1000                        | 1400                        | 10000                       |      |  |
| 1245         | 20.5                                 | 250                         | 1100                        | 15000                       | ---                         |      |  |
| 1300         | 0.0                                  | 200                         | 2100                        | 8000                        | 6000                        |      |  |

\* After 10 minutes settling in a one-litre graduated cylinder.

110. The injection of polymer did increase the settling rates of the material and reduce the supernatant turbidity. A direct comparison of coagulated vs. uncoagulated dredged material cannot be made because of the difficulty of collecting samples before or after polymer addition and being certain they were the same samples. The dredged material slurry changed from minute to minute from a solids concentration of less than 100 mg/l to greater than 400,000 mg/l. At times, heavy slugs of material would essentially plug the pipeline and several minutes of pumping river water were required to wash the material through the pipe. During these wide variations in flow and solids concentrations, underdosing or overdosing occurred. Figure 12 shows settling curves for samples collected at sampling point No. 9 from the effluent of the pipeline. Settling curves are shown for only four of the seven samples collected. For the other three samples either the solids concentration was so low that no floc formed or so high that no interface was apparent. The settling rate of the four samples shown in Figure 12 is approximately 0.25 ft/min, which is equivalent to an overflow rate of 2700 gal/ft<sup>2</sup>/day.

111. During Run No. 3, Magnafloc 581-C was injected into sampling Port No. 1 at 20.5 mg/l assuming a flow of 20 mgd. Table 15 gives the results of the turbidity analyses conducted on samples taken every 15 minutes at sampling points Nos. 2, 4, 6 and 9, and the influent to the lower containment area. Visual observations showed that Magnafloc 581-C produced a strong floc in the majority of samples collected. At times, variations in the dredged material composition caused the samples to be either under or overdosed. A review of the turbidity data shown in Table 15 indicates a significant reduction in turbidity due to polymer injection. The effect, if any, of collecting samples through a cracked two-inch gate valve is not readily apparent in the data. Variations in the supernatant turbidity after 10 minutes settling are probably related to variations in the flow and composition of the dredged material.

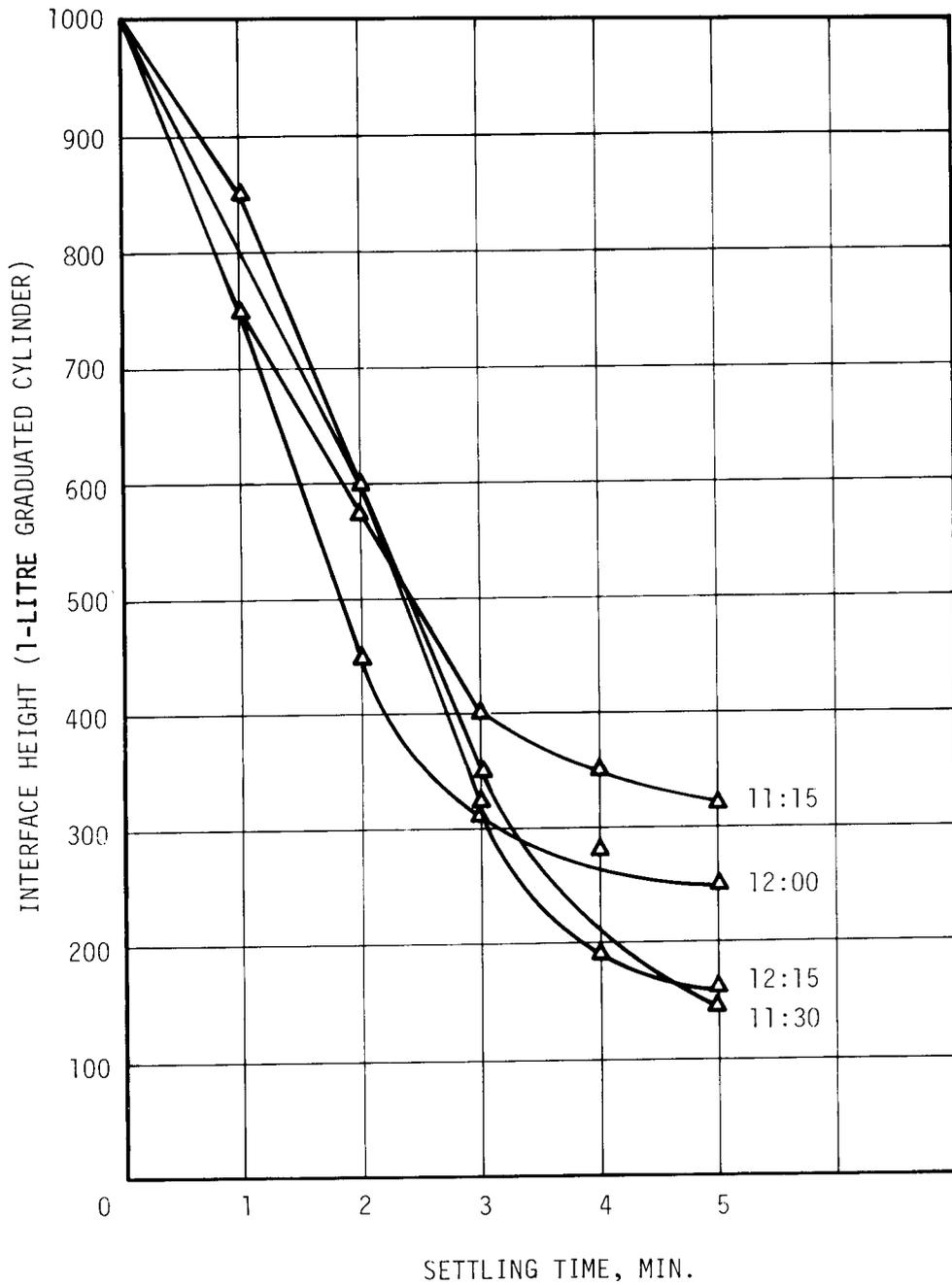


FIGURE 12. DREDGED MATERIAL SETTLING RATES, RUN NO. 2, SAMPLING POINT NO. 9

Table 15  
 Run No. 3, Injection Port No. 1, Magnafloc 581-C

| Time<br>(hr) | Average<br>Polymer<br>Dose<br>(mg/l) | Port                        |                             | Port                        |                             | Port |  |
|--------------|--------------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|------|--|
|              |                                      | No. 2<br>Turbidity<br>(NTU) | No. 4<br>Turbidity<br>(NTU) | No. 6<br>Turbidity<br>(NTU) | No. 9<br>Turbidity<br>(NTU) |      |  |
| 1600         | 20.5                                 | 100                         | 35                          | 73                          | 53                          |      |  |
| 1615         | 20.5                                 | 7000                        | 7200                        | 120                         | 750                         |      |  |
| 1630         | 20.5                                 | 150                         | 75                          | 200                         | 40                          |      |  |
| 1645         | 20.5                                 | 100                         | 27                          | 125                         | 52                          |      |  |
| 1700         | 20.5                                 | 110                         | 90                          | 65                          | 53                          |      |  |
| 1715         | 20.5                                 | 160                         | 17                          | 77                          | 150                         |      |  |
| 1730         | 20.5                                 | 115                         | 210                         | 40                          | 50                          |      |  |
| 1745         | 0.0                                  | 7000                        | 3000                        | 2000                        | 1000                        |      |  |

112. Figure 13 shows settling curves for the samples collected at sampling point No. 9, the discharge of the pipeline. The minimum settling velocities were for the samples collected at 1615 and 1715 hours. The approximate settling rate for these two samples was 0.19 ft/min, which is equivalent to an overflow rate of approximately 2100 gal/ft<sup>2</sup>/day.

113. During Run No. 3, Magnafloc 581-C was injected into sampling port No. 6. Assuming a flow of 20 mgd, the initial polymer dosage was 8.6 mg/l, which was increased to 23 mg/l for the remainder of the run. Samples were collected every 15 minutes from sampling points Nos. 7 and 9, the effluent of the upper containment area (No. 10) and the influent to the lower containment area (No. 11). Magnafloc 581-C produced a strong floc in the majority of samples collected. The addition of the polymer appeared to reduce the supernatant turbidity significantly when compared with samples collected when no polymer was added. See Table 16 for results of turbidity analyses on the supernatant of samples collected and settled for 10 minutes. Figure 14 shows the results of settling tests on samples collected at sampling point No. 9, the effluent of the dredge pipe. The minimum settling rate was approximately 0.15 ft/min, which is equivalent to an overflow rate of 1570 gal/ft<sup>2</sup>/day.

114. Run No. 5 was begun by injecting polymer at sampling point No. 8. After 23 minutes the run was cancelled because the dredge shut down for an extended period to make repairs.

115. Run No. 6 consisted of injection of Magnafloc 581-C into the overflow of the upper confined area. As previously stated, the upper confined area is connected to the lower confined area by 223 ft of 30-in. corrugated steel pipe. The invert elevation of the discharge is approximately 46 ft below the overflow weir in the upper confined area. Samples were collected from a point approximately halfway down the corrugated pipe and at the discharge into the lower containment area. The detention time within the pipe was 18 seconds.

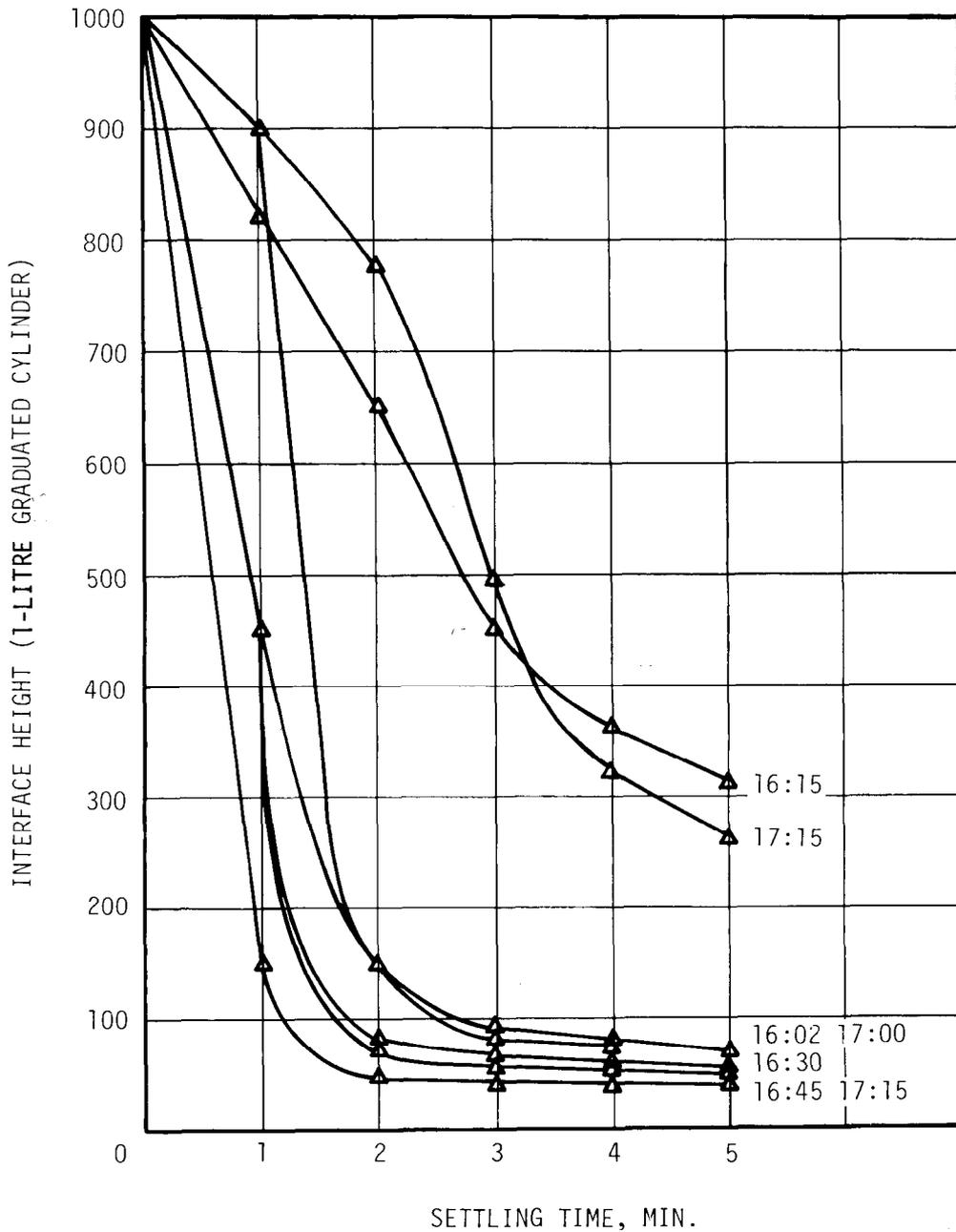


FIGURE 13. DREDGED MATERIAL SETTLING RATES, RUN NO. 3, SAMPLING POINT NO. 9

Table 16  
 Run No. 4, Injection Port No. 6, Magnafloc 581-C

| Time<br>(hr) | Average<br>Polymer<br>Dose<br>(mg/l) | Port<br>No. 7<br>Turbidity<br>(NTU) | Port<br>No. 9<br>Turbidity<br>(NTU) | Effluent, Upper<br>Containment Area<br>Turbidity<br>(NTU) | Influent, Lower<br>Containment Area<br>Turbidity<br>(NTU) |
|--------------|--------------------------------------|-------------------------------------|-------------------------------------|---|---|
| 0945         | 8.6                                  | 180                                 | 175                                 | 1250  | 2250  |
| 1000         | 23                                   | 180                                 | 165                                 | 81  | 175   |
| 1015         | 23                                   | 150                                 | 140                                 | 61  | 80  |
| 1030         | 23                                   | 32                                  | 22                                  | 28  | 35  |
| 1045         | 23                                   | 130                                 | 80                                  | 55  | 110   |
| 1100         | 23                                   | 425                                 | 100                                 | 86  | 117   |
| 1115         | 23                                   | 180                                 | 30                                  | 37  | 100   |
| 1130         | 0.0                                  | 1600                                | 1250                                | 18  | 105   |

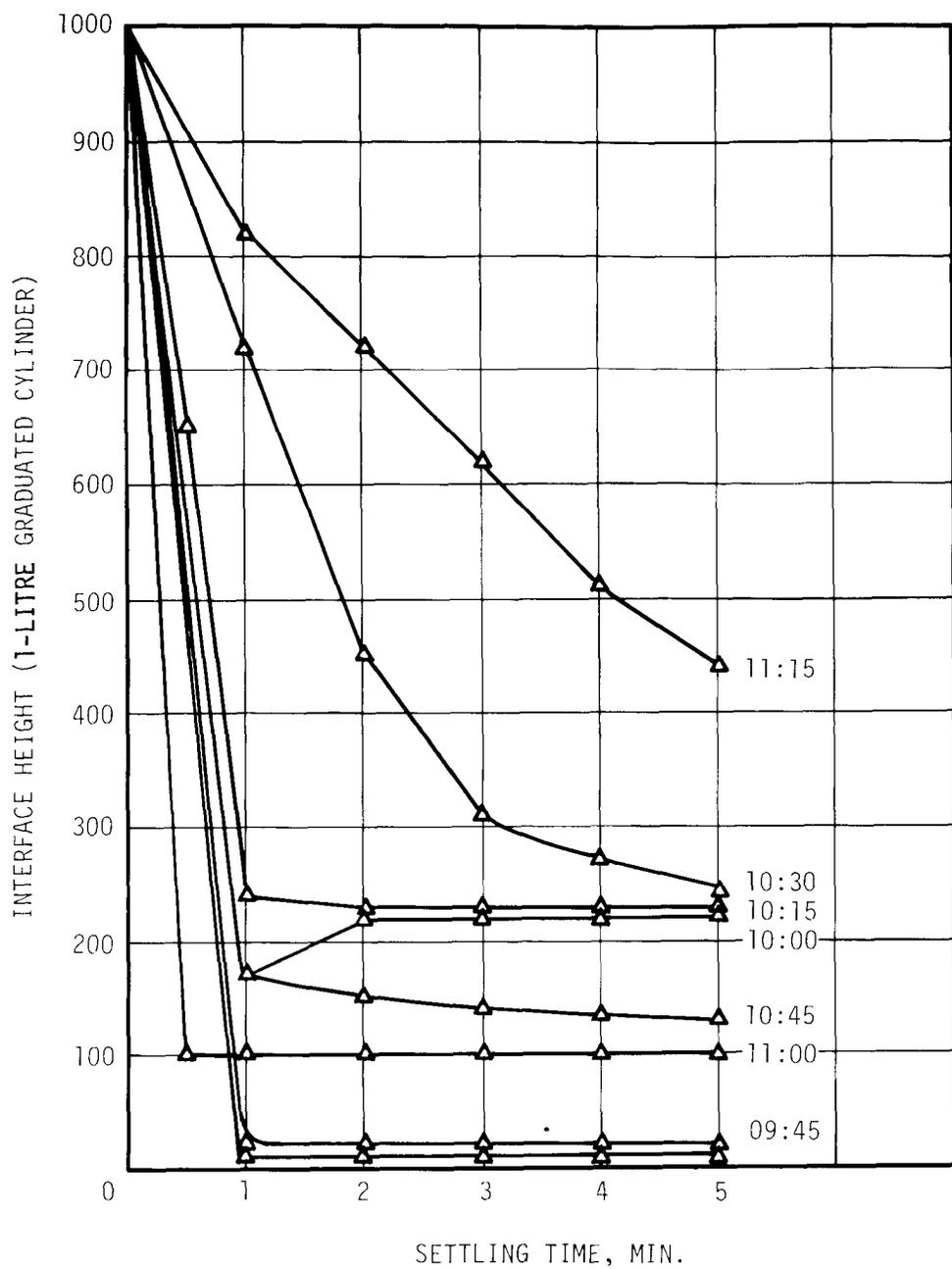


FIGURE 14. DREDGED MATERIAL SETTLING RATES, RUN NO. 4, SAMPLING POINT NO. 9

116. Table 17 shows the results of turbidity analyses on the samples collected every 15 minutes. Polymer dosages were increased as the run proceeded in an attempt to improve clarification. Floc was formed in all of the samples and the floc settled rapidly. However, sufficient information was not obtained to determine quantitatively the increase in efficiency for turbidity removal. The addition of Magnafloc 581-C tended to improve the clarification of the samples to some degree. It is unlikely that residual turbidity values of 7 and 14 NTU could be obtained without the addition of a polymer. Figure 15 shows the settling rates of the samples collected at the influent of the lower containment area. The minimum settling velocity was 0.39 ft/min, which is equivalent to an overflow rate of 4200 gal/ft<sup>2</sup>/day.

Table 17  
Run No. 6, Injection at Effluent, Upper Diked Area, Magnafloc 581-C

| Time (hr) | Average Polymer Dose (mg/l) | Sample Point A Turbidity (NTU) | Influent, Lower Containment Area Turbidity (NTU) |
|-----------|-----------------------------|--------------------------------|--|
| 1545      | 11.6                        | 63                             | 33   |
| 1555      | 15.0                        | 37                             | 14   |
| 1605      | 15.0                        | 170                            | 130  |
| 1615      | 36.0                        | 175                            | 130  |
| 1625      | 36.0                        | 33                             | 7  |
| 1635      | 0.0                         | 160                            | 105  |

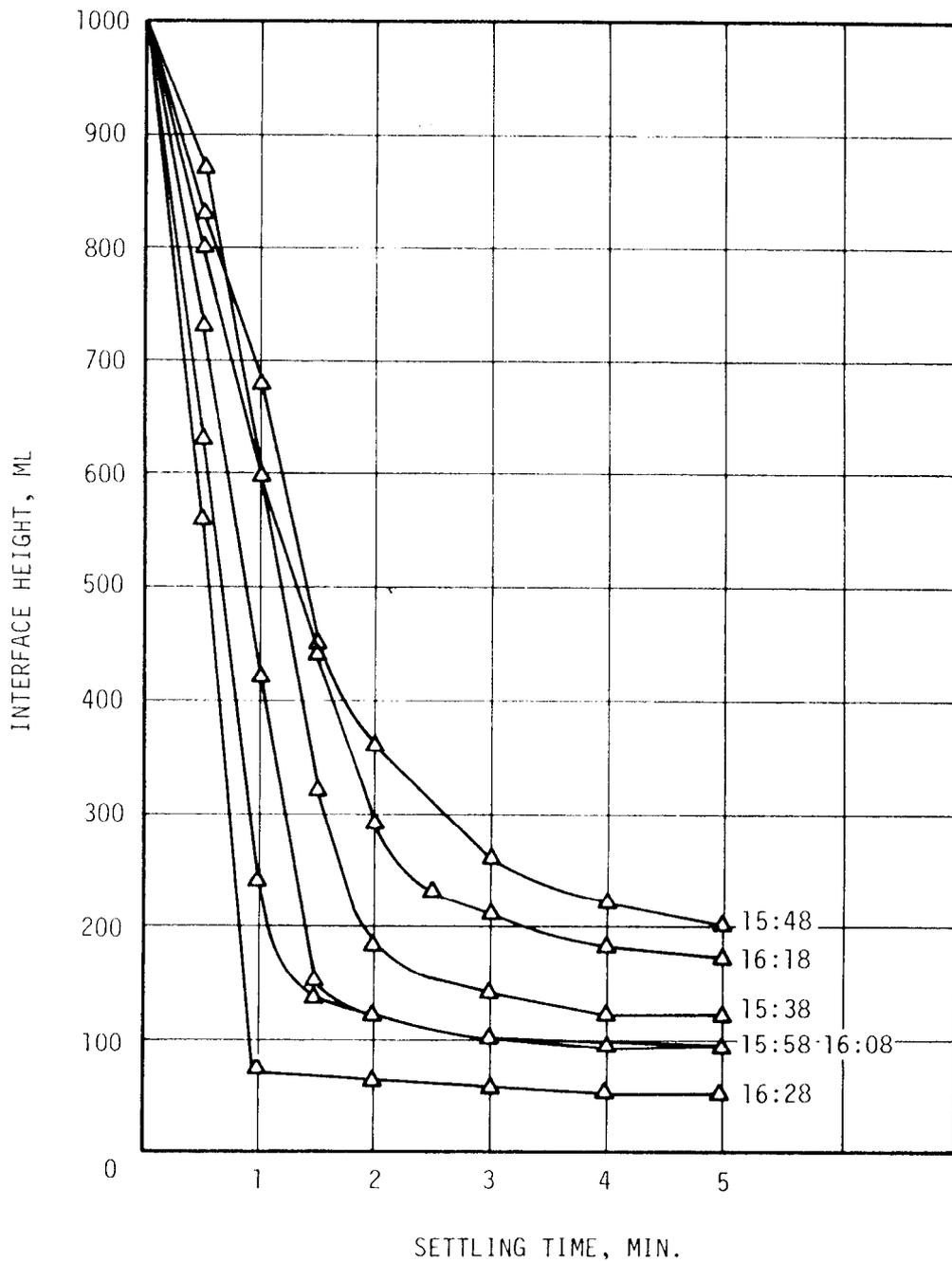


FIGURE 15. DREDGED MATERIAL SETTLING RATES, RUN NO. 6, SAMPLING POINT NO. 11

## PART VI: DESIGN OF POLYMER COAGULATION SYSTEMS

### Purpose

117. The purpose of this section is to provide the design engineer with information required for design of facilities to coagulate dredged material with polyelectrolytes. It is not desirable to provide a "cook book" approach because each project is unique and all the factors involved in a dredging project should be taken into consideration prior to final design. Sufficient information and design examples will be provided, however, to illustrate an approach to the design of a system suitable to a particular situation.

118. Polyelectrolytes may be added: (1) to a dredged material as it is being pumped by a hydraulic dredge to a confined area, or (2) to the effluent from a confined area. This report will not discuss other potential uses of polymers such as their addition into hopper dredges.

### Polyelectrolyte Injection into a Hydraulic Dredge Pipeline

#### Feasibility

119. The effectiveness of injecting a polyelectrolyte into hydraulic dredge pipelines has several limiting factors which include:

- a. High solids concentrations in the dredged material.
- b. Wide variations in solids concentrations.
- c. Wide variations of flow in the pipeline.
- d. Limitations on mixing conditions within a pipeline.

120. The polymer dosage rate required to achieve a specific removal efficiency is usually proportional to the concentration of solids in a dredged material. Therefore, high concentrations of solids will require a higher polymer dosage as compared with a low solids concentration.

121. Coagulation with polyelectrolytes to achieve optimum results requires that the polymer be added within a certain dosage range for a given solids content. Because of the wide variation in the solids

concentration and flow rates in a typical hydraulic dredge pipeline, it would be very difficult to maintain an optimum polymer dosage. A control system would be desirable which could instantaneously measure flow and solids concentration within the pipeline and adjust the polymer feed rate to match the conditions measured. Without this type of system the only alternative is to feed polymer at a constant rate so that the dosage is relatively effective over the range of conditions experienced.

122. The mixing intensity within a pipeline is constant throughout the length of the pipe assuming the pipe diameter and head loss remain constant. The mixing intensity within a hydraulic dredge pipeline is generally greater than  $500 \text{ sec}^{-1}$ , which is a high rapid mixing intensity. The sudden discharge of the dredged material from the hydraulic dredge pipeline into a confined area usually provides insufficient slow mix time and intensity to achieve optimum floc formation.

#### Required Information

123. The design of facilities to coagulate dredged material in a pipeline requires certain basic information before design can begin. The dredge operation may be the result of a new construction project or a maintenance dredging project. The first task is to obtain samples of typical types of materials to be dredged so that each of the different materials can be evaluated in the laboratory by jar tests described in a previous section of this report. The purpose of obtaining samples of various types of materials to be dredged is to determine if more than one type of polyelectrolyte will be required to coagulate the different material types and to obtain an indication of the required polymer dosage and treatment efficiency which might be expected.

124. It is recommended that the collection of various types of materials to be dredged be a part of the testing program required to define the quantity and characteristics of the material to be dredged. By using a grid system the location and quantity of the various materials can be defined. If more than one type of

polyelectrolyte will be required as the dredge advances through different material, preparations can be made for changing polyelectrolytes.

125. Before jar tests can be conducted it is also necessary to know the physical characteristics of the dredge and dredge pipeline. The length of the pipeline divided by the expected flow velocity in the pipeline will give the detention time available for mixing. The pipe diameter, the range of flows, and the viscosity of the dredged material determine the range of mixing intensity that will be experienced within the pipeline. The available detention time and the range of mixing intensity to be expected must be calculated so that jar tests can be conducted which will duplicate conditions within the pipeline. Appendix A gives a method for calculating mixing intensity within a pipeline and also provides examples of those calculations.

126. Previously described jar tests will be conducted to select a polymer or polymers which are most effective, the polymer dosage required, and the optimum detention time. The maximum detention time and the mixing intensity within the pipeline cannot be controlled as they are a function of the physical facilities. Once the jar tests have been completed, the following information will be available for design:

- a. Polymers to be used.
- b. Injection point(s) (mixing time).
- c. Concentration of polymer to be injected.
- d. Polymer dosage rate in mg/l and lb/hr.
- e. Volume of dilution water required.

#### Discussion

127. With the above information, the required polyelectrolyte injection feed equipment can be designed. The first step is to consider the type of polymer(s) to be purchased, how the polymer will be shipped, and how it will be stored on-site. Polyelectrolytes may be sold in either a liquid or dry form depending upon the specific polymer being used. Liquid polymer may be shipped in five-gallon

cans, 55-gallon drums, or in bulk tank trucks or railroad cars. Dry polymer may be shipped in 50-lb multiwall bags or lined drums. If liquid polymer is to be purchased in five-gallon cans or 55-gallon drums, facilities must be designed to store and handle the containers. The purchase of polymer in five-gallon cans, 55-gallon barrels, or bulk quantities will depend upon the quantity of polymer to be used in the project and the rate at which the polymer will be used. If the dredge project is to be a relatively short-term project with low dosages of polymer, then the use of five-gallon cans or 55-gallon barrels may be justified. If the dredge project is to be a long-term project with high dosages of polymer, then the purchase and storage of polymer in bulk quantities may be desirable. In general, the use of five-gallon cans or 55-gallon barrels will require more labor than if bulk quantities of liquid polymer are purchased. Once facilities have been designed to receive and store the polymer, the polymer feeding system must be designed.

128. Figure 16 shows a schematic diagram of one of the simplest types of liquid polymer feeding systems. The first part of this system consists of concentrated polymer storage facilities. Polymer may be pumped directly from 55-gallon drums or from a bulk storage tank. If five-gallon cans are used they will have to be emptied into a storage tank. The polymer feed pump may be any type of suitable positive displacement pump such as a gear pump or progressive cavity pump capable of handling the polymer to be used. The remaining part of the feed system is a dilution water system made up of a water supply, a flow controller, and a mixing eductor. This system serves to dilute the concentrated polymer to the desired concentration prior to injection. This system is not suitable for all liquid polymers because of the high viscosity of many polymers and insufficient mixing may occur in the eductor. Materials of construction will depend upon the polymer being used.

129. Another liquid polymer feed system is shown in Figure 17. This system is composed of bulk polymer storage facilities ranging from 55-gallon drums to storage tanks of any size. Concentrated polymer

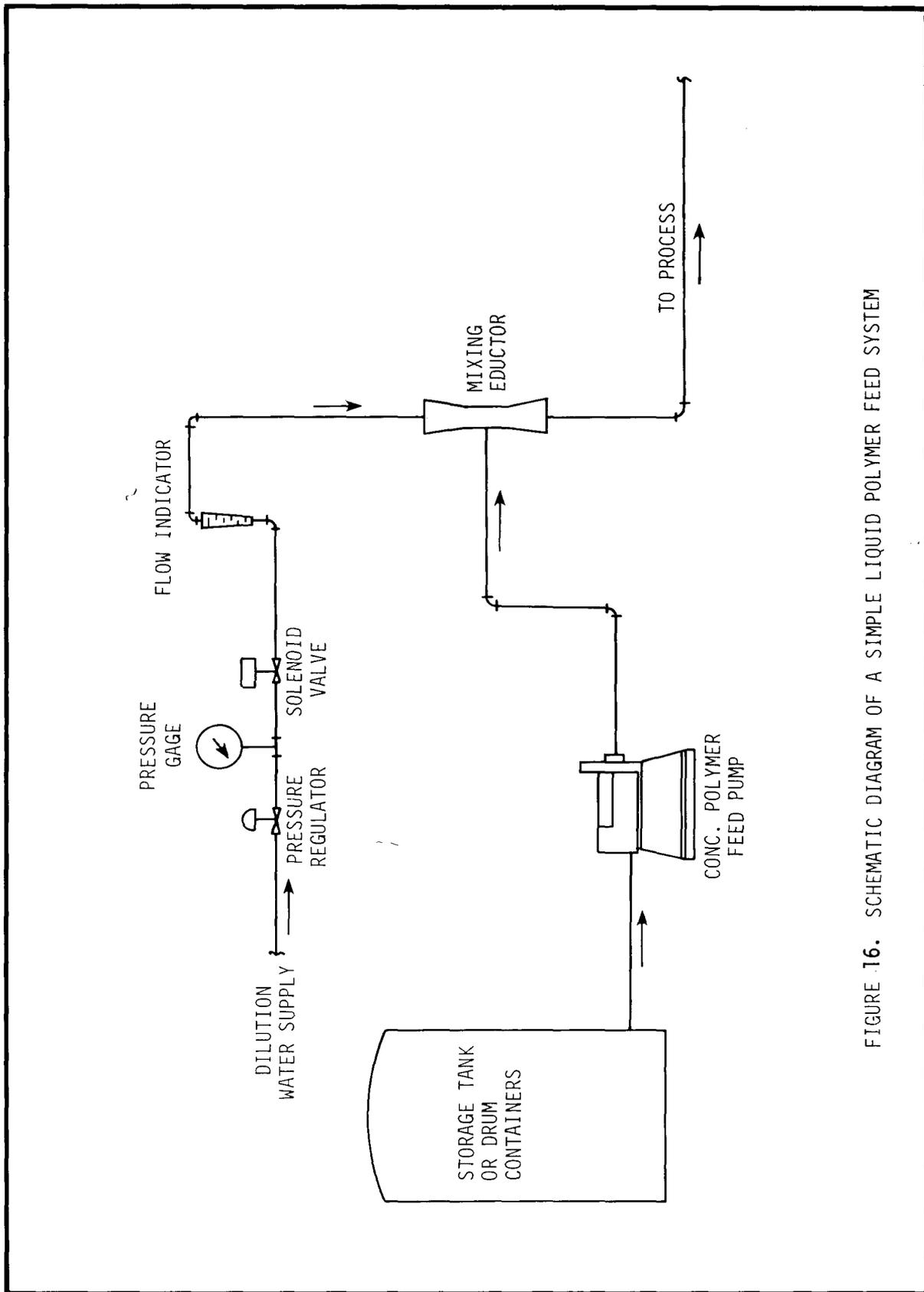


FIGURE 16. SCHEMATIC DIAGRAM OF A SIMPLE LIQUID POLYMER FEED SYSTEM

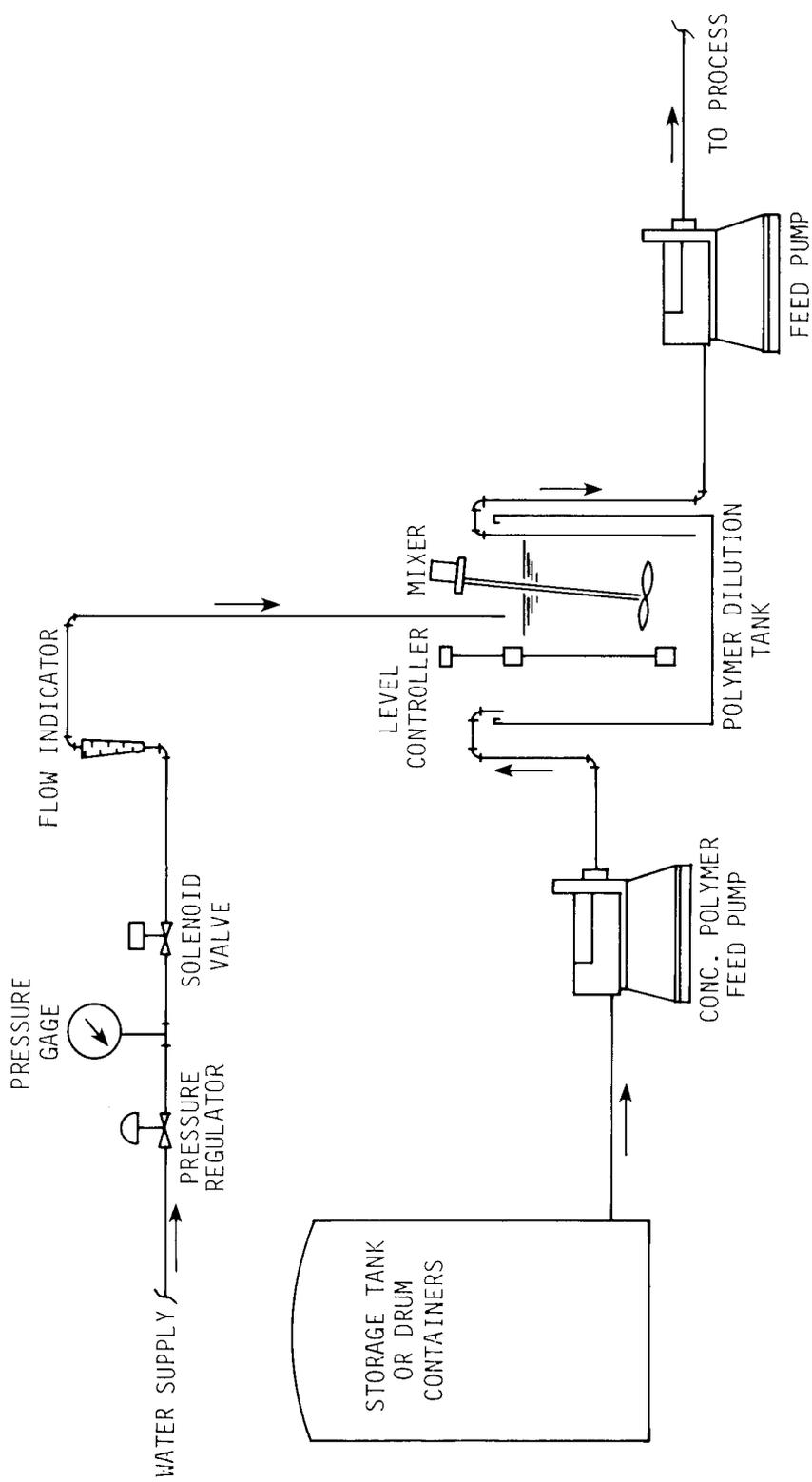


FIGURE 17. SCHEMATIC DIAGRAM OF A SINGLE TANK LIQUID POLYMER FEED SYSTEM

is pumped into a polymer dilution tank where it is mixed with water to prepare a dilute polymer solution. This solution may be fed directly to the process by a feed pump or diluted further if required by a mixing eductor prior to being fed to the process. This system may be manually operated or automated by level control switches which will automatically add polymer and water, then turn the mixer on and off depending upon the level in the polymer dilution tank and time clock controls. There is a disadvantage to this system in that once the polymer dilution tank has been emptied there is a period of time when no polymer can be fed while a new batch is being prepared. This may be overcome by duplicating the system or using a two-tank system as shown in Figure 18.

130. The two-tank system assures that a dilute solution of polymer is constantly available. In this system once a batch of polymer has been prepared in the polymer dilution tank it is transferred automatically to the polymer work tank. While polymer is being fed from the work tank another batch can be prepared in the polymer dilution tank. This system may be operated manually or be automated by level switches in the polymer dilution tank and the polymer work tank.

131. If jar tests determine that only liquid polymers will be used on a specific project and that the polymer can be effectively diluted by the system in Figure 16, then this system should represent the lowest capital and operating cost. However, if the liquid polymer cannot be effectively diluted in an eductor, then the two-tank liquid polymer feed system shown in Figure 18 should be used. If both a liquid and dry polymer are to be used during a specific project because of different materials to be coagulated, then it will be necessary to use a liquid and dry polymer feed system using two tanks as shown in Figure 19.

132. Several manufacturing companies sell "packaged" polymer feed systems. If the capacity of the packaged system is too small they may be duplicated or the design engineer may wish to design a polymer feed system around available components.

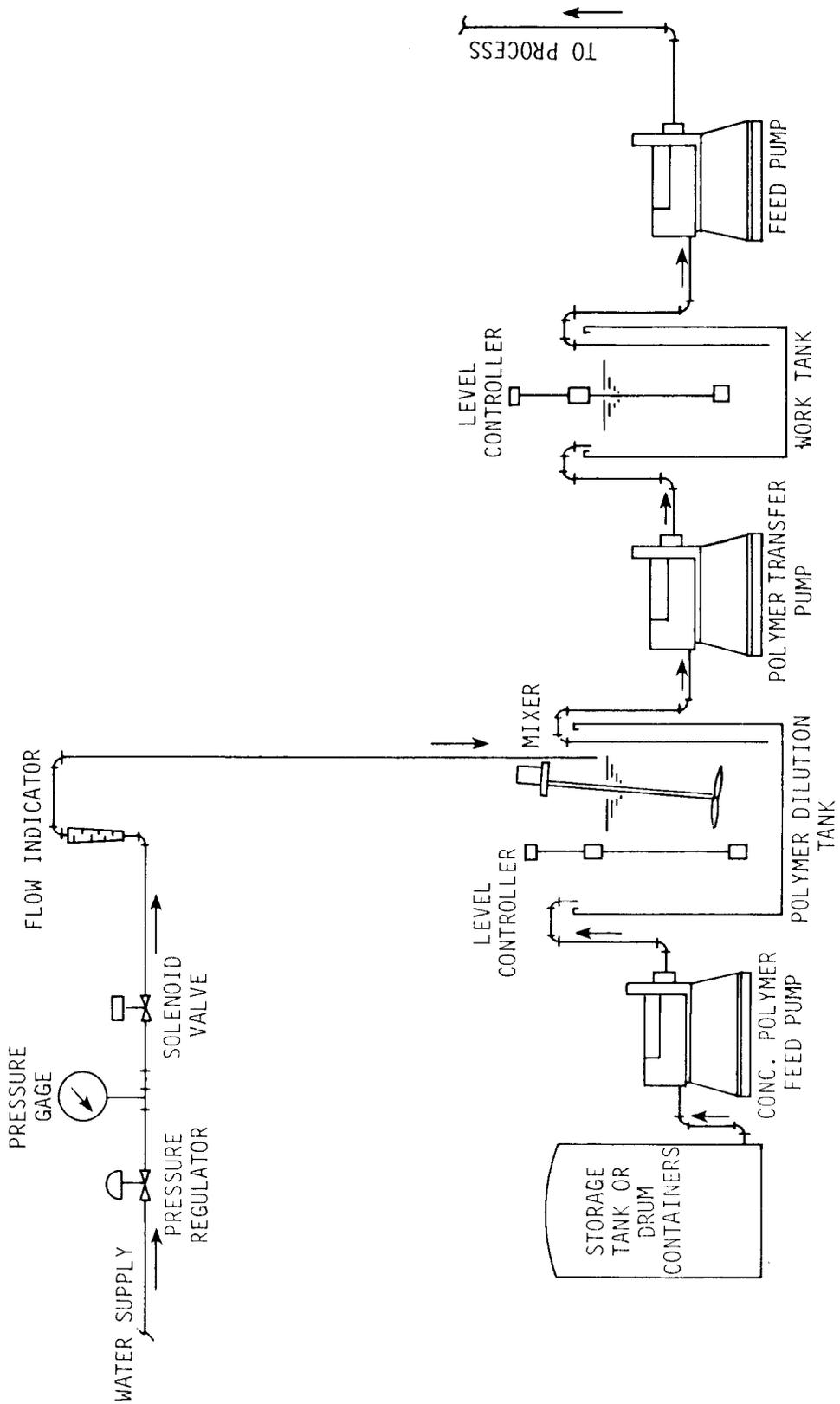


FIGURE 18. SCHEMATIC DIAGRAM OF A TWO-TANK LIQUID POLYMER FEED SYSTEM

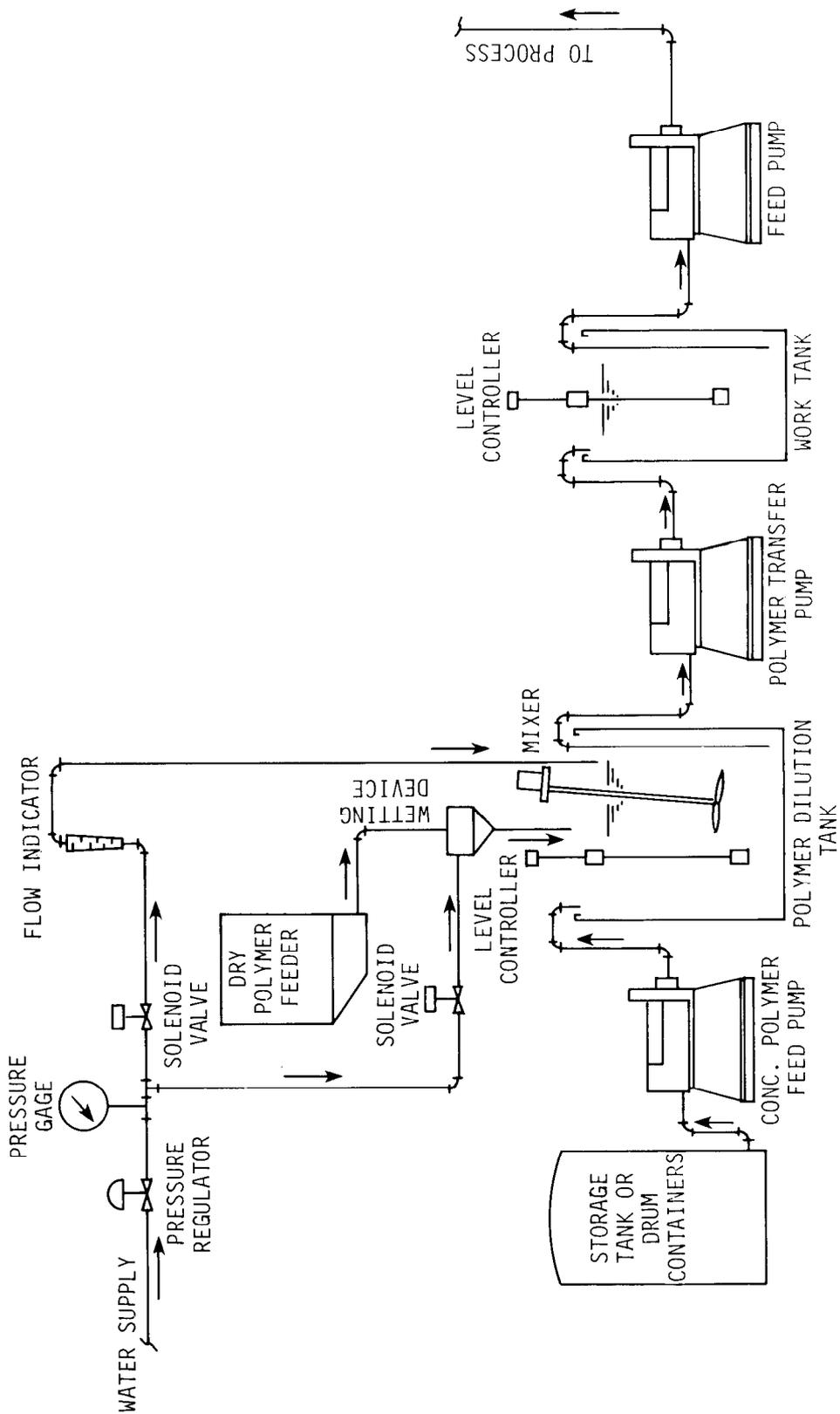


FIGURE 19. SCHEMATIC DIAGRAM OF LIQUID AND DRY POLYMER FEED SYSTEM USING TWO TANKS

## Design Example

133. Given:

- a. Two polymers will be required: (1) polymer ALPHA, a liquid polymer with a specific gravity of 1.0; and (2) polymer BETA, a dry polymer with a specific weight of 25 lb/ft<sup>3</sup>.
- b. Polymer ALPHA and polymer BETA may be effectively injected at an 0.5 percent solution.
- c. The maximum polymer dosage rate for both polymers is 20 mg/l or 174 lb/hr.
- d. The maximum flow rate in an 18 in. pipeline is 25 mgd.
- e. Volume of dilution water is approximately 100,000 gpd.

134. If 174 lb/hr of liquid or dry polymer are to be injected, facilities must be designed to receive and store an adequate quantity of polymer. The decision on how liquid or dry polymer should be shipped depends upon the quantity of polymer to be used and the duration of the project.

135. The polymer to be used each day is:

$$(174 \text{ lb/hr})(24 \text{ hr/day}) = 4176 \text{ lb/day}$$

$$4176 \text{ lb/day} \div 8.34 \text{ lb/gal} = 500 \text{ gal liquid polymer/day}$$

$$4176 \text{ lb/day} \div 25 \text{ lb/ft}^3 = 166.8 \text{ ft}^3/\text{day} = 42 \text{ 100-lb drums.}$$

136. Because the use of 4176 lb of liquid polymer/day is a significant quantity, it is desirable to purchase liquid polymer in tank truck quantities. The quantity of liquid polymer that can be hauled in a tank truck depends upon the specific gravity of the polymer and the weight restrictions on trucks in a particular state. Other considerations would include the time delay between placing an order and delivery, potential weather problems, strikes, etc. If a 30-day storage capacity with freeboard is assumed, a 20,000-gallon bulk polymer storage tank is suitable. Tank trucks would deliver polymer directly to the bulk storage tank by pumping.

137. Dry polymer would be handled in 50-lb bags or 100-lb drums. Sufficient weatherproof space must be provided to handle and store the dry polymer. If the polymer is delivered on pallets, then provisions for operating a fork lift can reduce the manpower required for unloading. The design of the dry polymer storage should facilitate

ease of handling of the dry polymer both while unloading and placing the polymer in the dry polymer storage bin.

138. Referring to Figure 19, the next part of the liquid polymer feed system to be designed is the concentrated polymer feed pump and polymer dilution tank. It is known that the maximum concentrated liquid polymer feed rate is 0.35 gpm. However, concentrated polymer will not be fed on a continuous basis because the polymer must be pumped to the work tank. Dry polymers require aging while liquid polymer normally requires only dilution. Aging time of a dry polymer may be defined as the time required to completely dissolve the polymer. If the aging time for polymer BETA is assumed to be one hour, then the minimum volume of the polymer dilution tank is equal to the volume of dilute polymer injected in one hour plus the time to fill the tank, plus the time to transfer the dilute polymer to the work tank, plus a safety factor. The capacity of the concentrated polymer feed pump is determined by the realistic time it would take to fill the tank with polymer and dilution water assuming there is no limitation on the flow rate of the dilution water.

139. The volume of diluted polymer pumped in one hour is 4167 gallons; therefore, at least this volume of dilute polymer must be available in the work tank each hour. Assuming the combined flow of the dilution water and concentrated polymer is 500 gpm, it would take 40 minutes to fill and transfer the liquid from a 10,000-gallon polymer dilution tank. If it is assumed that it will take 20 minutes to fill the tank, one hour to age the polymer, 20 minutes to transfer the polymer to the work tank, and a 20-minute safety factor, the volume of the polymer dilution tank should be  $(2.0 \text{ hr})(4167 \text{ gal/hr}) = 8334 \text{ gal}$ . A polymer dilution tank of approximately 10,000 gallons will provide adequate freeboard and room for a small amount of polymer to prevent the polymer transfer pump from running dry.

140. As can be seen from the above discussion, the aging time of the polymer and the rate that the polymer dilution tank can be filled and emptied control the size of the concentrated polymer feed pump and the size of the polymer dilution tank. If a 10,000-gallon

tank with a 8334-gallon working volume is used the actual time to fill the tank at 500 gpm is 16.7 minutes. The capacity of the concentrated polymer feed pump would have to be 2.5 gpm. Therefore, a variable capacity positive displacement pump should be installed with a maximum capacity of approximately 4.0 gpm.

141. The dilution water flow rate is quite high; therefore, careful analysis of the available water supply should be made. Considerable savings may be realized if the polymer can be diluted and aged at a higher percent concentration. After transfer to the work tank the polymer could be further diluted in a mixing inductor. The feasibility of this would depend on the characteristics of the polymer(s) to be used.

142. The dry polymer feed system will consist primarily of a bag or drum dump system which controls dust, a supply hopper, and a dry polymer feeder. In this case, the capacity of the dry feeder must be equal to 21 lb/minute. Several manufacturers can supply systems of this type and they should be contacted for further information.

143. The polymer transfer pump capacity has been assumed to be 500 gpm. This pump may be a centrifugal pump or other high capacity pump. The size of the work tank can be determined by assuming that a minimum volume of polymer will remain in the tank when the level controller turns on the polymer transfer pump, adding the volume of polymer transferred from the polymer dilution tank and adequate freeboard. Assuming that the polymer transfer pump will turn on when a 30-minute supply remains in the work tank, the volume remaining would be:

$$(30 \text{ min} \div 1440 \text{ min/day})(100,000 \text{ gpd}) = 2083 \text{ gal}$$

The volume of polymer to be transferred is 8334 gallons. If 2000 gallons of freeboard is assumed, the volume of the work tank would be approximately 12,500 gallons.

144. Assuming that all tanks are full, the system would operate in the following manner. The feed pump would pump at a maximum constant rate of 69.4 gpm unless automatic flow controllers are installed. When the level in the work tank reaches 2083 gallons, the level

controller would turn on the polymer transfer pump and 8334 gallons of diluted and aged polymer would be transferred to the work tank in 16.7 minutes. Because the feed pump is operating continuously, the level controller will again turn on the polymer transfer pump every 120 minutes. Once the polymer transfer pump has essentially emptied the polymer dilution tank, the level controller turns on the concentrated polymer feed pump or dry polymer feeder and the dilution water system. The polymer dilution tank is filled within 16.7 minutes, the polymer mixed and aged, and the polymer becomes ready to be transferred to the polymer transfer pump.

145. The above brief discussion of polymer feed systems is meant only to give the design engineer an indication of the variables that should be considered when designing such a system. There are numerous points that were not discussed, each of which may be important, and unless considered could cause significant problems or even cause the system to fail. It is recommended that all information concerning the potential polymer(s) be obtained from the polymer manufacturer. Manufacturers of polymer feed systems and components should be contacted to obtain information and recommendations.

### Polyelectrolyte Coagulation of Effluent from a Confined Area

#### Introduction

146. As previously discussed, polyelectrolytes may be used to coagulate dredged material either by injection into the hydraulic dredge pipeline or into the effluent from a confined area. There are many benefits to using polymers to coagulate the overflow from a confined area as compared to attempting to coagulate the concentrated slurry in the hydraulic dredge pipeline. These benefits will be:

- a. Lower suspended solids concentrations in confined area effluent.
- b. Less variation in effluent flow rate and composition.
- c. Ability to control mixing intensity.

147. All of the above benefits mean that a specified suspended solids criteria may be met on a continuous basis, whereas injection into a hydraulic dredge pipeline may not be as effective or predictable.

Facilities to coagulate the effluent from a confined area are composed of several separate units. Discussion of the design polymer feed system has been presented in a previous section of this report. The discussion of design of facilities to coagulate effluent from a confined area will be limited to:

- a. Rapid mix facilities.
- b. Slow mix facilities.
- c. Clarification.

148. The design of confined areas will not be a part of this discussion, nor will the design of facilities to handle or dispose of the settled dredged material from the clarifier. Design of these facilities will be discussed in a publication by Palermo et al.<sup>1</sup>

#### Design of Rapid Mix Facilities

149. The term rapid mix when using alum or iron coagulants may mean something completely different than when polyelectrolytes are used as coagulants. When alum or iron salts are used the purpose of the rapid mix process is to mix the chemicals with the water as rapidly as possible. Detention times of 15 to 30 seconds are normal. When polyelectrolytes are used the rapid mix process not only must mix the polymer with the water to be treated but it must also form small floc. The optimum theoretical detention time and mixing intensity in the rapid mix basin are determined by jar tests. It is not unusual to determine that the detention time in a rapid mix basin with a mixing intensity  $G$  of  $200 \text{ sec}^{-1}$  is 15 minutes or greater.

150. Rapid mixing may be achieved in pipes, round-the-end or over and under baffles, and in basins equipped with mechanical agitators. Nonmechanical mixing basins have certain disadvantages which may limit their use. The mixing intensity and detention time within a pipe or baffled basin are determined by head loss, which is a function of flow data through the basin. If the flow can be controlled, then both the detention time and mixing intensity may be controlled. Hydraulic pipeline dredges may vary the flow rate into a confined area; therefore, unless the overflow from the confined area is pumped it would be difficult to control the flow through the rapid mix facilities. As

the flow rate is reduced in a nonmechanical mixer, settling of solids may occur. This would not happen in a rapid mix basin equipped with a mechanical mixer. A mechanical mixer will also allow the operator to make adjustments to the mixing intensity in the rapid mixer as required to improve the treatment process. If a baffled basin is to be designed it is desirable to use the around-the-end type because it would be easier to drain and clean after the solids have settled out.

151. Design of a Rapid Mix Chamber Using Mechanical Agitation.

Procedures for designing a rapid mix chamber that utilizes mechanical agitation are as follows:

- a. Determine range of G and t values from jar tests.
- b. Select the volume, V, of the rapid mix chamber to provide a detention time, t, which corresponds to the upper end of the optimum range of rapid mixing times which were determined by jar testing, and for the mean effluent flow rate expected from the confined area.
- c. Determine the highest value of G which would be required in the rapid mix basin, based on the highest observed optimum value of G from the jar tests.
- d. Determine the absolute viscosity,  $\mu_s$ , of the suspension by the equation:

$$\mu_s = \mu \{1 + 2.5 C_V + 10.05 C_V^2 + 0.00273 \exp (16.6 C_V)\}$$

where  $\mu$  = absolute viscosity of the carrying water at T °F, lb-sec/ft<sup>2</sup>

$C_V$  = volumetric fraction of particles in suspension, expressed as a decimal

Since  $\mu$  is variable with temperature and dissolved solids content of the water, for the dredged material calculations,  $\mu$  should be based on the temperature and solids content of the water which will be the carrying medium during dredging.

- e. Determine the power, P, to be dissipated in the rapid mix basin from the equation:

$$G = \sqrt{\frac{550P}{V \mu_s}} \quad \text{for mechanical mixers}$$

Rearranging the terms gives:

$$P = \frac{G^2 \mu_s V}{550}$$

where P = water horsepower

G = the root-mean-square velocity gradient,  
in sec<sup>-1</sup>

$\mu_s$  = absolute viscosity of suspension,  
lb-sec/ft<sup>2</sup>

V = volume of basin, ft<sup>3</sup>

550 = number of ft-lb/sec ÷ HP

f. Determine the motor horsepower of the mixer:

$$\text{HP}_{\text{mixer}} = \frac{\text{HP}_{\text{water}}}{\text{efficiency of drive mechanism}}$$

g. Determine the dimensions of the mixing basin.

h. Select the mixer(s) to be used.

152. Design of a Rapid Mix Chamber Using Baffled Basins. The following steps are for the design of a rapid mix chamber that uses baffled basins:

- a. Determine the range of G and t values from jar tests.
- b. Select the volume, V, of the rapid mix chamber to provide a detention time, t, which corresponds to the upper end of the optimal range of rapid mixing times, which were determined by jar testing, and for the mean effluent flow rate expected from the confined area.
- c. Determine the highest value of G which would be required in the rapid mix basin, based on the highest observed optimum value of G from the jar tests.
- d. Determine the absolute viscosity,  $\mu_s$ , of the suspension by the equation:

$$\mu_s = \mu \{ 1 + 2.5 C_V + 10.05 C_V^2 + 0.00273 \exp (16.6 C_V) \}$$

where  $\mu$  = absolute viscosity of the carrying water at  
T °F, lb-sec/ft<sup>2</sup>

$C_V$  = volumetric fraction of particles in suspension, expressed as a decimal

Since  $\mu$  is variable with temperature and dissolved solids content of the water, for the dredged material calculation,  $\mu$  should be based on the temperature and solids content of the water which will be the carrying medium during dredging.

- e. Determine the headloss, H, required through the basin from the equation:

$$G = \sqrt{\frac{62.4H}{\mu_s t}} \quad \text{for baffled basins}$$

where H = headloss due to friction in feet  
t = detention time in seconds

Rearranging the terms gives:

$$H = \frac{G^2 \mu_s t}{62.4}$$

- f. Design the baffles to provide the calculated H.

153. Design Example. An 18-in. dredge will be used for a project and the average flow rate from the dredged material disposal area is anticipated to be 21.20 cfs. A series of jar tests has given a range of optimum rapid mix detention times of three to five minutes; therefore, use the upper end of this range, five minutes, as the detention time at average flow. The jar tests have resulted in a range of optimum G values of 100 to 140 sec<sup>-1</sup>; therefore, select a variable-speed mixer which can develop a G of 140 sec<sup>-1</sup>.

154. First, select a volume for the rapid mix chamber. Volume =  $Q_{ave} \times 5 = 21.20 \text{ cfs} \times \text{five min} \times 60 \text{ sec/min} = 6360 \text{ ft}^3$ . If site considerations and the depth of the primary settling basin dictate an allowable depth of 17 feet, the surface area of the rapid mix chamber is then  $6360 \text{ ft}^3 / 17 \text{ ft} = 374 \text{ ft}^2$ . Let the basin be a square 20 ft on a side. The design volume is then  $6800 \text{ ft}^3$ .

155. From a laboratory analysis of the suspension, the volumetric fraction of solids was found to be 0.44 percent, or 0.0044. Calculate the absolute viscosity of the suspension,  $\mu_s$ . The expected minimum temperature of the water which will be the carrying medium is 40 °F. The absolute viscosity of fresh water at 40 °F,  $\mu = 3.229 \times 10^{-5} \text{ lb-sec/ft}$  is:

$$\begin{aligned} \mu_s &= \mu \{1 + 2.5 C_V + 10.05 C_V^2 + 0.00273 \exp (16.6 C_V)\} \\ &= 3.229 \times 10^{-5} \times 1.014 = 3.274 \times 10^{-5} \text{ lb-sec/ft}^2 \end{aligned}$$

Calculate the power required to be dissipated in the basin by the mixer for the maximum G.

$$\begin{aligned}
 P &= \frac{G^2 \mu_s V}{550} = \left( \frac{140}{\text{sec}} \right)^2 \times (3.274 \times 10^{-5} \text{ lb-sec/ft}^2) \\
 &\quad \times (6800 \text{ ft}^3 \div 550 \text{ ft-lb/sec/HP}) \\
 &= 8.0 \text{ HP}
 \end{aligned}$$

The motor horsepower to drive a rapid mixer to dissipate 8.0 HP is dependent upon many factors including type of mixer, size of basin, etc. By consulting a manufacturer, it was determined that the efficiency of such a mixer would be 85 percent. Calculate the motor output HP to be:

$$\begin{aligned}
 \frac{8.0 \text{ HP}}{0.85} &= 9.4 \text{ HP at 75 percent load} \\
 \frac{9.4 \text{ HP}}{0.75} &= 12.5 \text{ HP at 100 percent load}
 \end{aligned}$$

### Design of Slow Mix Facilities

156. General. The purpose of slow mix facilities is to form large floc particles of sufficient size to rapidly settle. The design parameters for the slow mix facility are obtained in the same manner as for the rapid mix facilities. The design information obtained from jar tests include: The G values required for proper floc formation and to maintain the flocculated solids in suspension; the optimum detention time. Both minimum and maximum G values must be determined and mixing equipment (if a mechanical flocculator is used) installed to cover the range of G values appropriate for the system. Minimum G values are normally determined by the mixing intensity required to maintain the floc in suspension. Maximum G values are determined by the shearing of floc which prevents formation of large floc and rapid settling. Based on field experience, it is recommended that for mechanical mixers the maximum tip speed be limited to 2.0 fps for weak floc and 4.0 fps for strong floc.<sup>13</sup>

157. There are two general categories of flocculators: mechanically agitated flocculators and baffled chambers. Mechanical

flocculators have the advantage of being able to impose varying mixing intensities within the basin regardless of the flow rate. The mixing intensity within a particular baffled basin is determined by the flow rate through the basin. The design example presented in this report is for a mechanical flocculator which will follow the rapid mix basin designed previously.

158. Design Example. The flow rate from the rapid mixing basin in the previous design example was 21.20 cfs. Jar tests have shown that the minimum and maximum detention times for acceptable degrees of flocculation are five and 15 minutes, respectively, and the required G values varied from 12 to 49 sec<sup>-1</sup>.

159. First, determine the volume of the flocculation basin using the maximum detention time of 15 minutes:

$$\begin{aligned} \text{Volume} &= \text{Flow} \times \text{Time} \\ &= 21.20 \text{ cfs} \times 15 \text{ min} \times 60 \text{ sec/min} \\ &= 19,080 \text{ ft}^3. \end{aligned}$$

Maintain a depth of 17.0 ft as in the rapid mix basin, and divide the slow mix into three equal basins in series to reduce short circuiting. By using three basins 20 ft x 20 ft x 17 ft, which are the same size as the rapid mix basin, a total volume of 20,400 ft<sup>3</sup> would be provided. These should be arranged so that one or more basins may be bypassed so that the operator may change the detention time as required. Care must be taken in conveying the floc from basin to basin because mixing intensity over weirs or through pipes can easily exceed that necessary to shear floc.

160. The next step is to calculate power dissipated in each basin to obtain a G of 49 sec<sup>-1</sup>. The absolute viscosity,  $\mu_s$ , was previously calculated to be 3.274 X 10<sup>-5</sup> lb-sec/ft<sup>2</sup>.

$$\begin{aligned} P &= \frac{G^2 \mu_s V}{550} \\ P &= \left( \frac{49}{\text{sec}} \right)^2 \times 3.274 \times 10^{-5} \text{ lb-sec/ft}^2 \\ &\times \frac{20,400 \text{ ft}^3}{550 \text{ ft-lb/sec/HP}} = 2.9 \text{ HP} \end{aligned}$$

161. The motor HP required to drive a flocculator to dissipate 2.9 HP into the water is dependent upon many factors, including type of flocculator, physical dimensions of the flocculation basin, etc. By consulting a manufacturer of flocculators the proper flocculator and motor HP can be selected. It is advisable to install a variable-speed drive motor on the flocculator or provide for a mechanical means of changing the flocculator speed. This will provide the operator with the means to select a G value to fit field conditions, if conditions should change.

### Design of Sedimentation Units

162. General. As previously stated, standard test procedures are not available for determining clarifier surface loading rates for coagulated dredged material. Estimates of surface loading rates can be made by settling within two-litre beakers as previously described. Results of these static tests cannot duplicate actual field conditions; therefore, it is normal to use empirical safety factors based on experience. Under actual field conditions, short circuiting and turbulence can significantly reduce the theoretical efficiency of a settling basin. Commonly applied design safety factors for mechanical clarifiers are 1.25 to 1.75 for experimentally determined surface overflow rates.

163. Once the design surface loading rate has been selected, it is simply a matter of selecting the type clarifier to be utilized and, based on the design flow, calculate the physical dimensions of the facility. The design flow rate will normally be the maximum pumping rate of the dredge. A detailed discussion of clarification equipment, their advantages, and disadvantages may be found in Appendix B.

164. A major problem associated with the design of the sedimentation unit, which is not a portion of this report, is handling of coagulated dredged material and disposal. If earthen basins are utilized for the sedimentation units, then they may be designed for both suspended solids removal and storage. Basins of this type may be

the final disposal point for the settled dredged material or may be periodically re-dredged and reused as settling basins. If more conventional mechanically cleaned clarifiers are utilized, dredged material solids must be removed continuously. The handling of dredged material solids pumped from a clarifier will depend upon the conditions at a particular dredge site. Possible methods of handling the dredged material solids include:

- a. Pumping into the dredged material confined area.
- b. Pumping into a separate confined area.
- c. Dewatering on-site.

165. Design Example. Given flow = 21.20 cfs.

Surface loading rate = 1000 gal/ft<sup>2</sup>/day (includes safety factor).

Influent solids concentration, C<sub>i</sub> = 3000 mg/l.

Underflow solids concentration C<sub>u</sub> = 30,000 mg/l.

166. The surface area of a clarifier(s) required to handle the design flow is determined by:

$$A = \frac{Q}{\text{surface loading rate}}$$

$$A = \{(21.20 \text{ ft}^3/\text{sec})(60 \text{ sec/min})(1440 \text{ min/day}) \times (7.48 \text{ gal/ft}^3)\} \div 1000 \text{ gal/ft}^2/\text{day}$$

$$A = 13,700 \text{ ft}^2$$

167. The area required for clarification of 21.20 ft<sup>3</sup>/sec is 13,700 ft<sup>2</sup>. If one circular clarifier was installed it would have a diameter of 132 ft. It would be more effective to install two clarifiers of 94-ft diameter because of the flexibility of two units and the fact that smaller diameters (less than 100-ft diameter) are generally more efficient than large-diameter clarifiers.

168. The volume of waste sludge may be calculated by the formula:

$$Q_o C_i = Q_s C_u \text{ or } Q_u = \frac{Q_o C_i}{C_u}$$

where Q<sub>o</sub> = influent flow; C<sub>i</sub> = influent solids concentration; Q<sub>s</sub> = waste sludge flow; and C<sub>u</sub> = waste sludge concentration.

$$Q_u = \frac{(21.2 \text{ ft}^3/\text{sec})(5010 \text{ mg/l})}{41,750 \text{ mg/l}}$$

$$Q_u = 2.54 \text{ ft}^3/\text{sec}$$

$$= 1.64 \text{ mgd}$$

169. The above data are based on pilot plant tests previously discussed. They show that if the overflow from the containment area was 13.7 mgd (21.2 ft<sup>3</sup>/sec), then the underflow from the clarifier would be approximately 1.64 mgd (2.54 ft<sup>3</sup>/sec), a considerable flow to be handled. This 1.64-mgd flow is equivalent to five acre-ft/day. Even after 24 hours of storage, the dredged material solids volume would be three acre-ft/day. If the underflow from the clarifier were pumped into the dredged material confined area, then the design of the treatment system would have to be modified because of the increase in flow due to the 1.64 mgd of sludge.

## PART VII: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

170. The conclusions drawn from the analysis of data in this report are as follows:

- a. Chemical coagulation of overflow from a fine-grained dredged material confined area appears to be a viable method of treatment.
- b. The jar test procedure described in this report is effective for determining the most effective coagulant, coagulant dosage, and principal design parameters for a coagulation system.
- c. Chemical coagulation of fine-grained dredged material slurry within a hydraulic dredge pipeline can be expected to have a highly variable treatment efficiency. This is due to variations in flow and composition of dredged material slurry within a hydraulic dredge pipeline that make it extremely difficult to maintain an optimum chemical dosage.
- d. Continuous, highly efficient treatment of dredged material using chemical coagulation requires properly designed and operated coagulation systems.
- e. Although handling of settled sludge from a dredged material coagulation process was not part of this report, this problem should not be overlooked because of the large volumes of sludge that may result.

### Recommendations

171. Based on the results of this study, the following recommendations are made:

- a. A settling test for coagulated dredged material should be developed to provide more accurate settling data for designing clarification equipment/settling basins.
- b. Further investigation should be carried out on the feasibility of coagulating dredged material within a hydraulic dredge pipeline.
- c. A methodology and design guideline should be developed for handling and disposing of settled dredged material resulting from coagulation treatment.

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APPENDIX A: COAGULATION OF A DREDGED MATERIAL SUSPENSION

WITHIN A PIPELINE

Introduction

1. The mixing intensity which is imparted to a suspension of dredged material can be approximated by using equation (1) as defined by Davis.<sup>1</sup>

$$G = \sqrt{\frac{W}{\mu_s}} \quad (1)$$

where  $G$  is the mean velocity gradient as  $\text{sec}^{-1}$ ,  $W$  is the work done on the suspension by shear per unit of volume per unit of time expressed in  $\text{lb/ft}^2\text{-sec}$ , and  $\mu_s$  is the absolute viscosity of the suspension in  $\text{lb-sec/ft}^2$ .

2. For flow in a pipeline the amount of energy imparted to the fluid is given by equation (2).

$$W = \frac{g\rho_s h_f}{t} \quad (2)$$

where  $g$  is the gravitational acceleration constant of  $32.2 \text{ ft/sec}^2$ ,  $\rho_s$  is the mass density of the suspension in  $\text{slug/ft}^3$ ,  $h_f$  is the head loss due to friction in  $\text{ft}$ , and  $t$  is the retention time in the pipe in seconds.

3. The friction loss can be determined by using the Darcy-Weisbach equation (3) as defined by King and Brater.<sup>2</sup>

$$h_f = f \frac{L}{D} \frac{v^2}{2g} \quad (3)$$

where  $f$  is a dimensionless friction factor for the pipe,  $L$  is the length of pipe in feet between the polymer injection point and the discharge end of the pipeline,  $D$  is the diameter of the pipe in feet,  $v$  is the mean velocity of the suspension in the pipe in  $\text{ft/sec}$ , and  $g$  is the gravitational acceleration constant. The friction factor,  $f$ , is determined from a graph of the relative internal roughness of the pipe and the Reynolds number.<sup>2</sup>

4. Combining equations (2) and (3) gives the equation:

$$W = \frac{g\rho_s}{t} f \frac{L}{D} \frac{v^2}{2g} = \frac{\rho_s}{t} f \frac{L}{D} \frac{v^2}{2} \quad (4)$$

Since  $L/t$  is the mean velocity,  $v$ , of the suspension, the equation becomes:

$$W = \frac{\rho_s f v^3}{2D} \quad (5)$$

The density,  $\rho_s$ , can also be expressed as:

$$\rho_s = \frac{\gamma_s}{g} \quad (6)$$

where  $\gamma_s$  is the specific weight of the suspension in  $\text{lb/ft}^3$ .

Combining equations (2) and (3) gives the equation:

$$W = \frac{\gamma_s}{2g} \frac{f}{D} v^3 \quad (7)$$

Substituting this expression in equation (1) gives an equation which will permit the calculation of the approximate mixing intensity within a pipe

$$G = \sqrt{\frac{\gamma_s f v^3}{2gD\mu_s}} \quad (8)$$

The absolute viscosity of the suspension,  $\mu_s$ , is related to the absolute viscosity of the carrying water,  $\mu$ , by the equation:

$$\mu_s = \mu \{1 + 2.5 C_v + 10.05 C_v^2 + 0.00273 \exp (16.6 C_v)\} \quad (9)$$

where  $C_v$  is the volumetric fraction of solids in the suspension, expressed as a decimal.

5. Since  $\mu$  varies with temperature and the amount of dissolved solids in the water, the value of  $\mu$  used for dredged material hydraulic calculations should be representative of the temperature and mineral content of the water which will be the carrying medium during dredging.

6. The value of G for the pipe can be calculated from equation (8). The maximum retention or mixing time, t, is equal to L/v. After calculating the range of G and t values which may be developed in the dredge pipe for a range of flows and suspension concentrations, the optimum polyelectrolyte and polyelectrolyte dosage can be experimentally determined by conducting laboratory jar tests using these G and t values.

### Example Problem

7. Calculate the effects of flow and concentration on the mean G and t values in a hydraulic dredge pipeline for a dredging operation in a freshwater river. An 18" dredge pipe is being used, and the mean velocity varies from 12 to 20 ft/sec. The concentration of the dredge material suspension varies from five to 20 percent by weight, with specific gravities (S.G.) of 1.032 and 1.142, respectively. The specific gravity of the solids is 2.65. The water temperature is 60°F. The length of the steel discharge pipe is 4000 ft. Calculate and compare the G and t values for four cases:

- a. five percent solids at 12 ft/sec;
- b. five percent solids at 20 ft/sec;
- c. 20 percent solids at 12 ft/sec; and
- d. 20 percent solids at 20 ft/sec.

Case a. -- Five Percent Solids Suspension at 12 ft/sec

$$C_v = \frac{\text{(solids content of suspension by weight expressed as a decimal x S.G. of suspension)}}{\text{S.G. of Solids}} \quad (10)$$

$$= \frac{0.05 \times 1.032}{2.65} = \underline{0.0195, \text{ dimensionless}}$$

$$\mu \text{ for fresh water at } 60^\circ\text{F} = 2.359 \times 10^{-5} \text{ lb-sec/ft}^2.$$

$$\mu_s = \mu \{ 1 + 2.5 C_v + 10.05 C_v^2 + 0.00273 \exp (16.6 C_v) \}$$

$$= 2.359 \times 10^{-5} \text{ lb-sec/ft}^2 \{ 1 + 2.5(0.0195) + 10.05 (0.0195)^2 + 0.00273(2.71828)^{16.6 \times 0.0195} \} = \underline{\underline{2.491 \times 10^{-5} \text{ lb-sec/ft}^2}}$$

$$R, \text{ Reynolds number} = \frac{vD\rho}{\mu} \quad (11)$$

Combining equations (11) and (6) gives

$$\begin{aligned} R, \text{ Reynolds number} &= \frac{vD\gamma_s}{g\mu_s} \\ &= \frac{(12 \text{ ft/sec})(1.5 \text{ ft})(1.032 \times 62.4 \text{ lb/ft}^3)}{32.2 \text{ ft/sec}^2 \times 2.491 \times 10^{-5} \text{ lb-sec/ft}^2} \\ &= \underline{\underline{1.445 \times 10^6, \text{ dimensionless}}} \end{aligned} \quad (12)$$

For steel pipe, the internal roughness,  $\epsilon$ , is 0.0015 ft. For an 18" diameter pipe, the relative roughness,  $\epsilon/D$ , is  $1 \times 10^{-4}$ . For  $\epsilon/D = 1 \times 10^{-4}$  and  $R = 1.445 \times 10^6$  the friction factor,  $f$ , is 0.013 (see Figure 8.8 reference 3).

$$G = \sqrt{\frac{\gamma_s f v^3}{2g D \mu_s}} \quad (8)$$

$$\begin{aligned} &= \sqrt{\frac{(1.032 \times 62.4 \text{ lb/ft}^3)(0.013)(12 \text{ ft/sec})^3}{2(32.2 \text{ ft/sec}^2)(1.5 \text{ ft})(2.491 \times 10^{-5} \text{ lb-sec/ft}^2)}} \\ &= \underline{\underline{775 \text{ sec}^{-1}}} \end{aligned}$$

$$t = \frac{L}{v} = \frac{4000 \text{ ft}}{12 \text{ ft/sec}} = \underline{\underline{333 \text{ sec}}}$$

Case b. -- Five Percent Solids Suspension at 20 ft/sec

$$C_v = 0.0195, \text{ from Case a.}$$

$$\mu_s = 2.491 \times 10^{-5} \text{ lb-sec/ft, from Case a.}$$

$$\begin{aligned} R &= \frac{vD\gamma_s}{g\mu_s} = \frac{(20 \text{ ft/sec})(1.5 \text{ ft})(1.032 \times 62.4 \text{ lb/ft}^3)}{(32.2 \text{ ft/sec}^2)(2.491 \times 10^{-5} \text{ lb-sec/ft}^2)} \\ &= \underline{\underline{2.41 \times 10^6, \text{ dimensionless}}} \end{aligned} \quad (12)$$

For  $\epsilon/D = 1 \times 10^{-4}$  and  $R = 2.41 \times 10^6$ , the friction factor,  $f$ , is 0.0126 (See Figure 8.8 reference 3).

$$G = \sqrt{\frac{\gamma_s f v^3}{2g D \mu_s}} \quad (8)$$

$$= \sqrt{\frac{(1.032 \times 62.4 \text{ lb/ft}^3)(0.0126)(20 \text{ ft/sec})^3}{2 (32.2 \text{ ft/sec}^2)(1.5 \text{ ft})(2.491 \times 10^{-5} \text{ lb-sec/ft}^2)}}$$

$$= \underline{\underline{1642 \text{ sec}^{-1}}}$$

$$t = \frac{L}{v} = \frac{4000 \text{ ft}}{20 \text{ ft/sec}} = \underline{\underline{200 \text{ sec}}}$$

Case c. -- Twenty Percent Solids Suspension at 12 ft/sec

$$C_v = \frac{\text{solids content as a decimal} \times \text{S.G. of suspension}}{\text{S.G. of Solids}}$$

$$= \frac{0.20 \times 1.142}{2.65} = \underline{\underline{0.0862, \text{ dimensionless}}}$$

$$\mu_s = \mu \{1 + 2.5 C_v + 10.05 C_v^2 + 0.00273 \exp(16.6 C_v)\} \quad (9)$$

$$= 2.359 \times 10^{-5} \text{ lb-sec/ft}^2 \{1 + 2.5 (0.0862) + 10.05(0.0862)^2 + 0.00273 (2.71828)^{16.6 \times 0.0862}\}$$

$$= \underline{\underline{3.071 \times 10^{-5} \text{ lb-sec/ft}^2}}$$

$$R = \frac{v D \gamma_s}{g \mu_s} = \frac{(12 \text{ ft/sec})(1.5 \text{ ft})(1.142 \times 62.4 \text{ lb/ft}^3)}{32.2 \text{ ft/sec}^2 \times 3.071 \times 10^{-5} \text{ lb-sec/ft}^2} \quad (12)$$

$$= \underline{\underline{1.297 \times 10^6, \text{ dimensionless}}}$$

$$1 \times 10^{-4}$$

For  $\epsilon/D = 1.10^{-4}$  and  $R = 1.297 \times 10^6$  the friction factor,  $f$ , is 0.0132 (See Figure 8.8 reference 3).

$$\begin{aligned}
 G &= \sqrt{\frac{\gamma_s f v^3}{2g D \mu_s}} & (8) \\
 &= \sqrt{\frac{(1.142 \times 62.4 \text{ lb/ft}^3)(0.0132)(12 \text{ ft/sec})^3}{2(32.2 \text{ ft/sec}^2)(1.5 \text{ ft})(3.071 \times 10^{-5} \text{ lb-sec/ft}^2)}} \\
 &= \underline{\underline{740 \text{ sec}^{-1}}}
 \end{aligned}$$

$$t = \frac{L}{v} = \frac{4000 \text{ ft}}{12 \text{ ft/sec}} = \underline{\underline{333 \text{ sec}}}$$

Case d. -- Twenty Percent Solids Suspension at 20 ft/sec

$C_v = 0.0862$ , dimensionless, from Case c.

$\mu_s = 3.071 \times 10^{-5}$  lb-sec/ft, from Case c.

$$\begin{aligned}
 R &= \frac{vD\gamma_s}{g\mu_s} = \frac{(20 \text{ ft/sec})(1.5 \text{ ft})(1.142 \times 62.4 \text{ lb/ft}^3)}{(32.2 \text{ ft/sec}^2)(3.071 \times 10^{-5} \text{ lb-sec/ft}^2)} & (12) \\
 &= \underline{\underline{2.16 \times 10^6, \text{ dimensionless}}}
 \end{aligned}$$

For  $\epsilon/D = 1 \times 10^{-4}$  and  $R = 2.16 \times 10^6$  the friction factor,  $f$ , is 0.0127 (See Figure 8.8 reference 3).

$$\begin{aligned}
 G &= \sqrt{\frac{\gamma_s f v^3}{2g D \mu_s}} & (8) \\
 &= \sqrt{\frac{(1.142 \times 62.4 \text{ lb/ft}^3)(0.0127)(20 \text{ ft/sec})^3}{2(32.2 \text{ ft/sec}^2)(1.5 \text{ ft})(3.071 \times 10^{-5} \text{ lb-sec/ft}^2)}} \\
 &= \underline{\underline{1562 \text{ sec}^{-1}}}
 \end{aligned}$$

$$t = \frac{L}{v} = \frac{4000 \text{ ft}}{20 \text{ ft/sec}} = \underline{\underline{200 \text{ sec}}}$$

The calculated G values for these four cases are summarized in Table A-1.

Table A-1

| <u>Case</u> | <u>Percent Solids</u> | <u>Velocity (ft/sec)</u> | <u>G (sec<sup>-1</sup>)</u> |
|-------------|-----------------------|--------------------------|-----------------------------|
| a.          | 5                     | 12                       | 775                         |
| b.          | 5                     | 20                       | 1641                        |
| c.          | 20                    | 12                       | 740                         |
| d.          | 20                    | 20                       | 1562                        |

These results demonstrate that the G value is more affected by changes in velocity than by variations in the concentration of the suspension. The value of G decreases five percent with a 300 percent increase in solids content, but it more than doubles for a change in velocity from 12 to 20 ft/sec.

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APPENDIX B: REVIEW OF EQUIPMENT AVAILABLE FOR  
COAGULATION AND SEDIMENTATION OF  
DREDGED MATERIAL

PART I: INTRODUCTION

1. In 1976 the consulting engineering firm of Jones, Edmunds and Associates, Inc. of Gainesville, Florida, was contracted by the Corps of Engineers to prepare a report titled "Review of Equipment Available for Coagulation and Sedimentation of Dredged Material." This unpublished report, prepared in less than six weeks under a purchase order contract, was completed on June 10, 1976. Portions of this report are presented here as background material for the engineer designing a coagulation facility for a particular dredging operation.

2. Included in this appendix is information on "off the shelf" equipment for handling and feeding polyelectrolytes, rapid and slow mixing equipment and clarification equipment. Cost estimates are provided for unit processes designed for assumed conditions to illustrate the order of magnitude cost involved in utilizing existing equipment for coagulation of dredged material.

3. The equipment discussed is not necessarily the most efficient or cost effective for a particular dredging project. This is particularly true for clarification equipment where earthen basins are frequently the most economical solution.

4. When cost estimates are prepared, it is necessary to select equipment based on certain assumptions. The following section discusses those assumptions. When comparing costs, the design engineer should take into consideration the assumptions utilized in developing the cost data as they may vary widely from project to project.

## PART II: DESIGN ASSUMPTIONS USED FOR EQUIPMENT SURVEY

### Background

5. Coagulation treatment may be applied either to the dredged material slurry or to a containment area effluent. The solids concentration of the dredged material slurry may vary from that of the overburden water to greater than 20 percent. The solids concentrations in the effluent of a containment area may vary from less than 10 mg/l to greater than 10,000 mg/l. The wide range of conditions which may be encountered required basic assumptions to be made so that available equipment could be reviewed and cost estimates made.

### Assumptions

6. 1) The dredged material flow rates to be evaluated included 0.1 mgd, 1.0 mgd, 5.0 mgd, 10.0 mgd, 25.0 mgd and 50.0 mgd.
- 2) The percent solids in the dredged material slurry could range from 5.0 to 20.0 percent.
- 3) The suspended solids in the effluent from the confined areas could range from 100 to 10,000 mg/l.
- 4) Pretreatment equipment required to prevent damage to clarification equipment for dredged material slurry would be assumed to be installed, however, would not be a part of this report.
- 5) Only polyelectrolytes would be considered as coagulating agents.
- 6) Mixing would not be required when polyelectrolytes were injected into the dredged material slurry.
- 7) The maximum polyelectrolyte dosage for either dredged material slurry or the effluent from the confined area would be 20 mg/l.
- 8) The density of dry polyelectrolyte and the solution or aging time for the polymer would be those reasonable from the literature.

- 9) Settled solids dewatering equipment would not be considered in this report.
- 10) Pumping of settled solids would be considered.
- 11) An adequate supply of suitable water would be assumed to be available. Therefore, water supply and treatment would not be a part of this study.
- 12) Adequate power would be assumed to be available on-site.
- 13) Labor would be required 365 days per year, 24 hours per day. Labor cost would be \$20,000 per operator per year. Five operators required per week.
- 14) Power cost would be 5¢ per kilowatt hour and polymer cost would be \$1.00 per lb delivered on-site.
- 15) Water cost \$1.00 per 1000 gallons.
- 16) Maintenance cost on equipment would equal five percent of capital cost per year.
- 17) Portable equipment would be assumed mobile if it could be either trucked or moved by a barge sized 30 ft x 120 ft with seven ft draft when loaded.
- 18) Capital cost of equipment will be presented in May 1976 dollars.

## PART III: POLYELECTROLYTE FEED EQUIPMENT

### Introduction

7. The design and selection of polyelectrolyte feed equipment are made quite difficult by the large number of polyelectrolytes available, each with different chemical and physical properties. Selected equipment must be able to handle a wide range of polyelectrolytes, as the most effective polymer might not be known or might vary with the type of dredged material being handled. New polyelectrolytes are introduced into the market each year; therefore, any system should be as flexible as possible so as to handle a wide range of polymers. Certain polymers can only be purchased in a dry form, while others can only be purchased in a liquid concentrate. The polymer feed equipment required to handle these various polymers is discussed below.

### Dilution Water

8. Dilution water physical and chemical characteristics are very important in the use of polyelectrolytes. Dilution water should normally have a low total dissolved solids (TDS) and low suspended solids concentrations. Different polyelectrolytes react in various ways with chemicals in dilution water. For example, certain anionic polymers may be made completely ineffective by using brackish water for dilution water. Although dilution water is not part of this study, the investigator should be aware that there are potential problems and should ensure that a satisfactory supply of dilution water is made available for any installation. The manufacturer of any particular polymer should be requested to supply information on the effects of dilution water characteristics of their polymer.

### Liquid Polyelectrolytes

9. Polyelectrolytes may be purchased in either a liquid or dry form. Liquid polymers are already in a concentrated liquid form; therefore, the feeding systems may be somewhat less complex than the systems required to handle dry polymers. Figure B1 shows a schematic

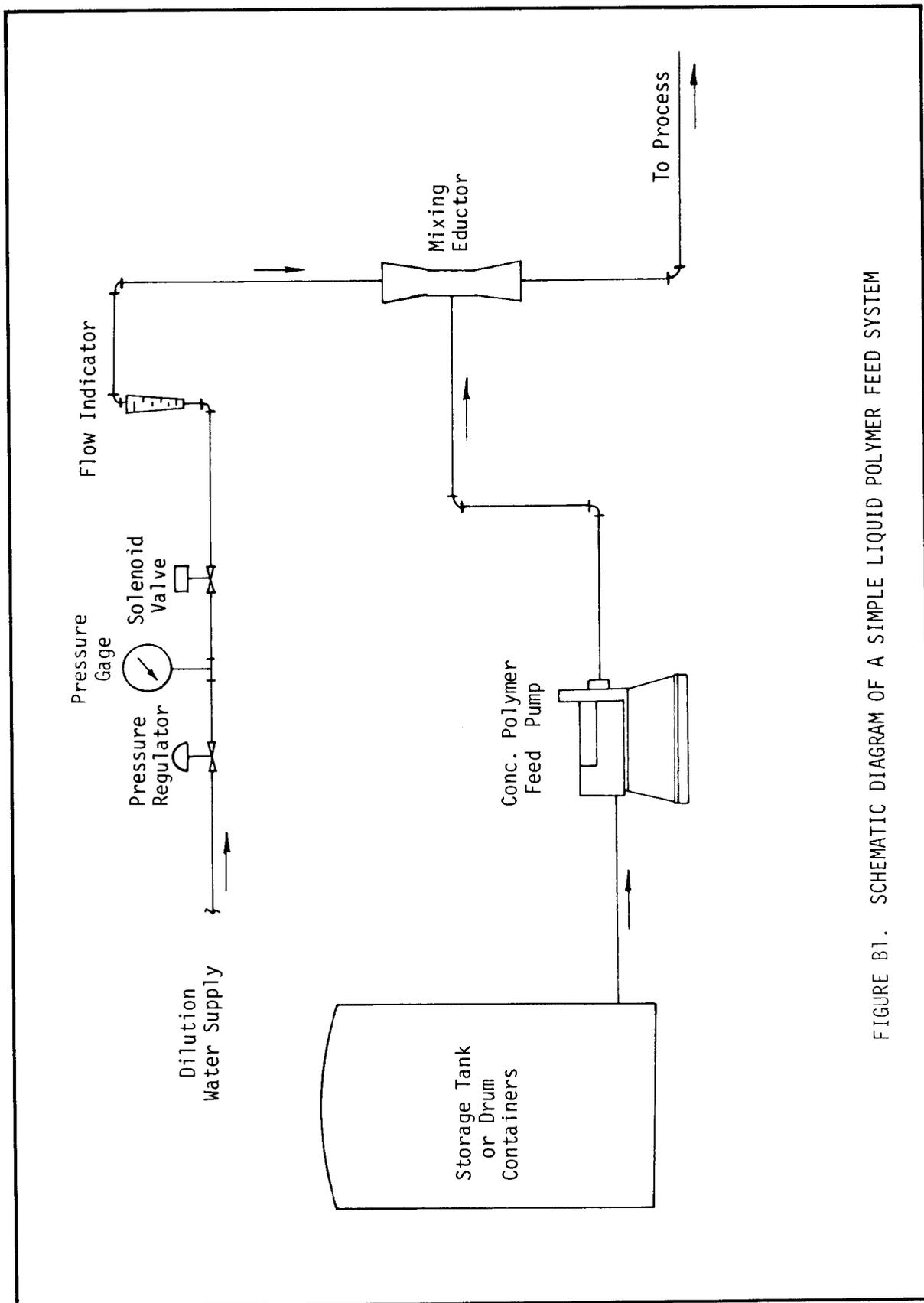


FIGURE B1. SCHEMATIC DIAGRAM OF A SIMPLE LIQUID POLYMER FEED SYSTEM

diagram of one of the simplest types of polymer feeding systems. The first part of this system consists of concentrated polymer storage facilities. Polymer storage may range from 55-gallon drums to large bulk storage tanks depending upon the quantity of polymer required to be fed during any given time period. The second part of the system is a variable capacity feed pump. This pump may be any type of positive displacement pump such as a diaphragm pump or progressive cavity pump. The last part of the feed system is a dilution system made up of a water supply and a flow controller and a mixing eductor. This system serves to dilute the concentrated polymer to the desired concentration prior to feeding it to the point of application. This system may be automated by measuring the flow of the process stream and automatically controlling the quantity of polymer fed. Feed pumps are normally protected from running dry by a pump protection device.

10. Another liquid polymer feed system is shown in Figure B2. This system is composed of bulk polymer storage facilities ranging from 55 gallon drums to storage tanks of any size. Concentrated polymer is pumped into a polymer dilution tank where it is mixed with water to prepare a dilute polymer solution. This solution may be fed directly to the process by a feeding pump or diluted further by a mixing eductor prior to being fed to the process. This system may be manually operated or automated by level control switches which will automatically add polymer and water, then turn the mixer on and off depending upon the level in the polymer dilution tank and time clock controls. There is a disadvantage to this system in that once the polymer dilution tank has been emptied, there is a period of time when no polymer can be fed while a new batch is being prepared. This may be overcome by duplicating the system or using a two-tank system as shown in Figure B3.

11. The two-tank system assures that a dilute solution of polymer is constantly available. In this system once a batch of polymer has been prepared in the polymer dilution tank it is transferred automatically to the polymer work tank. While polymer is being fed from the work tank, another batch can be prepared in the polymer dilution

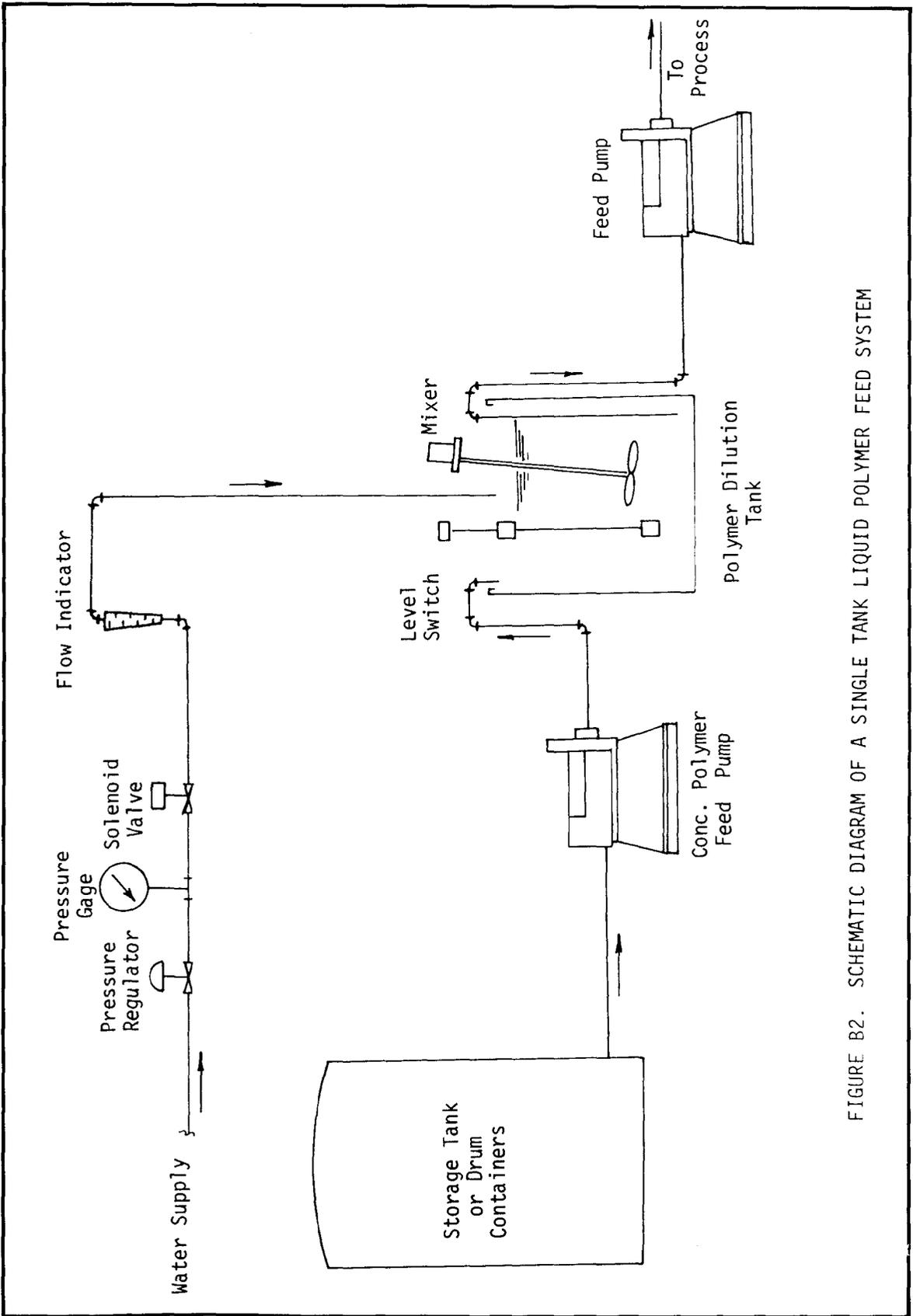


FIGURE B2. SCHEMATIC DIAGRAM OF A SINGLE TANK LIQUID POLYMER FEED SYSTEM

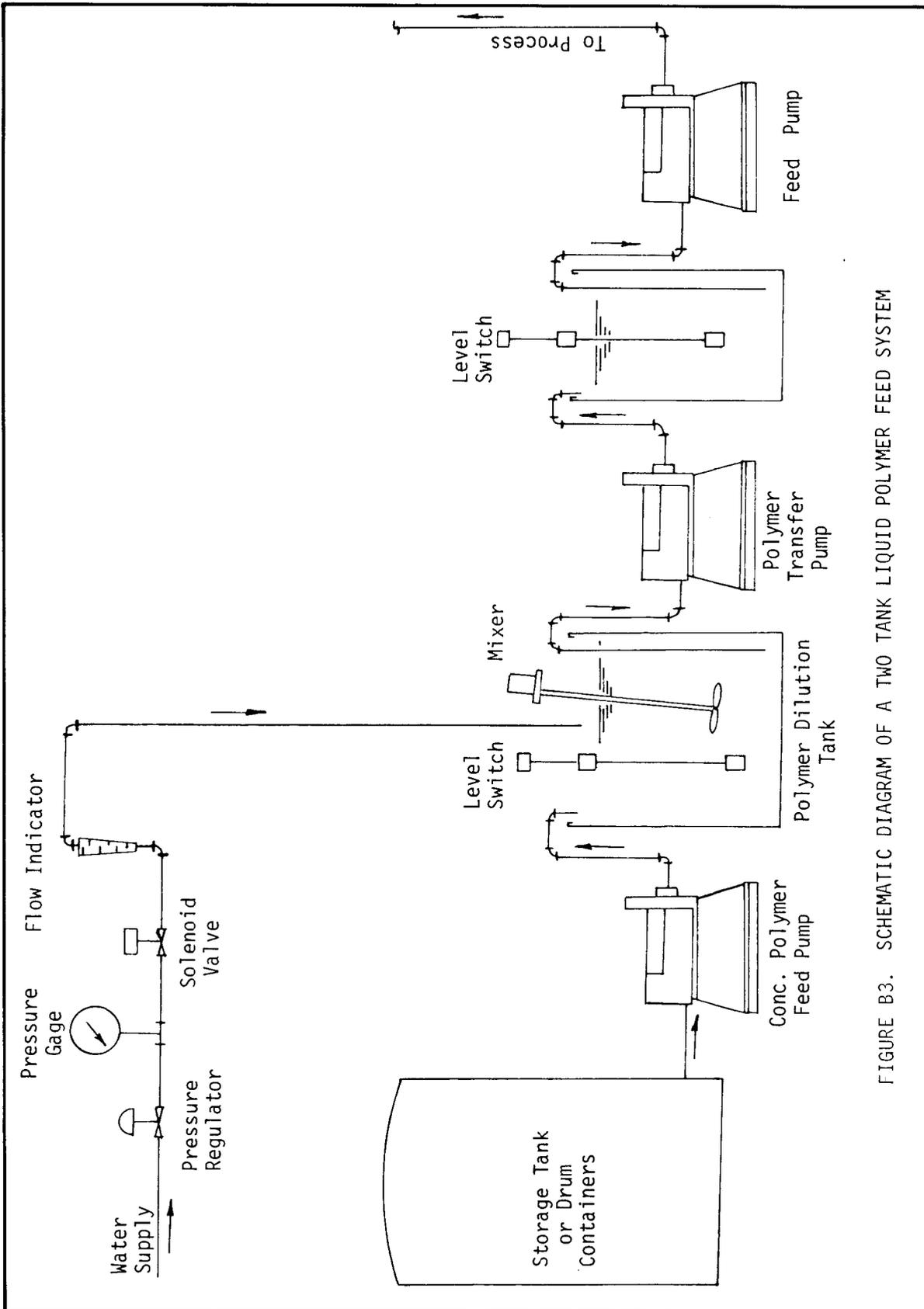


FIGURE B3. SCHEMATIC DIAGRAM OF A TWO TANK LIQUID POLYMER FEED SYSTEM

tank. This system may be operated manually or be automated by level switches in the polymer dilution tank and polymer work tank.

### Dry Polyelectrolytes

12. Dry polyelectrolytes are more difficult to handle than liquid polyelectrolytes because they are shipped in a dry form and must be placed into solution on-site. The major difference between liquid and dry polyelectrolyte feed equipment is that special equipment must be provided to store, feed, and wet the polymer prior to placing it in the polymer dilution tank. Once the dry polyelectrolyte has been placed into solution, the polymer feeding equipment is the same as that required to handle liquid polymers. In fact, there is little difference in the design of polymer feed equipment from manufacturer to manufacturer, other than the dry polymer wetting devices.

13. Dry polyelectrolytes are normally transported and stored in 50-lb bags or in lined drums. Dry polymer may be placed directly into the storage hopper of the dry polymer feeder or into a large storage hopper from which it is conveyed into the hopper of the feeder. The hopper of the feeder is generally equipped with a heating mechanism to help keep the polymer dry and a vibrator or other device to help move the polymer to the feeder. The polymer feeder will feed the dry polymer to the feeder. The polymer feeder will feed the dry polymer at a controlled rate into a wetting device. Wetting devices vary in design from manufacturer to manufacturer and may be patented. These wetting devices are designed to provide wetting of each polymer particle prior to their being placed in the dilution tank. The wetted particles may be discharged by gravity to the dilution tank or moved by an eductor to the dilution tank.

14. Unlike liquid polyelectrolytes which are ready for use once they have been diluted to the proper concentration, dry polyelectrolytes after wetting must be given sufficient time to totally dissolve or "age". Figure B4 shows a schematic diagram of a dry polymer feed system using two tanks. The only difference between the liquid polymer feed system shown in Figure B3 and this system is removal of the concentrated liquid polymer feed system and replacing it with the dry polymer feed system.

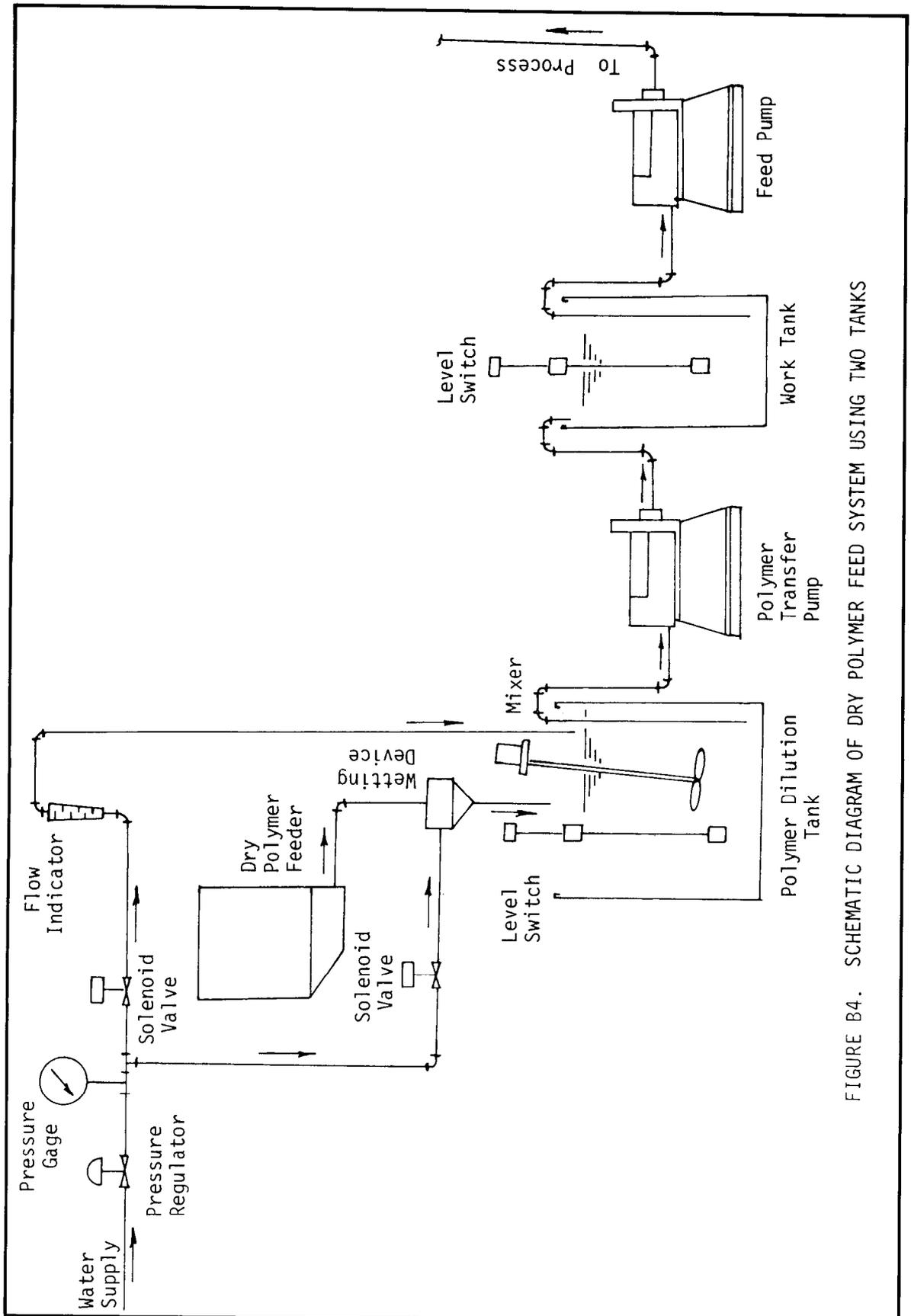


FIGURE B4. SCHEMATIC DIAGRAM OF DRY POLYMER FEED SYSTEM USING TWO TANKS

15. A system capable of handling both liquid and dry polymer requires that both a concentrated liquid polymer feed system and a dry polymer feed system be present to feed into the polymer dilution tank. The control system will have an added system so that either the liquid polymer or the dry polymer feed system may be operated. A system of this type is shown in Figure B5.

#### Recommended Polymer Feed System

16. The general assumptions made in selecting the recommended polymer feed systems are: 1) The system must be able to handle either liquid or dry polymers; and 2) The system must be able to feed polymer to the process on a continuous basis.

17. Based on the above assumptions, it is recommended that a two tank system as shown in Figure B5 be used. Other systems could also be used, such as a duplicate single tank system which would consist of a duplication of the system shown in Figure B5, minus the work tank. This system would be somewhat more costly, however. All of the systems are assumed to be automated so that they will add polymer to the dilution tank and feed it to the process on a continuous basis. Dry polymer would have to be fed into the hopper manually and the use of 55-gallon drums for liquid polymer would mean that the change over from drum to drum would be manual.

#### Cost of Polyelectrolyte Feed Systems

18. There are numerous manufacturers and suppliers that can furnish component parts that make up polyelectrolyte feed systems. These component parts are available so that engineers may design polyelectrolyte feed systems that can most effectively and economically function under a specific set of design conditions. When the exact design conditions are unknown, it is best to select a system which can adequately function under a wide range of conditions.

19. The purpose of this study was to review available equipment including package type polyelectrolyte feed systems which would function under the conditions expected, and to estimate their cost. The estimated costs presented are for the recommended two-tank system which will automatically prepare the proper solution of either liquid

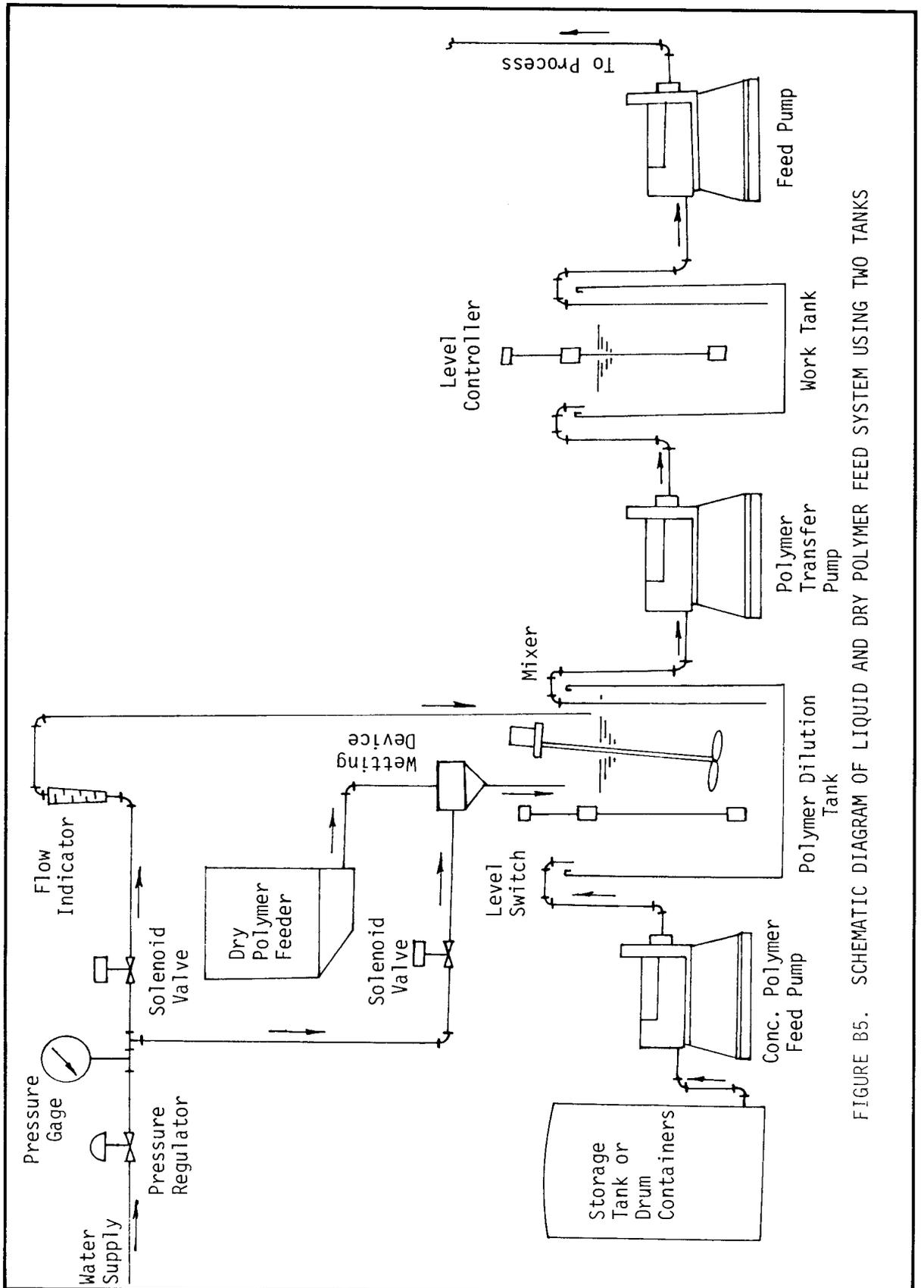


FIGURE B5. SCHEMATIC DIAGRAM OF LIQUID AND DRY POLYMER FEED SYSTEM USING TWO TANKS

or dry polymer and feed it continuously to the process. The cost for systems to handle up to 10 mgd is based on factory packaged systems. Above 10 mgd the systems costs were determined by designing a system from available component parts.

20. The polyelectrolyte feed systems are assumed to consist of the following major components:

- 1) Concentrated polymer storage facilities
- 2) Concentrated liquid polymer transfer pump
- 3) Dry polymer hopper and feeder
- 4) Dry polymer wetting device
- 5) Water measuring and control system (does not include water supply system)
- 6) Dilution (aging) tank with mixer and water level control switches
- 7) Transfer pump
- 8) Work tank with polymer level control switches
- 9) Polymer feed pump with provision for further dilution, if needed
- 10) Automatic control system
- 11) All electrical and piping material between components.

21. The cost of packaged polyelectrolyte feed systems will be shown for systems with increasing tank volumes and polymer feed capacity. The tank sizes shown are the working volumes of the tanks and not the total tank capacity which will be somewhat more than the volumes shown. Tank volume was chosen as the common term in describing the available systems because most manufacturers list the tank volumes along with the model numbers. The actual polymer feed capacity of any system depends upon the many variables previously discussed.

22. The feeding capacity of the systems was calculated based on the following assumptions:

- 1) Feeding of concentrated liquid polymer or dry polymer was not a limiting factor.
- 2) Each batch required a 3.0 hour cycle time, including two hours of aging.

- 3) Maximum polyelectrolyte concentration in system equals 0.5 percent.
- 4) Feeding of dilute polymer to the process was not a limiting factor.
- 5) Dry polymer would be stored in bags or drums.
- 6) Concentrated liquid polymer would be stored in either 55-gallon drums or bulk storage tanks with minimum 6000-gallon capacity (tank truck load).

Table B1 shows the quantity and volume of polyelectrolyte required each day for the assumed flow rates and assumed operating conditions. The volume of dilute polymer required for a 0.25 and 1.0 percent solution is shown to emphasize the significant effect the required dilute polymer feed solution concentration has on the volume to be handled.

23. Table B2 shows the tank volume required in a two-tank polyelectrolyte feed system. The volumes shown are the working capacity that the dilution tank and work tank must have for the flow rates shown. The volumes shown may be the volume of either single or multiple tanks. Tank volumes for a 0.25 and 1.0 percent polymer solution are shown to demonstrate the significant effect the required concentration of the dilute polymer solution has on the design of the systems. Table B3 shows the cost summary for polymer feed systems.

Table B1  
Quantity and Volumes of Polyelectrolyte Required

| Flow<br>(mgd) | Polymer*<br>Required<br>lbs/Day | Polymer Volume**<br>0.25% Feed<br>Solution<br>(Gal/Day) | Polymer Volume**<br>0.5% Feed<br>Solution<br>(Gal/Day) | Polymer Volume**<br>1.0% Feed<br>Solution<br>(Gal/Day) |
|---------------|---------------------------------|---|--|--|
| 0.1           | 16.7                            | 800   | 400  | 200  |
| 1.0           | 167                             | 8000  | 4000   | 2000   |
| 5.0           | 834                             | 40000   | 20000  | 10000  |
| 10.0          | 1668                            | 80000   | 40000  | 20000  |
| 25            | 4170                            | 200000  | 100000   | 50000  |
| 50            | 8340                            | 400000  | 200000   | 100000   |

\* Assuming maximum 20-mg/l polymer dosage.

\*\* Assuming specific gravity of 1.0.

Table B2  
Tank Volume Required for Two-Tank Polyelectrolyte Feed Systems

| Flow<br>(mgd) | Tank Volume*<br>@ 0.25% Solution<br>(Gal) | Tank Volume*<br>@ 0.5% Solution<br>(Gal) | Tank Volume*<br>@ 1.0% Solution<br>(Gal) |
|---------------|---|--|--|
| 0.1           | 100                                       | 50                                       | 25                                       |
| 1.0           | 1000                                      | 500                                      | 250                                      |
| 5.0           | 5000                                      | 2500                                     | 1250                                     |
| 10            | 10000                                     | 5000                                     | 2500                                     |
| 25            | 25000                                     | 12500                                    | 6250                                     |
| 50            | 50000                                     | 25000                                    | 12500                                    |

\* Assuming three hours per batch cycle, volume given in a two-tank system is the total volume of the dilution tank or work tank.

Table B3  
Cost of Polyelectrolyte Feed Systems

| Dredge Pumping Rate (mgd) | Polymer Required (lbs/day) | Dilution & Work Tank Volume (gallons) | Dry Polymer Storage | Liquid Polymer Storage | H.P. | Labor (Manhours/day) | Capital Cost (\$) | Operating Cost (\$/year) | Maintenance Cost (\$/year) |
|---------------------------|----------------------------|---------------------------------------|---------------------|------------------------|------|----------------------|-------------------|--------------------------|----------------------------|
| 0.1                       | 16.7                       | 50                                    | Bags                | Drums                  | 2.0  | 6.0                  | 17,000            | 51,900                   | 850                        |
| 1.0                       | 167                        | 500                                   | Bags or Drums       | Drums                  | 3.0  | 6.0                  | 24,000            | 88,400                   | 1,200                      |
| 5.0                       | 834                        | 2,500                                 | Bags or Drums       | Drums                  | 5.0  | 12.0                 | 45,000            | 363,000                  | 2,250                      |
| 10.0                      | 1,668                      | 5,000                                 | Bags or Drums       | Drums or Bulk Tank     | 10.0 | 24                   | 97,000            | 727,000                  | 4,850                      |
| 25                        | 4,170                      | 12,500                                | Bags or Drums       | Bulk Tank              | 25   | 36                   | 210,000           | 1,717,000                | 10,500                     |
| 50                        | 8,340                      | 25,000                                | Bags or Drums       | Bulk Tank              | 50   | 48                   | 350,000           | 3,333,000                | 17,500                     |

## PART IV: RAPID MIXING EQUIPMENT

### Introduction

24. Rapid mixing may be defined as a unit operation in which two or more materials are blended to achieve a desired degree of uniformity. It is accomplished by causing turbulence within the combined materials to be mixed. The importance of rapid mixing is well known because studies have shown that ineffective mixing can greatly increase the dosage requirements of coagulating chemicals such as alum or iron salts and can reduce the overall efficiency of clarification. Rapid mixing is required when polyelectrolytes are used as coagulants to rapidly disperse the polymer and to begin the formation of floc particles.

### Types of Mixing Devices

25. The earliest type of mechanical mixing device was perhaps the introduction of chemicals into the suction side of a pump. This may be the most effective method of mixing when polyelectrolyte is added to the dredged material slurry. This material does not lend itself to the use of conventional mixing equipment because of the high solids content and debris which is normally present. Injecting polyelectrolytes into the suction side of a pump is not sufficiently efficient to be considered as a potential rapid mix process for the overflow from containment areas.

26. The use of round-the-end and over and under baffled mixing systems as shown in Figures B6 and B7 found wide use in many of the earlier water treatment systems in the country. Except for small flows the outside walls of these units were constructed of concrete with either concrete or wooden baffles used to provide turbulence. The degree of turbulence through these systems depends upon the velocity of the liquid and placement of the baffles. Any change in velocity from the optimum can significantly reduce the efficiency of these units. These types of devices should not be considered for

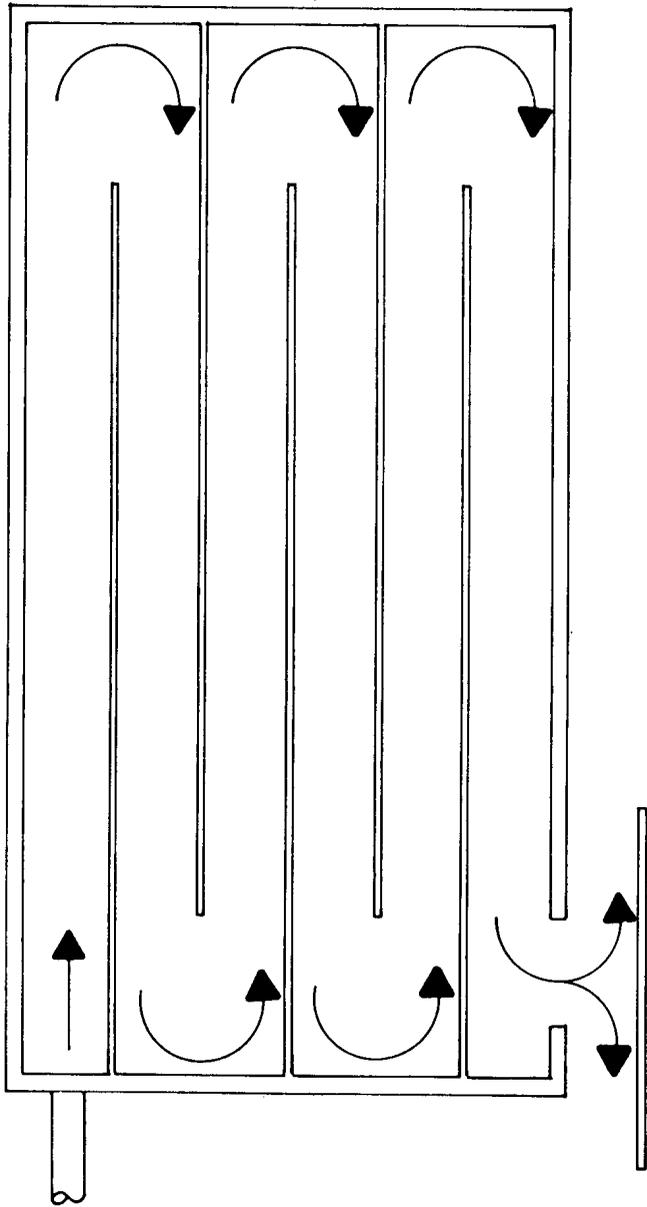


FIGURE B6. ROUND-THE-END BAFFLED RAPID MIXING BASIN (PLAN VIEW)

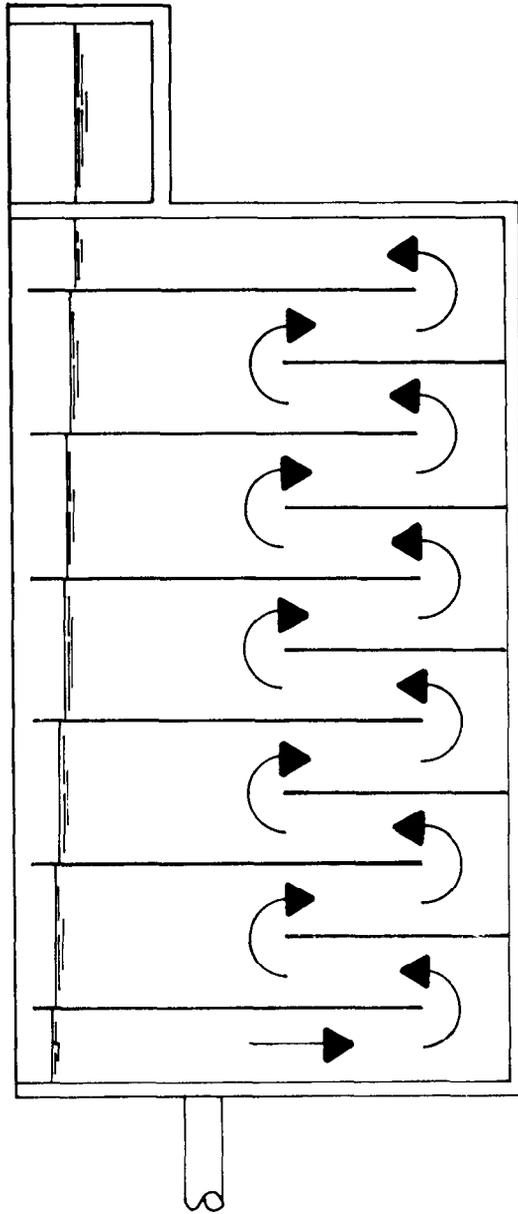


FIGURE B7. OVER AND UNDER BAFFLED RAPID MIXING BASIN (ELEVATION)

use to provide rapid mixing for containment area overflow unless the flow rates can be controlled. The main reasons are because, if uncontrolled, the range of flow may vary widely and suspended solids in the diked area effluent could cause silting in a mixing device of this type. These systems could be used, however, if the effluent flow rate was controlled. These systems would have to be designed for each application, but would be significantly more economical than a mechanical device.

27. Several types of mechanical mixers which are available on the market are shown in Figures B8 through B11. Figure B8 shows a standard single cell rapid mixer with one motor and turbine. There are numerous modifications to this type mixer including the use of multiple turbines or propellers. These systems are effective and should be satisfactory for use with polyelectrolyte treatment of confined area overflow.

28. Figures B9 and B10 show two types of rapid mixers which use multiple compartments in an attempt to achieve plug flow. These mixers, although effective, require a somewhat more complex mixing chamber and equipment. The mixers in Figures B8 through B10 are composed of two basic parts: the mixer itself and the mixing basin. Many manufacturers may supply the mixer alone and require the engineer to design and have fabricated the mixing basin separately. Other manufacturers may supply standard mixers and the mixing basin as separate items or as a package. Mixing basins may be fabricated out of concrete or steel. Concrete is typically used for fixed facilities while steel may be used for the smaller portable units. The H.P. requirements for rapid mixers may range up to 1.0 H.P./mgd flow. The detention time in rapid mixers is normally 15 to 30 seconds for inorganic coagulants and several minutes for polyelectrolytes.

29. Figure B11 shows a rapid mixer called in inline mixer. These units are capable of creating high velocity gradients in water in a short period of time. The trend in the water treatment industry using inorganic coagulants is toward use of inline mixers. They are relatively low in capital cost and are purchased as a single unit

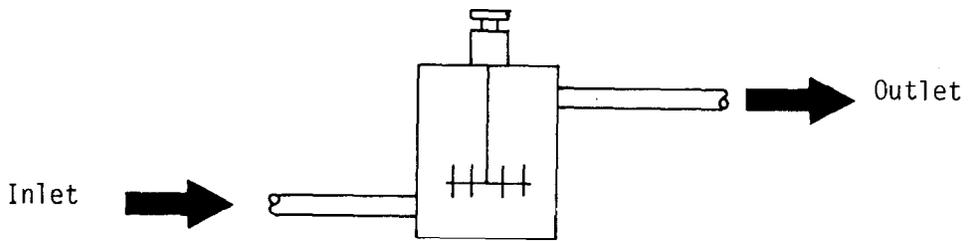


FIGURE B8. SINGLE CELL WITH VERTICAL TURBINE RAPID MIXER

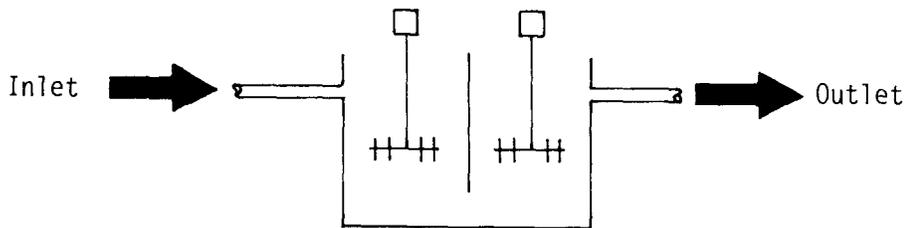


FIGURE B9. MULTICELL VERTICAL TURBINE RAPID MIXER

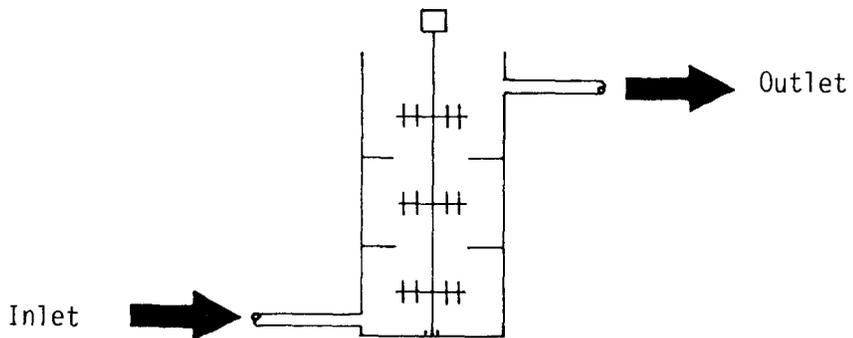


FIGURE B10. MULTICELL VERTICAL TURBINE RAPID MIXER

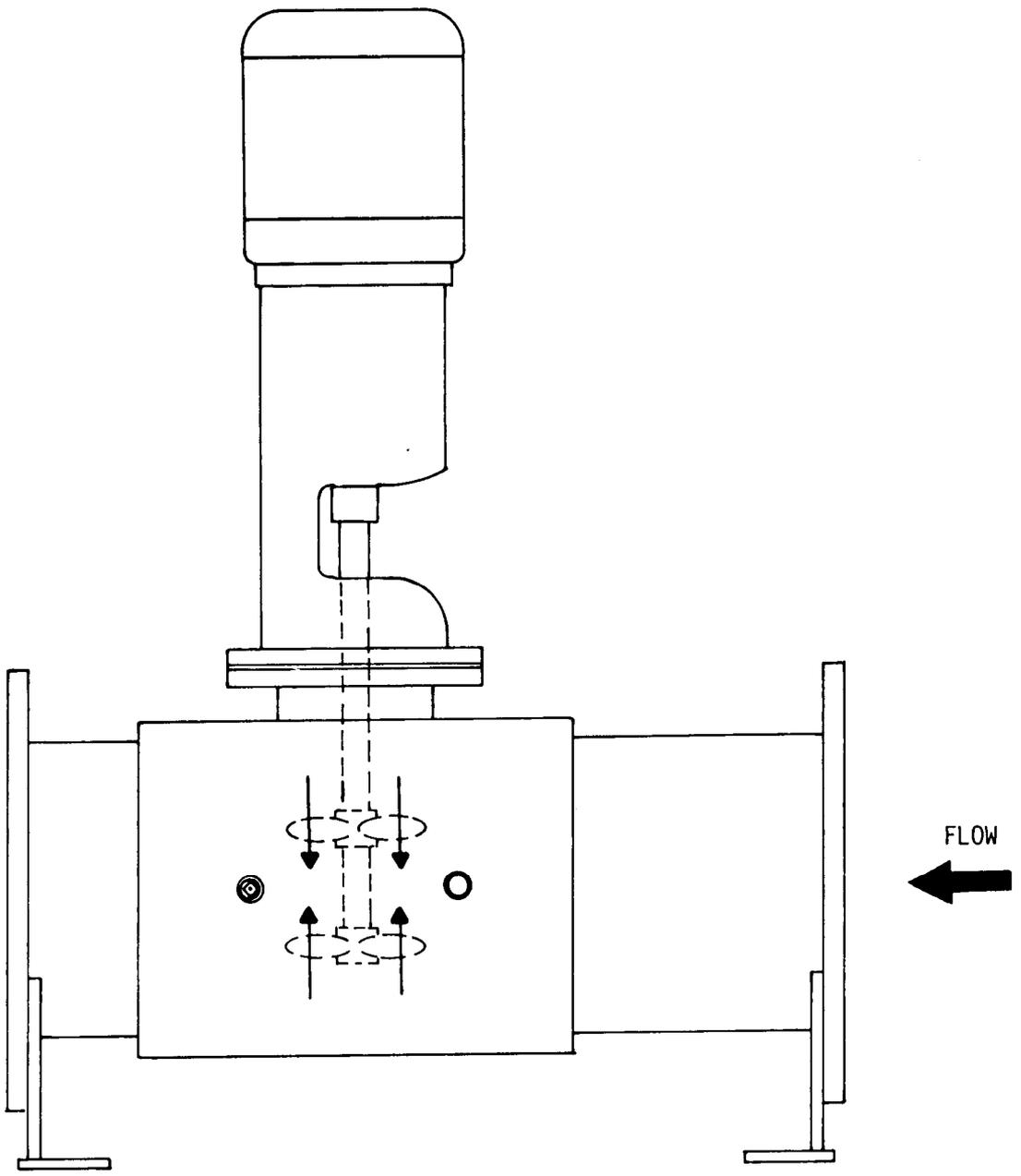


FIGURE B11. INLINE RAPID MIXER

ready to be bolted as a spool into a pipeline. These mixers are equipped with internal baffles and chemical feed tubes which might make it necessary to prescreen the confined area overflow to prevent clogging. A cleanout port would be most helpful if trash found its way into the mixer but could not pass the baffles.

30. It is recommended that a standard single cell mixer or an inline mixer be used for rapid mixing polyelectrolytes with diked area overflow. The required detention time for both rapid and slow mix facilities should be determined from jar tests. If it is felt that trash or similar material may find its way into an inline mixer, then either prescreening may be required or the use of the more conventional single cell mixer using either a turbine or propeller.

31. As previously mentioned, complete rapid mix units are normally not sold as a packaged unit alone. Usually the manufacturer will supply the mechanical drive unit and the design engineer will design the basin as he desires. The basin may be constructed in the field or fabricated and transported to the field. There are exceptions to this, however, in the smaller sizes as some manufacturers will supply complete units based on flow alone.

32. The cost for rapid mixing units shown in Table B4 are based on the use of a single cell rapid mixing unit. The drive would be a vertical shaft with electric drive using either a propeller or turbine for agitation. Detention time is assumed to be approximately 15 seconds.

Table B4  
Cost of Rapid Mix Systems

| <u>Flow Rate (mgd)</u> | <u>Volume (Gal)</u> | <u>H.P.</u> | <u>Capital Cost (\$)</u> | <u>Operating Cost (\$/Yr)</u> | <u>Maintenance Cost (\$/Yr)</u> |
|------------------------|---------------------|-------------|--------------------------|-------------------------------|---------------------------------|
| 0.1                    | 17.4                | 0.05        | 2,500                    | 80                            | 125                             |
| 1.0                    | 174                 | 0.5         | 4,000                    | 160                           | 200                             |
| 5.0                    | 868                 | 2.5         | 7,500                    | 650                           | 375                             |
| 10.0                   | 1,736               | 5.0         | 12,000                   | 1,630                         | 600                             |
| 25                     | 4,340               | 12.5        | 22,500                   | 4,100                         | 1,125                           |
| 50                     | 8,680               | 25          | 44,000                   | 8,200                         | 2,200                           |

## PART V: SLOW MIX BASINS

33. Slow mix basins are used to flocculate the dredged material after leaving the rapid mix basin. Flocculation may be defined as the grouping and compacting of coagulated particles into larger agglomerations called floc. Flocculation is a critical unit process needed to assure proper clarification. Little information is available on the flocculation of dredged material. As previously mentioned in the Rapid Mix section, neither rapid mixing nor flocculation equipment will be assumed to be used on dredged material slurry.

34. Short-circuiting in flocculating basins may be a serious problem and equipment design should be such that short-circuiting is minimized. It has been determined that in a single compartment flocculation basin, 40 percent of the input is retained less than half of the nominal detention time of the basin. This compares with a flocculation basin with five compartments where only 12 percent of the water escapes in less than half the nominal detention time. Short-circuiting allows a significant percentage of the water flow to undergo inadequate flocculation thereby reducing the efficiency of the system. A solids-contact flocculator with a single mixing compartment overcomes part of the short-circuiting problems apparently because the water comes in contact with solids slurry during passage through the basin.

35. There are two general categories of flocculators: 1) baffled basins; and 2) mechanically agitated flocculators. As discussed in the previous section on rapid mixing, baffled basins may be of the over and under or the around-the-end type. The advantages of these devices for flocculation are the absence of complicated and expensive equipment and freedom from short-circuiting. The disadvantages are that the flow through the system should be controlled and the systems are not readily available as an off-the-shelf item from equipment manufacturers. Significant savings could, however, be realized by using baffled basins as compared with mechanical basins. Each basin would be a special design, probably with moveable baffles to vary the velocity

gradients. These devices would require that the flow through them be controlled. Since baffled basins are not items readily available from manufacturers, they will not be discussed further in this report.

36. Mechanical flocculators may be classified by the type of agitators used: 1) rotary, and 2) reciprocating. A rotary agitator may have either a vertical or horizontal shaft including reel type units, axial flow impellers, turbine type impellers, and various paddle designs. Reciprocating type units would include walking beam agitators or reciprocating agitators with blades or metal ribbons. Figures B12 through B17 show examples of these various types of flocculators.

37. Horizontal shaft rotary units have underwater bearings which can cause maintenance problems. These units may be driven by equipment located in a dry well; however, this requires passing the shaft through a stuffing box which must be maintained. Overhead drivers may be used with either chains or V-belts. V-belts have less maintenance, but may tend to slip in icy weather unless heated.

38. Vertical shaft rotary units do not have underwater bearings. These units require a support bridge for the unit and can only accommodate a single compartment whereas a horizontal shaft unit can accommodate multiple agitators in multiple compartments. Vertical shaft rotary units are readily adapted for use in circular tanks. Multiple vertical shaft units are often used in large basins.

39. A variation in the rotary type of flocculating unit which is finding wider use in the water treatment industry is shown in Figure B18. This unit is known as a solids contact unit and has found widespread use for lime-soda ash water softening. Its use has spread into the treatment of wastewater and chemical coagulation and flocculation of surface waters for public water supplies.

40. The benefits reported for this unit include an inherent size reduction when compared to separate facilities for rapid mixing, flocculation, and clarification. Theoretically, this reduction in size is due to the ability of the unit to maintain a high concentration of previously formed floc and the physical design which allows three unit processes to be combined into one unit.

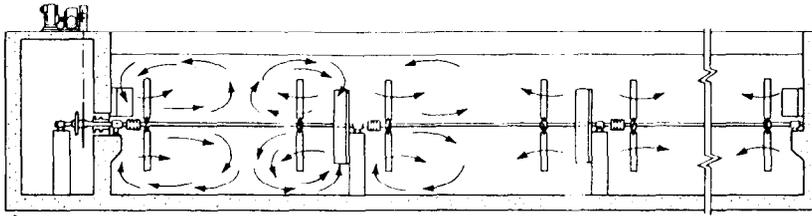


FIGURE B15. HORIZONTAL SHAFT AXIAL-FLOW PROPELLER FLOCCULATOR

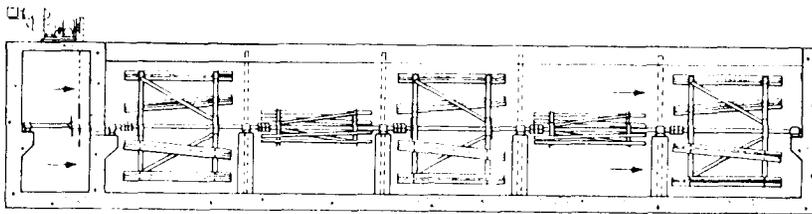


FIGURE B16. HORIZONTAL SHAFT PADDLE REEL FLOCCULATOR

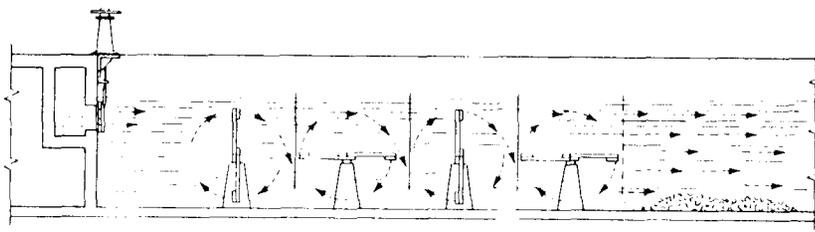


FIGURE B17. HORIZONTAL SHAFT PADDLE TYPE FLOCCULATOR

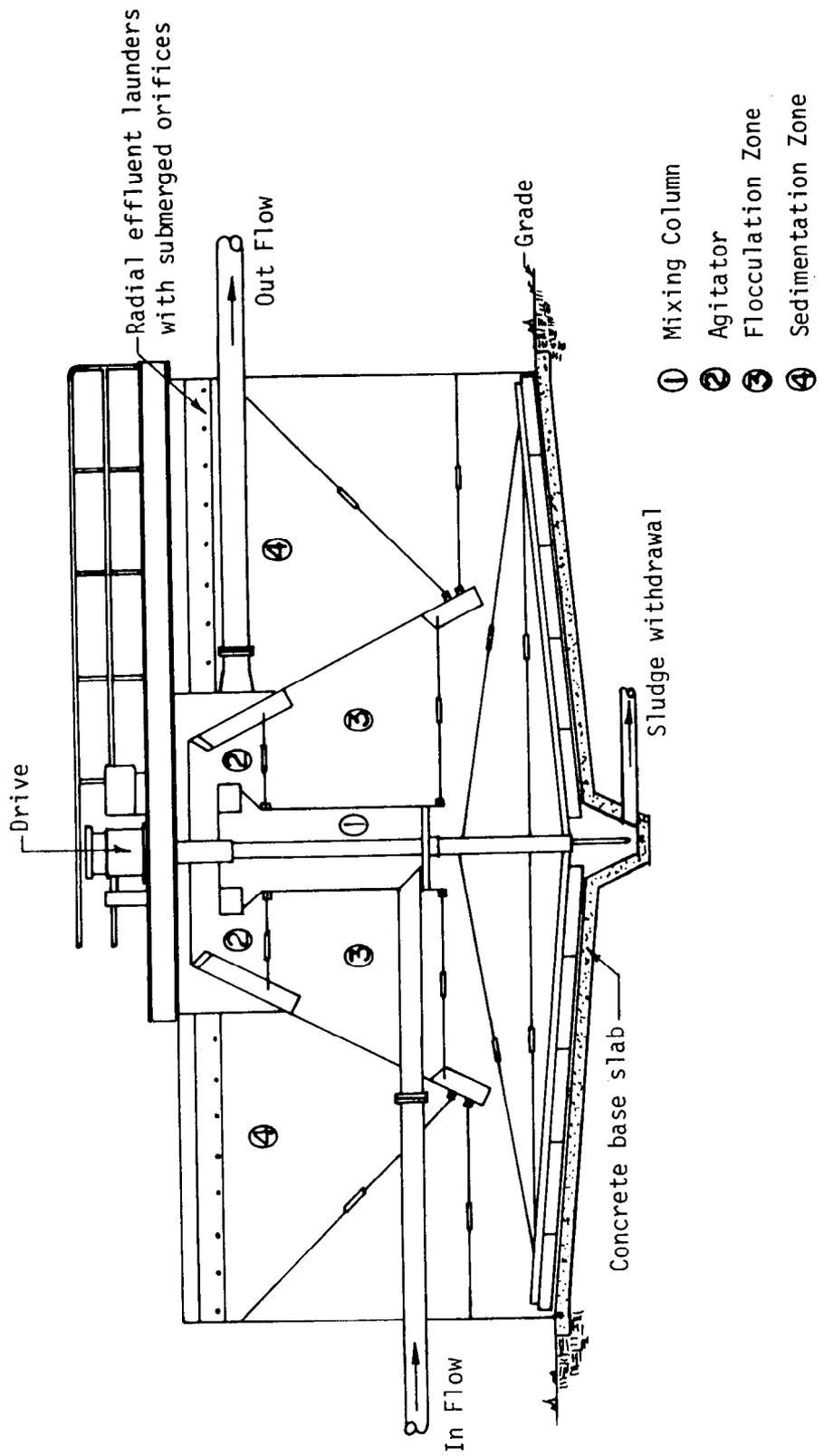


FIGURE B18. SUSPENDED SOLIDS CONTACT CLARIFIER

41. The feasibility of using the solids contact unit for clarification of confined area overflow is essentially unknown. If it can be used it may have advantages over the conventional type inline units used for coagulation, flocculation, and sedimentation. The only solids contact unit known by the authors which might be comparable to the application being discussed is one in Louisiana. A paper mill located on the Mississippi River is using a solids contact unit to treat river water to obtain process water. The chemical used is a cationic polyelectrolyte and the results have been reported to be excellent.

42. The selection of a recommended type of flocculation unit is difficult because of the lack of available information on coagulation and flocculation of confined area overflow. Based on available information and discussions with manufacturers, it is recommended that vertical shaft mixers with turbine or paddle agitators be used. If pilot plant studies are performed, not only should the more conventional flocculation units be tested, but a solids contact type reactor should also be investigated.

43. Meaningful comparison of the cost of the various flocculation equipment available on the market is difficult. A few manufacturers produce package type flocculation units as part of complete package type water treatment systems. These systems are predesigned, factory fabricated, and, except for very small sizes, field erected. Rarely does the rated capacity of these systems exceed two or three mgd. The design of these systems normally assumes that alum or iron salts will be used for the coagulating chemical; therefore, the flocculation time is quite short, often 15 minutes or less. These systems are usually not designed for the use of polyelectrolytes alone as the efficiency of flocculation with cationic polyelectrolytes increases with detention time. Flocculator detention times of 60 minutes would mean that the package unit with a 15-minute detention time at its rated capacity could only handle one-fourth its rated capacity if polyelectrolytes were used as a coagulant.

44. If packaged units were used, then for the higher flows multiple units would have to be purchased. As a typical example, one large

manufacturer produces a package type flocculator that, if selected to handle a 50.0-mgd flow, would require 24 units in parallel. The thought of trying to use 24 parallel units is frightening from an economical and practical standpoint.

45. The only way to obtain meaningful cost comparisons of equipment is to first determine the design criteria to be used. This can best be accomplished by laboratory studies followed by pilot plant tests of the potential processes selected in the laboratory. Once pilot plant studies have been completed and design criteria selected, design of full-scale systems to handle various flows can be produced. Once detailed design has been accomplished, cost comparisons can be made of the various equipment on the market which will satisfy the design criteria. The equipment available on the market is for the most part mechanical mixing equipment which is built to fit into a basin designed by an engineer. Therefore, cost of flocculating units is composed of the equipment and the basin containing the equipment.

46. The following cost (Table B5) of flocculation units is based on assumed design criteria. The cost of the equipment is representative of that on the market. The basins are assumed to be steel with mixing to be provided by vertical turbine flocculators with variable-speed drives. A detention time of 60 minutes was assumed with three cells in each flocculation unit to reduce short-circuiting. Table B5 gives the description of the designed flocculation units. The cost is the installed cost of the steel basins and flocculating equipment only. The cost does not include foundation or electrical cost. No operating cost is shown as it is assumed that the minimum operation requirements will be included in the polymer feed system or clarification system.

Table B5

Description of Flocculators

| Flow<br>(mgd) | Number of<br>Cells | Approximate<br>Cell Dimensions | Parallel<br>Units | Required H.P.<br>Cell No. |      |       |
|---------------|--------------------|--------------------------------|-------------------|---------------------------|------|-------|
|               |                    |                                |                   | 1                         | 2    | 3     |
| 0.1           | 3                  | 6'x6'x7'                       | 1                 | 0.06                      | 0.03 | 0.005 |
| 1.0           | 3                  | 12'x12'x14'                    | 1                 | 0.6                       | 0.3  | 0.05  |
| 5.0           | 3                  | 28'x28'x14'                    | 1                 | 3                         | 1.5  | 0.25  |
| 10.0          | 6                  | 28'x28'x14'                    | 2                 | 3                         | 1.5  | 0.25  |
| 25.0          | 6                  | 40'x40'x16'                    | 2                 | 7                         | 3.5  | 0.6   |
| 50.0          | 12                 | 40'x40'x16'                    | 4                 | 7                         | 3.5  | 0.6   |

| Flow<br>(mgd) | Capital<br>Cost<br>(\$) | Operating Cost<br>(Electrical)<br>(\$/Yr) | Maintenance<br>Cost<br>(\$/Yr) |
|---------------|-------------------------|---|--------------------------------|
|               |                         |   |                                |
| 1.0           | 24,400                  | 320                                       | 1,220                          |
| 5.0           | 65,000                  | 1,630                                     | 3,250                          |
| 10.0          | 122,000                 | 3,270                                     | 6,100                          |
| 25.0          | 191,000                 | 7,250                                     | 9,500                          |
| 50.0          | 382,000                 | 14,500                                    | 19,000                         |

## PART VI: CLARIFICATION EQUIPMENT

47. Historically, sedimentation basins have varied from simple excavations in the ground to elaborate multi-story structures. More commonly, such basins have taken the form of long narrow rectangular tanks, square tanks, or circular tanks. Size, density, and flocculating properties of suspended solids determine settling basin geometry. Volumetric concentration and contemplated depth of storage establish dimensions of the clarifier bottom zone. All such properties can typically be determined only by quiescent settling analysis of suspensions whose characteristics are unknown, or by application of basins designed for similar suspensions. A review of the literature and correspondence with clarifier manufacturers indicate that little information is available on application of clarifiers to the variety of suspensions likely to be encountered in dredging operations, and suggestions for generalized design parameters are not possible at this time. However, in order to compare advantages and disadvantages of available general equipment styles, some assumptions must be made. The geometry and features of clarification equipment discussed in this chapter are based on the following assumptions, unless otherwise noted in subsequent discussions:

- a. Two clarification cases are considered:
  1. Clarification of suspensions with concentrations of five percent to 20 percent by weight discharged directly from a dredge slurry pipe with rough screening but no preliminary sedimentation.
  2. Clarification of suspensions with concentrations of 100 to 10,000 mg/l overflowing from a diked settling basin.
- b. Quiescent settling analysis predicts an acceptably clarified effluent for a design settling velocity of 0.035 centimeters per second. Such settling analysis might have been run on a flocculated suspension after polymer addition. In the latter case, this settling velocity would correspond to the terminal velocity

expected from a silt particle of effective diameter 0.0226 millimeters with a specific gravity of 2.65 settling in water at 50°F.

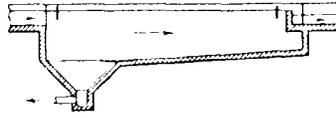
- c. The above-mentioned quiescent settling analysis predicts a satisfactory clarified effluent for a sedimentation basin detention time of 1.0 hour minimum.
- d. A safety factor of 1.5 is to be applied both to settling velocity and detention period. This safety factor might be based on experience with similar basin applications, further testing and analyses, etc.
- e. Where necessary, basin geometry based on hydraulic requirements for satisfactory basin performance may supersede basin geometry based on the above design parameters.
- f. The result of Assumptions a through c is a design surface loading rate of approximately 500 gpd/ft<sup>2</sup> and a design detention time of approximately 1.5 hours.

48. Cost estimates for various types of clarification units were based on equipment costs and pertinent information from manufacturers and the following assumptions:

- a. Steel costs 30¢/lb for materials, plus 20¢/lb for fabrication and erection.
- b. Power costs 5¢/kwh.
- c. Equipment will be used 24 hr/day, 365 days/yr.
- d. Operating labor costs \$20,000/man-year, (eight-hr shift) and includes daily cleanup, but not maintenance.
- e. Yearly maintenance cost is five percent of equipment capital cost.

#### Rectangular Clarifiers

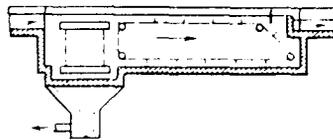
49. Perhaps the oldest and most adaptable sedimentation basin configuration is the rectangular clarifier. Figure B19 shows just a few of the more common of the many variations in basin configuration. Rectangular clarifiers have been subject to hydraulic investigation for



(a) MANUALLY CLEANED



(b) TWO STORY - MANUALLY CLEANED



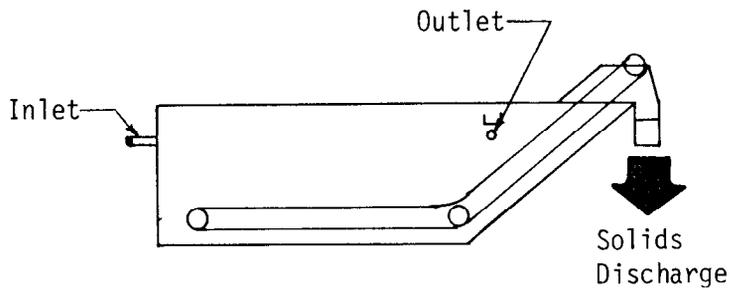
(c) MECHANICALLY CLEANED

FIGURE B19. Typical Rectangular Clarifier Configurations

the purpose of improving efficiency and performance for the better part of half a century. Such investigations have led to at least the following conclusions:

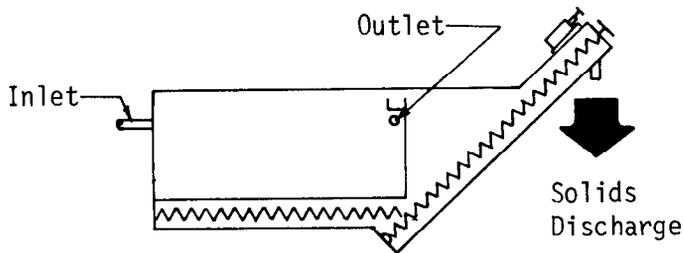
- a. Long narrow basins are hydraulically more stable and more efficient (i.e., result in a greater percentage of plug flow than short wider basins).
- b. Baffling within the basin and distribution of effluent area to promote the effect of a series of smaller basins provides a more stable and hydraulically more efficient use of volume than promoting the effect of just one basin within the design volume.
- c. Inlet structures must distribute the influent suspension uniformly over the cross section of the settling zone and initiate parallel flow. Also, the inlet structures must dissipate the velocity of the influent jet. This has recently been promoted by the use of rationally designed permeable inlet baffles.
- d. Long effluent weirs extending well upstream of the outlet end of the tank or uniformly distributed over the tank surface area promote uniform rise velocities and help to prevent solids carry-over due to short-circuiting.

50. Solids have been removed from rectangular clarifiers either manually or by application of various mechanized arrangements. Figure B20 shows four such solids removal arrangements. Because the settled solids to be expected from dredging operations may be difficult to remove from sedimentation basins, it is suggested that mechanical removal be used wherever possible. An additional advantage of mechanical solids removal is that a certain amount of decanting of water from the solids as they are lifted out of the basin occurs, thus concentrating them further. Removal of settled material from clarifiers taking flow directly from the dredge slurry pipe poses a most difficult problem. For example, assuming a basin influent suspension concentration of 20 percent by weight at the design surface loading rate of  $500 \text{ gpm/ft}^2$  (based on clarification), 0.58 pounds per minute per square



(a) INCLINED DECK

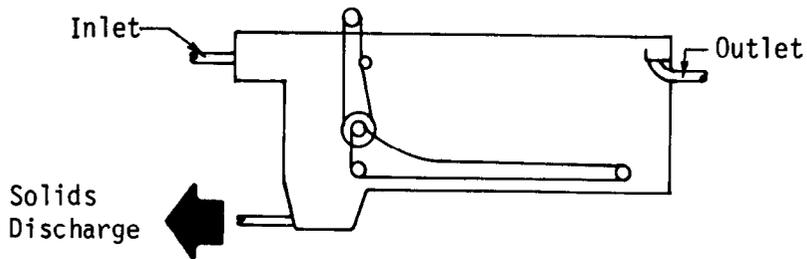
Settled solids are scraped along bottom of tank by chain scrapers and elevated up incline for discharge.



(b) SCREW CONVEYOR COLLECTORS

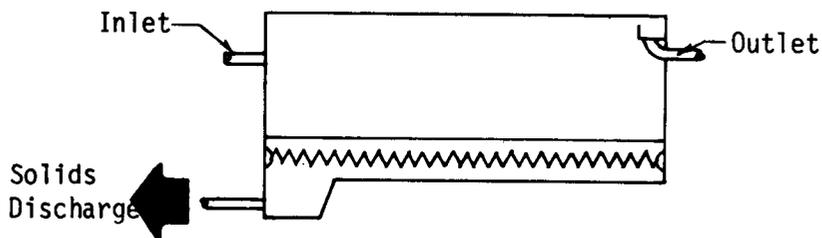
Settled solids are conveyed along trough in tank bottom by first screw conveyor, then elevated to discharge point by second conveyor.

FIGURE B20. Rectangular Sedimentation Basin Solids Removal Equipment



(c) CHAIN SCRAPERS AND PUMP

Chain scrapers convey settled solids along tank bottom to collecting hopper. This arrangement is generally used where settled solids are in an extremely wet form. Pumps are used to withdraw solids from hopper.



(d) SCREW CONVEYOR AND PUMP

Screw conveyor conveys settled solids along tank bottom to collecting hopper. This design is generally used with narrow tanks and where sludge volumes are extremely small.

FIGURE B20. Rectangular Sedimentation Basin Solids Removal Equipment

foot of dry solids must be removed from the basin. Such a high solids loading rate cannot be accommodated without modifying the solids handling equipment conventionally installed in settling basins. For the rectangular clarifier, the mechanism shown in Figure B20(a) might be employed, in modified form, to accommodate such solids loading rates. This would be done by adding additional scrapers to the scraper mechanism and increasing scraper speed. For example, to remove 0.58 pounds of sand per minute per square foot, scraper spacing might decrease from the typical 10 feet apart to two feet apart, and scraper speed might increase from the typical two feet per minute to eight feet per minute. Heavy duty chain would be required. Chain and scraper maintenance would be high. Turbulence due to the increased speed might retard settling.

51. Of all clarification equipment, rectangular clarifiers offer the greatest flexibility in size and layout. Common wall construction of parallel basins offers economy of structure when compared to multiple circular basins. Rectangular clarifiers seem best suited to installation aboard a barge, since long narrow basins are most efficient. In the following cost estimates basin sizes have been chosen which could be installed aboard 30-foot-wide by 120-foot-long barges. With the exception of very small "packaged" units (say, 0.25 mgd at 500 gpd/ft<sup>2</sup>), rectangular clarifier basins are typically custom fabricated and field erected. It seems likely that basins such as those chosen for the following cost estimates could be designed so as to be fabricated in sections which could be crane handled and assembled either on land or aboard a barge. Only the 0.1-mgd basin could be trucked without disassembly.

52. Rectangular clarifiers offer the following advantages and disadvantages when compared to other clarification equipment:

Advantages

- a. They are mechanically simpler and more rugged than circular clarifiers.
- b. They are more adaptable for use on barges than circular clarifiers.

- c. They are capable of much higher solids loading rates than other clarifiers.
- d. Solids may be mechanically removed more easily than from other units.
- e. They would be easier to disassemble and reassemble than circular units.
- f. Long narrow tanks properly baffled with well designed inlet and outlet configurations can be hydraulically more economical than multiple circular clarifiers.

Disadvantages

- a. Long narrow tanks make less efficient use of construction materials and are very often more expensive than single circular tanks.
- b. Mechanical solids removal equipment very often requires much maintenance due to abrasion by settled solids.
- c. Without proper baffling and inlet and outlet configurations, short, wide basins are susceptible to hydraulic short-circuiting and lowered efficiency.

53. In the following cost analyses, tank volume has been sized in accordance with the previous assumptions. For the case of injecting suspensions directly into the clarifier from the dredge slurry pipe, it has been assumed that extra heavy-duty solids removal equipment would be required. In both the case where the suspension would be injected directly into the dredge slurry pipe and the case where the suspension would result from effluent from a diked impoundment, it has been assumed that a basin configuration similar to Figure B20(a) would be employed. In every case but the smallest (0.1-mgd flow), the rectangular tank would be fabricated by someone other than the manufacturer. With the exception of the 0.1-mgd unit, all units would have to be designed so as to disassemble in sections for removal from either aboard a barge or to another shore site. Based on the barge dimensions of 30 ft wide by 120 ft long, it is seen that the 0.1-mgd unit and the 1.0-mgd unit would each fit aboard a single barge. In the larger flow cases, more barges would be required to contain additional sedimentation basins as follows:

|         |           |
|---------|-----------|
| 5 mgd:  | 2 barges  |
| 10 mgd: | 4 barges  |
| 25 mgd: | 6 barges  |
| 50 mgd: | 12 barges |

When considering that, in addition to containing sedimentation basins, solids handling equipment and solids storage area must be provided for barge operation, it does not seem practical to consider the use of these basins aboard barges in any but the lower flow cases. Despite the solids being removed from the basins in the most compacted and easiest to handle form by the removal equipment recommended, relocation of removed solids from one barge to another might be a difficult problem. However, on land, such materials could be much more easily handled by means of power equipment.

54. Table B6 shows estimated cost of rectangular clarifiers for the assumptions made.

#### Circular Clarifiers

55. Circular clarifiers represent the extension of two dimensional horizontal flow sedimentation theory to the radial flow case. Figure B21 depicts a conventional circular flow unit. Because of the circular shape, these clarifiers make more efficient use of construction materials and site surface area than single rectangular basins. However, many researchers have noted that units similar to that shown in Figure B21 have not been as efficient hydraulically as long narrow rectangular units. Inlet and outlet zones have been modified and relocated in attempts to increase basin efficiency, mostly in applications for secondary clarification of municipal wastewater. Few of the configurations developed for municipal wastewaters seem applicable to clarification of dredged suspensions.

56. As Figure B21 shows, settled solids are scraped down the sloped floor to a central sludge hopper by a revolving scraper mechanism. No manufacturer contacted by the authors would recommend application of the conventional scraper mechanism to solids loadings expected from suspensions taken directly from a dredge slurry pipe. Several

Table B6

Cost for Rectangular Clarifiers

| Flow<br>(mgd) | Suspended<br>Solids<br>Concentration<br>(%) | Capital<br>Cost<br>(\$) | Operating<br>Cost<br>(\$/Yr) | Maintenance<br>Cost<br>(\$/Yr) |
|---------------|---|-------------------------|------------------------------|--------------------------------|
| 0.1           | 5-20  | 38,300                  | 12,700                       | 1,900                          |
| 0.1           | 0.01-1.0                                    | 32,150                  | 12,700                       | 1,630                          |
| 1.0           | 5-20  | 131,500                 | 26,600                       | 6,600                          |
| 1.0           | 0.01-1.0                                    | 106,000                 | 25,400                       | 5,300                          |
| 5.0           | 5-20  | 436,000                 | 56,600                       | 20,000                         |
| 5.0           | 0.01-1.0                                    | 367,000                 | 50,700                       | 18,400                         |
| 10.0          | 5-20  | 873,000                 | 113,000                      | 44,000                         |
| 10.0          | 0.01-1.0                                    | 734,000                 | 101,000                      | 37,000                         |
| 25            | 5-20  | 2,200,000               | 233,000                      | 110,000                        |
| 25            | 0.01-1.0                                    | 1,850,000               | 204,000                      | 92,000                         |
| 50            | 5-20  | 4,360,000               | 466,000                      | 220,000                        |
| 50            | 0.01-1.0                                    | 3,700,000               | 410,000                      | 184,000                        |

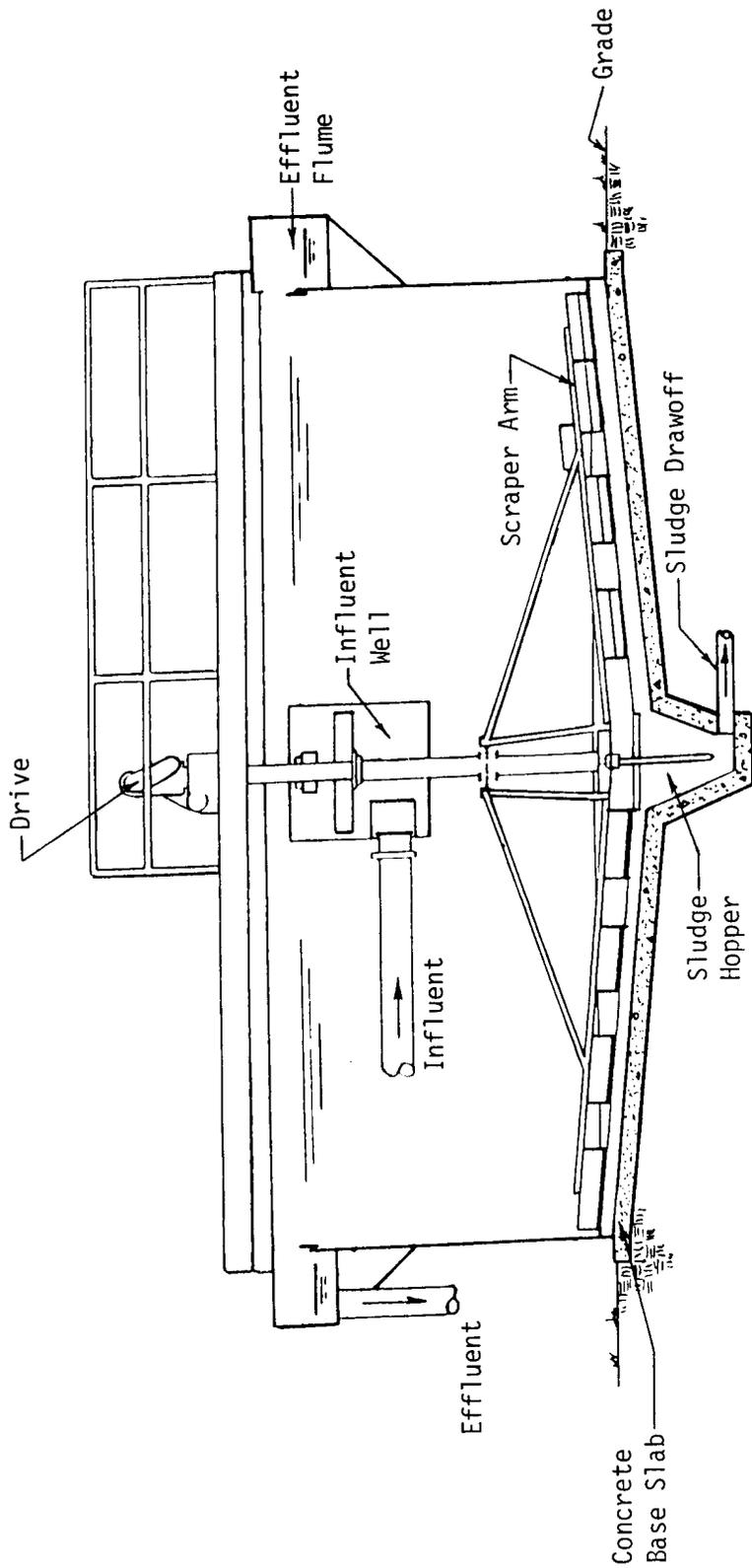


FIGURE B21. Circular Clarifier

manufacturers did suggest application of heavy-duty internal mechanisms as are used in gravity thickeners for concentration of industrial and mining suspensions. Such mechanisms have deep, heavy trusses and rugged drive mechanisms. Such basins are sized and designed not only for clarification and thickening, but for solids loadings which will not overload solids removal equipment. Manufacturers have suggested 10 to 30 square feet of thickener area per ton of dry solids per day as typical solids loading rates. At 20 percent influent suspended solids concentration, the resulting hydraulic loading rate would be approximately 40 gpd/ft<sup>2</sup> to 120 gpd/ft<sup>2</sup>, with a resulting increase in basin size and number of from four to 13 times that of clarifiers sized for 500 gpd/ft<sup>2</sup> surface loading rates. In the following cost estimates (Table B7), a 100-gpd/ft<sup>2</sup> surface loading rate was assumed for the case of clarification of influent from the dredge slurry pipe.

57. Settled material is typically pumped from the sludge hopper at the center of the basin. This produces a sludge slurry which is often less concentrated than the solids elevated mechanically from the rectangular clarifier, particularly since pipe plugging problems increase with concentration of sludge being pumped.

58. Circular clarifiers and mechanisms are shipped partially assembled and must be field assembled. Tanks are similarly field erected. It is doubtful if any but the smallest diameter units should be considered for use aboard a barge. Fabrication in sections and removal and reassembly from site to site would be possible, but more difficult than with rectangular units. As Figure B21 shows, the circular clarifier's sloped bottom, sludge hopper, and sludge pipe usually require the casting in place of a concrete base slab. The necessity for casting such slabs in place and then removing them upon completion of a dredging project would introduce an expense and inconvenience to moving circular clarifiers from job site to job site that would be difficult to justify. No attempt has been made to provide a cost allowance for such demolition in subsequent cost estimates.

59. Some advantages and disadvantages of the circular clarifier basin are as follows:

Table B7  
Cost for Circular Clarifiers

| Flow<br>(mgd) | Suspended<br>Solids<br>Concentration<br>(%) | Capital<br>Cost<br>(\$) | Operating<br>Cost<br>(\$/Yr) | Maintenance<br>Cost<br>(\$/Yr) |
|---------------|---|-------------------------|------------------------------|--------------------------------|
| 0.1           | 5-20  | 71,400                  | 13,200                       | 3,600                          |
| 0.1           | 0.01-1.0                                    | 39,000                  | 13,000                       | 1,950                          |
| 1.0           | 5-20  | 243,000                 | 15,100                       | 12,100                         |
| 1.0           | 0.01-1.0                                    | 89,200                  | 13,000                       | 4,200                          |
| 5.0           | 5-20  | 1,220,000               | 75,600                       | 61,000                         |
| 5.0           | 0.01-1.0                                    | 207,000                 | 13,500                       | 10,400                         |
| 10.0          | 5-20  | 2,431,000               | 161,000                      | 121,000                        |
| 10.0          | 0.01-1.0                                    | 415,000                 | 27,000                       | 21,000                         |
| 25            | 5-20  | 6,080,000               | 378,000                      | 304,000                        |
| 25            | 0.01-1.0                                    | 1,040,000               | 67,000                       | 52,000                         |
| 50            | 5-20  | 12,157,000              | 756,000                      | 608,000                        |
| 50            | 0.01-1.0                                    | 2,073,000               | 135,000                      | 104,000                        |

### Advantages

- a. Makes more efficient use of space and construction materials than rectangular clarifiers (this is often offset by common wall construction where rectangular clarifiers can be adjacently placed). Circular clarifiers are thus often less expensive in capital cost than rectangular clarifiers on a single unit basis.
- b. Because of the length of chain or other equipment required by rectangular clarifiers, maintenance on the rakes of an internal mechanism of the circular clarifier is often less expensive.

### Disadvantages

- a. The circular configuration is hydraulically less efficient than long narrow rectangular channels, with correspondingly less settlement of flocculant materials for the same detention time and/or hydraulic surface loading rate.
- b. Circular clarifiers would be more difficult and costly to disassemble and transport from project to project than rectangular or high rate units.
- c. Not suitable for use aboard barge except in smallest sizes.
- d. Removal of settled material by pumping from the sludge hopper is less reliable than mechanical elevation and removal as in the rectangular basin. Pumping produces a less concentrated material and subsequent thickening is often necessary.

60. Table B7 provides cost data on circular clarifiers for the assumptions made.

### High Rate Clarification Equipment

61. Proponents of high rate settling equipment have postulated that shallow settling basins with small detention times can be configured so as to provide superior sedimentation. Based on previously

discussed discrete particle settling theory, in which particle removal is a function only of basin hydraulic surface loading rates, such researchers have suggested that extremely shallow multiple channels have a number of advantages over conventional horizontal flow configurations:

- a. Multiple "stacked" channels create a proportional increase in settling surface area and thus increase removal rates within a given basin volume.
- b. Trays, plates, tubes, partitions, etc., induce optimum hydraulic characteristics for sedimentation by guiding the flow, reducing short-circuiting, and reducing Reynold's Number (thus creating a more nearly laminar flow condition) and promote better velocity distribution.

62. Early attempts at high rate sedimentation by means of stacked tray clarifiers met with limited success due to the difficulty in removing settled sludge, unstable hydraulic conditions often encountered in wide shallow trays, and the limiting of minimum tray spacing due to vertical clearance required for mechanical sludge removal equipment. Recently, tube-settling modules have been successfully applied in water treatment and wastewater treatment applications. Similarly, plate and lamella sedimentation units have been successfully applied. Tube module inserts for installation in existing clarifiers, either circular or rectangular, have been installed to attempt to increase capacity in existing sedimentation basins or improve clarification performance. All such configurations have plates, tubes, or lamella installed at an angle approximately  $60^\circ$  with the horizontal. This has the effect of increasing effective surface area within each multiple channel. Incoming solids settle to the channel bottoms, slide downward, exit the multiple channels, and settle to the floor of the basin. Figure B22 schematically shows a basin configuration typical for tube, plate, or lamella separators. Figure B23 shows tube-settling modules installed in existing circular or rectangular clarifiers. Manufacturers claim that high rate settling basins and

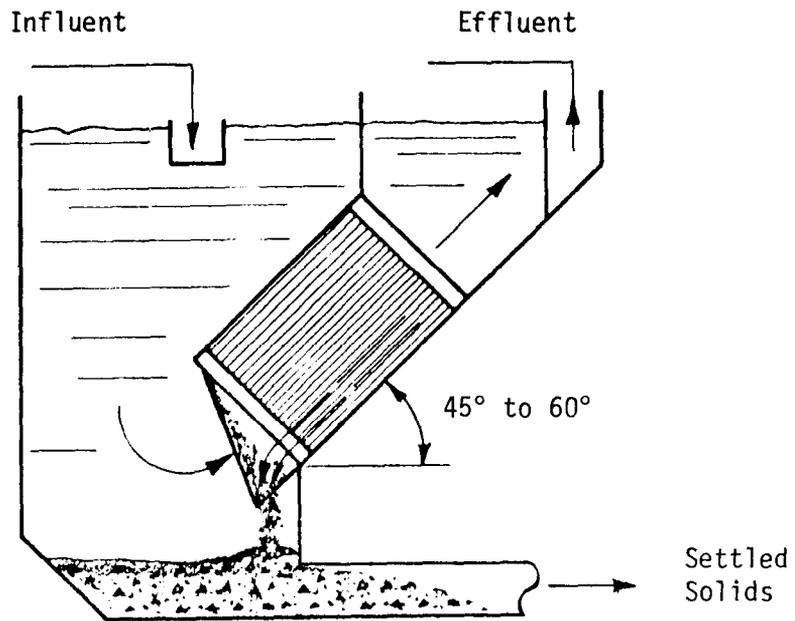
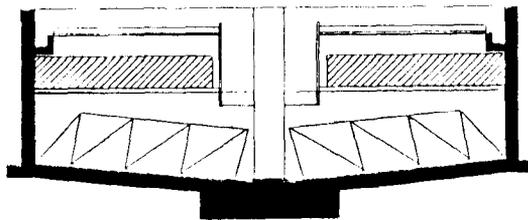
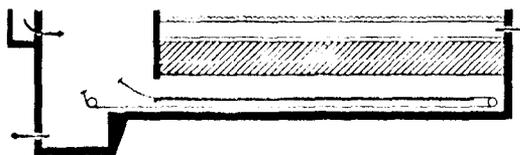


FIGURE B22. Typical Tube, Plate, or Lamella Basin Configuration



(a) CIRCULAR BASIN



(b) RECTANGULAR BASIN

FIGURE B23. High Rate Tube-Settling Modules Installed In Existing Sedimentation Basins

existing conventional settling basins modified as shown can achieve comparable solids removals at from twice the surface hydraulic loading rate (tube) to ten times the surface hydraulic loading rate (plate and lamella) of that of a conventional basin. Assuming such claims are reliable, high rate settling techniques would seem to offer substantial savings in capital cost over conventional sedimentation equipment. One possible drawback in applying such equipment to dredged slurry settling might be solids buildup within, and plugging of settling channels by cohesive sediments. As Figure B22 shows, settled solids are less concentrated than solids mechanically elevated from the basin as suggested for the rectangular clarifier; however, modification to provide completely mechanical removal would not seem to be difficult.

63. High rate settling basins are typically manufactured in the "packaged" configuration and have been most successfully marketed to industrial users. Maximum hydraulic loading for the largest such packaged units has been approximately 1000 to 2000 gpm, depending upon the suspension and degree of clarification desired. Because of their "packaged" configuration, such units are ideally suited to relocation from job site to job site and should be transportable both by truck (with minor disassembling) and by barge. Similarly, such units are ideally suited for use aboard barges, although removal of settled solids by wholly mechanical means should be investigated for either land-based or barge-based use.

64. So far, one manufacturer has reported clarification of a 10 percent suspension of 100 mesh aggregate fines; however, no applications to sand-silt-clay suspensions approaching 20 percent concentration have come to the author's attention. Because of uncertainty concerning application of "packaged" high rate settling basins to clarification of influent from a dredge slurry pipe, cost estimates have been developed only for the case of clarification of effluent from a diked settling area. These estimates were developed by using basin hydraulic loading rates recently applied by plate and lamella

equipment manufacturers to the clarification of suspensions from concrete aggregate manufacturing facilities.

65. Assuming the manufacturers' claims are correct, the following advantages and disadvantages are suggested:

Advantages

- a. Comparable solids removal may be possible at from two to ten times conventional loading rates of conventional settling basins with the consequent cost savings and decreased space requirements.
- b. Improved settling basin hydraulic efficiency and stability over conventional rectangular and circular settling basins.
- c. Due to the unit's volumetric efficiency and "packaged" configuration, transportation from job site to job site and adaptability for use aboard barge seems superior to other clarification equipment.

Disadvantages

- a. Typical high rate settling basin contains hopper from which settled solids are pumped out, thus producing less concentrated solids than when solids are mechanically elevated from basin (as suggested for rectangular basin).
- b. Possible plugging of channels by "mudballs" and cohesive materials.
- c. Little information is available on possible operating problems.

Costs for High Rate Clarification Equipment

66. Based on basin hydraulic loading rate applied by lamella clarifier manufacturers to clarification of suspensions from concrete aggregate manufacturing facilities, the costs of high rate clarification equipment are shown in Table B8.

Costs for Circular and Rectangular Clarifiers with Tube Module Inserts

67. The following cost estimates (Tables B9 and B10) assume that researchers and manufacturers' claims of equivalent clarification with

Table B8  
Cost of High Rate (Lamella) Clarifiers

| Flow<br>(mgd) | Suspended<br>Solids<br>(%) | Capital<br>Cost<br>(\$) | Operating<br>Cost<br>(\$/Yr) | Maintenance<br>Cost<br>(\$/Yr) |
|---------------|----------------------------|-------------------------|------------------------------|--------------------------------|
| 0.1           | 0.01-1.0                   | 18,000                  | 13,000                       | 1,900                          |
| 1.0           | 0.01-1.0                   | 43,500                  | 13,000                       | 2,200                          |
| 5.0           | 0.01-1.0                   | 217,500                 | 65,000                       | 11,000                         |
| 10.0          | 0.01-1.0                   | 360,000                 | 91,000                       | 18,000                         |
| 25            | 0.01-1.0                   | 927,000                 | 160,000                      | 46,000                         |
| 50            | 0.01-1.0                   | 1,800,000               | 192,000                      | 90,000                         |

basin surface loading rates are equal to twice the original design surface loading rates by installation of tube-settling modules. Circular clarifiers (thickeners) receiving influent from the dredge slurry pipe are not considered, since solids loading rate determines basin area. See Tables B9 and B10 for cost data on rectangular and circular clarifiers with tube insert modules.

### Suspended Solids Contact Clarifiers

68. The preceding sedimentation equipment has been developed in accordance with the sedimentation theory for horizontal flow settling, with some variations. An interesting basin configuration has evolved which incorporates hindered settling principles to create a sludge "blanket" near the water surface. Figure B18 schematically presents such a basin. As shown, the suspension enters a mixing column and is mixed with recirculating solids from within the basin (1). This flow passes through an agitation zone where rapid mixing takes place (2) and passes into a flocculation zone (3). Flocculation continues in the clarification zone (4) where a sludge "blanket" is maintained that acts as a filter to remove impurities and light particulates by agglomerating them with the flocculated particles suspended in the blanket. This blanket can be controlled by the rate of sludge withdrawal. Because of the upward expanding cross-sectional area in the tank, the water velocity decreases as it rises until it corresponds to the still water settling velocity of a particular floc particle size. These larger particles tend to coalesce at a certain level in the tank and form a "blanket" which performs as a sort of filter mat for smaller particles that would otherwise rise to a higher level. Above this blanket, the clarified water rises to collecting channels distributed across the water surface and flows to the tank outlet. Some researchers have reported superior hydraulic efficiency in this basin due to the uniformly distributed upflow velocity field and the low velocities approaching the outlet structures as compared to conventional circular and rectangular basins. An additional advantage to this basin is that the functions of rapid mix, flocculation, and clarification are contained

Table B9  
Cost of Rectangular Clarifiers with Tube Insert Modules

| Flow<br>(mgd) | Suspended Solids<br>Concentration<br>(%) | Capital<br>Cost<br>(\$) | Operating<br>Cost<br>(\$/Yr) | Maintenance<br>Cost<br>(\$/Yr) |
|---------------|--|-------------------------|------------------------------|--------------------------------|
| 0.1           | 5.0-20.0                                 | 26,000                  | 12,700                       | 1,300                          |
| 0.1           | 0.01-1.0                                 | 22,500                  | 12,700                       | 1,100                          |
| 1.0           | 5.0-20.0                                 | 90,000                  | 14,100                       | 4,500                          |
| 1.0           | 0.01-1.0                                 | 77,400                  | 12,800                       | 3,900                          |
| 5.0           | 5.0-20.0                                 | 314,000                 | 31,600                       | 15,700                         |
| 5.0           | 0.01-1.0                                 | 280,000                 | 25,700                       | 14,000                         |
| 10.0          | 5.0-20.0                                 | 602,000                 | 63,000                       | 30,000                         |
| 10.0          | 0.01-1.0                                 | 533,000                 | 51,000                       | 26,600                         |
| 25            | 5.0-20.0                                 | 1,504,000               | 133,000                      | 75,000                         |
| 25            | 0.01-1.0                                 | 1,331,000               | 102,000                      | 67,000                         |
| 50            | 5.0-20.0                                 | 3,009,000               | 266,000                      | 150,000                        |
| 50            | 0.01-1.0                                 | 2,662,000               | 207,000                      | 133,000                        |

Table B10

## Cost of Circular Clarifiers with Tube Insert Modules

| Flow<br>(mgd) | Suspended Solids<br>Concentration<br>(%) | Capital<br>Cost<br>(\$) | Operating<br>Cost<br>(\$/Yr) | Maintenance<br>Cost<br>(\$/Yr) |
|---------------|--|-------------------------|------------------------------|--------------------------------|
| 0.1           | 0.01-1.0                                 | 35,600                  | 13,000                       | 1,800                          |
| 1.0           | 0.01-1.0                                 | 80,400                  | 13,000                       | 4,000                          |
| 5.0           | 0.01-1.0                                 | 253,000                 | 13,500                       | 13,000                         |
| 10.0          | 0.01-1.0                                 | 407,000                 | 14,500                       | 20,400                         |
| 25            | 0.01-1.0                                 | 1,057,000               | 42,000                       | 53,000                         |
| 50            | 0.01-1.0                                 | 2,037,000               | 72,000                       | 102,000                        |

within one structure, thus providing a capital cost advantage. Of course, such a basin offers less flexibility than exists in a series type configuration with each process in its own basin. These basins have been successfully applied both in lime softening of waters and coagulation of waters to remove suspended solids and turbidity. Most applications have been in water treatment; however, some manufacturers report application to tertiary processes in wastewater treatment and in treatment of industrial wastes. Some researchers and manufacturers report that surface loading rates twice those of conventional circular and rectangular clarifiers are possible because of superior basin hydraulic characteristics and the filtering effect of the sludge blanket.

69. The following cost estimates (Table B11) have been developed by using hydraulic loading rates of from approximately 560 to 720 gpm/ft<sup>2</sup>. These rates correspond to the lowest surface loading rates typically recommended by manufacturers for treatment of surface waters, an application similar in nature to clarification of effluent from a diked settling area. No attempt to include polymer costs has been made. Manufacturers have recommended against considering this unit for clarification of influent from a dredge slurry pipe.

70. Suspended solids contact clarifiers are shipped partially assembled for field erection. Tanks are field erected. Thus, land transport of such units from site to site would entail disassembly of basins and mechanisms prior to shipment. The cast-in-place concrete base slab would be abandoned or demolished upon basin removal. Because of the unit's circular configuration and the usual necessity for a cast-in-place foundation slab, it is doubtful that any but the smallest diameter units should be considered for use aboard barges.

71. Assuming that researchers' and manufacturers' claims are accurate, the following advantages and disadvantages are suggested:

Advantages

- a. Comparable solids removal at possible twice the conventional settling basin surface loading rates with consequent cost savings.

Table B11  
Cost of Suspended Solids Contact Clarifiers

| Flow<br>(mgd) | Suspended Solids<br>Concentration<br>(%) | Capital<br>Cost<br>(\$) | Operating<br>Cost<br>(\$/Yr) | Maintenance<br>Cost<br>(\$/Yr) |
|---------------|--|-------------------------|------------------------------|--------------------------------|
| 0.1           | 0.01-1.0                                 | 42,500                  | 28,300                       | 2,100                          |
| 1.0           | 0.01-1.0                                 | 107,000                 | 29,000                       | 5,400                          |
| 5.0           | 0.01-1.0                                 | 331,000                 | 62,000                       | 16,500                         |
| 10            | 0.01-1.0                                 | 554,000                 | 66,000                       | 28,000                         |
| 25            | 0.01-1.0                                 | 1,004,000               | 134,000                      | 50,000                         |
| 50            | 0.01-1.0                                 | 2,007,000               | 268,000                      | 100,000                        |

- b. Improved settling basin hydraulic efficiency and stability over conventional rectangular and circular settling basins.
- c. The convenience of containing rapid mixing, flocculation, and sedimentation processes within one basin.
- d. Makes more efficient use of space and construction materials than a single rectangular clarifier, with proportionate cost savings.

Disadvantages

- a. As with the circular sedimentation basin, settled solids are typically pumped out of the sludge hopper, producing less concentrated solids than mechanically handled and elevated solids (as suggested for rectangular basin).
  - b. This configuration may provide less flexibility than when rapid mixing, flocculation, and clarification processes are each contained within their own basins.
  - c. The solids "blanket" must be built up for filtering action to occur. Thus, basin start-up, loss of chemical feed, variations in flow, etc., can cause carry-over of solids and, in some cases, loss of entire blanket.
  - d. More difficult and costly to remove and transport to new job sites.
  - e. Not suitable for use aboard barge except in smallest sizes.
72. See Table B11 for cost of suspended solids contact clarifiers.

PART VII: EQUIPMENT SUPPLIER LIST

Polyelectrolyte Feeding Equipment

Acrison, Inc.  
180 Broad St.  
Caristadt, NJ 07072

Allis-Chalmers Corp.  
Custom Pipe Div.  
Box 50184  
Milwaukee, WI 53201

BIF, Unit of General Signal  
1600 Division Rd.  
West Warwick, RI 02893

Calgon Corp.  
Calgon Center  
Box 1346  
Pittsburgh, PA 15230

Capital Controls Co.  
201 Advance Lane  
Colmar, PA 18915

Chemfix, Inc.  
505 McNeilly Rd.  
Pittsburgh, PA 15226

Cherry-Burrell Co.  
2400 Sixth St., SW  
Cedar Rapids, Iowa 52406

Crane Co.  
300 Park Avenue  
New York, NY 10022

Cromaglass Corp.  
Box 1146  
Williamsport, PA 17701

EZ Distributing Co., Inc.  
3155 NW 82nd Avenue  
Miami, FL 33122

Crown Div., Construction Machinery Co.  
Box 545  
Waterloo, Iowa 50704

Davco-Defiance  
Box 200  
Thomasville, GA 31792

Diversified Electronics, Inc.  
119 N. Morton Avenue  
Evansville, IN 47711

Dorr-Oliver, Inc.  
77 Havemeyer Lane  
Stamford CT 06904

Ducon Fluid Transport  
650 Park Avenue  
King of Prussia, PA 19406

Eimco Div., Envirotech Corp.  
One Davis Rd.  
Belmont, CA 94002

Envirex Inc., A Rexnord Co.  
1901 S. Prairie Avenue  
Waukesha, WI 53186

Environmental Dynamics Corp.  
Water Pollution Control Div.  
Box 675  
Oconomowoc, WI 53066

Environmental Products Inc.  
Box 2385  
Hickory, NC 28601

F.B. Leopold Co.  
227 S. Division Rd.  
Zelienople, PA 16063

FMC Corp, Industrial Chem. Div.  
633 Third Avenue  
New York NY 10017

Fischer & Porter Co.  
County Line Road  
Warminster, PA 18974

Fuller Company  
124 Bridge St.  
Catassauqua, PA 18032

Hercules Inc.  
910 Market St.  
Wilmington, DE 19899

Ingersoll-Rand, Environ. Div.  
Box 503  
Nashua, NH 03060

ISCO  
4700 Superior Ave.  
Lincoln, NB 68505

Jaeco Pump Co.  
539 Ford St., W  
Conshohocken, PA 19428

Jeffrey Manufacturing Co.  
274 E. First Ave.  
Columbus, OH 43216

Kay-Ray, Inc.  
516 W. Campus Dr.  
Arlington Heights, IL 60004

Komline-Sanderson Engrg. Corp.  
Holland Ave.  
Peapack, NJ 07977

Sigmamotor Inc.  
14 Elizabeth St.  
Middleport, NY 14105

Telecommunications Ind., Inc.  
100 N. Strong Ave.  
Lindenhurst, NY 11757

Met Pro Systems, Inc.  
5th St. & Mitchell Avenue  
Lansdale, PA 19446

F.E. Myers & Brothers Co.  
400 Orange Street  
Ashland, OH 44805

Nalco Chemical Co.  
2901 Butterfield Rd.  
Oak Brook, IL 60521

Neptune Microfloc Inc.  
1965 Airport Rd.  
Corvallis, OR 97330

Peabody Barnes  
651 N. Main St.  
Mansfield, OH 44902

Permutit Co.  
E49 Midland Ave.  
Paramus, NJ 07652

Pielkenroad Separator Co., Inc.  
3604 Garrott St.  
Houston, TX 77005

Portec Inc.  
945 Blackstone Ave.  
Waukesha, WI 53186

Robbins & Myers, Moyno Pump Div.  
1345 Lagonda Ave.  
Springfield, OH 45501

Milton Roy Co.  
Box 12169  
St. Petersburg, FL 33733

Wallace & Tiernan Div., Pennwalt Corp.  
25 Main St.  
Belleville, NH 07109

Waste Water Systems, Inc.  
Central & Ella Rds.  
Hoffman Estates, IL 60172

Toran Corp.  
1761 Lakewood Dr.  
Holladay, UT 84117

Wemco Div., Envirotech Corp.  
721 North B St.  
Sacramento, CA 95814

Rapid Mixing Equipment

Air-O-Lator, Div. of Roycraft Ind. Infilco Degremont, Inc.  
8100 Paseo St. Box 2118  
Kansas City, MO 64131 Richmond, VA 23216

Aqua-Aerobic Systems Inc. Jeffrey Manufacturing Co.  
6306 N. Alpine Rd. 274 E. First Avenue  
Rockford, IL 61111 Columbus, OH 43216

Atara Inc. Keene Corp.  
299 Forest Ave. 1740 Molitor Road  
Paramus, NJ 07652 Aurora, IL 60507

Borg-Warner Industrial Drives F.B. Leopold Co.  
Box 486 Main Station 227 S. Division Rd.  
Tulsa, OK 74101 Zelienople, PA 16063

Ralph B Carter Co. Louis Allis  
192 Atlantic St. 427 E. Stewart St.  
Hackensack, NJ 07602 Milwaukee, WI

Consolidated Electric Co. Mixing Equipment Co., Inc.  
141 S. Lafayette Freeway 235 Mt. Read Blvd.  
St. Paul, MN 55107 Rochester, NY 14603

Dorr-Oliver, Inc. Nalco Chemical Co.  
77 Havemeyer Lane 2901 Butterfield Rd.  
Stamford, CT 06904 Oak Brook, IL 60521

Eimco Div., Envirotech Corp. Neptune Microfloc Inc.  
One Davis Rd. 1965 Airport Rd.  
Belmont, CA 94002 Corvallis, OR 97330

Envirex Inc., A Rexnord Co. Passavant Corp.  
1901 S. Prairie Ave. Box 2503  
Waukesha, WI 53186 Birmingham, AL 35201

FMC Corp., Indust. Chem. Div. Penberthy Div., Houdaille Industries  
633 Third Ave. Box 112  
New York, NY 10017 Prophetstown, IL 61277

Hinde Engineering Co. Permutit Co.  
654 Deerfield Rd. E49 Midland Ave.  
Highland Park, IL 60035 Paramus, NJ 07652

Philadelphia Mixers Corp.  
181 S. Gulph Rd.  
King of Prussia, PA 19406

Phipps & Bird, Inc.  
303 S. Sixth Street  
Richmond, VA 23235

Polcon Corp.  
222 Cedar Lane  
Teaneck, NJ 07666

Richards of Rockford Inc.  
6308 Material Ave.  
Rockford, IL 61111

Schramm Inc.  
800 E. Virginia Ave.  
West Chester, PA 19380

U.S. Electrical Motors  
Old Gate Lane  
Milford, CT 06460

Walker Process Div., Chicago  
Bridge & Iron Co.  
Box 266  
Aurora, IL 60506

Wemco Div., Envirotech Corp.  
721 North B St.  
Sacramento, CA 95814

WER Industrial  
3036 Alt Blvd.  
Grand Island, NY 14072

Wheelabrator Water & Wastewater  
Systems  
115 Office Park Dr.  
Birmingham, AL 35223

Zurn Industries Inc.  
Water & Waste Treatment Div.  
Erie, PA 16512

#### Flocculators

Aqua-Aerobic Systems, Inc.  
6306 N. Alpine Rd.  
Rockford, IL 61111

Borg-Warner Industrial Drives  
Box 486 Main Station  
Tulsa, OK 74101

Ralph B. Carter Co.  
192 Atlantic St.  
Hackensack, NJ 07502

Consolidated Electric Co.  
141 S. Lafayette Freeway  
St. Paul, MN 55107

Crane Co.  
300 Park Ave.  
New York NY 10022

Dorr-Oliver Inc.  
77 Havemeyer Lane  
Stamford, CT 06904

Dow Chemical USA  
2020 Dow Center  
Midland, MI 48640

Eimco Div., Envirotech Corp.  
One Davis Rd.  
Belmont, CA 94002

Envirex Inc., A Rexnord Co.  
1901 S. Prairie Ave.  
Waukesha, WI 53186

Environmental Elements Corp.  
Water Treatment Systems  
Box 1318  
Baltimore, MD 21203

FMC Corp., Industrial Chemicals  
Div.  
633 Third Ave.  
New York, NY 10017

General Filter Co.  
Box 350  
Ames, Iowa 60010

Hendrick Screen Co.  
2942 Medley Rd.  
Owensboro, KY 42301

Ingersoll-Rand, Environmental  
Div.  
Box 503  
Nashua, NH 03060

Jaeco Pump Co.  
539 Ford St., W  
Conshohocken, PA 19428

Jeffry Manufacturing Co.  
274 E. First Avenue  
Columbus, OH 43216

Keene Corp.  
1740 Molitor Road  
Aurora, IL 60507

Lakeside Equipment Corp.  
1022 E. Devon Avenue  
Bartlett, IL 60103

F.B. Leopold Co.  
227 S. Division Rd.  
Zelienople, PA 16063

Louis Allis  
427 E. Stewart St.  
Milwaukee, WI

Mixing Equipment Co., Inc.  
235 Mt. Read Blvd.  
Rochester, NY 14603

Neptune Microfloc Inc.  
1965 Airport Rd.  
Corvallis, OR 97330

Passavant Corp.  
Box 2503  
Birmingham, AL 35201

Penberthy Div., Houdaille Industries  
Box 112  
Prophetstown, IL 61277

Permutit Co.  
E49 Midland Ave.  
Paramus, NJ 07652

Petrolite Corp.  
369 Marshall Avenue  
St. Louis, MO 63119

Phipps & Bird, Inc.  
303 S. Sixth St.  
Richmond, VA 23235

Pielkenroad Separator Co., Inc.  
3604 Garrett St.  
Houston, TX 77006

U.S. Electrical Motors  
Old Gate Lane  
Milford, CT 06460

Walker Process Div., Chicago Bridge  
& Iron Co.  
Box 266  
Aurora, IL 60506

Wallace & Tiernan Div., Pennwalt  
Corp.  
25 Main Street  
Belleville, NJ 07109

WER Industrial  
3036 Alt Blvd.  
Grand Island, NY 14072

Wheelabrator Water & Wastewater Systems  
115 Office Park Dr.  
Birmingham, AL 35223

Zeta-Meter Inc.  
1720 First Ave.  
New York, NY 10028

## Clarifiers

American Marine & Machinery Co.  
Box 1067  
Nashville, TN 37202

Aqua-Aerobic Systems, Inc.  
6306 N. Alpine Rd.  
Rockford, IL 61111

Can-Tex Industries  
Box 340  
Mineral Wells, TX 76067

Ralph B. Carter Co.  
192 Atlantic St.  
Hackensack, NJ 07602

Clow Corp.  
1211 West 22nd St.  
Oak Brook, IL 60521

Crane Co.  
300 Park Ave.  
New York, NY 10022

Davco-Defiance  
Box 200  
Thomasville, GA 31792

Dorr-Oliver Inc.  
77 Havemeyer Lane  
Stamford, CT 06904

Ecodyne Corp., Smith & Loveless  
Div.  
14040 W. Santa Fe Trail  
Lenexa, KN 64129

Eimco Div., Envirtech Corp.  
One Davis Rd.  
Belmont, CA 94002

Envirex Inc., A Rexnord Co.  
1901 S. Prairie Avenue  
Waukesha, WI 53186

Environmental Elements Corp.,  
Water Treatment Systems  
Box 1318  
Baltimore, MD 21203

FMC Corp., Industrial Chem. Div.  
633 Third Ave.  
New York, NY 10017

General Filter Co.  
Box 350  
Ames, Iowa 50010

Hendrick Screen Co.  
2942 Medley Rd.  
Owensboro, KY 42301

Hoffman Air & Filter  
107 Fourth Ave.  
New York, NY 10003

Infilco Degremont, Inc.  
Box 2118  
Richmond, VA 23216

Jeffrey Manufacturing Co.  
274 E. First Avenue  
Columbus, OH 43216

Kahl Scientific Instrument Corp.  
Box 1166  
El Cajon, CA 92022

Kay-Ray, Inc.  
516 W. Campus Dr.  
Arlington Heights, IL 60004

Keene Corp.  
1740 Molitor Rd.  
Aurora, IL 60507

Komline-Sanderson Engineering Corp.  
Holland Ave.  
Peapack, NJ 07977

Lakeside Equipment Corp.  
1022 E Devon Ave.  
Bartlett, IL 60103

F.B. Leopold Co.  
227 S. Division Rd.  
Zelienople, PA 16063

Met Pro Systems, Inc.  
5th St. & Mitchell Ave.  
Lansdale, PA 19446

Neptune Microfloc Inc.  
1965 Airport Rd.  
Corvallis, OR 97330

Parkson Corp.  
5601 NE 15h Ave.  
Ft. Lauderdale, FL 33308

Passavant Corp.  
Box 2503  
Birmingham, AL 35201

Peabody Welles  
Roscoe, IL 61073

Penberthy Div., Houdaille Ind.  
Box 112  
Prophetstown, IL 61277

Permutit Co.  
E49 Midland Ave.  
Paramaus, NJ 07652

Petrolite Corp.  
369 Marshall Ave.  
St. Louis, MO 63119

Pieldenroad Separator Co., Inc.  
3604 Garrett St.  
Houston, TX 77006

Richards of Rockford, Inc.  
6308 Materials Ave.  
Rockford, IL 61111

SOAF  
Centre de la Fresnaie B.P. 363  
44012 Nantes France

Sanitaire-Water Pollution Control Corp.  
Box 744  
Milwaukee, WI 53201

Sweco Inc.  
6033 E. Bandini Blvd.  
Los Angeles, CA 90051

Technology, Inc.  
1719 Kenny Rd.  
Columbus, OH 43212

Tenco Hydro/Aerosciences, Inc.  
5220 E. Avenue  
Countryside, IL 60525

Ulmaelektro Oy  
Palkaneentie 20  
00510 Helsinki, Finland

Walker Process Div., Chicago Bridge  
& Iron Co.  
Box 266  
Aurora, IL 60506

Western States Machine Co.  
Box 327  
Hamilton, OH 45012

Wheelabrator Water & Wastewater  
Systems  
115 Office Park Dr.  
Birmingham, AL 35223

Zurn Industries, Inc.  
Water and Waste Treatment  
Erie, PA 16512

## Subnatant Pumps

Allis-Chalmers Corp.  
Custom Pipe Div.  
Box 50184  
Milwaukee, WI 53201

Aurora Pump, Unit of General  
Signal  
800 Airport Rd., N.  
Aurora, IL 60542

BIF, Unit of General Signal  
1600 Division Rd.  
West Warwick, RI 02893

Badger Meter Inc.  
4515 W. Brown Deer Rd.  
Milwaukee, WI 53223

Big Wheels, Inc.  
Box 278  
Paxton, IL 60957

Borg-Warner Industrial Drives  
Box 486 Main Station  
Tulsa, OK 74101

Can-Tex Industries  
Box 340  
Mineral Wells, TX 76067

Ralph B. Carter Co.  
192 Atlantic St.  
Hackensack, NJ 07602

Cherry-Burre-1 Co.  
2400 Sixth St., SW  
Cedar Rapids, IA 52406

Clow Corp.  
1211 West 22nd St.  
Oak Brook, IL 60521

Colt Industries, Fairbanks Morse  
Pump Div., 3601 Kansas Ave.  
Kansas City, Kansas

Consolidated Electric Co.  
141 S. Lafayette Freeway  
St. Paul, MN 55107

Crane Co.  
300 Park Ave.  
New York NY 10022

Cromaglass Corp.  
Box 1146  
Williamsport, PA 17701

Crown Div., Construction Machinery  
Company, Box 545  
Waterloo, IA 50704

Davco-Defiance  
Box 200  
Thomasville, GA 31792

Diversified Electronics, Inc.  
119 N. Morton Ave.  
Evansville, IN 47711

Dorr-Oliver Inc.  
77 Havemeyer Lane  
Stamford, CT 06904

EZ Distributing Co., Inc.  
3155 NW 82nd Ave.  
Miami, FL 33122

Ecodyne Corp1, Smith & Loveless Div.  
14040 W. Santa Fe Trail  
Lenexa, Kansas 64129

Eimco Div., Envirotech Corp.  
One Davis Rd.  
Belmont, CA 94002

Enpo-Cornell Pump Co.  
420 E. Third St.  
Piqua, OH 45356

Environmental Products Inc.  
Box 2385  
Hickory, NC 28601

FMC Corp., Industrial Chem. Div.  
633 Third Ave.  
New York, NY 10017

Fischer & Porter Co.  
County Line Rd.  
Warminster, PA 18974

Flygt Corp.  
129 Glover Ave.  
Norwalk, CT 06856

Fuller Company  
124 Bridge St.  
Catassauqua, PA 18032

G-A Industries, Inc.  
1116 Ridge Ave.  
Pittsburgh, PA 15233

General Electric Co.  
One River Rd.  
Schenectady, NY 12305

Gorman-Rupp Co.  
305 Bowman St.  
Mansfield, OH 44902

Honeywell Process Control  
1100 Virginia Dr.  
Ft. Washington, PA 19090

Hydr-O-Matic Pump Co.  
Haynesville, OH 44838

ITT Marlow  
Box 200  
Midland Park, NJ 07432

Jaeco Pump Co.  
539 Ford St., W.  
Conshohocken, PA 19428

Kay-Ray, Inc.  
516 W. Campus Dr.  
Arlington Heights, IL 60004

Keene Corp.  
1740 Molitor Rd.  
Aurora, IL 60507

Komline-Sanderson Engrg. Corp.  
Holland Ave.  
Peapack, NJ 07977

Lakeside Equipment Corp.  
1022 E. Devon Ave.  
Bartlett, IL 60103

Leeds & Northrup Co.  
Sunneytown Pike, PA 19454

F.B. Leopold Co.  
227 S. Division Rd.  
Zelienople, PA 16063

Louis Allis  
427 E. Stewart St.  
Milwaukee, WI

M-D Pneumatics, Inc.  
4840 W. Kearney St.  
Springfield, MO 65803

Frank W. Murphy Manufacture Inc.  
Box 36638  
Houston, TX 77036

F.E. Myers & Brothers Co.  
400 Orange St.  
Ashland, OH 44805

Pacific Pumping Co.  
9201 San Leandro St.  
Oakland, CA 94603

Passavant Corp.  
Box 2503  
Birmingham, AL 35201

Peabody Barnes  
651 N. Main St.  
Mansfield, OH 44902

Penberthy Div., Houdaille Industries  
Box 112  
Prophetstown, IL 61277

Pollution Equipment Co.  
Box 1668  
Orlando, FL 32802

Robbins & Myers, Moyno  
Pump Div.  
1345 Lagonda Ave.  
Springfield, OH 45501

Milton Roy Co.  
Box 12169  
St. Petersburg, FL 33733

Sequence Controller Corp.  
1551 NE 17th Terrace  
Ft. Lauderdale, FL 33334

Sigmamotor, Inc.  
14 Elizabeth St.  
Middleport, NY 14105

Square D Co.  
Box 9247  
Columbia, SC 29290

Stevens International  
429 S. Walnut St.  
Kennett Square, PA 19348

Taylor Instruments  
95 Ames St.  
Rochester, NY 14601

Toran Corp.  
1761 Lakewood Dr.  
Holladay, Utah 84117

Usemco, Inc.  
Box 583  
Tomah, WI 54660

Wallace & Tiernan Div.,  
Penwalt Corp.  
25 Main St.  
Belleville, NJ 07109

Waste Water Systems, Inc.  
Central and Ella Rds.  
Hoffman Estates, IL 60172

Wemco Div., Envirotech Corp.  
721 North B St.  
Sacramento, CA 95814

WER Industrial  
3036 Alt Blvd.  
Grand Island, NY 14072

Worthington Pump Corp.  
270 Sheffield St.  
Mountainside, NJ 07092

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Jones, Richard H

Development and application of design and operation procedures for coagulation of dredged material slurry and containment area effluent / by Richard H. Jones, Jones, Edmunds and Associates, Inc., Gainesville, Fla., and Randall R. Williams, Thomas K. Moore, Environmental Laboratory, U. S. Army Engineer Waterways Experiment Station. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

95, 8, 67 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-54)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit No. 6B08.

References: p. 95.

1. Coagulation. 2. Containment areas. 3. Dredged material. 4. Dredged material disposal. 5. Flocculation. 6. Pipeline dredges. 7. Polyelectrolytes. 8. Slurries. 9. Waste disposal

(Continued on next card)

Jones, Richard H

Development and application of design and operation procedures for coagulation of dredged material slurry and containment area effluent ... 1978. (Card 2)

sites. I. Moore, Thomas K., joint author. II. Williams, Randall R., joint author. III. Jones, Edmunds and Associates, Inc. IV. United States. Army. Corps of Engineers. V. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-78-54.

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