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LABORATORY STUDY OF AERATION AS A FEASIBLE TECHNIQUE FOR DEWATERING FINE-GRAINED DREDGED MATERIAL

ENVIRONMENTAL ENGINEERING CONSULTANTS, INCORPORATED
STILLWATER, OKLAHOMA

DECEMBER 1976

DREDGED MATERIAL RESEARCH PROGRAM

CONTRACT REPORT D-76-10

LABORATORY STUDY OF AERATION AS A FEASIBLE TECHNIQUE FOR DEWATERING FINE-GRAINED DREDGED MATERIAL

by

Environmental Engineering Consultants, Inc.
Stillwater, Okla. 74074

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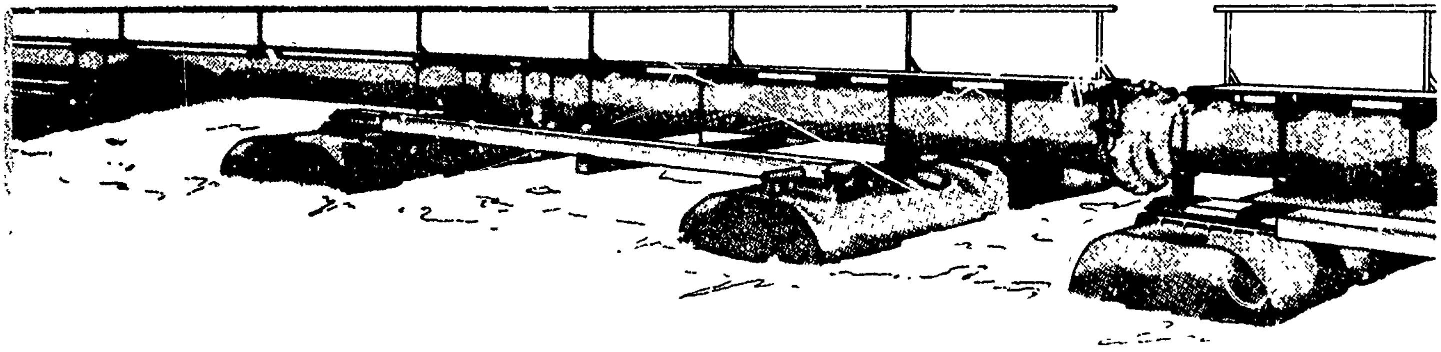

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U. S. Army Engineer Waterways Experiment Station
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The purpose of this study was to examine analytically and experimentally the potential feasibility for employment of aeration as a means of hastening the drying of fine-grained dredged material. Laboratory experiments were conducted on two materials in which 3- and 6-ft cylindrical columns of slurry were aerated at various airflow rates employing various initial moisture contents from 200 to slightly over 300 percent. It was shown that bubbling of diffused air into the (Continued)

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slurry increased the rate of the moisture loss. Statistical analyses of these data led to an empirical formula for predicting moisture content from initial moisture content, depth, and unit airflow rate for the two materials. The equation provided reasonable predictions for results obtained in another laboratory-scale slurry pit. Costs for using diffused air to enhance drying under field conditions will be rather high but may be warranted depending on the cost of purchasing and developing new sites. It was concluded that the process showed sufficient potential to recommend that field demonstration and design criteria studies be undertaken.

DEPARTMENT OF THE ARMY
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P. O. BOX 631
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IN REPLY REFER TO: WESYV

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1. The contract report transmitted herewith represents the results of a study of a dredged material dewatering concept evaluated as part of Task 5A (Dredged Material Densification) of the Corps of Engineers' Dredged Material Research Program (DMRP). This task, included as part of the Disposal Operations Project of the DMRP, is concerned with developing and/or testing promising techniques for dewatering or densifying (i.e., reducing the volume of) dredged material using mechanical, biological, and/or chemical techniques prior to, during, and after placement in containment areas.

2. Rapidly escalating requirements for land for the confinement of dredged material, often in the midst of urbanized areas where land values are high, have dictated that significant priority within the DMRP be given to research aimed at extending the life expectancies of existing or proposed containment facilities. While increased life expectancies can be achieved to some extent by improved site design and operation and to a greater extent by removing dredged material for use elsewhere, the attractive approach being considered under Task 5A is to densify the in-place dredged material. Densification of the material would not only increase site capacity but also would result in an area more attractive for various subsequent uses because of improved engineering properties of the material.

3. The concept considered in this study is that of increasing the rate of water removal from fine-grained dredged material by forced aeration. The concept was one of several recommended for further investigation by experts attending the first Task 5A Planning Seminar. Other concepts considered included progressive trenching, gravity and vacuum-assisted subdrains, electro-osmosis, vegetation, mechanical mixing, and vacuum wellpoints. The purpose of this study, conducted by Environmental Engineering Consultants, Inc., Stillwater, Oklahoma, was to examine analytically and experimentally in the laboratory the potential feasibility of hastening the drying rate of dredged material by forcing air from the bottom of the material to the surface.

4. Laboratory experiments were conducted on fine-grained dredged material obtained from a saltwater and a freshwater environment. Tests of dredged material at various initial moisture contents from 200 to slightly over 300 percent were conducted in columns that were 4 in. in diameter and were either 3 or 6 ft high. It was shown that bubbling of diffused air into the slurry increased the rate of water loss. Statistical analysis of these data led to an empirical equation for predicting moisture content for the two materials from the initial moisture content, depth, and unit airflow rate. The equation provided reasonable predictions for results obtained in a laboratory-scale slurry pit. Potential aeration systems and costs were also investigated.

5. The results of this study indicated that aeration of fine-grained dredged material slurries can form a useful portion of an overall site-management strategy. Aeration should not be applied to all disposal areas nor should it be applied over an entire area. The aeration devices are envisioned as items of movable equipment that can be stationed at particular areas containing the highest fraction of fine-grained material. Also, aeration is most applicable for moisture contents that range from approximately 250 to 125 percent. Surface drainage can better be employed at moisture contents greater than 250 percent, and piping or chimneys would develop at moisture contents below about 125 percent. For an initial slurry depth of 4 to 6 ft, the cost of the system per cubic yard of space created would approach $4.00.

6. Major field studies of the other dewatering techniques listed in paragraph 3 are under way in Mobile, Alabama. Aeration was not included as part of the field study since it was felt that the use of the technique, although feasible, would be limited by its cost and small area of applicability.

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

SUMMARY

The expected increased use of confined dewatering sites for dredged material as well as the increasing costs of land for such sites indicate that ways and means should be sought to create additional volume and extend the useful life of the site. Thus it is important to examine ways of hastening the drying process. One way which has been suggested is by aerating the dredged slurry in the disposal site.

The goal of this study was to determine if there was some basis of potential feasibility for aeration dewatering of dredged material. A search of the literature revealed little information of direct applicability to the aeration of fine-grained dredged material at the moisture contents encountered in disposal sites. However, the search of literature over the widest possible range of interest indicated that the general drying behavior of this material should be consistent with current kinetic concepts for drying of other materials.

Laboratory experiments were designed to test, in as critical a manner as possible, the effect of aeration on the drying process. Drying rates were determined for various airflow rates, depth of submergence of aerators, and initial moisture contents for dredged material from two sites. It was found that all three factors exerted some effect on the time required for drying. Statistical analysis of the experimental data led to the following equation for approximating the moisture content:

$$\text{Percent Moisture} = 10.9 - 5t - 0.043\ Q_{\mu} + M_i + 6.8\ H_i$$

t = Time, days

Q_{μ} = Unit airflow rate, $\text{cm}^3/\text{min}/\ell$

M_i = Initial moisture content, percent

H_i = Initial slurry depth, ft

It is not known whether the equation applies to materials other than those tested.

The predictive value of this formula was checked by using it to estimate the percent moisture in a laboratory-scale slurry pit. The closeness of the predicted and observed values lent confidence in making cost estimates for field application of the aeration process. The costs per unit volume of slurry are rather high and aeration would be considered only where land costs and availability warrant its use.

Considerations were given to design of equipment and operational modes for the process. Existing proprietary aeration equipment did not lend itself to this operation although it might be possible for manufacturers to modify existing aeration devices. For the purpose of making cost analyses, 50- x 50-ft modular grids which could be clustered or used individually were designed. These modules can be moved about where needed at a disposal site. Aeration was concluded to be an expedient which was best applied to "trouble spots" in a dredged material disposal site; thus semi-portable equipment was envisioned.

PREFACE

The work described in this report was performed under Contract No. DACW39-75-C-0123 and Modification No. DACW39-75-C-0123-P001, "A Laboratory Study of Aeration as a Feasible Technique for Dewatering of Fine-Grained Dredged Material," between the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, and Environmental Engineering Consultants, Inc., Stillwater, Oklahoma.

The report consists of critical evaluation of the literature, results of laboratory experimentations, use of laboratory data in formulating a prediction equation for rate of drying, preliminary cost estimates, and recommendations for field demonstrations and design criteria studies. Samples of dredged material taken from sites in Mobile and Toledo were obtained jointly by the contractor and the contract manager. The contractor is particularly grateful to Mr. Michael R. Palermo for his invaluable help and cooperation throughout the investigative period.

A. F. Gaudy, Jr., was designated by Environmental Engineering Consultants, Inc., as Engineer in Charge of the investigation. The contract was managed by Mr. Palermo of the Environmental Engineering Division of the Environmental Effects Laboratory (EEL), WES, under the supervision of Mr. Charles C. Calhoun, Jr., Manager, Disposal Operations Project, and Dr. J. Harrison, Chief, EEL. Dr. T. A. Haliburton, WES, was a consultant to the project. The Directors of WES during the study and preparation of the report were COL G.H. Hilt, CE, and COL J.L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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INTRODUCTION

1. There are hundreds of U. S. Army Corps of Engineers dredging projects which employ confined disposal of dredged material. It is expected that the use of confined disposal sites will increase because of the increased amount of dredging in developed areas, harbors, etc., and because of possible contamination problems associated with open-water disposal. The fact that sites are difficult to find and extremely costly suggests that every effort should be made to extend the life of existing sites for future dredged material disposal operations.

2. Effective use of existing disposal sites indicates that consideration be given to two major factors. First it is necessary to seek ways and means to hasten dewatering so that the dredged material can be densified in place to reduce its volume and perhaps later transported to another site for ultimate disposal or use. Secondly, consideration must be given to possible water contamination control problems during the dewatering process and during any subsequent re-excavation and use of the dried dredged material.

3. The present investigation is concerned primarily with the first aspect, i.e., hastening the dewatering process. Many possibilities have been suggested, one of the most promising being desiccation or evaporation. One of the methods suggested for hastening the

evaporation process has been forced aeration of the fine-grained dredged material slurry within the containment area. Increased drying could result from mass transfer of moisture to the rising air bubbles; whereupon, after reaching the surface, the moisture is exposed to natural evaporative forces in the atmosphere. The rising air bubbles also provide agitation of the slurry and might be expected to hinder formation of evaporation-retarding crusts on the surface.

4. The aim of the study was to conduct laboratory experiments which would provide results from which tentative conclusions could be made regarding the technological potential for air densification of dredged material. If the process appeared to be potentially feasible, techniques for employing it in the field were to be considered.

LITERATURE REVIEW

5. The general topics of aeration, drying, and desiccation concern many applied areas, for example, chemical engineering, agronomy, soils engineering, environmental engineering, etc. Literature in these fields over the past decade and a half were examined for information applicable to aeration of fine-grained dredged material. Over two dozen sources of abstracts of information were consulted as well as scientific journals and various reports of the U. S. Army Engineer Waterways Experiment Station (WES).

Soil Drying Concepts

6. The rate of drying for moisture-laden solids is generally held to take place in two distinct phases when drying occurs under essentially constant conditions. Above a "critical moisture content" the drying rate is constant and below that moisture content the rate of drying decreases with decreasing moisture content. It is generally held that during the period of constant rate drying, the surface of the solid grains in contact with air are wholly wetted; the evaporation rate is thus independent of the solids and is the same or nearly so as the rate of evaporation from a free liquid surface. As long as the surface is wetted, drying is independent of the mechanism of moisture movement to the surface. In this stage the rate of drying may be expected to be controlled by such factors as air temperature, humidity, and air velocity.

7. While the water is supplied to the air-liquid surface as fast as evaporation can take place from the surface, the drying rate will remain constant. When a moisture content is reached at which this is no longer true, the critical moisture content has been attained and the rate of drying may decrease (sometimes linearly, but not in all cases). This period of the drying cycle is termed the falling rate. It is understood that as the drying rate continues to decrease, a second falling rate stage may ensue. In brief the drying solid mass may go through a series of rate-controlling events. All such events appear to be concerned with mechanisms of moisture transport from within the mass to the water-air surface. Generally a second falling stage may signal a condition wherein the surface is totally dry and the moisture from within the drying mass now passes through a mat or mulch of dried material. Some material may undergo shrinkage. The actual surfaces exposed to air may be altered; a hardened layer or crust which seriously retards moisture flow may develop and the material may warp or crack, thus creating a new set of drying conditions.[1]

Sludge Drying Studies

8. In the water pollution control field, various investigators have studied drying of sludge in shallow open beds. Coackley and Allos[2] have presented drying results for raw, primary digested, and secondary digested sludge which indicate that these sludges behave in general accord with the principles outlined above.

9. Nebiker[3] conducted controlled field studies on a number of

types of wastewater treatment plant sludges. All samples were held in aluminum containers 40 cm in diameter. Containers of three depths were employed, 18, 28, and 48 cm, and these were filled to 10, 20, and 40 cm, respectively. Nebiker found that the drying rate for digested sludge could be classified into constant and falling rate periods. The drying rate in the constant rate phase was approximately five percent greater than from a water surface in a container which held no sludge (i.e., the evaporation ratio, e^* = 105%). Results varied in that in some cases there was no dependence of evaporation on filling depth, solids content, or sludge type. In some tests there appeared to be a dependence on the type of sludge and on the solids content. After attainment of the critical moisture content, the falling rate period of drying began and was concluded to be a function of evaporation potential of the air and the weight of solids. It is emphasized that in these studies there was evidence for gassing of the sample which caused some flotation of solids; this in turn aided in crack formation. In brief, because of the unique nature of these solids, it is difficult to extract information pertinent to the behavior of dredged fines. However, it is significant to note that the general sequence of events of constant drying rate, attainment of critical moisture content, followed by a falling rate period was observed.

10. Quon and Ward[4] reported that there was a relationship between drying rate and depth; during the falling rate period, drying rate decreased with greater depth of sludge. Harper and Mar[5] have studied the drying of mixtures of sand and digested sludges. They

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*For convenience, symbols and unusual abbreviations are listed and defined in the notation (Appendix A).

were interested in predicting moisture content of sand-sludge mixtures being used as fill material. As with the studies cited previously, the work has limited value for the present concern but their finding that sand grain size and depth of material did not significantly affect the drying rate in the falling rate period is of interest.

11. Blight[6] has investigated the use of air wells for in situ aeration of tailings. It was concluded that the flow of air through a unit area of soil followed Fick's law. It would appear that such findings would not be helpful in the present study because of the amount of fines in dredged material. However, if a forced air grid were submerged in dredged material, it might be expected that at some moisture content bubbling would cease and there would be a free standing column or chimney of rising air, i.e., the equivalent of a well through which the forced air could carry moisture to the horizontal surface.

12. It is known that, if left undisturbed, the surface of the drying mass of dredged material forms a crust and often a pattern of shrinkage cracks. Adams et al.[7] studied evaporative water loss from the walls of a simulated soil shrinkage crack. The walls were lined with porous ceramic plates connected to a water supply. The simulated crack was installed in the floor of a laboratory wind tunnel in a controlled environment room. The top of the crack was level with the floor and at right angles to the wind stream. Both crack width (10, 30, 50, and 70 mm) and depth (30, 45, and 60 cm) were varied as was wind velocity (0, 2.2, 4.5, 6.7, and 8.9 m sec^{-1}). Evaporation rate increased with increasing wind velocity, crack width, and crack

depth. Wind velocity had the greatest effect on evaporation followed by depth and width of the crack. It was concluded that air movement circulated and replaced the air within the shrinkage crack and was the major factor affecting evaporation. Visual observation of smoke circulation indicated that turbulent air movement occurred within the crack. From these findings one might surmise that air chimneys could enhance evaporation of dredged material even after a moisture content was attained which precluded bubble formation.

Aeration Studies

13. Evaporative drying by use of diffused air has been investigated for the Department of the Navy by Harding-Lawson Associates.[8,9]

14. Preliminary study of aeration of a slurry of dredged material (1-m graduated cylinder) indicated that the moisture content was reduced from 230 percent to approximately 50 percent in 8 hours. Also, plastic tubing (0.005-in. diameter holes on 1-in. centers) was used to conduct air through a shallow (3-in.) depth of slurry. Air was bubbled for three days and the moisture content was reduced from 200 percent to 150 percent moisture.[8] It is not known what flow rates were employed to aerate the samples.

15. In continuing studies, laboratory tests were conducted in plastic-lined boxes 36-in. long, 18-in. wide, and either 24-in. or 12-in. deep. Aeration and raking (deep and shallow) were investigated as a means of enhancing drying rates. In the controls which received no raking or aeration, a crust formed on the surface and greatly impeded drying. For water contents of approximately 150 percent and 200 percent, free water came to the surface between periods of surface

stirring. However, in the undisturbed control no water came to the surface once the crust had formed even though the overall moisture content of the control sample was higher than that of the other samples. It was observed that mixing of any kind enhanced the drying rate over the rate of the control, and it was concluded that the reason for this was the prevention of a crust from forming at the surface. Deep mixing was more effective than shallow or surface mixing especially during the latter part of any given test, i.e., when the moisture content was considerably lower than the initial moisture content. When material near the surface approached a moisture content between 80 percent to 100 percent, it tended to "ball up" and became difficult to mix even though the moisture content below the top layer was higher than 80 percent to 100 percent. Harding-Lawson Associates concluded that bubbling air through the slurry under the conditions of their test did not seem to affect the drying rate. Also they observed that at a moisture content of approximately 150 percent,air tunnels or chimneys were formed in the slurry and bubble formation ceased. The investigation was carried to the field where experiments were conducted on the effects of full-depth mixing, surface mixing, and a combination of these types of mixing. Studies on the effect of diffused aeration were not carried to the field.

16. The final report by Harding-Lawson Associates[9] indicated that both airflow rate and depth of submergence would exert effects on the efficiency of evaporation due to aeration. Other studies conducted to gain insight into site geometry recommended deep singly baffled basins rather than shallow basins.[10] Also, it was known that many of

the U. S. Army Engineer dredged material disposal sites contained slurries of considerable depth. Thus the conclusions of Harding-Lawson Associates were not necessarily applicable to the conditions at dredged material disposal sites.

LABORATORY INVESTIGATIONS

17. Fine-grained dredged material from two sites was examined in this study. Dredged material from the Upper Polecat Bay disposal area (Mobile, Mobile District CE) was selected as representative of dredged fines from salty or brackish waters and dredged material from the Old Island disposal site (Toledo Harbor, Detroit District CE) was selected as representative of that from freshwater disposal sites. The material from Mobile was chosen for more detailed study largely because it contained a considerable amount of organic matter and because a large amount of engineering and environmental data was already available on this material. Thus, these laboratory studies could add to the information being collected at the Mobile site. Also, if the results of the present study indicated possibilities for successful application of aeration to dredged materials, the Mobile site would be the logical one for larger scale studies.

Experimental Apparatus

18. Since the primary scientific aim of the study was to assess the effectiveness of diffused aeration in enhancing the rate of drying of dredged material, it was decided to conduct the study in such a way as to minimize the effect of the surface area of the container. For this reason most of the experiments were conducted in apparatus which provided a "confined column" of aerating slurry (Figure 1).

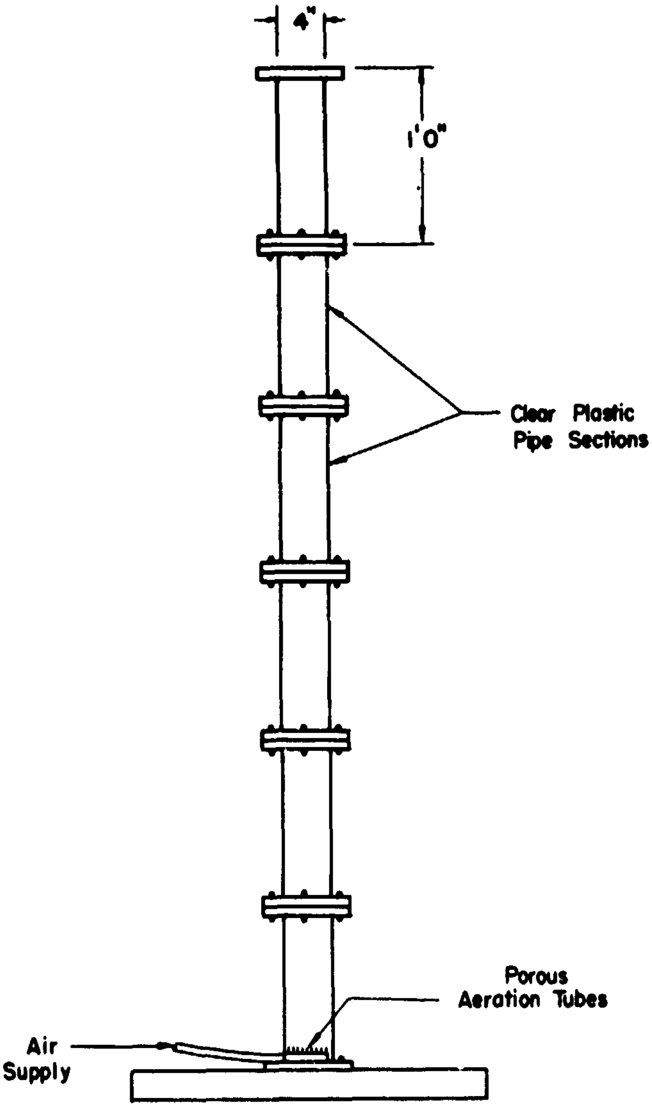

Figure 1. Aeration column for confined column aeration experiments

The columns were made of 1-ft. sections of 4-in. diameter Plexiglas tubing. Porous diffusers were installed as aerators. The tubes were set up in banks of five; two such banks were employed during the studies in order to run concurrent experiments. Four airflow rates were employed, 1,000, 2,000, 3,000, and 4000 cm^3/min, and a control was run at zero airflow rate. These airflow rates covered a sufficient range to enable assessment of effect of airflow rate for the formulation of a prediction equation.

19. After the confined column studies an experiment was run in an aeration chamber apparatus (Figure 2) consisting of three movable aeration tees evenly spaced along the length of the chamber and at right angles to the long side. Such an apparatus provides a large volume of slurry in relation to the rising air bubble column. It was felt that the drying rate data obtained, as well as the observations which could be made on the amount of spreading of the rising air column, could provide useful insights for design of possible further studies in the field should the work in the confined columns provide information that aeration was helpful in increasing the drying rate.

Experimental Protocol

20. Material shipped from the field sites was made up to the desired moisture concentration in the laboratory. In these experiments initial moisture content was varied from slightly above 300 percent (dry-weight basis) to slightly under 200 percent. Field experience had indicated that the fine-grained material could contain approximately this much water after decantation of surface water immediately following disposal operations. Since both the Mobile and Toledo dredged

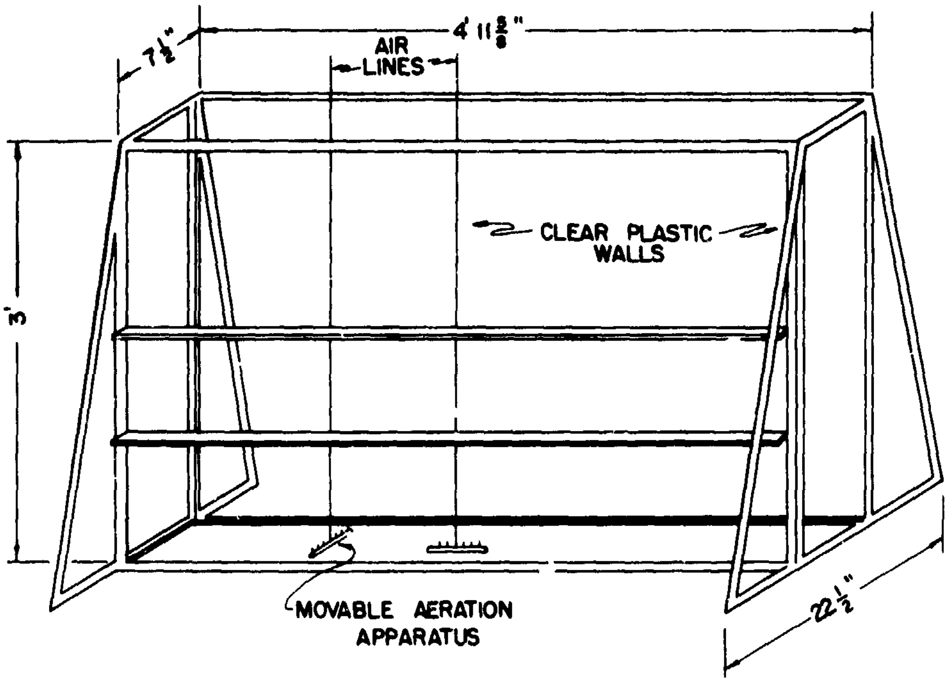

Figure 2. Aeration chamber for laboratory-scale slurry pit aeration experiments

materials were obtained at a moisture content of approximately 100 percent, it was necessary to dilute the samples prior to each experiment.

The Mobile dredged material was diluted with synthetic seawater of the following composition:[11]

Sodium Chloride $NaCl$ = 24.5 g/ℓ
Magnesium Chloride $MgCl_2$ = 5.2 g/ℓ
Sodium Sulfate Na_2SO_4 = 4.1 g/ℓ
Calcium Chloride $CaCl_2$ = 1.2 g/ℓ
Potassium Chloride KCl = 0.7 g/ℓ
Sodium Bicarbonate $NaHCO_3$ = 0.2 g/ℓ

The Toledo dredged material was brought to the desired initial moisture content with tap water.

21. Dredged fines of the desired moisture content were placed in the confined columns to a depth of 2.5 ft in the 3-ft columns and 5.5 ft. in the 6-ft. columns and aerated with compressed air. Air pressure was regulated at 30 psi and the airflow rates of 1,000, 2,000, 3,000, and 4,000 cm^3/min refer to airflow at standard conditions of temperature and pressure. Samples were withdrawn at 24- or 48-hour intervals for various analyses. All experiments were run at a temperature of 22°C ± 2°. Unless otherwise indicated, all analyses were performed in accordance with the standard methods for the examination of water and wastewater.[12] Moisture content was measured as the ratio of the weight of water and the dry weight of the solids. Volatile content of the dry solids was also measured on many samples.

22. It was known that the dredged material contained organic

matter. If the material contained some microorganisms, aeration could provide ideal conditions for metabolism of the organic matter thus reducing possible contamination problems due to biochemical oxygen demand (BOD). Thus, in some experiments both biochemical and chemical oxygen demands (BOD and COD) were run on whole samples and on filtrate or centrifugate from which suspended solids were removed; i.e., soluble BOD and COD were measured. Organic nitrogen, ammonia nitrogen, nitrate nitrogen, and nitrite nitrogen analyses were made. An attempt was made to estimate the viable microorganism count using nutrient agar plates.

Results

Confined column experiments

23. In all, five experiments were conducted in the confined columns to study the effects of airflow rate, initial moisture content, and depth of submergence on drying rate. Experiments 1 through 4 were conducted on the material collected from the Mobile site and experiment 5 was conducted on the Toledo dredged material.

Experiment No. 1: effect of airflow rate

24. The results of the first experiment, aeration at the four rates with an initial slurry depth of 2.5 ft, are shown in Figure 3. A control (unaerated) column was also included, but at the relatively high initial moisture content (320 percent), a supernatant layer developed and it was extremely difficult to measure the overall moisture content of the quiescent control. The data obtained on the control were rather erratic; however, there was an indication that the loss of moisture was somewhat less than that observed for the

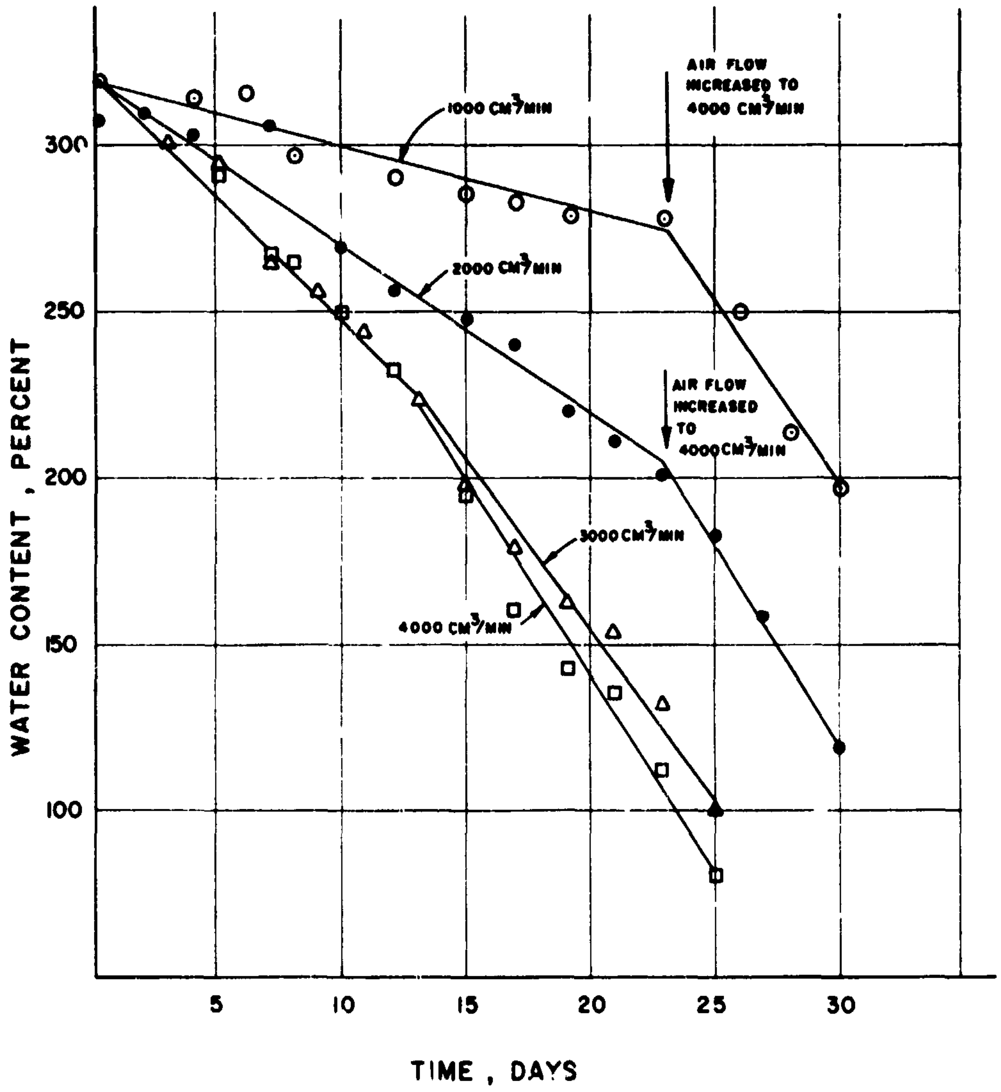

Figure 3. Experiment No. 1, effect of different airflow rates on the drying rates (initial slurry depth 2.5 ft, Mobile sample)

column which was aerated at 1,000 cm^3/min. The results of this experiment leave no doubt that diffused air enhanced drying and that the drying rate increased with an increase in airflow rate. In the 1,000 and 2,000 cm^3/min columns, the airflow rate was increased to 4,000 cm^3/min (see note on Figure 3), and there was an increase in rate of drying. The drying rate in these columns roughly paralleled that obtained in the columns aerated at 3,000 and 4,000 cm^3/min.

25. In the columns aerated at 3,000 and 4,000 cm^3/min, it is seen that the overall course of moisture loss appeared to follow two linear rates, with the second rate being greater than the first. It is recalled that drying generally occurs first at a constant rate and then at a falling or decreasing rate. Thus, at first glance the results seem to be at odds with practical drying concepts. However, since the volume of aerating slurry decreased due to drying and removal of sample, the airflow rate per unit volume of aerating material increased as the experiment progressed; this increased unit airflow rate increased the drying rate. In the field, sampling volume would have a negligible effect on the volume of aerating slurry, but the evaporative loss would be expected to have the effect of increasing the unit airflow rate if the total airflow rate was held constant as it was in these experiments. Thus the increasing trend can be expected to occur in the field under forced diffused air, but the effect would be of lower magnitude and would in all probability not be observable.

Experiment No. 2: effect of initial moisture content

26. This experiment was conducted at an initial depth of slurry of 2.5 ft, but two initial moisture contents were employed (220 and

295 percent). An unaerated control was set up for one of the systems at 220 percent initial moisture content; since there was little or no supernatant at this moisture content, credible data could be obtained for the control. The results are shown in Figure 4 where it can be seen that the difference of approximately 100 percent water content did exert an effect on the drying rate. The system with the higher water content experienced a slightly higher constant rate of evaporation (compare data at both initial moisture contents for systems aerated at 4,000 cm^3/min).

27. In this experiment bubble formation ceased at a water content of approximately 150 percent. It is interesting to note that even after cessation of bubble formation, the moisture content was reduced at a greater rate in the second drying rate phase. As in experiment 1, the increase in drying rate (second slope) is attributable primarily to the increasing unit airflow rate as this experiment progressed. It seems apparent that the small chimney of rising air was sufficient to influence the rate of drying in the 4-in. diameter column of dredged fines. Time limitations for the experimentation did not permit investigation of the extent and useful radius of influence for such a chimney of air, but it would appear from these results that the radius of influence would extend beyond two inches.

Experiment No. 3: effect of greater depth of submergence

28. It was important to determine the effect that a greater depth of submergence would have on the rate of drying. Accordingly an experiment was set up in which 6-ft columns were employed. Slurry of an initial water content of 275 percent was added to the aeration columns

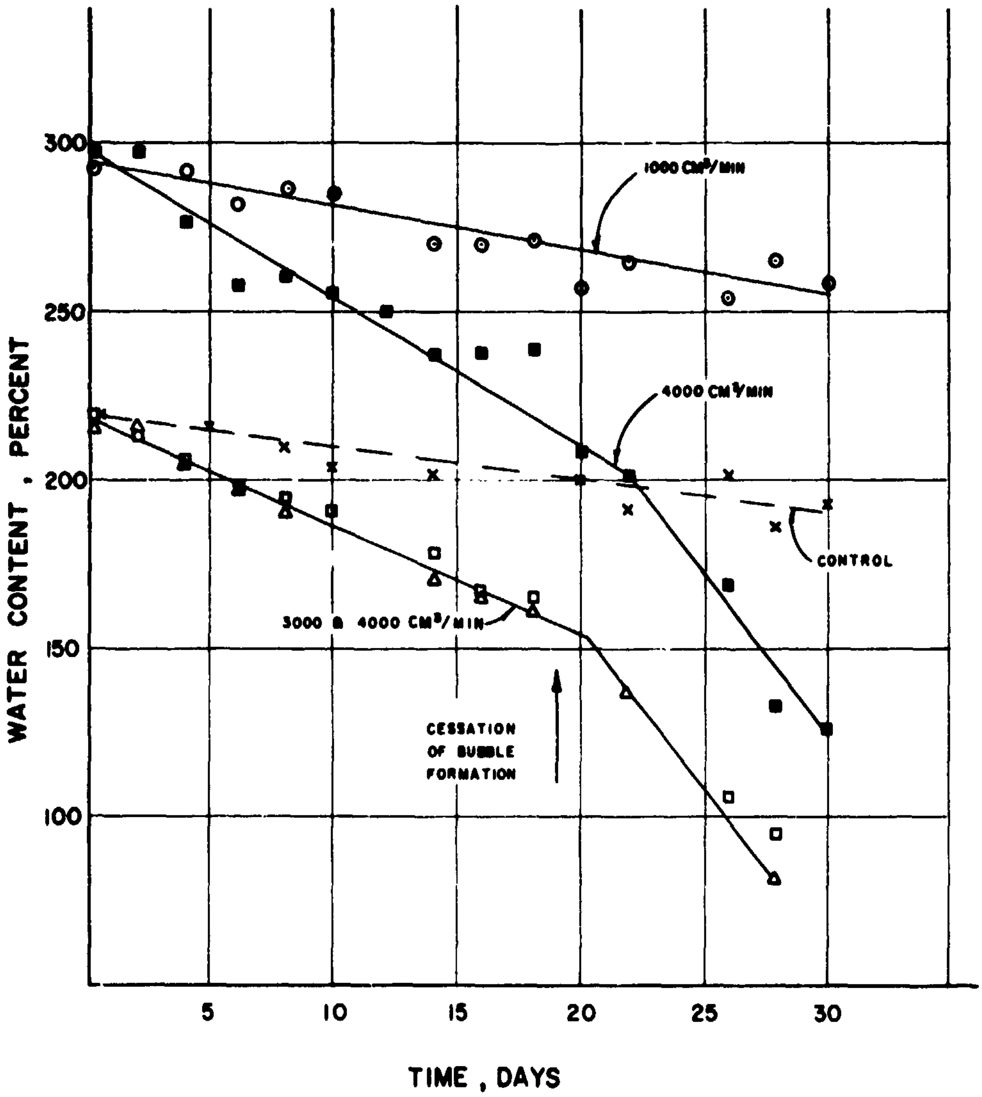

Figure 4. Experiment No. 2, effect of different initial moisture contents on the drying rate (initial slurry depth 2.5 ft, Mobile sample)

to a depth of 5.5 feet and aerated at the four rates. Another column used as a control was not aerated. As with the two previous experiments, Mobile dredged material was investigated. Again it is seen (Figure 5) that diffused aeration significantly enhanced the rate of moisture loss compared to a non-aerated control. Also it is seen that increasing airflow rate effected an increase in drying rate. Also comparison of the results shown in Figure 5 with those of Figures 3 and 4 indicates that increasing the depth of slurry decreases the rate of moisture loss due to forced aeration in the confined column.

Experiment No. 4: effect of variable depth

29. From the previous experiment it was apparent that at constant initial depth, airflow rate (as well as initial unit airflow rate) affected the rate of drying. It was of interest to determine the relative effects when airflow rate was constant and depth was varied. It was decided to vary the depth as follows: 2.5, 2.0, 1.5, and 1.0 ft. The 2.5-ft depth of slurry was aerated at 4,000 cm^3/min, or a unit airflow rate of 740 $cm^3/min/\ell$. Aeration at other depths was adjusted to yield the same unit airflow rate. The results are shown in Figure 6. It is seen that with constant intensity of aeration there appears to be a decrease in drying rate with increasing depth.

Experiment No. 5: effect of freshwater slurry

30. An experiment was undertaken to determine if there were any significant differences in the drying rates between the materials collected at the saltwater and freshwater sites. An experiment was

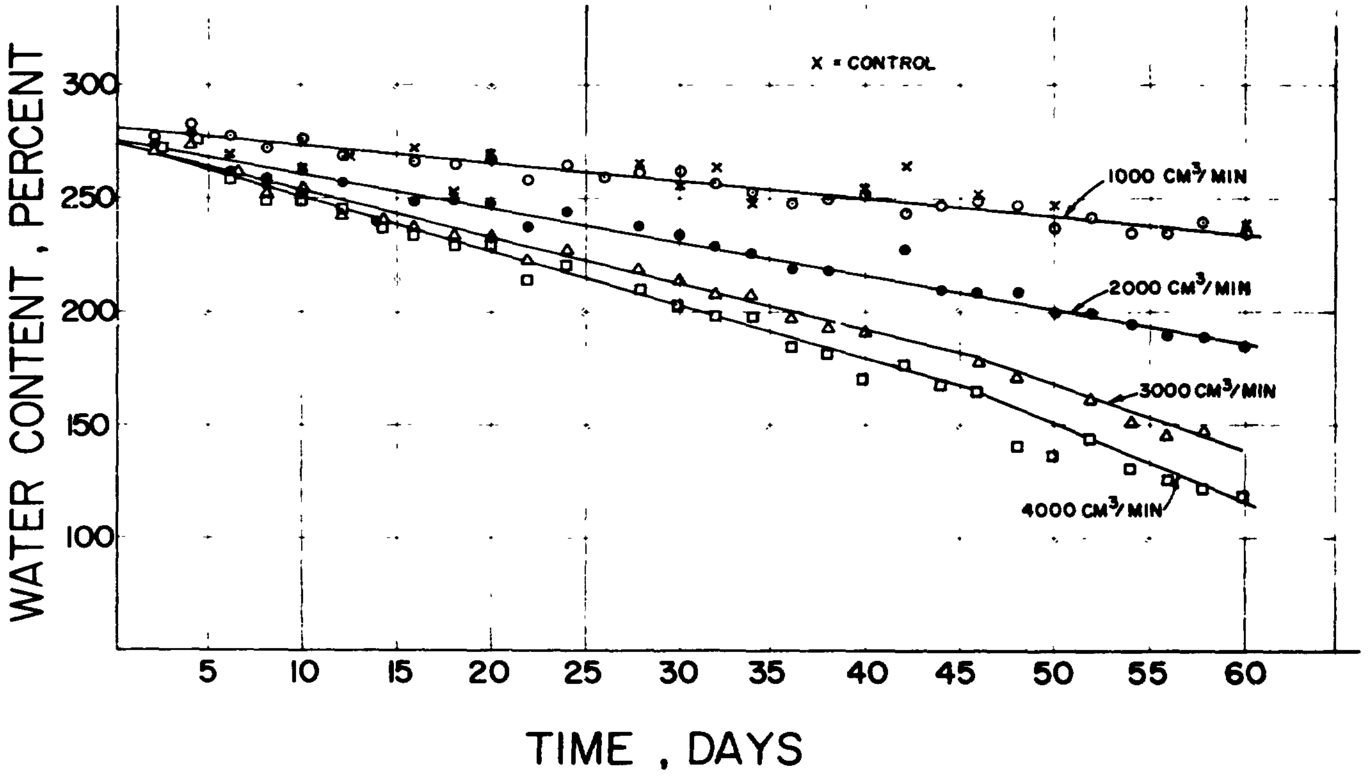

Figure 5. Experiment No. 3, effect of depth of submergence on the drying rate (initial slurry depth 5.5 ft, Mobile sample)

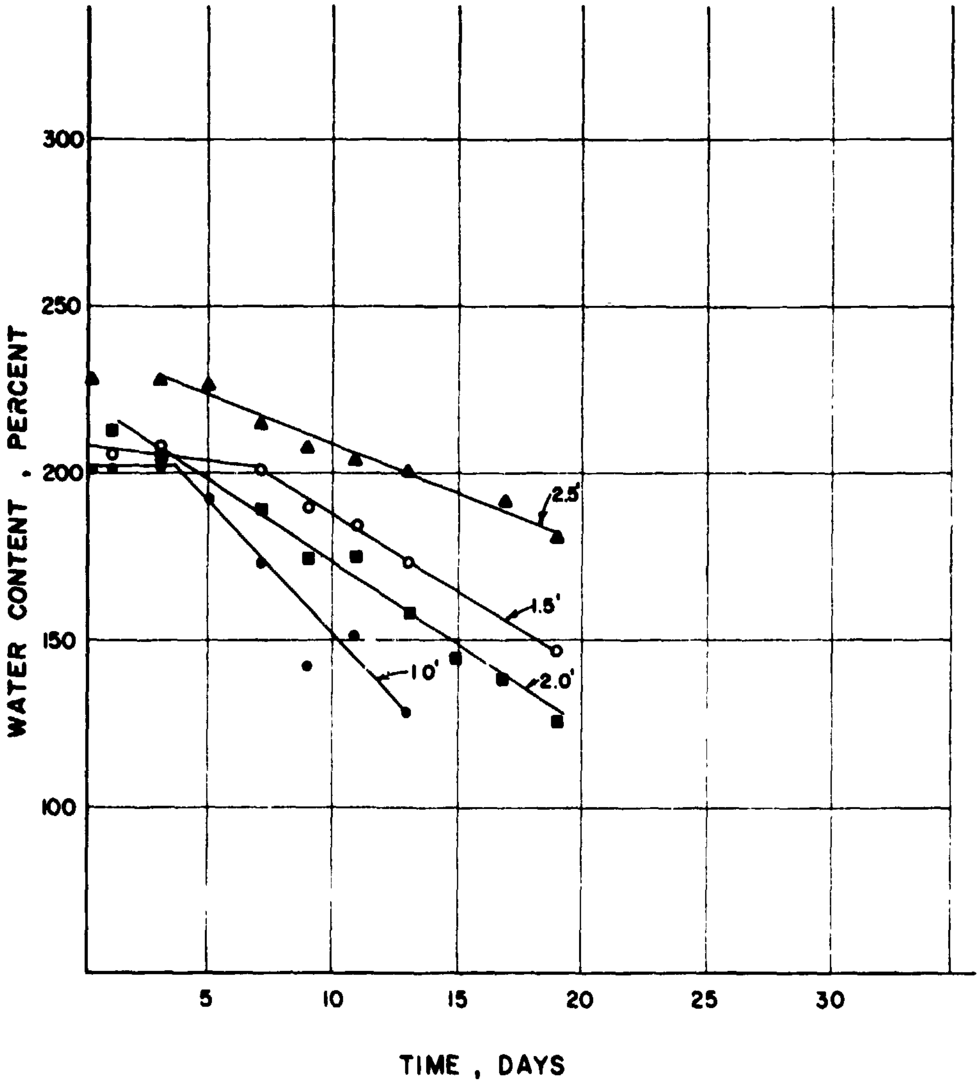

Figure 6. Experiment No. 4, effect of variable depth on the drying rate when unit airflow rate, $cm^3/min/\ell$, is constant (depths shown on the plots are initial depths of slurry in their respective columns)

conducted at the four aeration rates in the 3-ft. confined columns; the initial moisture content was approximately 200 percent. The results are shown in Figure 7. It is apparent that diffused aeration enhanced the drying rate; also there was not any apparent increased drying rate as airflow was increased from 2,000 to 4,000 cm^3/min.

Summary

31. Table 1 summarizes the results of the five experiments shown in Figures 3 through 7. The drying rates expressed in percent per day are those calculated as the initial slopes of the curves shown in the figures. The increase in drying rate with increasing airflow rate is clearly seen. The results also indicate that within the range of moisture contents studied, the higher the initial moisture content the greater will be the drying rate. Moisture contents higher than 320 percent were not considered of significant interest in this investigation since above this moisture content, moisture is reduced easily by surface drainage. With regard to the effect of the initial moisture content, attention is called to systems aerated at 4,000 cm^3/min in experiment 1 and 2. Here it is seen that initial moisture contents of 320, 295, and 220 percent corresponded to drying rates of 7.5, 4.4, and 3.3 percent per day. In Table 1 (experiment 4) are summarized the results of an experiment in which the initial unit airflow rates (i.e., the airflow rates per liter of slurry) were held constant and the depths were varied (see Figure 6). The general trend of the results indicates a decrease in drying rate at increasing depth. It is interesting to note that comparison of the 2.5-ft depth in experiment 4 with the 4,000 cm^3/min result in experiment 2 (both experiments were

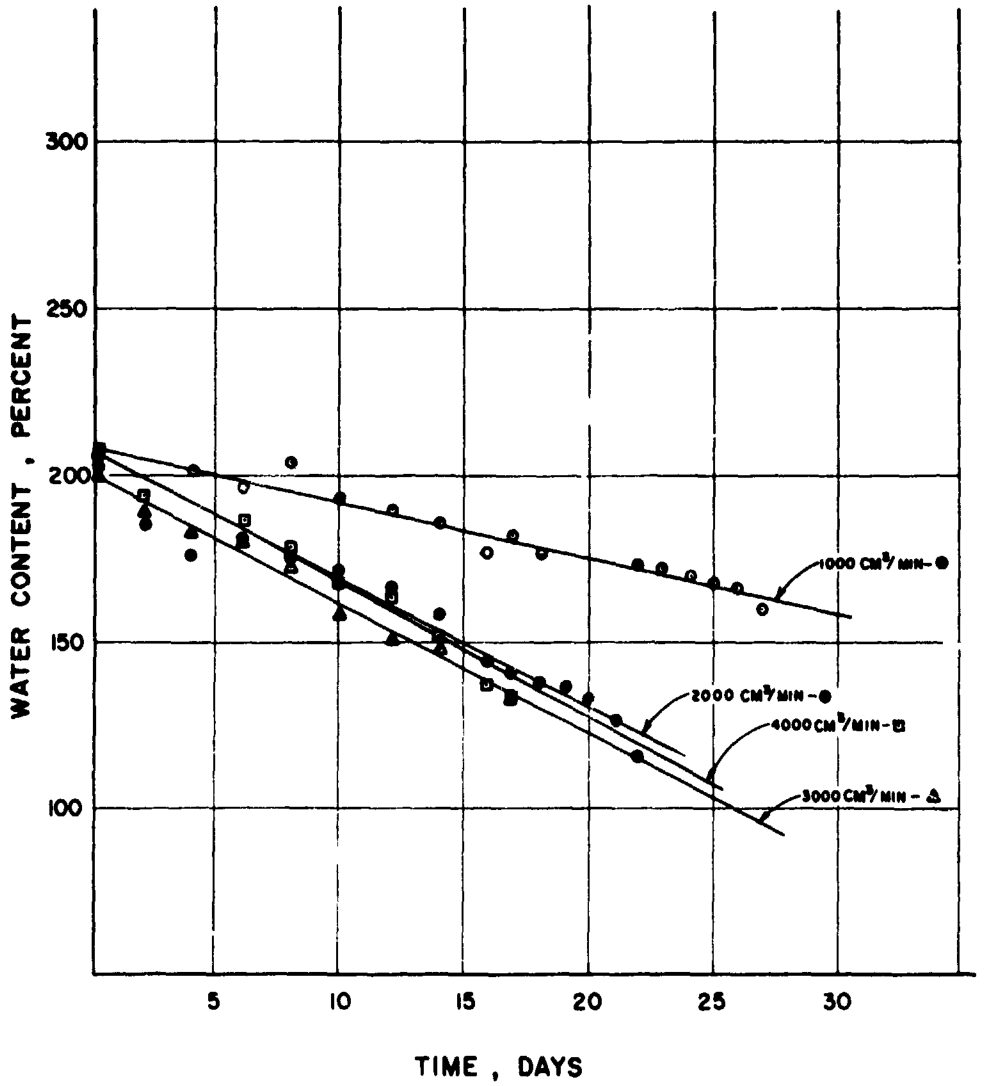

Figure 7. Experiment No. 5, effect of freshwater slurry on the drying rate (initial slurry depth 2.5 ft, Toledo sample)

Table 1

Results of Experiments on Factors Affecting the Rate of Drying

Experiment No.	Factor Varied	Sample Source	Initial Slurry Depth Ft	Initial Moisture %	Airflow Rate cm^3/min	Approximate Drying Rate %/day
1	Airflow Rate	Mobile, brackish	2.5	320	0	-
			2.5	320	1,000	2.0
			2.5	320	2,000	5.0
			2.5	320	3,000	7.5
			2.5	320	4,000	7.5
2	Initial Moisture, Airflow Rate	Mobile, brackish	2.5	220	0	1.0
			2.5	220	3,000	3.3
			2.5	220	4,000	3.3
			2.5	295	1,000	1.3
			2.5	295	4,000	4.4
3	Submergence Depth	Mobile, brackish	5.5	275	0	-
			5.5	275	1,000	0.8
			5.5	275	2,000	1.5
			5.5	275	3,000	2.1
			5.5	275	4,000	2.4
4	Initial Depth	Mobile, brackish	1.0	201	741	8.0
			1.5	197	741	4.5
			1.5	216	0	-
			2.0	228	741	5.0
			2.5	228	741	2.9
5	Site	Toledo, freshwater	2.5	203	0	-
			2.5	204	1,000	1.7
			2.5	206	2,000	3.8
			2.5	201	3,000	3.9
			2.5	208	4,000	4.0

accomplished at approximately the same unit airflow rate, slurry depth, and initial moisture content) provides a fairly good check on the reproducibility of the drying rate data (i.e., compare 2.9 percent vs 3.3 percent).

32. The results of the first four experiments on Mobile dredged material leave little doubt that aeration rate does significantly enhance the rate of moisture loss. It also appears that the initial moisture content and the depth play important roles in determining the drying rate.

33. Table 1 also summarizes the results of the confined column studies using the Toledo dredged material (experiment 5). The main purpose in running this experiment was to determine if there were any significant differences in the drying rates between the material collected at the saltwater and freshwater sites. Comparison of the results shown for experiment 5 with those under comparable conditions in experiments 1, 2, and 4 (Table 1) indicates that the Toledo material may dry at a slightly faster rate than the Mobile dredged material. However, there was nothing to indicate that there were any gross differences in drying behavior of the two materials.

Laboratory-scale slurry pit experiment

34. Figure 8 shows the results of an experiment conducted in the laboratory-scale slurry pit which was shown in Figure 2. The initial volume of slurry was 120 ℓ; the initial depth 1.4 ft; and the initial moisture content was 265 percent. Three aeration tees, each fitted with six diffusers, were evenly spaced along the length of the tank and submerged in the slurry 3 in. above the tank bottom. Airflow rate for

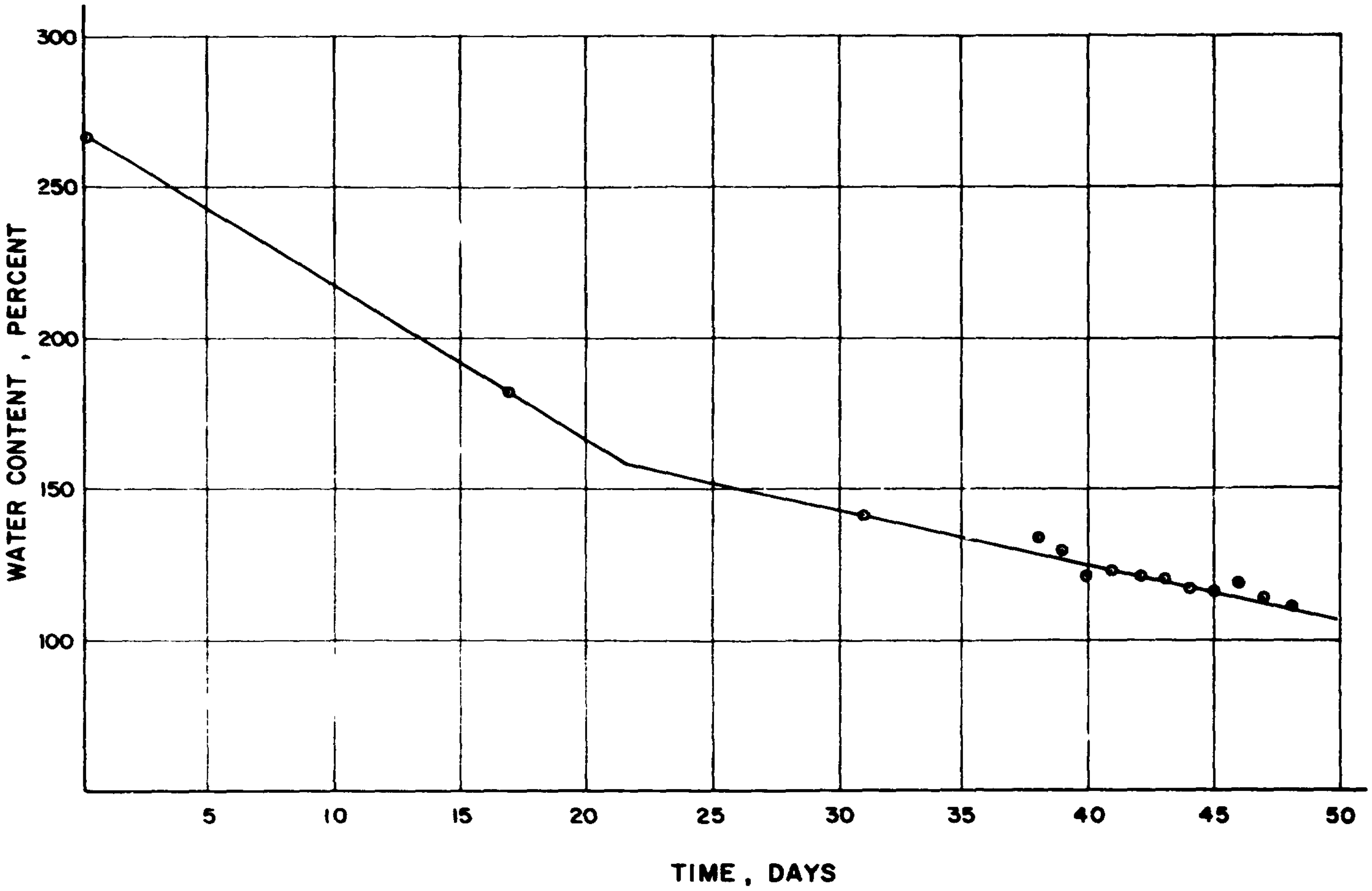

Figure 8. Loss of water during slurry pit experiment

each of the 3 tees was 4,000 cm^3/min; thus the total airflow rate in the tank was 12,000 cm^3/min.

35. During this experiment samples were taken at three depths and two horizontal locations along the length of the tank. With regard to horizontal sampling, samples were extracted near the aeration tees and midway between them. However, using this procedure the overall moisture loss for the entire volume of slurry could not really be assessed because of the classification of moisture content which occurred early in the experiment; the moisture content was high at the surface and decreased with depth. Thus in order to estimate overall moisture content the contents were stirred at various times during the run.

36. Classification of moisture content may be expected to occur in field application and would appear to be ideal since the rate of drying was observed in the previous experiments to increase at higher moisture content. In the field the surface of the slurry pond can be expected to add significantly to the surface available for evaporation.

37. Figure 8 shows the moisture contents at various residence times in the pit. Samples were taken immediately after gently stirring the contents of the pit in order to obtain a credible figure for average moisture content. Beginning on day 38 the contents were stirred daily and the only parameter of interest was the average moisture content. This experiment was set up, initially, in order to determine the patterns of aeration when the aerating slurry was not held in a confined column and the major interest was in the classification of moisture contents. Therefore, there is a paucity of data

on overall drying rate during the first 30 days of the experiment. Assuming an approximately linear rate between days 0, 17, and 30, the drying rate is slightly greater than 4 percent. The data between days 35 and 50 leave little doubt that the drying rate was linear. The drying rate during this period was approximately 1.8 percent per day.

38. The initial volume of aerating dredged material was 120 ℓ and unit airflow rate was 100 cm^3/min/ℓ. The initial drying rate i.e., during the first 30 days, was roughly the same as the drying rate (4.5 percent) per day obtained in experiment 4 at the 1.5-ft slurry depth and 740 cm^3/min/ℓ unit airflow rate (Table 1) even though there was a sevenfold difference in unit airflow rate. This result tends to indicate that those obtained in the confined columns represent a somewhat conservative estimate of the results which might be expected in the field at comparable airflow rates. It also seems that one might be able to effect comparable drying rates in the field at less expenditure of diffused air than employed in the confined column studies. A possible reason for drying rate results in the pit being comparable with those in the confined columns, despite less forced aeration per liter of aerating slurry in the laboratory slurry pit, is the larger surface area of the pit.

39. During this experiment it was noted that there was considerable vertical classification of moisture content. The moisture content at the top was approximately three times greater than at the bottom of the slurry. Also it was noticed that the sphere of influence of the rising bubble column was approximately 3 to 5 in. in

width. It was apparent from the vertical distribution of moisture content as well as from visual observations that the unit airflow rate of 100 $cm^3/min/\ell$ was not enough to cause mixing of the solid particles but was enough to bring water to the surface. Thus aeration with fixed aerators could be expected to classify rather than mix the contents of a dredged material disposal site. It is reasoned that such classification is advantageous in that it increases the moisture content near the surface of the pit thus enhancing evaporation. It was also noted that aeration caused non-mixed portions of the slurry where clear supernatant stood on the surface. It would thus appear that aeration might, in addition to its help in hastening evaporation, enhance the draining process as well.

Moisture Content Prediction Equation

40. Data from the confined column experiments in which Mobile dredged material was examined (Figures 3, 4, 5, and 6) were employed in making statistical analyses to determine a prediction equation for moisture content. In making these analyses, the variables taken as governing ones, i.e., aeration rate, initial moisture content, and initial depth of slurry, were those examined in the four experiments.

41. The initial analysis was concerned with the comparison of four possible models with respect to their ability to fit the observed data of the first experiment (Figure 3) for the constant rate period, i.e., the initial drying rate. It should be noted that the models used were convenient linear models and are not necessarily based on theoretical considerations. The four models considered were as follows:

(1) $\% \text{ Moisture} = a + b(\text{Time})$

(2) $\% \text{ Moisture} = a + b(\text{Time}) + c(\text{Time})^2$

(3) $\log(\text{Moisture}) = a + b(\text{Time})$

(4) $\log(\text{Moisture}) = a + b(\text{Time}) + c(\text{Time})^2$

All judgment as to adequacy of the fit of a model which is not based on a theoretical equation can only be of a subjective nature aided by various statistics. The statistics used in each case were the R^2 statistic, the mean square error after each model had been fitted, the t-test for significance of each of the parameters a, b, and c which were estimated, and an examination of the residuals obtained after fitting each of the models.

42. Based on these analyses, model (1) was deemed adequate for the first 12 - 14 days of data. This model was also found to be adequate in further experiments conducted on the Mobile dredged material involving 6-ft columns of material, different initial moisture conditions, and various aeration rates.

43. Based on these models, observations on the changes in the parameters a and b with changes in aeration rate, initial moisture, and depth of dredged material in the column, led to the final overall model. As in the initial study, several models were tried and the model selected was the one deemed best in light of the R^2 statistic, mean square error, t-tests for the variables in it, and the examination of the residuals after it had been fitted.

44. All computations were made on the Oklahoma State University IBM 360/65 Computer using the multiple linear regression routine (PROC REGR) supplied in the Statistical Analysis System. The data were best

represented by the following equation:

$$\text{Percent } M = 10.9 - 5t - 0.008\,Q + M_i + 6.8\,H_i \tag{1}$$

t = Time, days

Q = Airflow rate, cm^3/min

M_i = Initial moisture content, percent

H_i = Initial slurry depth, ft

For Q in terms of unit airflow rate, $cm^3/min/\ell$, the equation is as follows:

$$\text{Percent } M = 10.9 - 5t - 0.043\,Q_\mu + M_i + 6.8\,H_i \tag{2}$$

t = Time, days

Q_μ = Unit airflow rate, $cm^3/min/\ell$

M_i = Initial moisture content, percent

H_i = Initial slurry depth, ft

It is not known whether these equations would apply to materials other than those herein tested.

45. Applying the above equation to the conditions in the rectangular tank in Figure 8, (Q_μ = 100 $cm^3/min/\ell$, H_i = 1.4 ft., M_i = 265 percent), the calculated moisture content at 15 days is 207 percent. This compares favorably to the observed value of 190 percent.

46. Another example is obtained by applying the equation over the first 10 days of the second linear rate shown in Figure 8. At this time the initial conditions were M_i = 160 percent, H_i = 0.9 feet, Q_μ = 160 $cm^3/min/\ell$. The calculated moisture content was 120 percent, which compares rather favorably with the observed value of approximately 135 percent shown in Figure 8.

47. Although the equation predicted moisture content

satisfactorily, the agreement between calculated and observed values in these examples is in no way a guarantee of the general utility of the equation. It does, however, lend some credence to its use in making estimates of cost and in designing large-scale field studies.

Change in Water Quality During Aeration

48. The Mobile dredged material was known to contain significant amounts of organic materials, and the containment and drainage of such material could possibly cause water contamination problems. Evaporation of water would cause much of the organic material to remain in the disposal site. This would cut down on surface water contamination during the consolidation process. However, there is a growing need to conserve space in dredged material disposal sites and the dried material if excavated and relocated could be a source of organic contaminants. These considerations engendered an interest in performing some investigations on changes in organic material content during aeration.

49. It is well known that aerobic biological treatment of organic waste hastens aerobic decay and so alleviates water contamination problems. Whether aeration could reduce the oxidizable organic material in dredged material depends upon many factors. These are essentially the same ones considered in making treatability studies for organic wastes. They include such characteristics as pH, presence of a nitrogen source, presence of a microbial population capable of metabolizing the organic matter, the nature and concentration of the organic material, etc. However, biological treatment aspects were not within the scope of this investigation.

50. The dredged material from Mobile was characterized by multiple determination of COD and BOD_5 on filtrates from a membrane filter of 0.45μ pore size and on unfiltered samples. The former analysis provided a measurement of soluble COD and BOD, i.e., COD_s and BOD_{5s}. The latter yielded estimates of total COD and BOD_5, i.e., COD_t and BOD_{5t}. Multiple analyses were also run for volatile solids, organic nitrogen, ammonia nitrogen, nitrite and nitrate nitrogen, pH, and viable aerobic bacteria. The range of values for these parameters found for the Mobile dredged material is given in Table 2.

51. It is seen from Table 2 that the Mobile dredged material contained a rather large fraction of organic matter which was readily available to microorganisms. The data indicate the nitrogen source for microbial growth was in relative balance with carbon source. Generally the ratio of BOD_5 to available nitrogen source recommended for biological treatment is approximately 20:1. The BOD_5:N ratio present in the Mobile material may be estimated as follows. The dredged material at 200 percent moisture is approximately one-third solids, i.e., approximately 300,000 ppm. The BOD_5 derives from the volatile portion which at 10 percent volatiles (see Table 2) is estimated at 30,000 ppm. Using the 2 percent value for nitrogen concentration, the organic nitrogen is approximately 600 ppm. Generally about half of the organic nitrogen concentration can be considered available to satisfy the nitrogen requirement for microbial growth. All of the NH_3 may be considered available. Thus the available nitrogen was in the range of 300 to 400 ppm. Comparing this value with the BOD_{5t} concentration indicates that there was a favorable BOD_5:N ratio. Thus biological

Table 2

General Water Quality Characteristics of the Mobile, Alabama, Dredged Material at ± 200% Moisture

Test	Units	Range of Values
COD_t	mg/ℓ	97,000 - 120,000
COD_s	mg/ℓ	63,000 - 96,000
BOD_{5t}	mg/ℓ	7,400 - 8,300
BOD_{5s}	mg/ℓ	6,200 - 6,400
Volatile Solids	% of total solids	10 - 12
Organic Nitrogen	% of volatile solids	1.3 - 2.0
Ammonia Nitrogen, NH_3-N	mg/ℓ	70 - 88
Nitrite Nitrogen, NO_2-N	mg/ℓ	-
Nitrate Nitrogen, NO_3-N	mg/ℓ	-
pH		6.9 - 7.0
Total Viable Bacteria Count*	cells/ml	±5 x 10^5

*On Nutrient agar and aerobically incubated removal of BOD would probably not be hampered by the nitrogen content.

52. The data also indicate that the initial pH would be favorable. In addition, the fact that a reasonably high viable cell count existed provides an indication that any possible toxic materials which may be present are of insufficient concentration to prevent growth.

53. In Figures 9 and 10 the course of removal of COD_t and BOD_{5t} are shown for the different rates of aeration in the confined column with initial slurry depth of 5.5 ft. The COD and BOD values are in mass units, milligrams, since concentration values, milligram/liter, are affected by evaporation taking place in the column. Thus a true evaluation of organic removals is obtained using mass units. Although there is some scatter to the data,it is obvious that aeration enhanced removal of oxidizable organic material contained in the dredged material. Results such as these provide some assurance that aeration can, in addition to enhancing drying rate, also provide a considerable degree of biological treatment thereby reducing problems of excavation and relocation of the dried material if such is desired.

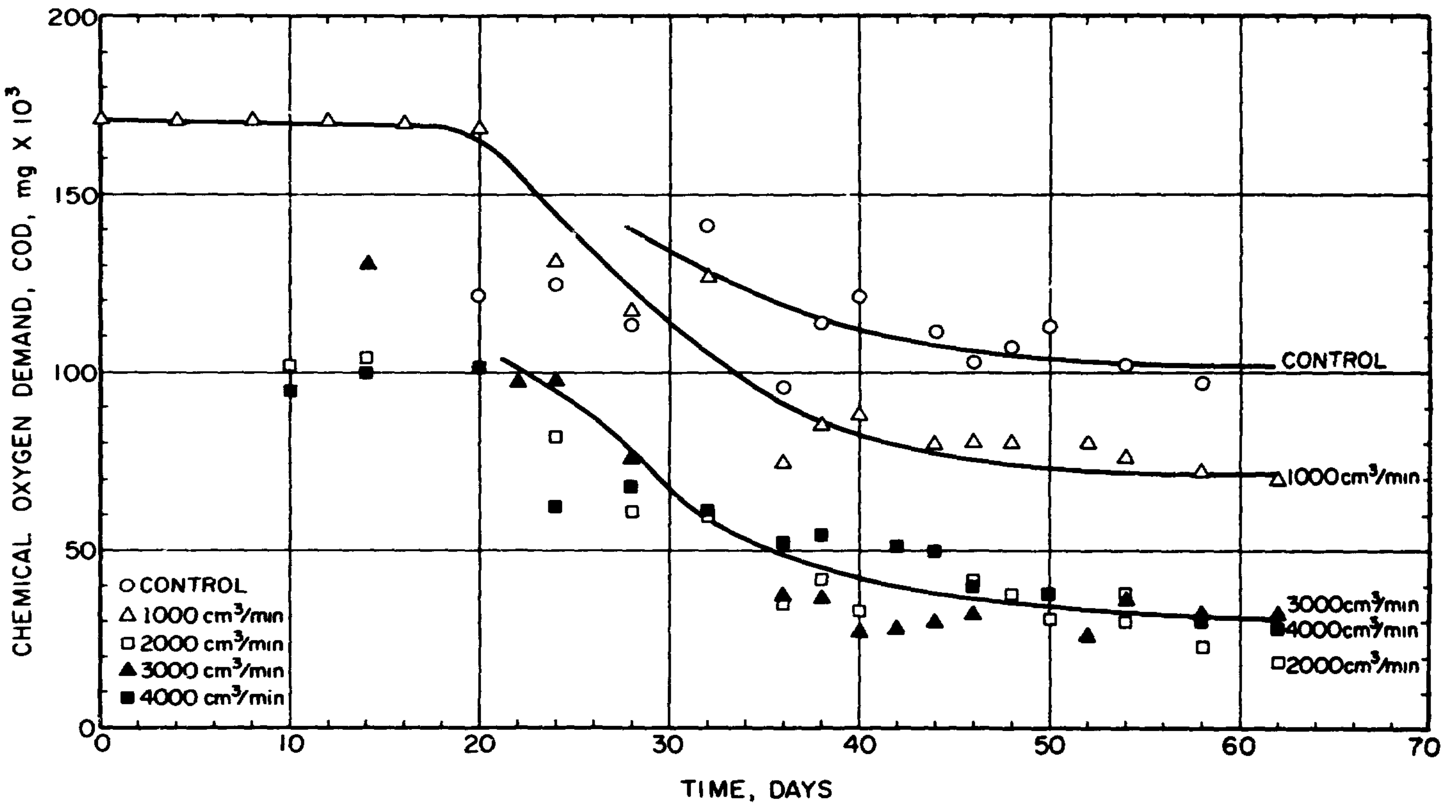

Figure 9. COD removal by aeration

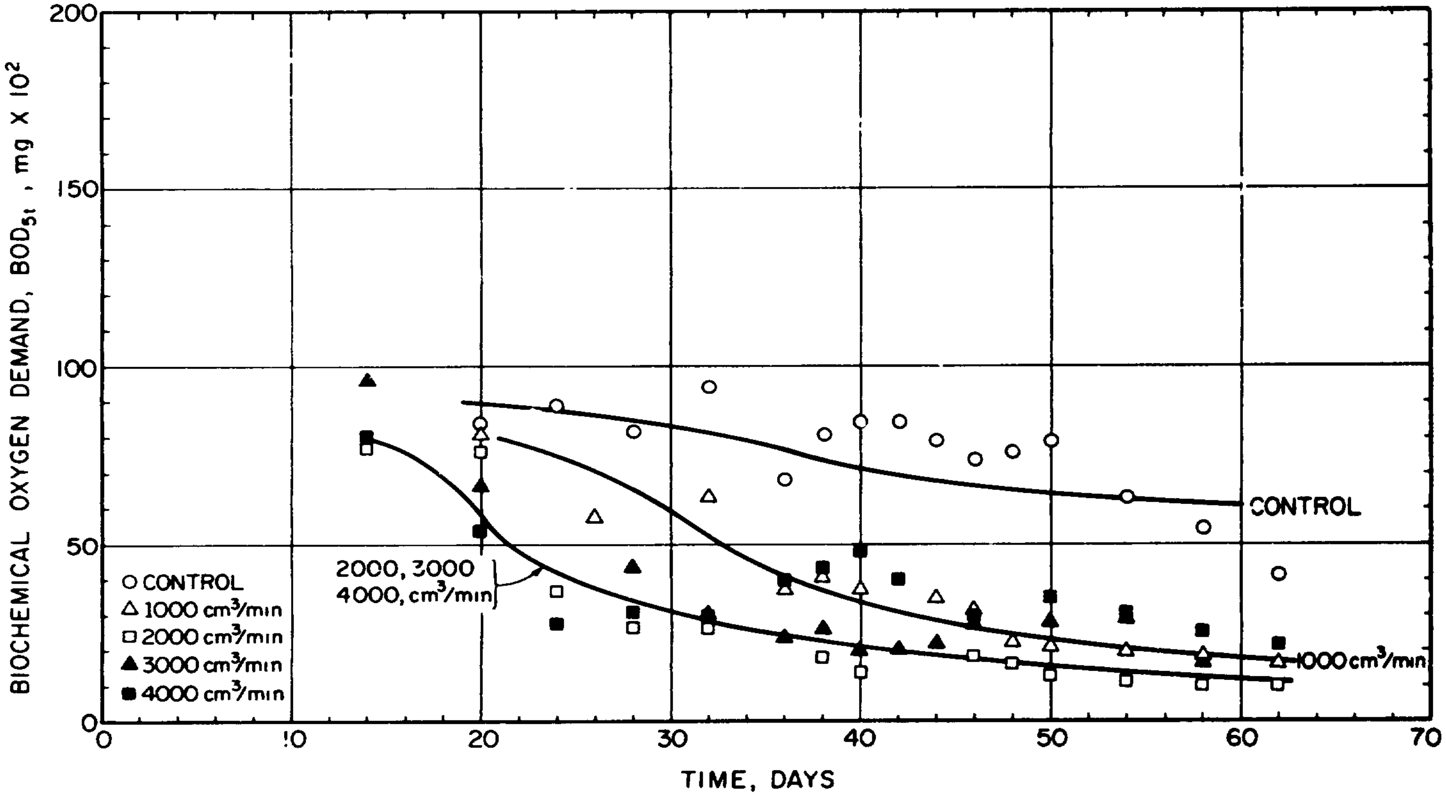

Figure 10. BOD removal by aeration

CONSIDERATION OF FIELD IMPLEMENTATION

54. It was apparent from the results that aeration of the dredged material did enhance the drying rate. It was thus deemed important to consider ways and means which might be employed to implement the aeration of dredged material at field sites. In this section of the report, the following considerations are discussed:

(1) Types of proprietary aeration equipment available

(2) Custom-made equipment which could be employed

(3) Use of the prediction equation in estimating drying time and costs per unit volume of dredged slurry

Types of Proprietary Aeration Equipment Available

55. There are two basic methods of aeration:

(1) mechanical agitation of the material so as to promote solution of air from the atmosphere

(2) introduction of compressed air into the material with submerged porous diffusers or air nozzles

Mechanical aerators

56. Mechanical aerators function by pumping the material to be aerated through the aeration device and discharging it into the atmosphere in a high-velocity spray pattern. This type of aeration is very popular in wastewater treatment. However, it is important to remember

that the wastewaters for which the equipment is designed have very high water contents (approximately 3,000 percent or more). After investigation of the various proprietary devices, it was concluded that this type of aeration equipment would not be practical for materials with a water content of 300 percent or less.

Diffused aerators

57. The diffusers commonly used in aeration systems can be subclassified as either small bubble or large bubble diffusers. Small bubble diffusers are generally tubes or plates constructed of aluminum oxide or silicon oxide grains bound together with a ceramic matrix to form a porous mass. With these diffusers, it is essential that the air supplied be clean and free of dust particles that might clog the pores. Nonceramic porous diffusers are also available. These are corrugated stainless steel cylinders with numerous, relatively large, multiple outlets in the valleys of the corrugations. The outsides of the tubes are wrapped with a twisted plastic cord which provides about the same bubble size as obtained from 40-permeability ceramic tubes.

58. Several types of coarse-bubble diffusers are available. These include the Sparjer, the Deflectofuser, the Disfuser, and diffuser hose. All these diffusers produce larger bubbles than the porous type of diffuser. Thus, they have a slightly lower oxygen-transfer efficiency. However, they offer the advantage of lower cost, less maintenance, and less clogging from dirty air.

Blowers

59. There are two types of blowers in common use, centrifugal

and rotary positive-displacement blowers. Centrifugal blowers are almost always used where the unit capacity is equal to, or greater than, 15,000 ft^3/min of air. Examples of companies manufacturing these blowers are Elliot, Ingersoll Rand, Allis-Chalmers, Roots-Connersville, and De LaVal.

60. Centrifugal blowers have a head-capacity curve similar to that of a centrifugal pump. The operating point is determined, as for a centrifugal pump, by the intersection of the head-capacity curve and the system curve. In selecting a blower, it must be remembered that the pressure developed and the weight flow of air will vary with the inlet conditions. Therefore, blowers must be selected to have adequate capacity on hot summer days and must be provided with a motor of adequate horsepower for the coldest winter weather.

Custom-made Equipment Which Could Be Employed

61. After examination of the various types of aeration equipment available, it was concluded that due to the high solids content of dredged material slurry, a diffused air system would be the only type which might be feasibly employed at a field site. Examination of the rising air columns both in the confined column and the laboratory slurry pit studies indicated that small bubbles rapidly coalesced in the slurry. This observation together with the enhanced clogging opportunities due to the very fine-grained material in the slurry led to the conclusion that production of fine bubbles, which is a usual aim with most types of proprietary air diffusion equipment, would not offer any particular advantage in aeration of dredged material. On the contrary it might even reduce the effective drying rate or otherwise require excessively

high air pressures in order to retard clogging. Thus it was concluded that 1/2-in.-diameter pipe air outlets would most probably suffice.

62. The spacing of the aeration devices presents a problem since the sphere of drying influence of the rising air column could not be estimated with any high degree of confidence. However, it was concluded to be considerably greater than the approximately 2 ft used in the laboratory slurry pit. For purposes of preliminary practical design, a spacing of 5 ft seemed reasonable.

63. It was felt that as much of the system as possible should be reuseable; also that it would be ideal if the aeration system equipment could be somewhat portable in order to employ it on trouble areas at existing sites. That is to say, the design concepts were not restricted to planning for new sites. An arrangement which appears to hold some promise is the 50- x 50-ft angle iron grid shown in Figure 11. Air hoses or pipes are suspended from the grid and buoyancy is provided by 55-gal. drums. With such devices aeration can be applied in modular fashion at various locations at a site where fines collect and aeration could be beneficial. It is not envisioned that entire dredged material sites be aerated. Such a procedure would not seem needed or desirable. The most troublesome spots in regard to drying would appear to be those containing the highest percentage of fines, i.e., those areas most remote from the dredged material outlet pipe.

Use of the Moisture Content Prediction Equation in Estimating Drying Time and Cost per Unit Volume of Dredged Slurry

64. The costs associated with dewatering dredged material

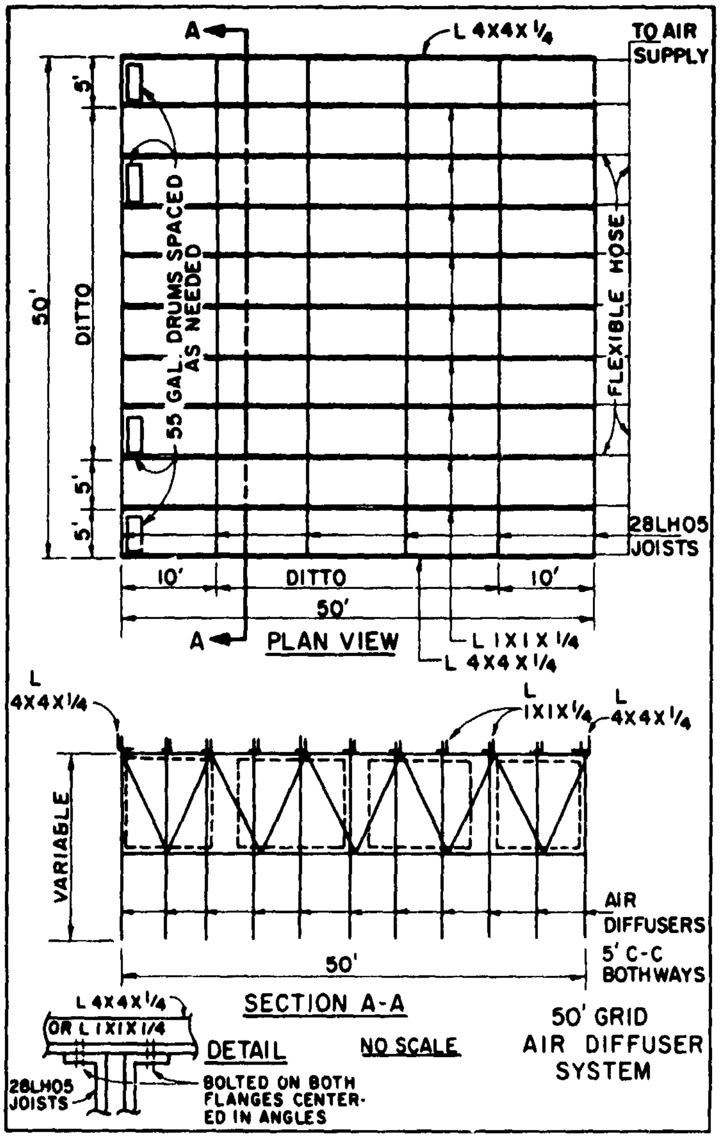

Figure 11. 50- x 50-ft air diffuser system

by aeration devices such as the one shown in Figure 11 were determined for a unit area of one acre. In making the cost analysis, initial moisture content was assumed to be 250 percent and the final moisture content 125 percent.

65. The prediction equation developed from the laboratory studies was used as the means for calculating the days required for achieving a moisture content of 125 percent. The prediction equation is repeated below:

$$\text{Percent } M = 10.9 - 5t - 0.043\, Q_{\mu} + M_i + 6.8\, H_i \qquad (2)$$

t = Time, days

Q_{μ} = Unit airflow rate, $cm^3/min/\ell$

M_i = Initial moisture content, percent

H_i = Initial slurry depth, ft

The required aeration time for various unit airflow rates and depths are shown in Table 3.

66. The total airflow rates required for aerating one acre are shown in Table 4. These were calculated in the following manner:

$$\text{Total airflow rate } (ft^3/min) = 0.1\ \frac{ft^3/min}{ft^3} \times 43{,}560\ \frac{ft^2}{acre} \times \text{depth}$$

67. The costs associated with dewatering one acre of fine-grained dredged material include the capital costs of the aeration grid and the air compressor plus the operating costs for power and labor. The capital cost for the 50- x 50-ft aeration grid would be:

7,000 lb steel @ $0.25 per lb	=	$1,750
Cost of air lines, hoses, etc.	=	3,250
Fabrication cost	=	1,250
Total		$6,250

Table 3

Required Aeration Time*

Unit Airflow Rate		Slurry Depth	Number of Days
cm^3/min/ℓ	ft^3/min/ft^3	ft	
100	0.1	0.25	22
		0.5	23
		1.0	23
		2.0	25
		4.0	27
		6.0	30
		8.0	33
		10.0	36
300	0.3	0.25	21
		0.5	21
		1.0	22
		2.0	23
		4.0	26
		6.0	28
		8.0	31
		10.0	34
500	0.5	0.25	19
		0.5	19
		1.0	20
		2.0	21
		4.0	24
		6.0	27
		8.0	29
		10.0	32
700	0.7	0.25	17
		0.5	17
		1.0	18
		2.0	20
		4.0	22
		6.0	25
		8.0	28
		10.0	30

*From initial moisture content of 250% to final moisture content of 125%

Table 4

Required Total Airflow Rates for Aerating One Acre at Standard Conditions

Unit Airflow Rate		Slurry Depth	Total Airflow Rate
$cm^3/min/\ell$	$ft^3/min/ft^3$	ft	ft^3/min
100	0.1	0.25	1,000
		0.5	2,000
		1.0	4,000
		2.0	9,000
		4.0	18,000
		6.0	26,000
		8.0	35,000
		10.0	44,000
300	0.3	0.25	3,000
		0.5	7,000
		1.0	13,000
		2.0	26,000
		4.0	53,000
		6.0	79,000
		8.0	105,000
		10.0	130,000
500	0.5	0.25	5,000
		0.5	11,000
		1.0	22,000
		2.0	44,000
		4.0	87,000
		6.0	131,000
		8.0	175,000
		10.0	218,000
700	0.7	0.25	8,000
		0.5	15,000
		1.0	30,000
		2.0	61.000
		4.0	122,000
		6.0	183,000
		8.0	245,000
		10.0	305,000

Sixteen of these grids would be required for aerating one acre and the cost would be 16 x \$6,250 = \$100,000.

68. The capital cost of the air compressors would be approximately \$20 per ft^3/min capacity. This cost figure was determined by contacting several manufacturers of air compressors. There appears to be no economy due to scale factor.

69. The power costs would be a function of the horsepower of the compressors and the number of aeration days required to lower the moisture content from 250 percent to 125 percent.

70. The required brake horsepower was calculated using the following equation:

$$bhp = \frac{wRT}{550nE}\left[\left(\frac{P_2}{P_1}\right)^n - 1\right] \qquad (3)$$

where: w = weight flow of air, lb/sec

$$\left(ft^3/min \times \frac{1}{60\ sec/min} \times 0.075\ \frac{lbs}{ft^3}\right)$$

R = Gas constant (53.5)

T = Absolute inlet temperature, ^oR

P_1 = Absolute inlet pressure, psia

P_2 = Absolute outlet presure, psia

n = A constant equal to 0.283 for air

E = Efficiency (use 70 percent)

71. The brake horsepower was calculated for standard conditions; therefore, P_2 = 14.7 psia, P_1 = 14.7 + 15 = 29.7 psia, and T= 460 + 68 = 528^oR. The required brake horsepower for various unit airflow rates and depths of dredged material is shown in Table 5.

Table 5

Required Brake Horsepower

Unit Airflow Rate		Slurry Depth	Brake Horsepower
$cm^3/min/\ell$	$ft^3/min/ft^3$	ft	
100	0.1	0.25	70
		0.5	140
		1.0	280
		2.0	630
		4.0	1,200
		6.0	1,800
		8.0	2,500
		10.0	3,100
300	0.3	0.25	210
		0.5	490
		1.0	900
		2.0	1,800
		4.0	3,600
		6.0	5,500
		8.0	7,300
		10.0	9,100
500	0.5	0.25	350
		0.5	770
		1.0	1,500
		2.0	3,100
		4.0	6,100
		6.0	9,200
		8.0	12,200
		10.0	15,300
700	0.7	0.25	560
		0.5	1,100
		1.0	2,100
		2.0	4,300
		4.0	8.600
		6.0	13,000
		8.0	17,100
		10.0	21,400

72. An example calculation of the capital and operating costs is given below:

Unit airflow rate = 0.1 $ft^3/min/ft^3$

Depth of dredged material = 6.0 ft

The total airflow rate for dewatering one acre (from Table 4) = 26,000 ft^3/min

Cost of Compressor = \$20 x 26,000 = \$520,000

Aeration grid = 100,000

Total Capital Costs \$620,000

73. The capital costs are amortized using an interest rate of 6-1/8 percent and a useful life of 20 years with no salvage value at the end of the 20 years. Thus the amortized cost would be:

0.0003747 x Capital Cost x days of operation, i.e.,

0.0003747 x 620,000 x 30 = \$6,900

74. The power costs were calculated as follows:

$$\text{Power Costs} = \text{hp} \times \text{hours of operation} \times 0.7457 \frac{\text{kw}}{\text{hp}} \times \$0.01/_{\text{kw-hr}}$$

$$= 1800 \times 30 \times 24 \times 0.7457 \times 0.01 = \$9{,}700$$

75. The labor costs were based upon an 8-hour working day at \$10 per hour. Thus the labor costs would be: 8 x 30 x \$10 = \$2,400.

76. The total cost for dewatering one acre of dredged material six feet deep from an initial moisture content of 250 percent to a final moisture content of 125 percent would be:

Amortized capital costs = \$6,900

Power Costs = 9,700

Labor Costs = 2,400

Total Costs \$19,000

77. The cost per acre-ft would be $3,200. The dewatering costs versus dewatering time for various unit airflow rates are shown in Figure 12. Figure 13 shows a grid arrangement which also considers the depth of dredged material to be dewatered.

78. Table 6 shows the unit costs per cubic yard of space created for various unit airflow rates. In determining the space occupied by the dredged material a specific gravity of 2.1 was used. This value was determined experimentally and is representative of values generally reported for dredged materials. The cost per cubic yard of space created was calculated as follows:

$$\text{Cost per yd}^3 \text{ space created} = \frac{\text{Total cost of drying}}{\text{Original Volume} - \text{Final Volume}}$$

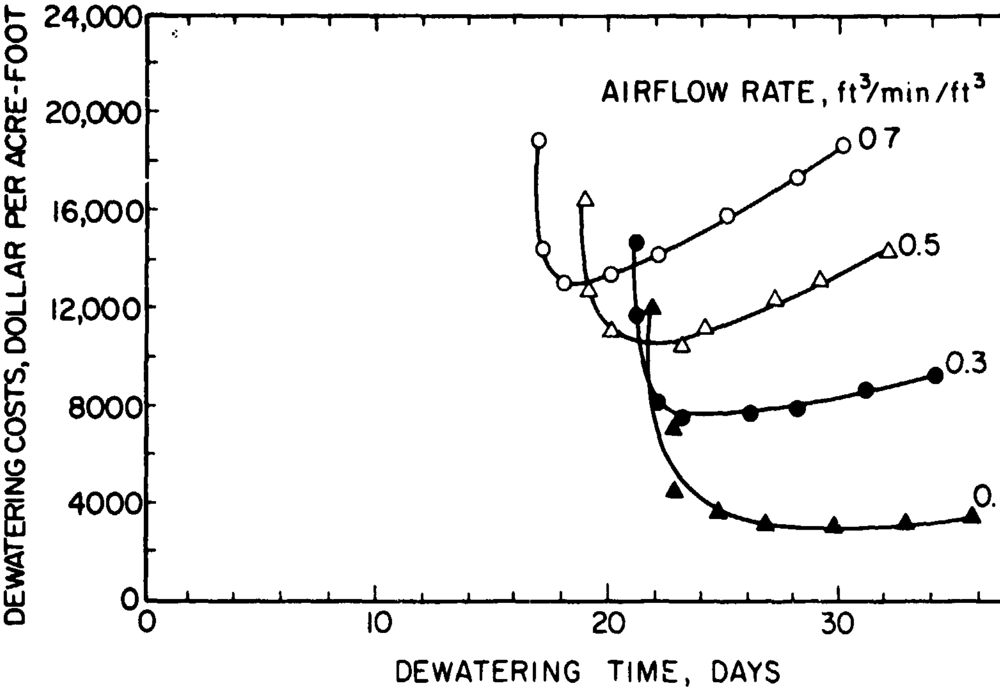

Figure 12. Dewatering costs per unit airflow rate

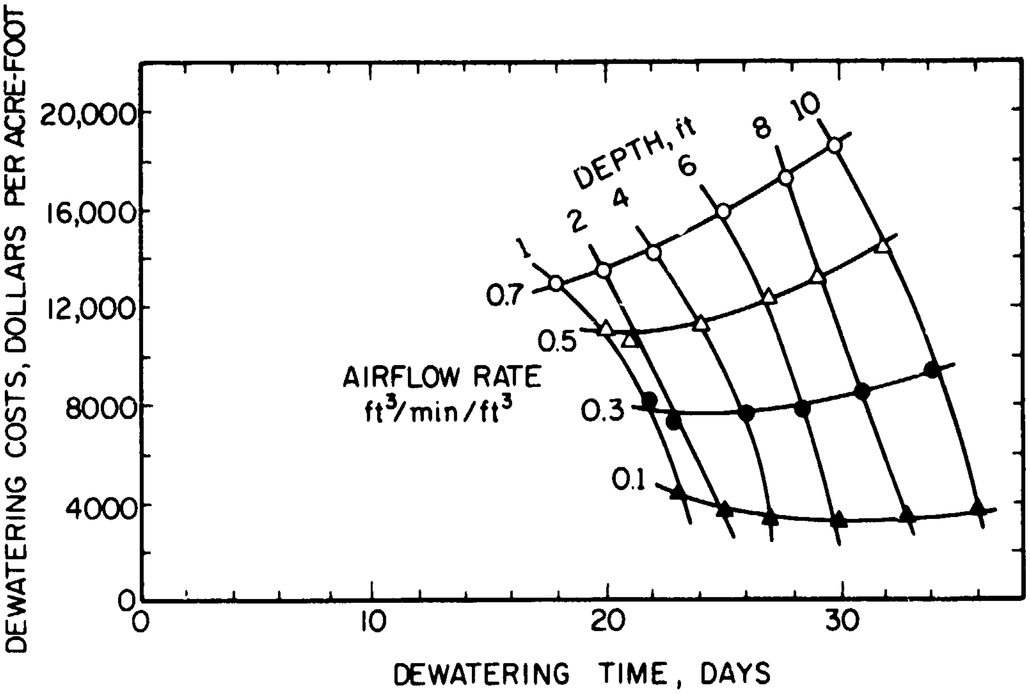

Figure 13. Dewatering costs per unit airflow rate and depth

Table 6

Unit Costs per yd^3 Space Created

Unit Air-flow Rate $ft^3/min/ft^3$	Slurry Depth ft.	Initial Volume yd^3	Final Volume yd^3	Volume Created yd^3	Cost per yd^3 Space Created, $
0.1	0.25	403	199	204	14.70
	0.50	807	398	409	8.80
	1.0	1,613	795	818	5.50
	2.0	3,227	1,591	1,636	4.52
	4.0	6,453	3,181	3,272	3.85
	6.0	9,680	4,772	4,908	3.87
	8.0	12,907	6,363	6,544	4.17
	10.0	16,133	7,954	8,179	4.41
0.3	0.25	403	199	204	18.14
	0.50	807	398	409	14.43
	1.0	1,613	795	818	10.02
	2.0	3,227	1,591	1,636	8.86
	4.0	6,453	3,181	3,272	9.23
	6.0	9,680	4,772	4,908	9.66
	8.0	12,907	6,363	6,544	10.47
	10.0	16,133	7,954	8,179	11.31
0.5	0.25	403	199	204	20.10
	0.50	807	398	409	15.40
	1.0	1,613	795	818	13.45
	2.0	3,227	1,591	1,636	12.84
	4.0	6,453	3,181	3,272	13.63
	6.0	9,680	4,772	4,908	15.12
	8.0	12,907	6,363	6,544	16.00
	10.0	16,133	7,954	8,179	17.56
0.7	0.25	403	199	204	23.04
	0.50	807	398	409	17.60
	1.0	1,613	795	818	15.77
	2.0	3,227	1,591	1,636	16.44
	4.0	6,453	3,181	3,272	17.30
	6.0	9,680	4,772	4,908	19.44
	8.0	12,907	6,363	6,544	21.44
	10.0	16,133	7,954	8,179	22.85

RECOMMENDATIONS

79. It is recommended that aeration be tried at a field site. Because aeration is rather expensive and because demonstration does not depend upon full-scale tryout, it is recommended that aeration grids of the size 20 x 20 ft be constructed for use in field tests (see Figure 14). Also it is emphasized that the present study was designed to examine the feasibility of the process; the results indicate it is potentially feasible. There is need now to obtain design data for use in making final decisions regarding methodologies for site dewatering and in making design and operational recommendations to Corps of Engineer Districts. Thus it would be best to make field tests with smaller, more flexible equipment. Some suggestions for a field testing program are outlined below.

80. The Upper Polecat Bay disposal site in the Mobile District seems an ideal location for field tests. Considerable data have already been collected at this site. In addition, it is fairly close to Vicksburg, which facilitates monitoring the work by WES personnel. Three experimental slurry pits could be constructed within the disposal site. These could be used to examine drying rates at various initial moisture contents and with several diffuser grid spacings. Drying rates at various depths of slurry could also be examined. In this way much field test data suitable for purposes of demonstration as well as

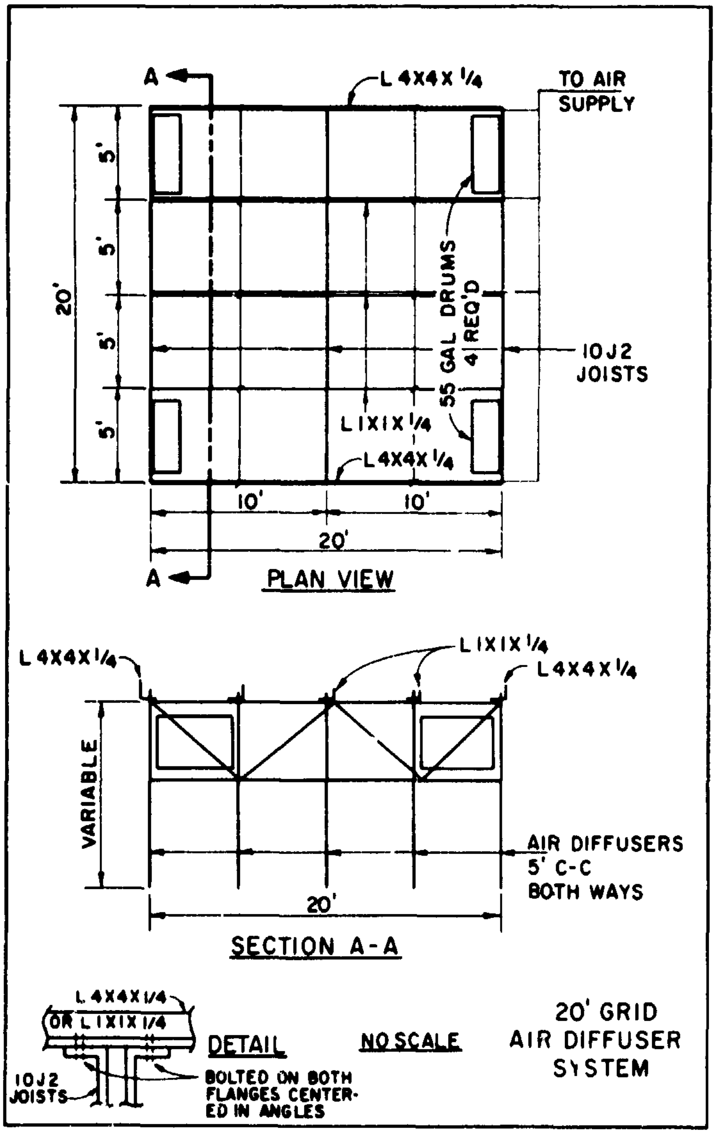

Figure 14. 20- x 20-ft air diffuser system

obtaining design criteria could be amassed in a relatively short time. The time required to conduct each experiment would be approximately one month (M_i = 250%, M_f = 125%). Table 7 shows aeration requirements for experiments at various depths of dredged material using the 20 x 20 ft. aeration grid. Table 8 provides a guide to estimating costs for running such field tests. This table is based on use of 0.1 $ft^3/min/ft^3$ (100 $cm^3/min/\ell$) and initial and final moisture contents of 250 and 125 percent. Not considered in this estimate are costs for constructing and maintaining the slurry pits and cost of sampling and making chemical analyses, etc. In all probability sufficient design criteria could be obtained by operating the slurry pits for a period of six months or less.

Table 7

Aeration Requirements of 20- x 20-ft Unit*

Slurry Depth ft.	Aeration Time Days	Total Airflow ft^3/min	Brake Horsepower
4	27	160	11
6	30	240	17
8	33	320	23

* Requirements based on use of aeration grid under the following conditions:

unit airflow rate = 0.1 $ft^3/min/ft^3$ (100 $cm^3/min/\ell$)

initial moisture = 250%

final moisture = 125%

Table 8

Cost Estimate for Field Testing Program
Using the 20- x 20-ft Aeration Grid*

Slurry Depth ft.	Capital Costs, $		Operating Costs,$	
	Compressor	Aeration Grid	Power**	Labor†
4	3,200	1,000	50	2,000
6	4,800	1,000	90	2,400
8	6,400	1,000	140	2,600

---

*Estimate based on use of aeration grid with unit airflow rate of 0.1 $ft^3/min/ft^3$ (100 $cm^3/min/\ell$).

**Power Costs = hp x hours of operation at 0.7457 $\frac{kw}{hp}$ x \$0.01/kwhr.

†Labor @ 8 hours per day, \$10 per hour.

CONCLUSIONS

81. It is apparent from the results of the study that diffused aeration of fine-grained dredged material slurries can hasten moisture loss. It is also seen from the cost analysis that use of aeration in the field will entail significant expense. The optimal depth of slurry is seen to be (Table 7) in the range of 4 to 6 feet at a unit airflow rate of 0.1 $ft^3/min/ft^3$. At these depths the cost is slightly under \$4 per yd^3 of space created. Although this cost seems rather high, aeration dewatering and subsequent additional volume gained at the site may be an economically feasible alternative to purchase or lease of new land.

82. Through the conduct of this investigation,it is concluded that aeration can form a useful portion of an overall dredge site management strategy. Aeration should not be applied to all dredged material disposal sites nor should it be applied over an entire disposal area. For this reason the cost analysis was made assuming the use of a custom-made portable grid. The aeration devices are envisioned as items of movable equipment which can be stationed at particular areas containing the highest fraction of fine-grained material. Also, aeration is most applicable in that range of moisture content from approximately 250 to 125 percent. Surface draining can be better employed at moisture contents greater than 250 percent and air piping or chimneys develop at moisture contents of approximately 125 percent. Also at the lower moisture content, the material behaves more like soil than slurry and is more amenable to working by conventional earthmoving equipment.

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APPENDIX A : NOTATION

BOD_5	Biochemical oxygen demand exerted in the standard 5-day period of incubation.
BOD_{5s}	Five-day BOD due to soluble organic materials in the sample
BOD_{5t}	Five-day BOD due to total organic (soluble and particulate) materials in the samples.
COD	Chemical oxygen demand
COD_s	Soluble COD
COD_t	Total COD
E	Efficiency
e	Evaporation ratio
H_i	Initial slurry depth, ft
M_f	Final moisture content, percent
M_i	Initial moisture content, percent
n	A constant used in equation 3. $n = 0.283$ for air
P_1	Absolute inlet pressure, psia
P_2	Absolute outlet pressure, psia
Q	Airflow rate, cm^3/min
Q_μ	Unit airflow rate, $cm^3/min/l$
R	Gas constant (53.5)
T	Absolute inlet temperature, ^{o}R
t	Time, days
W	Weight flow of air

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Environmental Engineering Consultants, Inc.
Laboratory study of aeration as a feasible technique for dewatering fine-grained dredged material, by Environmental Engineering Consultants, Inc., Stillwater, Okla. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.
71 p. illus. 27 cm. (U. S. Waterways Experiment Station. Contract report D-76-10)
Prepared for Environmental Effects Laboratory, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., under Contract No. DACW39-75-C-0123 (DMRP Work Unit No. 5A05).
Literature cited: p. 69-70.

1. Aeration. 2. Dewatering. 3. Dredged material. 4. Laboratory tests. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Contract report D-76-10)
TA7.W34c no.D-76-10