SLUDGE PRODUCTION AND DISPOSAL FOR SMALL COLD CLIMATE BIO-TREATMENT PLANTS

COMPLETION REPORT

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by

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INTRODUCTION

Ultimate disposal of wastewater sludge has long been a problem which to a large degree has been ignored. Haney (1971) stated that: "Until process sludge can be handled with minimum environmental impact, we cannot claim to have a viable wastewater treatment process". The relationship of sludge disposal to total treatment processes is emphasized by the fact that sludge handling and disposal represents up to 50 percent of the total treatment capital and operating costs (Burd, 1968). Processing of wastewater sludge will, no doubt, receive increased attention in the future because of environmental concerns for our air, land and water.

The present technology for processing wastewater treatment plant sludge is well established and includes conditioning, dewatering, and disposal. Many of these processes are highly sophisticated and relatively expensive. Most of the more advanced processes are unsuitable for small wastewater treatment facilities in Alaska.

The extended aeration modification of activated sludge has been widely used as a small-unit, biological waste treatment process. Although several types of waste treatment processes have been constructed and operated with varying degrees of success in the remote regions of Alaska, the extended aeration modification appears to be one of the most promising systems available. Nonetheless, extended aeration, as with most biological waste treatment processes, produces more activated sludge than can be autooxidized within the aeration chamber. This excess activated sludge is an inherent characteristic of the process which is well documented in the literature (Grube and Murphy, 1969; McKinney, 1965; Stewart, 1964). Excess sludge from extended aeration activated sludge is, in many instances, intentionally discharged with the plant effluent. Even though the material is well oxidized, it can be detrimental to the receiving stream, particularly during the winter months when many of Alaska's streams have relatively little flow. It is anticipated that regulatory agencies will prohibit such disposal practices in the future.

Many solutions to the sludge disposal problem have been developed, but most are either uneconomical for the small installations or are unfeasible for the severe climatalogical conditions inherent to Alaska. The presently used processes of vacuum filtration, incineration, and centrifugation are satisfactory but too expensive for the small plants found in Alaska, which are generally in the 500-5000 population equivalent range.

One solution to waste sludge disposal which appears feasible for small installations in Alaska consists of a combination of conventional sand drying beds and the freeze-thaw technique. Research on the freezing and thawing of sewage sludge has shown that this technique yields sludge having good dewatering characteristics (Burd, 1968). This fact, coupled with Alaska's natural refrigeration, suggests the potential for use of the process in cold regions.

OBJECTIVE

The objective of this study was to evaluate a sludge disposal process consisting of modified sand drying beds in combination with the freeze-thaw technique utilizing natural refrigeration. Special consideration was given to designating a process that was simple to operate and easy to maintain. The purpose of freeze-thawing sewage sludge is principally to condition the sludge so that it is readily dewaterable and therefore yields a reduced volume of solids to be further processed. The mechanism of the freeze-thaw cycle is not fully understood, as is evidenced by the various theories proposed in the literature. These theories propose concepts including: 1) cell wall rupture on freezing followed by dewatering; 2) coagulation, dehydration, and dewatering; and 3) destabilization of colloidal dispersions (Garinger, 1971).

Research on the freezing of sewage sludge dates back as early as 1929 (Babbitt and Schlenz, 1929). More recent studies indicate that artificial freezing and thawing of sewage sludge cannot economically compete with the more established methods currently available for sludge conditioning (Burd, 1968). Some investigators have suggested the use of natural freezing as a sludge conditioning process; however, it has been rarely used. Alaska, having an abundance of natural refrigeration, is an ideal location for evaluating this mode of sludge conditioning.

LITERATURE REVIEW

The technology pertaining to the removal of suspended and colloidal material from wastewater is well established. This solid material is usually removed by utilizing the physical process of settling in conjunction with chemical or biological flocculation. Removals of greater than 90 percent of the suspended material via conventional secondary treatment are considered routine. The separation of the solids from the wastewater yields two products in a sewage treatment plant; namely, the liquid effluent which is usually discharged to a water-course and a slurry of solids, or sludge, which normally must be subjected to further treatment prior to ultimate disposal.

Since sludge production is associated with even the rudimentary forms of sewage treatment, the technology pertaining to its handling is also well established; nonetheless, more attention has been focused on overall treatment efficiency than on sludge handling. Sludge conditioning, dewatering, and ultimate disposal have been achieved using one of, or a combination of, the following unit processes (Burd, 1968):

thickening
blending
anaerobic digestion
elutriation
lagooning-landfilling
land disposal of liquid sludge
pipeline transportation
ocean disposal-dilution
underground disposal
composting
soil conditioning
incineration
air drying
heat drying
vacuum filtration

A totally satisfactory method of sludge treatment and disposal has not been developed for small subarctic biological treatment plants, although sludge production from such plants has been reported to be prolific (Clark *et al.*, 1970a; 1970b). The conventional methods are often overly sophisticated, requiring skilled operations, or are uneconomical for small sewage treatment plants. Several investigators (Benn and Doe, 1969; APHA, 1966; Farrell *et al.*, 1970; Bishop and Fulton, 1968) have reported excellent inprovements in water treatment plant sludge dewatering performance after the sludge had been subjected to freezing and thawing. The rejection of dissolved organic and inorganic material by freezing has been used as a method of water treatment (Bardulin *et al.*, 1963; FWPCA, 1968; USPHS, 1965; Applied Science Laboratories, 1971; Baker, 1967). The freezing of sewage sludge has been tried experimentally by several workers (Babbitt and Schlenz, 1929; Katz and Mason, 1970; Noda *et al.*; Clements *et al.*, 1950; Coackley, 1955). Two prototype installations (Bishop and Fulton, 1968; Fulton, 1970) are using natural refrigeration to freeze and condition water treatment plant sludge. All investigators have given positive indication that the freeze conditioning of sludge, both inorganic and organic, is feasible. However, when artificial means of freezing must be used, the economics of the freezing process are poor (Burd, 1968; Balakrishnan *et al.*, 1970).

Subarctic Alaska has an abundance of natural refrigeration. The mean annual temperature is 26F, and there are 160 days of the year when the maximum temperature is less than 32F (Osterkamp, 1971). Subarctic Alaska is experiencing an increase in population, and there is evidence that sewage treatment facilities will continue to be installed and upgraded in more and more communities. Since the minimum acceptable sewage treatment generally allowable by state law is secondary treatment, it is reasonable to forecast that ever increasing volumes of sludge will be produced.

There is little argument in the literature as to whether freezing is effective in conditioning sludge prior to dewatering. Remarkable improvements in dewatering rates have been exhibited for both water treatment sludge, which is primarily inorganic in nature, and sewage sludge, which is primarily organic. However, the mechanism of enhanced dewatering after a freeze-thaw cycle is not unanimously agreed upon. Some authors take only a fleeting look at the mechanism and accept it lightly while others delve into the theory more deeply. A significant portion of the literature pertains to a distinct facet of freeze-thaw treatment, that is, the purification of water using this mechanism. It is important to note the fundamental distinction between freeze-thaw treatment of sewage sludge and the treatment of water. The freeze-thaw process is applied to sludge so that it will dewater more readily, thus reducing the volume of solids to be handled further. The freeze thaw process has been applied to water to concentrate dissolved impurities in a liquid fraction; this is effected as pure ice crystals grow.

Water Purification by Freeze-Thaw

A brief study of the mechanism of water purification by freeze-thaw is presented so as to facilitate understanding of the mechanisms involved in the freezing of sludge.

The freezing and gas hydrate processes for demineralizing sea water were adapted in a preliminary design to renovate municipal waste waters in a project supervised by the U. S. Public Health Service (Bardulin *et al.*, 1963). Continuous reuse of water necessitates the removal of dissolved solids since a single use by a municipality adds approximately 300 mg/1 total dissolved solids. The freezing-hydrate process is designed to remove pure water from its aqueous solution. To achieve good results, practically all suspended matter must be removed before freezing. Subsequent to freezing, a small number of large crystals are washed. It was found that COD could be reduced by a factor of 3-7 and chlorides by a factor of 7-10 by this process. The process essentially involves partial freezing and draining followed by washing and melting the ice crystals. The majority of the impurities are concentrated in the mother liquor; therefore, purification depends on how much of the mother liquor can be removed. The process has a high cost but wastewater renovation by this method was found to be more economical than saline water conversion by conventional methods.

The follow-up report by FWPCA (1968) also discusses the removal of inorganic material from effluents by the freezing method. The process is similar to that discussed above. The feed water is cooled and slowly frozen; the ice is separated from the unfrozen brine, washed with clean water, and melted to produce purified water. Although the process is considered to be one of demineralization, it is also capable of removing organic materials from water. However, washing the organics from the ice crystals proved to be difficult in a pilot plant operation. It was found that freezing could not compete economically with carbon adsorption and electrodialysis. Carbon adsorption and electrodialysis were reported to cost 25-35 cents per thousand gallons while the freezing process cost 48 cents per thousand gallons of wastewater treated. Demineralizing sea water by the freezing process was reported to cost 53 cents per thousand gallons.

A summary report by USPHS (1965) stated that 85 percent of organic contaminants and 90 percent of inorganic contaminants can be removed from wastewater effluent by the freezing process.

A study conducted by R. A. Baker (1967) used partial freezing of aqueous-organic solutions to achieve removal of trace organic contaminants. Single stage and double stage concentration, using acetophenone, volatile fatty acids and phenols as contaminants, were effected. Baker experienced difficulty measuring trace organic substances not readily measured by the most sensitive of presently available analytical devices.

Applied Science Laboratories (1971) conducted a study pertaining to purification of mine water by freezing. By partial freezing, to the extent of about 50 percent conversion to ice, they managed a reduction of various metal and acid components in the product water of 85 to 90 percent, generally. It was also found in this study that suspended solids or colloidal particles must be removed before partial freezing because they are likely to contaminate the ice by being trapped within it. When a pure ice crystal forms from a solution, the impurities that were dissolved in the water, which formed the ice crystal, are left behind in the solution surrounding the ice crystal. Consequently, each ice crystal just after the moment of its formation is surrounded by a solution that is more concentrated than the original solution. The next ice crystal is thus more likely to be contaminated than the previously formed ice. In general, all dissolved metal salt impurities remain in the mother liquor when any kind of water is partially frozen but organic impurities vary in their behavior, as do acids. The authors reported that a low rate of freezing would be expected to favor a high percentage reduction of impurities in natural ice if outdoor freezing were utilized. The authors were noncommittal in forecasting whether the method would be feasible for removal of organic material from sewage or wastewater solutions.

Wagner (1971) carried out a series of experiments to evaluate the feasibility of using the freezing process as a method of concentration and treatment of raw domestic sewage. The results of single-stage batch freezing indicated that, although it was possible to concentrate the waste, the recovery efficiencies were not high enough to warrant further study at that time.

Water Treatment Plant Sludge Dewatering

Complete water treatment plants, utilizing the unit processes of coagulation, sedimentation and filtration, often produce large amounts of sludge and wastewater. The sludge emanates from the sedimentation tanks where coagulated material, with enmeshed suspended solids and turbidity from the raw water, settle out. The nature of the sludge will depend upon the composition of the raw water, the treatment process used, and the type of coagulant used. Very frequently the coagulant is aluminum sulfate [$Al_2(SO_4)_3$] or alum. In this case, a large part of the sludge will be gelatinous aluminum hydroxide [$Al(OH)_3$] with the entrapped turbidity and suspended solids. If the water treatment plant is removing hardness by chemical precipitation with lime and soda ash, the sludge would be chiefly calcium carbonate [$CaCO_3$] and magnesium hydroxide [$Mg(OH)_2$]. In brief, the sludge produced by a complete water treatment plant is largely inorganic, which is usually in the form of a salt or a hydroxide. Wastewater and some sludge will result from backwashing the filters. Traditionally, the wastewater and sludge were discharged to the nearest water course with little effort given to treatment. With recent environmental concern being at the forefront and with increasing volumes of water treatment plant sludge being produced yearly, a move is afoot to handle this sludge in a less environmentally damaging fashion. Little can be done on an economical basis to recover the inorganic salts from the sludge; the attention has been focused on reducing the volume of sludge to be handled for ultimate disposal. One method that has been used to condition the sludge in preparation for dewatering is freezing and thawing.

Bishop and Fulton (1968) have suggested lagooning and freezing for the disposal of water plant sludge. The lagoons would be used as both settling and thickening facilities. They suggest that two lagoons be used, each with a large enough surface area that the depth of sludge poured thereon during the summer could be completely frozen during the following winter. During transition periods one lagoon would be used exclusively as a freezing facility while the other lagoon would receive fresh sludge. Fall decanting of supernatant would reduce the volume of sludge to be frozen during the winter. The authors predict that sludge could be accumulated over several seasons and the bearing strength would be sufficient to have the sludge removed with a front-end loader. Although cost figures were not presented, it was suggested that the cost would be very little in comparison to the cost of an overall filtration plant, providing land is available. This technique is feasible economically only if natural freezing can be utilized. The authors contend that it is the water of hydration, contained in the aluminum hydroxide holding the enmeshed turbidity particles, that is released by freezing. The total solids concentration of the sludge was increased from 3.5 to 17.5 percent and a significant volume reduction occurred after one freeze-thaw cycle. When the sludge thawed it did not return to its original gelatinous state; the sludge drained and dried to a consistency that could be easily handled. The freezing rate was not mentioned and was probably not considered to be an important factor since such good results were obtained even while ignoring it.

Fulton (1970) describes a New York community water treatment plant which is presently using the freeze-thaw method of sludge conditioning. Rather than constructing lagoons, this design simply used an existing headrace of an adjacent abandoned power plant. The headrace was divided into two sections in order that freezing could be effected during the autumn transition period. Consolidated solids would also be pumped from one basin to the other for freezing in the winter time. Freezing will be effected in layers as dictated by volumes withdrawn from the first to the second basin. Again, it is stated that freezing changes the jelly-like consistency of aluminum hydroxide suspension to a readily settleable granular form. The theory of dewatering and freezing rate was not discussed in this paper.

Benn and Doe (1969) used artificial freezing in an attempt to reduce the quantity of sludge to be handled from coagulation and backwashing procedures at a complete water treatment plant in England. Although good results were achieved, the authors concluded that the process was uneconomical and would always be so unless larger volumes of sludge could be frozen artificially. Further, they stated that flash freezing will not produce the same effect as slow freezing. Repeated stresses on the freezing tank necessitated heavy construction, which caused high capital cost, and periodic replacement of components, which resulted in significant operating cost. With the freezing apparatus used, the authors stated that pure ice crystals began to grow on the sides of the freezing vessel and grew toward the center. The sludge is forced toward the center and is eventually trapped between coalescing ice crystals. Ultimately, the sludge is either dehydrated or enmeshed in the ice. The resulting pressure reportedly compresses the sludge into fine, hard grains. During thawing, the grains of sludge fall through the supernatant to the bottom of the container. The authors report that the only limitation on the process is that freezing proceed slowly enough to allow pure ice crystals to form. When the sludge has been frozen and separated, it will not revert to its original form. A change in state from gelatinous sludge to a texture resembling coffee grains was reported; the resultant material has good bearing strength. This is an important consideration if ultimate disposal is to be to a landfill.

Sewage Sludge Dewatering

Sewage sludge dewatering has long been a problem confronted by sanitary engineers. It has been found that dewatering has often been enhanced by using a conditioning process before the actual dewatering step. The more common conditioning processes are heat addition, coagulant addition, elutriation and thickening (Burd, 1968; Andrews, 1967). Over the past twenty years, some interest has been shown in freeze-thaw sewage sludge conditioning although the beneficial effects of freezing sludge were exhibited as early as 1929 (Babbitt and Schlenz, 1929). It is generally conceded that artificial freezing cannot compete economically with more established methods of sludge dewatering such as polymer addition followed by vacuum filtration. Although many investigators have suggested that natural freezing would be a feasible sludge conditioning process, it is rarely used. In fact, the literature surveyed turned up only one installation (Bubbis, 1962) where sludge is frozen on a routine basis. Even at this location freezing occurs only incidentally and is not an integral part of the dewatering process.

Babbitt and Schlenz (1929) reported on the effect of freezing on the drying of sludge. The experiment happened quite by accident when samples of fairly well digested sludge were placed on two sets of drying beds and the outside temperature turned cold. Upon thawing, the beds dried without releasing any considerable amount of free water. The final dried sludge was found to have a dry spongy appearance, little cohesion, was easily pulverized, had no odor, and separated easily from the sand on the bed. The authors found that freezing alters the draining qualities of sludge and allows the entrained water to separate very quickly during thawing. The final moisture content was much lower in the sludge that had been frozen than sludge which was dried without freezing. From microscopic examinations it was theorized that the effect of freezing was to overcome the attraction of the colloidal particles for water and to permit this water to drain rapidly upon thawing. In conclusion, the authors stated that it was not only feasible but advantageous to draw sludge onto the drying beds in cold weather.

In the late 1940's Clements, Stephenson, and Regan (1950) did extensive experimentation with the freezing of primary, digested, and activated sludge. They also experimented with the addition of chemicals prior to freezing in order to investigate their effect on subsequent sludge dewatering. All freezing was done by artificial means. Their conclusions are summarized as follows:

1. The settlement of all types of sewage sludge is promoted by freezing.
2. Settlement is accelerated by freezing with chemicals, but the percentage settlement at the end of an hour is approximately the same whether chemicals are used or not.
3. Filtration after freezing with chemicals is remarkably accelerated.
4. The chemicals used were chlorinated ferrous sulfate, chlorine gas, and aluminum sulfate, and doses were up to 1,000 mg/l of the active ion.
5. The best results were obtained by the use of aluminum sulfate, dry solids production reaching 350 lbs/ft/hr.
6. Complete freezing is essential: freezing must be fairly slow; "flash" freezing is ineffective.
7. Some saving of latent heat of fusion is practicable in a suitable installation.
8. The method of thawing is immaterial, so long as it is not associated with vigorous agitation.
9. The supernatant liquids on settlement are, on an oxygen absorption basis, not much worse than ordinary sewage.

The authors theorized that, in freezing, water is separated from colloidal matter and an ice network is formed, in the centers of the meshes of which are colloidal particles. If these particles are not readily dispersible in water, as is sludge, a system is formed on thawing which is irreversible. Slow freezing is more effective than fast freezing because it leads to a relatively small number of crystallization centers with comparatively large ice crystals. Fast freezing produces a much larger number of crystallization centers, leading to the formation of a glass composed of microscopic crystals. Adding chemicals was said to cause a continually increasing concentration of electrolyte in the interstitial liquor surrounding the colloidal sludge particles, as water is abstracted to ice crystals. Because the colloids are negatively charged, the strongly electropositive charges on the electrolyte would neutralize these colloids and irreversible precipitation would occur. A dehydration effect was also attributed to pressure produced during slow freezing.

Bruce, Clements, and Stephenson (1953) have described further work on the sludge freezing process. Sludge was artificially frozen in cans lowered into brine tanks. Upon thawing, dewatering was effected on various filter media. Elutriation was tried and yielded negative results.

Dewatering was also attempted in a centrifuge; the results in concentrating sludge were not encouraging. It was also found that the digestion of activated sludge did not improve its response to freezing with chemicals. Some tests were conducted on the availability of nitrogen in sludges; low values were found and it was suggested that the slow-acting nature of a substantial part of the nitrogen in sewage sludge may account for its unpopularity as a nitrogenous fertilizer. Presumably the conversion of ammonia to nitrates is slow. A loss in nitrogen was experienced through sludge digestion.

Coackley commenced research on the dewatering of sewage sludges at University College, London in 1950. His initial program was to study the effect of ultrasonic vibrations, freezing, and the action of direct current on the dewatering of sludge (Coackley, 1955). After Clements, Stephenson, and Regan published their paper, work on the freezing process at University College was stopped. The results obtained prior to curtailment of the program were in agreement with those published by Clements *et al.*, 1950. Coackley studied the freezing process microscopically, and his observations showed that the ice crystals pushed the sludge particles together, making larger aggregates. No evidence was found for the theory that cells were burst open, liberating water.

In 1962, Bubbis published a paper regarding the operation of sludge drying lagoons at Winnipeg, Canada (Bubbis, 1962). The normal procedure at these lagoons is to apply a 10-inch layer of digested sludge, allow it to stand for 14 days, and then decant the surface liquor. When the lagoon is filled, the sludge is removed with a heavy equipment scraper. Freezing was mentioned only incidentally in that lagooning is also used in the winter, when extremely cold temperatures occur. The author suggested that the sludge could be removed from the lagoons in the winter, using a ripping and scraping procedure.

Agardy and Kiado (1966) have discussed the effects of refrigerated storage on the characteristics of waste. The discussion included effects of simple cooling and freezing, which was done at -5C. They found that the colloidal character of a sample is altered by the freezing and thawing process, and coagulation occurs. They contend that the increase in suspended solids and volatile suspended solids as a result of freezing is a clear indication of the colloidal nature of many waste constituents.

Andrews (1967) has published a comprehensive treatise on sludge treatment and disposal in which he mentions that, in Winnipeg, frozen sludge is removed from beds and placed on concrete pads where it rapidly dewaters in spring. He suggests that the effect of freezing is to overcome the attraction of the colloidal particles for water and that this permits the water to drain rapidly upon thawing.

A study of sludge handling and disposal done by Burd (1968) stated that sludge frozen by nature and later thawed in sand drying beds or lagoons had good dewatering and soil-conditioning properties. He suggests that the thawed sludge is stable and dewaters rapidly if provisions are made for water drainage. Artificial freezing can aid in sludge dewatering; however, it will never be economical except in very isolated cases. Problems were reported to be encountered in high operating costs, partially because of the need for dewatering equipment to handle high production rates.

In 1970, the Federal Water Quality Administration also reported briefly on the freezing process for sludge conditioning (Balakrishnan *et al.*, 1970). It was stated that freezing disrupts the cell walls that retain the internal moisture in sludge and thereby allows the water to be released and drained. Slow and complete freezing was reported to be necessary for good dewatering results. It was also reported that 28 BTU were required to lower the temperature of one pound of sludge from 60F to 32F, and 142 BTU were then required to freeze this pound of sludge. Again, it was pointed out that artificial freezing would require greatly improved economics to be feasible in prototype installations.

An extract translated from Japanese (Noda *et al.*) considered freezing temperatures, freezing time, thawing cycles, and standing time after thawing. It was concluded in this brief article that in sludge freezing there exists an optimum product of freezing temperature and time.

Katz and Mason (1970) have used freezing methods to condition activated sludge prior to dewatering. Their results indicated that high solids production rates on the order of 55 lb of dry solids per square foot per hour were obtained during vacuum filtration of freeze-conditioned activated sludge. The filtrate and filter cake quality produced were equivalent or better than that produced from conventional vacuum filtration operation. It was also concluded that freeze-conditioned sludge can be dewatered by gravity drainage using wire screen cloth (40-80 mesh). The authors theorize that the conditioning effect produced by freezing is a result of dehydration and pressure exerted on the sludge particles by the ice structure. Further, they point out that the freezing rate is important because it affects the dehydrating and pressure-producing properties of the ice structure.

Cheng, Updegraff, and Ross (1970) experimented with freezing sludge via the film-freezing principle in which freezing time and the temperature driving force are greatly reduced over those used for the extended freezing process. They contend that the addition of at least 20 mg/l of aluminum [as $Al_2(SO_4)_3$] is necessary for efficient dewatering. The integral difference in using the film-freezing principle is that a very thin ice film is used; this thin ice film allows the rapid removal of heat, even at small temperature differences, because of a large thermal admittance. An external heat transfer mechanism, the cooling bath stirring rate, controls the process. Samples of primary, activated, and digested sludge were used in the experiment. After being frozen and thawed, the sludge was filtered and gave solids production results similar to those obtained by Clements *et al.* (1950). The authors felt that this method will improve the economics of artificial freeze-conditioning of sewage sludge.

As a cooperative effort with the project for which this report was written, Osterkamp performed experiments at the University of Alaska in the early spring of 1971. His attentions were focused directly on the structural features of wastewater sludge ice. He utilized ambient air temperatures, internally controlled by insulation and a heat tape, to effect one-dimensional freezing of thick activated sludge. The experiments showed that the ice structure was cellular in nature. The mechanism of improved dewatering after freezing was explained in three steps. First, the growth conditions of the ice and the presence of ionic impurities cause the formation of a cellular interface morphology. Secondly, the sludge particles and other impurities are mechanically trapped in the grooves between these cells, forming sludge pockets, which results in coagulation of the sludge particles. Thirdly, dehydration of the coagulated sludge particles occurs as the sludge pockets are subjected to lower temperature and the water in them freezes out. Reportedly, these processes are irreversible. Osterkamp (1971) reported that, when the ice matrix melts, the coagulated sludge particles settle rapidly and leave a relatively clear supernatant. He explains that the poor results with quick freezing are due to the failure of a cellular interface to develop. Dehydration is also retarded during a quick freeze. Supercooling is reported to be an exception to the failure of quick freeze methods on account of the ordering of the water molecules in the liquid phase. The author contends that coagulation is the primary process in the success of the sludge freezing technique, while dehydration is a secondary process.

Drainability

Nebiker, Sanders, and Adrian (1969) investigated sludge dewatering rates and reported that initial solids content, depth, specific resistance, coefficient of compressibility, and filtrate viscosity are the important parameters affecting the time required for dewatering.

Factors affecting drainability of activated sludge were discussed by Randall, Turpin, and King (1971). They suggest that there are two steps to dewatering:

1. Applied sludge settles and compacts on drying bed.
2. Drainage pores develop in the settled sludge layer.

There are several factors affecting drainability but solids concentration reportedly has the greatest effect. The authors state that in general the variation in sludges depends on how disperse the microbial solids are and that the effect of sludge property on drainability usually depends on how it affects dispersion. In conclusion, they suggest that none of the standard tests presently utilized are sensitive enough to measure dispersion.

Summary

Water and sewage effluent purification by the freeze-thaw method involves the rejection of dissolved materials, both organic and inorganic, by pure ice crystals growing in a mother liquor. The rejection phenomenon is relevant to the mechanism by which sludges are conditioned by freeze-thaw prior to dewatering. However, with sludges attention is focused on the suspended and colloidal material whose concentration is at least 10 times that of the dissolved material. Osterkamp (1971) alluded to the importance of a certain ionic strength in order that a cellular interface morphology form. Otherwise, dissolved impurities were not of any concern to the investigators of the freeze-thaw process insofar as it pertained to sludges.

The theories presented for the freeze-thaw mechanism which enhances dewatering were often vague and usually speculative. There seems to be no clear-cut distinction between the theories offered for water treatment plant sludge and sewage treatment plant sludge. There is little support for the theory that freezing disrupts cell walls and allows water to drain away freely upon thawing. Intensive investigations did not support this theory. Osterkamp (1971) along with Clements, Stephenson and Regan (1950) have done intensive work and offer the most coherent theories regarding the mechanism of sludge dewatering. These investigators contend in a convincing fashion that the mechanism involves: 1) coagulation of the sludge particles as the result of the crystal growth of ice, 2) dehydration of the trapped sludge particles as the result of freezing, and 3) release of the water upon thawing.

The effect of the freezing rate was ignored by some investigators and touched upon lightly by others. A relatively slow freeze appears to be necessary, expecially to achieve large crystals and good coagulation. An increase in the freezing rate would likely reduce the coagulation process before it would affect the dehydration process. Too quick a freeze would interfere with both mechanisms.

A third mechanism which is likely of less significance than coagulation and dehydration was suggested by some investigators (Andrews, 1967; Babbitt and Schlenz, 1929). This theory propounds that freezing breaks the attraction of the colloids to water and allows the water to drain freely upon thawing. This theory would suggest that sewage sludge is, in fact, a hydrophilic colloidal dispersion and that freezing effects electrokinetic changes which destabilize this dispersion. None of the investigators pursued this theory to any degree, but it appears to be noteworthy.

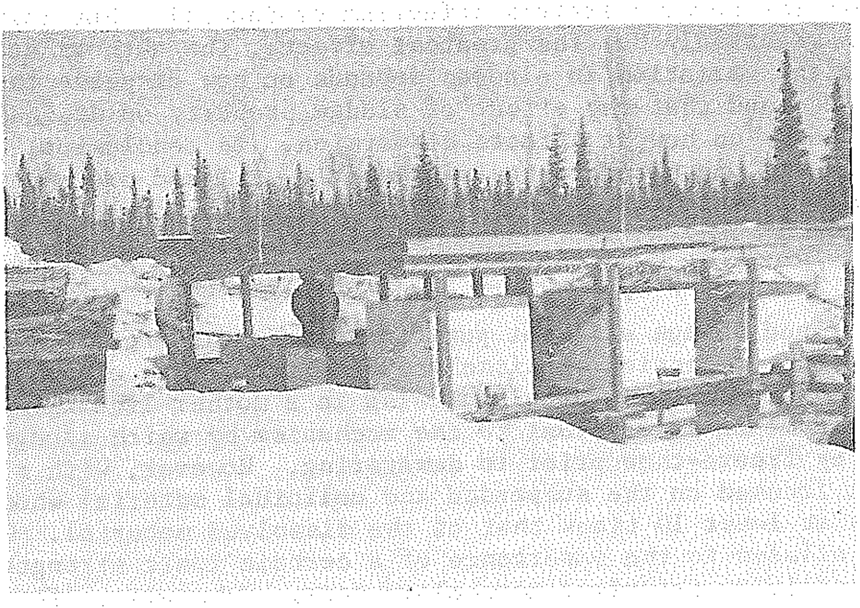

Fig. 1. Model sludge drying beds.

EXPERIMENTAL PROCEDURES

Field portions of this research project were conducted on site at the College Utilities Corporation waste treatment facility located in College, Alaska. This treatment facility is an extended aeration activated sludge system of the oxidation ditch configuration. The system treats approximately 300,000 gallons per day of domestic sewage from the surrounding community (Grube and Murphy, 1969). Excess sludge from the facility is wasted in the plant effluent.

Nine model sludge drying beds (Fig. 1) were used during this study. Each drying bed was four feet square and was enclosed on the bottom and sides by a wooden box. Each of the beds contained a twelve-inch sand base which was saturated with water and frozen prior to placement of the sludge in order to minimize infiltration.

The study consisted of three separate evaluations using three model drying beds for each respective run. Two of the beds were studies at sludge depths of six-inches and the third bed was evaluated at an eighteen-inch sludge depth. The eighteen-inch bed was provided with a four-inch drain tile, located in the sand base, to facilitate collection of leachate from the sludge. One of the two six-inch model beds along with the eighteen-inch model bed were insulated with two-inch polyurethane in order to simulate one-dimensional freezing during the early stages of the evaluation. Run number one was initiated on February 12, 1971; run number two on February 27, 1971; and run number three on March 19, 1971. All runs were terminated during late spring of 1971.

Settled activated sludge for placement on the model beds was obtained from the sedimentation tank of the College Utilities oxidation ditch. Temperature of the sludge during the evaluations was monitored by use of thermocouples at a multitude of locations in the beds. The thermocouples were constructed of 20-gauge copper constantan, PVC-covered, thermocouple wire. Thermocouple monitoring was conducted utilizing a Leeds and Northrup 12 point strip chart recorder and a Honeywell Electronic 15 Multipoint (24 channels) strip chart recorder. The sludge temperature data, in conjunction with ambient air temperature, were used to calculate the approximate rate of sludge freezing and thawing. Freezing and thawing of the sludge were allowed to occur naturally as determined by the elements. The only attempt to control the freezing rate consisted of the insulation provided as part of the drying beds.

Analytical determinations were performed on portions of the raw sludge, the frozen sludge, the thawed, dewatered solids, and the supernatant. Sample analyses included: Biochemical Oxygen Demand, Chemical Oxygen Demand, pH, sludge drainability, and settleable, total, total volatile, suspended, and volatile suspended solids.

Frozen sludge samples were obtained by using a coring device and a chain saw. Core samples were wrapped in polyethylene bags and stored in a laboratory freezer until analyses were commenced.

Relative humidities were measured using a Bacharach Sling Psychrometer.

All analyses, with the exception of sludge drainability, were conducted according to *Standard Methods for the Examination of Water and Wastewater* (APHA, 1966) and were performed in the laboratory of the Institute of Water Resources at the University of Alaska. Sludge drainability was assessed by the method of Babbitt and Schlenz (1929).

TABLE 1. SLUDGE CHARACTERISTICS, AVERAGE VALUES

Run Number	Settleability mls/1000mls			pH	COD mg/1	BOD mg/1	BOD/COD	Solids %
	1 hr	10 hrs	20 hrs					
1	990	930	900	6.7	61,400	14,600	0.238	5.28
2	980	870	820	7.0	37,700	15,500	0.411	3.91
3	940	520	490	7.7	18,200	16,200	0.902	1.94

TABLE 2. SUPERNATANT ICE CHARACTERISTICS:

SUMMARY FROM TOP OF FROZEN SLUDGE BEDS

	pH	BOD mg/1	COD mg/1	T.S. mg/1	T.U.S. mg/1
Average	7.7	480	540	1,120	540
High	8.7	19,500	53,500	33,100	31,800
Low	7.1	50	150	240	130

TABLE 3. DEGREE-HOURS (°C-hr.) FOR COMPLETE FREEZING AND THAWING

	Run Number	6-inch Uninsulated	6-inch Insulated	18-inch Insulated
FREEZING				
	1	1265	1872	3184
	2	1506	----	5536
	3	266	415	850
THAWING				
	1	----	----	----
	2	----	----	----
	3	964	1434	2550

RESULTS

Average values for the raw waste activated sludge characteristics are given in Table 1. The values for BOD, COD, and total solids were relatively high for run numbers one and two because of the prolonged settling time intentionally induced to ensure a concentrated sludge. The sludge used for these experiments was relatively unsettleable as determined by a 30-minute settling test. Settleability of the material over a 24-hour time period indicated the sludge from run number three to be substantially more pronounced than the sludge used for run numbers one and two.

Fig. 2 is a graph showing average daily ambient air temperature during the study period. The minimum average daily air temperature of 30.6C (31.0F) occurred on March 5, 1971.

Fig. 3 is a graph of average daily sludge temperature versus time for the six-inch insulated bed of run number one. This graph is an example of the temperature monitoring for the nine sludge beds studied. Evaluation of the thermocouple data indicated that thin sludge was more responsive to air temperature fluctuations than was thick sludge. The greatest amount of heat transfer occurred through the bed surfaces while lesser amounts of heat loss through the bed walls were evident. Significant heat loss through the bottom of the eighteen-inch beds resulted from the four-inch drain tile installed in the sand base. It appeared that heat transfer through the walls of the insulated beds was reduced; however, the data were not sufficient to conclude this.

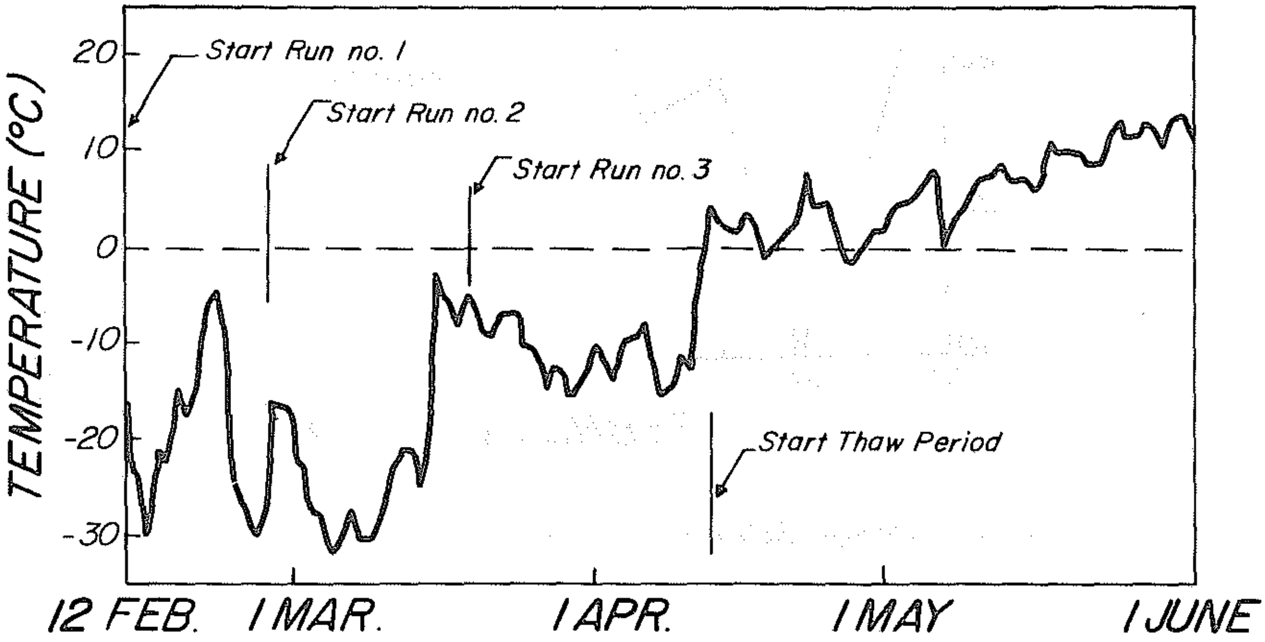

Fig. 2. Average daily ambient air temperatures.

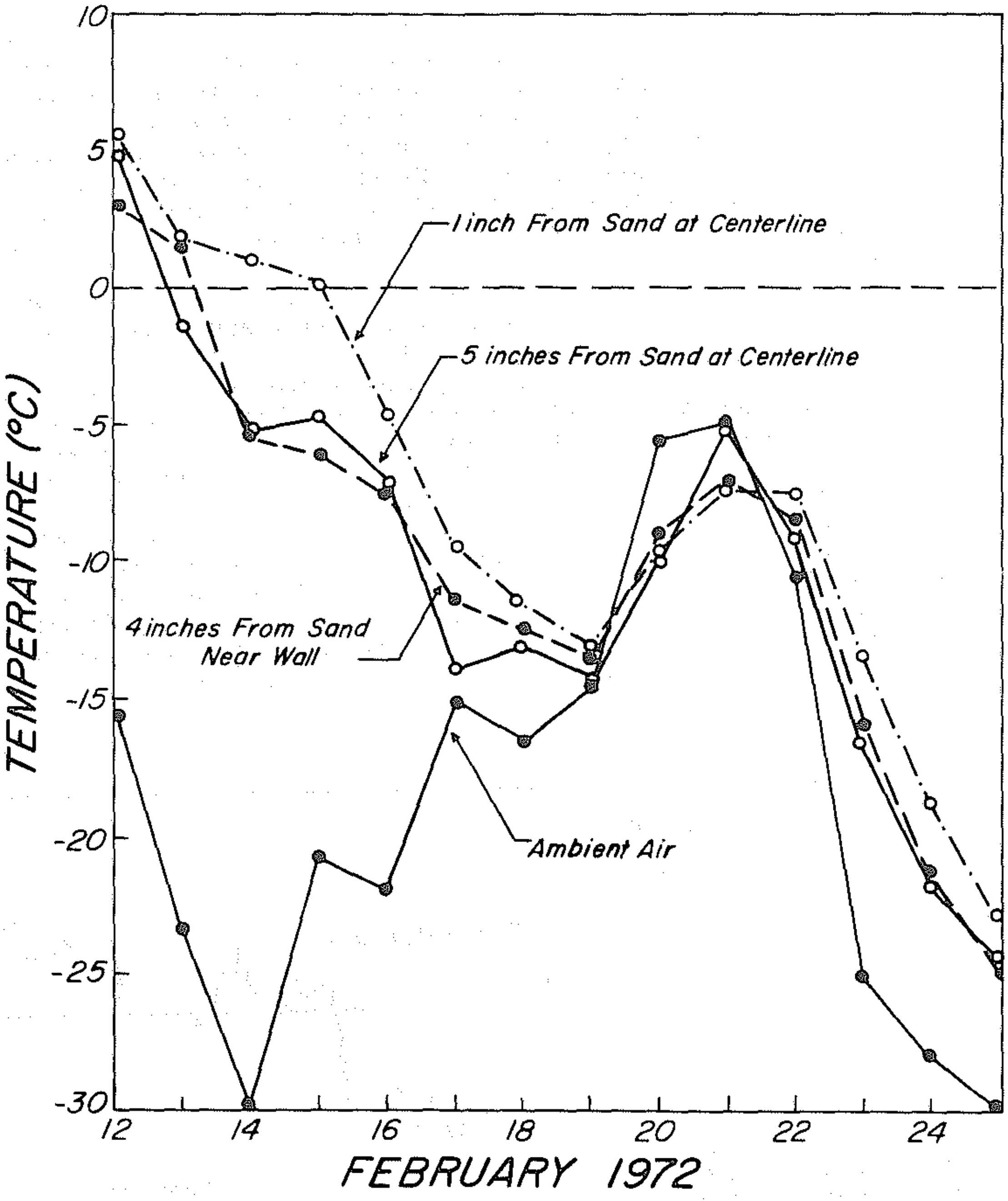

Fig. 3. Average daily sludge temperature, Run 1: 6-inch insulated bed.

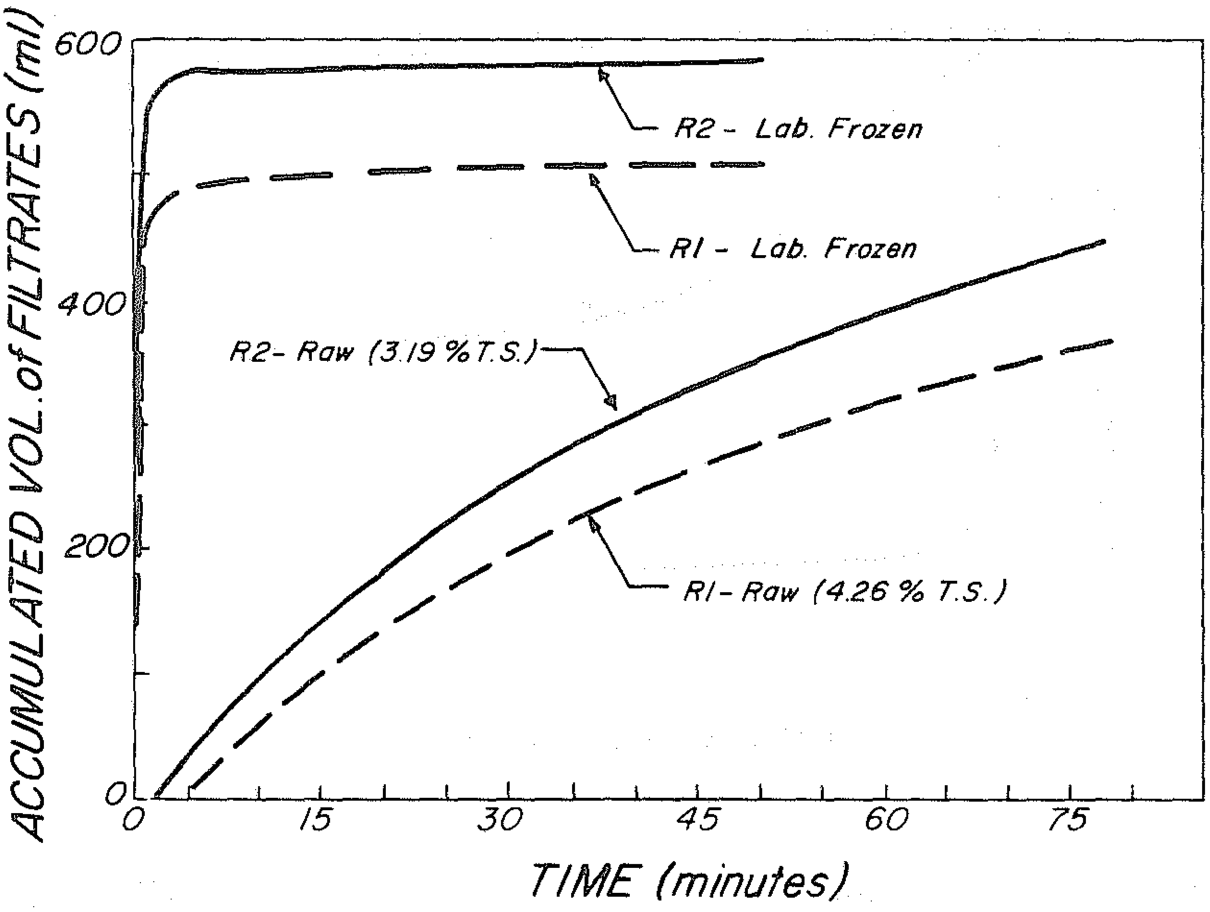

Fig. 4. Drainability of lab frozen sludge and raw sludge.

Tests were conducted on ice samples taken from the top of the frozen sludge beds in order to ascertain the strength of potential leachate occurring during the thaw period. The results of these analyses are presented in Table 2. The characteristics of the "supernatant" ice are approximately two to three times those of domestic sewage. The average values presented do not include the high values shown which were due to one eighteen-inch sludge bed that had virtually no settled solids as indicated by the total solids values listed.

Drainability tests were conducted on raw sludge and laboratory frozen/thawed sludge. Fig. 4 indicates the increased dewaterability of the freeze-thaw conditioned activated sludge. Laboratory freezing improved the sludge drainability but to a lesser degree than did slow, field freezing. Settleability of the sludge was also improved by the freeze-thaw technique as shown in Fig. 5.

Core samples of frozen sludge subjected to laboratory thawing followed by gravity dewatering resulted in increased solids concentration ranging from 12.1 to 17.5 percent. These values were 225-920 percent of the raw sludge concentrations presented in Table 1. The greater percentage increase in solids concentration occurred in the thinner sludge used in run

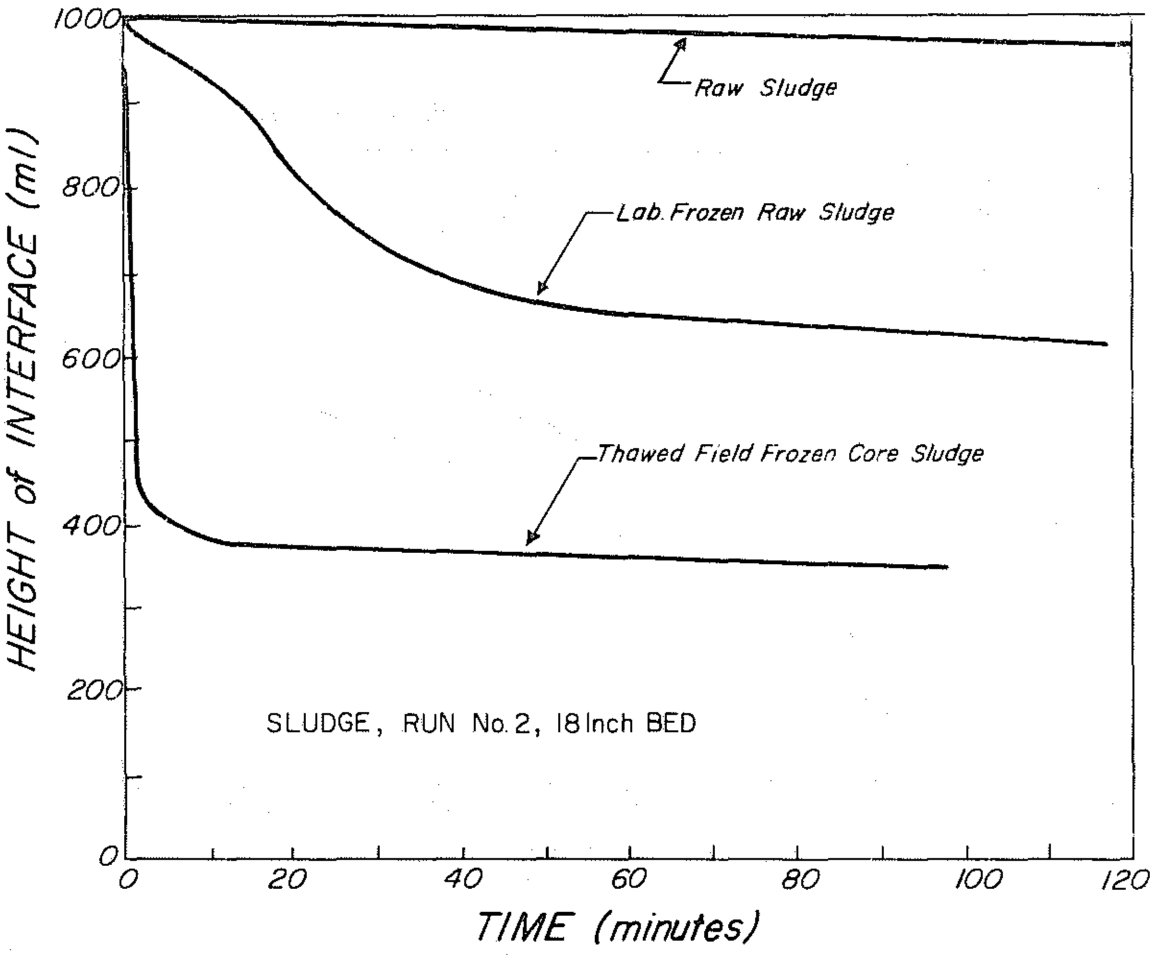

Fig. 5. Settleable solids: raw versus frozen sludge.

number 3. Fig. 6 is a photograph of an eighteen-inch frozen sludge core sample from run number 2; it shows definite solids separation from the liquid fraction.

Table 3 presents the degree-hours (°C-hr.) for complete freezing and thawing during the project. It is evident from the data that the insulated six-inch beds enhanced one-dimensional freezing and as a result required a longer period of time for complete freezing. Additionally, it is apparent that thinner sludge requires less driving force to effect freeze and thaw than is required for thick sludge. Insufficient thermocouples prevented extensive evaluation of the thawing process.

Fig. 7 shows sections of a six-inch core sample prior to laboratory induced thawing. Fig. 8 shows the same sample following thawing and illustrates solids separation from the liquid.

Thawing of the sludge in the field units was allowed to occur naturally. The degree-hours to accomplish thawing are presented in Table 3. Drying of the sludge during the thawing process was monitored and is presented graphically in Fig. 9. An unusually high rate of drying occurred in two of the six-inch beds because of exposure to direct sunlight. Relative humidity during the thaw period ranged from 10 to 75

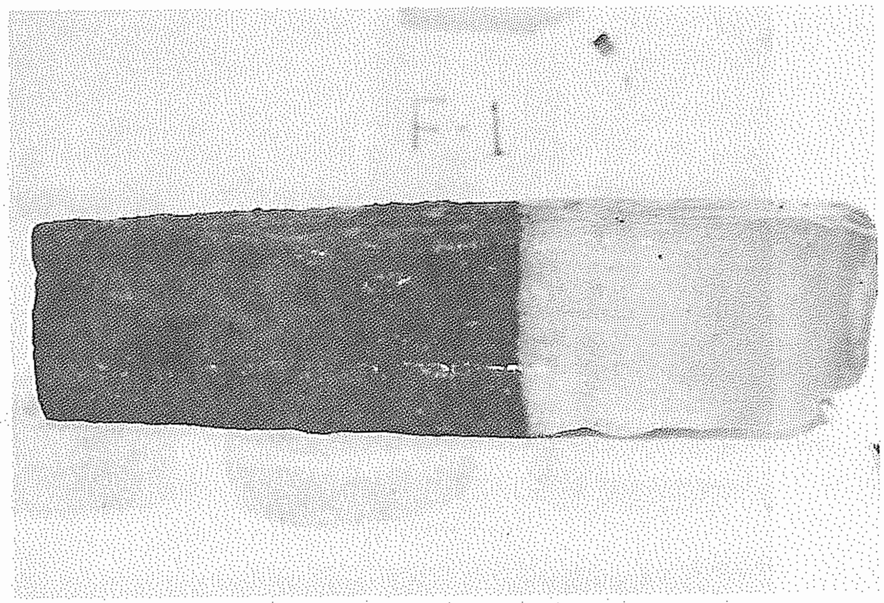

Fig. 6. 18-inch frozen sludge core sample.

Fig. 7. 6-inch core sample before thawing.

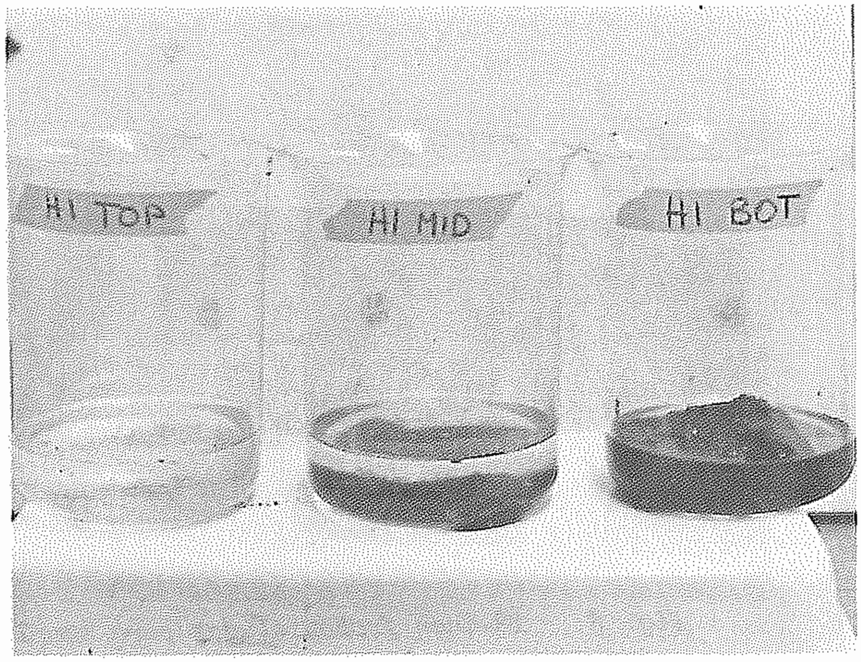

Fig. 8. 6-inch core sample after thawing.

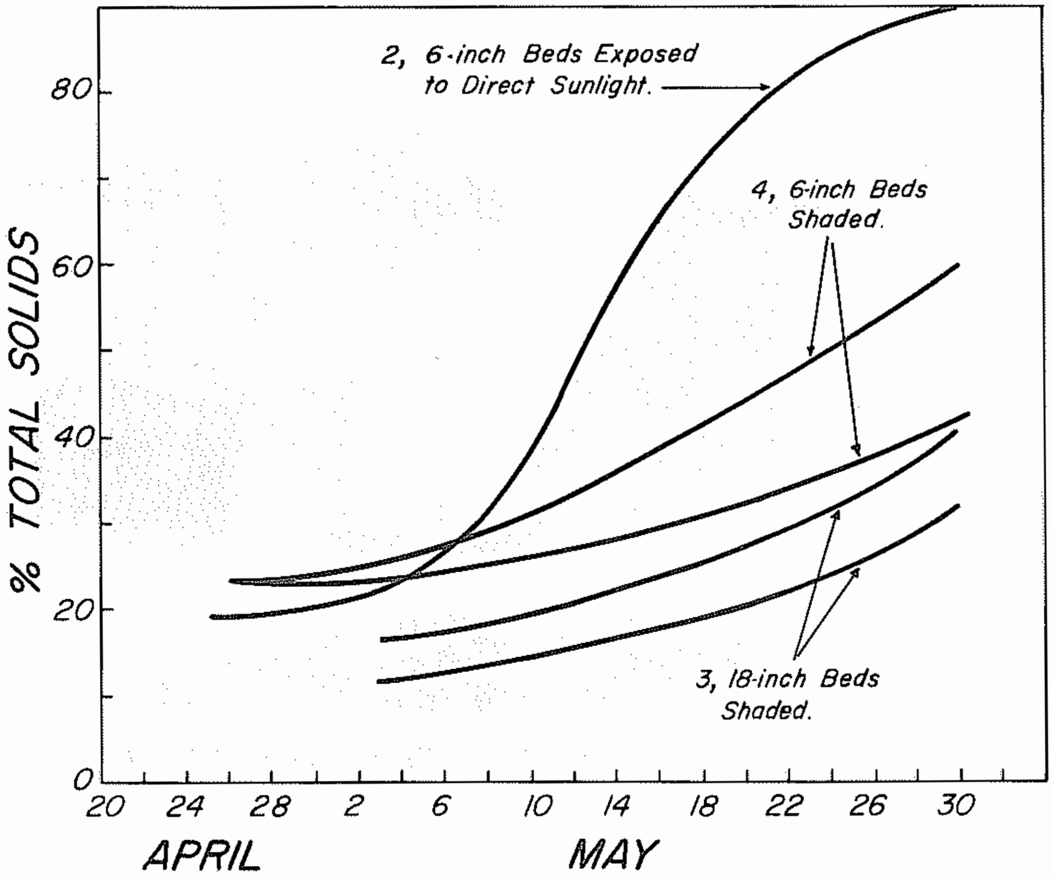

Fig. 9. Sludge solids content during thaw period.

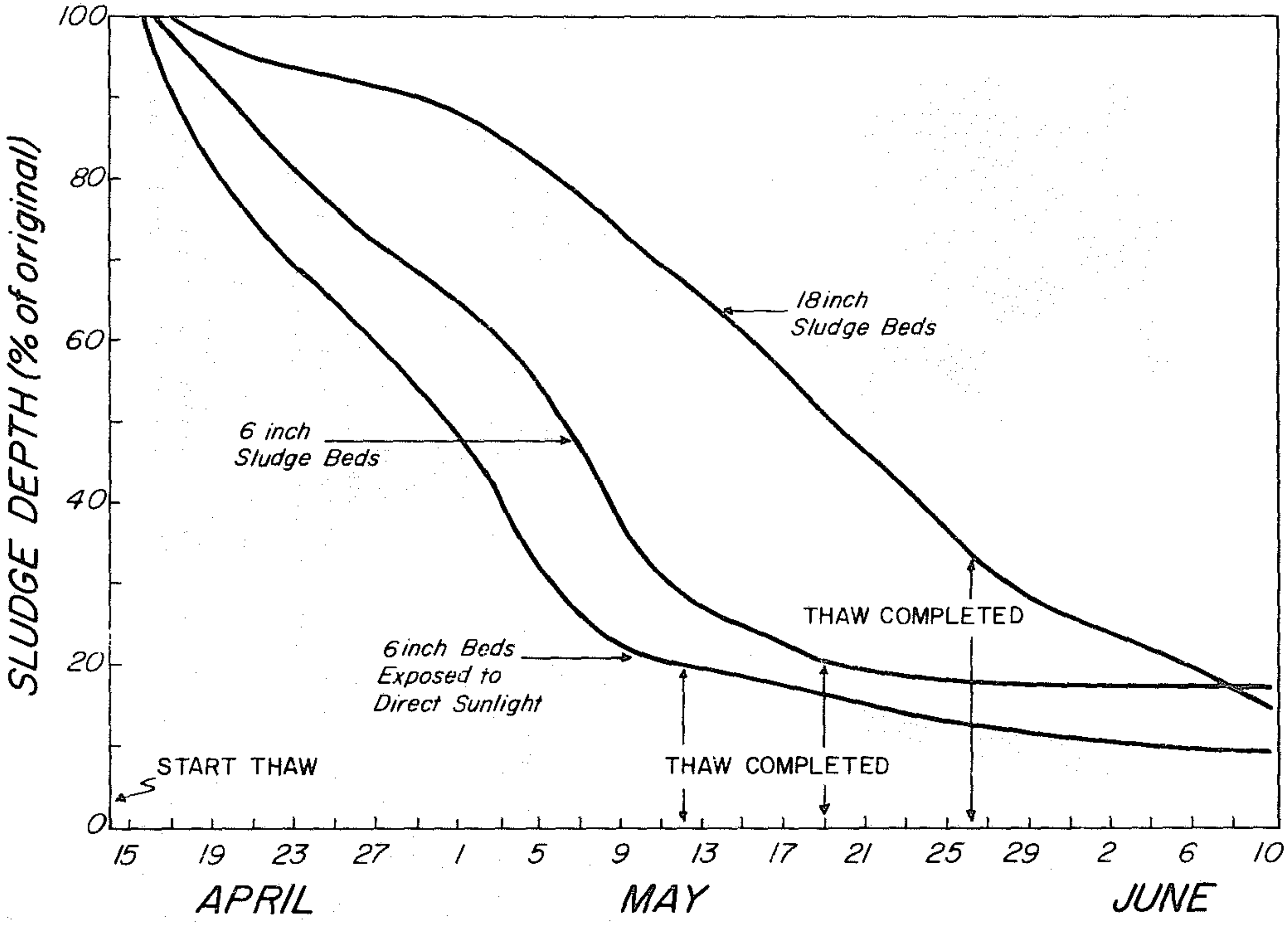

Fig. 10. Sludge depths versus time.

Fig. 11. Sludge after thawing and dewatering.

percent and averaged 33.2 percent. Natural thawing was accomplished in a period ranging from 30-50 days. Longer thaw periods were required for increased sludge depth.

Fig. 10 is a graph of sludge depth versus time. As the frozen sludge proceeded to thaw, the loss of water to evaporation resulted in a depth reduction of the sludge. The values presented are average values, and the graph shows that the deeper sludge beds required extended periods for thawing. Volatile solids content of the sludge during the thaw period averaged 60-65 percent and was observed to decrease slightly.

Evaporation calculations (Chow, 1964) for the thaw period indicated that all of the liquid from the six-inch beds could be absorbed by the atmosphere. Approximately half of the liquid from the eighteen-inch beds could have been loss to evaporation. The residual 9 inches of water would have to have been absorbed by the sand base or as produced leachate in the drain tube. Nevertheless, the reliability of these calculations is questionable because of insufficient climatological data. However, no leachate was observed from any of the beds during the thaw period.

The freeze-thaw conditioning of the sludge resulted in a material resembling organic peat soil in consistency, being easily manageable and free of obnoxious odor. Fig. 11 illustrates the tightly coagulated sludge solids from a six-inch bed following natural thawing and gravity draining.

DESIGN CONCEPT

General

The design of many extended aeration wastewater treatment plants incorporates sludge holding tanks in which excess sludge may be stored or sand drying beds on which excess sludge may be applied. Many investigators (Clark *et al.*, 1970b; Berk, 1967; Guillaume, 1964; Chandhuri, 1970; Morris *et al.*, 1963) have pointed out that sludge wasting is necessary to rid the system of built-up inert polysaccharides and to maintain an active metabolism in the biological reactor. However, it is rare that routine sludge wasting schedules are followed. Grube and Murphy (1969) indicated that auto-sludge wasting occurs at the oxidation ditch serving the University of Alaska partly as the result of failure to waste sludge. Chandhuri (1970) stated that it was originally thought that oxidation ditches could operate without sludge wasting since the accumulation of solids in the system would be negligible as the period of aeration was extended. He indicated that subsequent investigations disproved this belief and demonstrated that non-biodegradable fractions of microbial mass accumulated in the system. Burchinal and Jenkins (1969) reported on an oxidation ditch operating in West Virginia through a two year period without using sludge wasting, even though sand drying beds were provided for this purpose. Solids were washed from the system during high flows. Morris *et al.* (1963) stated that plant efficiency for extended aeration treatment plants is directly related to the amount of solids lost as a result of fluctuations in raw waste flow or as a result of denitrification and rising solids in the sedimentation basin and consequent overflow. They suggested that with the addition and use of sludge wasting facilities or effluent-polishing units, these plants would be capable of efficient, continuous operation for long periods of time.

Guillaume (1964) suggested that 4,000 mg/l should be the upper limit on the MLSS in an oxidation ditch prior to sludge wasting. Berk (1967) suggested that normal operation of an oxidation ditch should allow MLSS to accumulate to 8,000 mg/l in the ditch, or to the level where the dissolved oxygen falls between zero and 0.5 mg/l, before sludge wasting should be effected. There appears to be an optimum MLSS level for each plant between 4,000 mg/l and 8,000 mg/l.

McKinney (1970) stated that there is no easy way to handle waste activated sludge from a conventional plant but that extended aeration sludge can be dewatered directly upon a sand drying bed. He suggested that the period of wasting is a function of the organic load, the size of the aeration tank, and the amount of inert solids in the incoming waste. Grube and Murphy (1969) stated that the sludge produced by an oxidation ditch may be air-dried for ultimate disposal. Baars (1962) contended that oxidation ditch sludge can be dried or kept in storage tanks without producing any bad odor due to fermentation. Clark, Coutts, and Christianson (1970b) suggested that sludge wasting from extended aeration sewage treatment plants is even more important in cold climate operation because of the following reasons:

1. excess solids production increases with decreasing temperature;
2. shorter detention times to prevent freezing will also in-

crease solids production at a given MLSS level;

3. auto-induced sludge wasting may be expected to be more severe, placing greater potential stress on the receiving water; and
4. the receiving water has retarded assimilation capacities at cold temperatures.

Quantity of Waste Sludge

There is very little literature published regarding the quantity of sludge that should be wasted from an extended aeration activated sludge treatment plant. To obtain an accurate estimate for a given plant it would be necessary to do an in-plant evaluation in order to determine the coefficients for the classical sludge growth equations.

Several investigators have estimated the amount of excess sludge to be wasted from extended aeration processes (Clark *et al.*, 1970b; Baars, 1962; Eckenfelder, 1970). On the basis of information gathered from Ranganathan and Murphy (1971), the amount of sludge to be wasted at the College Utilities oxidation ditch ranges from 145 to 249 pounds, dry weight basis, per day. Using the values of 249 pounds per day for a conservative design and assuming a waste sludge concentration of 1.5 percent solids, one can calculate that the volume to be wasted daily is 1,992 gallons.

DESIGN CONSIDERATIONS

Lagoons used for thickening and freezing sludge have been used in Winnipeg, as reported by Bubbis (1962). There, ten inches of completely digested sludge is applied to one of four 20-acre lagoons; the sludge is left 14 days and then decanted. Sludge removal from the lagoon is accomplished with heavy equipment scrapers. A ripping and scraping procedure is used for the frozen sludge in the winter time. Pescod (1970) reported that lagooning is the most common method of sludge dewatering in tropical developing countries. He stated that lagoons should be used only for drying and not as ultimate disposal. Fielding (1966) contended that lagoons are effective in producing a thickened sludge with up to 50 percent volume reduction but are not effective in producing a dry sludge. He advocated the use of a portable syphon to decant supernatant from sludge lagoons. A floating pipe is used with a hand-operated diaphragm pump to start the system. When the pipe encounters heavy sludge, the syphon is automatically broken. He recommended a thickening time of 25 days more than the time required to add the volume of sludge to the lagoons. A consistency of 11 percent total solids is recommended as the maximum for solids which are to be pumped. Four-inch diameter polyvinyl chloride (PVC) pipe is used to transport the sludge. In the *Manual of Practice* for sludge dewatering (WPCF, 1969) is discussed the design of sludge lagoons. There it is suggested that warmer arid climates produce the best results for sludge lagoons. Included in the design considerations are recommendations for the placing of the lagoons with respect to dwellings, the possibility of ground water pollution from lagoons, insect breeding problems, and fencing. It is recommended that sludge drying lagoons be constructed with a two-foot freeboard and that they not be constructed in a marshy area. Depth of sludge in the drying lagoons should not exceed 15 inches. The recommended withdrawal time, if sludge is placed to a depth of 15 inches or less, is from three to five months after application. The wet sludge will not dry enough to be forkable and therefore would have to be removed by mechanical equipment. If the sludge cake is to be used for a fertilizer or soil conditioning purposes, it should be stockpiled after removal to allow additional drying. Burd (1968) reported that lagooning is the most popular sludge disposal technique at industrial wastewater treatment plants. He suggested that lagoons may be natural or artificial depressions in the ground and may be used for either digested or undigested sludge. He further recommended landfilling as an inexpensive ultimate disposal process to follow lagooning. Burd concluded that lagooning of sludge will continue to be popular as long as inexpensive land is available relatively close to the treatment plant site.

Pescod (1971) reported that sand beds are less popular than lagoons for sludge handling in tropical developing countries. He suggested that drainage and evaporation are the major mechanisms for water removal from sludge placed on sand drying beds. Van Kleeck (1953) stated that the normal depth of sludge on drying beds is 8-10 inches. Drainage through the sand is reportedly negligible after the first 24 hours, and subsequent drying is due to evaporation. He reported that drying time can be reduced by one-third if alum is used as a pretreatment.

Design criteria for sand drying are outlined in the *Manual of Practice* for sludge dewatering (WPCF, 1969). It is stated that regional climatic conditions greatly affect sludge dewatering on drying beds: the drying time is shortest in regions of greatest sunshine, low rainfall, and low humidity. These conditions closely resemble conditions in the interior of Alaska in the summer, when there are very long periods of sunshine and low humidity. An eight-inch layer of digested sludge is reported to be capable of drying to a forkable consistency in two or three weeks. No data are given for dewatering undigested sludge from an extended aeration activated sludge plant.

Burd (1968) stated that the higher the initial water content of the sludge, the greater is the percentage of water removed by drainage on sand beds. He outlined the effect of solids concentration on drainable water, drainage time, and cake moisture content. He stated that the "10 States' Standards" and Seelye design criteria for drying bed size recommend 1.75 square feet of sand bed per capita for open beds and 1.35 square feet per capita for covered beds. These sizes were applicable for an area between 40° and 45°N latitude. Burd also discussed the effect of chemical pretreatment of sludge prior to sand drying or dewatering.

HYPOTHETICAL DESIGN AND APPLICATION OF RESEARCH RESULTS

Design of a system to utilize the freeze-thaw technique for conditioning waste sludge with natural refrigeration should result in a simple process relatively free from mechanical intricacies and suitable for small operations under cold-climate conditions. Absolute design of the system will be influenced by the availability of equipment and materials, size and type of sewage treatment facility, and local physiographic conditions.

In general, there are two basic processes on which the design could be based, including sludge freezing and drying lagoons and sludge freezing and sand drying beds. Consideration of the literature reviewed in conjunction with this study indicates that a process of sludge freezing with sand drying beds offers little advantage over a lagoon installation. However, it is conceivable that in specific situations sand beds could be advantageous over lagoons.

The proposed design would incorporate two operational phases: summertime drying and wintertime freezing. Two lagoons will be used to provide capacity and storage during the spring thaw and the transitional period in the fall.

The summertime phase would operate from April 1 to September 30. From April 1 to June 1 sludge would be pumped to the lagoons daily and allowed to accumulate to a depth not exceeding 12 inches. Starting June 1, sludge would be pumped to a second lagoon to a depth not exceeding six inches. On October 1, the sludge would be removed from the first lagoon and subjected to final disposal either by landfilling or incineration. This lagoon would then be ready to receive a twelve-inch depth of sludge through the period from October 1 to April 1. The six inches of capacity left on the second lagoon would be used to handle fresh sludge during the thaw and dewatering period of the frozen sludge. A depth of 12 inches has been selected arbitrarily. The twelve-inch depth will ensure complete freezing of the sludge and should result in a relatively rapid rate of thawing. Increased depth could be utilized in order to reduce the area of land required. The depth limitation is dependent on the maximum depth of freeze possible under local climatological conditions. Additionally, the depth is limited to that which can be thawed in a reasonable period of time. If the sludge lagoon is not covered by a canopy, and the sludge is exposed to direct sunlight during the thaw period (assuming snow removal), thaw to perhaps a five-foot depth is possible. Nonetheless, this parameter needs extensive evaluation under field conditions to determine operational problems.

Each lagoon would be constructed large enough to receive the entire sludge volume wasted for an entire year. This would allow for plant expansion and repairs on one lagoon while the other is receiving fresh sludge.

Because of the strong characteristics determined for the sludge supernatant during this project, a provision should be incorporated into the design for processing any supernatant or leachate occurring during the thaw period. All supernatant could be decanted by means of a portable syphon and returned to the treatment plant. Alternatively, an adjustable weir could be installed in the lagoon to allow drainage, as the supernatant forms, to a storage tank and eventually return to the treatment plant. In areas where ground water contamination could occur, the lagoons should be lined with well-compacted, impermeable clay or an artificial, impermeable layer.

Dewatered sludge could be removed from the lagoons by use of a front-end loader, twice yearly. The dewatered sludge could be processed in an incinerator, if available, or discharged to a sanitary landfill. For reasons of safety the lagoon site should be surrounded by a security fence.

Design Dimensions

The hypothetical design is based on the following assumptions:

1. that the waste sludge is from an extended aeration activated sludge treatment plant, with a daily sewage flow of 300,000 gallons;
2. that sludge is wasted at a rate of 1.5 percent of the solids concentration, or 1,992 gallons per day; and
3. that the climatology allows freezing of the sludge during the period of October through March; the climate is typical of interior Alaska, i.e., subarctic and continental.

The following values were used in the calculations:

waste sludge = 1,992 gallons per day
= 727,080 gallons per year
lagoon sludge depth = 12 inches
lagoon surface area = 97,000 square feet
two lagoons, each = 220 feet by 440 feet
lagoon freeboard = 2 feet
lagoon depth = 3 feet

Many modifications to the above design are possible. These include the possibility of increased depth of the sludge in the lagoon. Additionally, a portable canopy might be considered to protect the lagoon from precipitation. Consideration might also be given to the possible removal of frozen sludge prior to the thaw period and subsequent sludge dewatering outside of the lagoon itself. The dewatered sludge might possibly be used as a soil conditioner.

Economic Considerations

In Table 4 are listed the expected capital and operating costs of the proposed sludge lagoon design. A comparison of the cost of this design to alternative designs is incorporated in Table 5. The cost data used in constructing these tables were taken from Burd (1968), Bubbis (1962), Mar (1969), and Wheeler (1967). It is readily seen that a lagoon installation utilizing optimum summertime drying conditions and the wintertime freeze-conditioning is not only feasible from a logistical viewpoint but also is economical. The cost of ultimate disposal is not included since this would be common to all dewatering processes. It is suggested that ultimate disposal could be incorporated with a municipal solid waste disposal program and could consist of incineration (Burd, 1968), composting (Shell and Boyd, 1969; Wiley, 1966), landfilling (Burd, 1968), or soil conditioning. A twice-yearly removal of sludge from the lagoon could be effected feasibly with existing municipal equipment in most locations.

In conclusion it is appropriate to quote Mar (1969):

> "...socio-economic considerations should establish that

TABLE 4. COST OF PROPOSED SLUDGE LAGOON*

Initial Capital Cost	
Pumps	$ 3,000.00
Excavation and Berm Construction	8,000.00
Piping and Fittings	500.00
Fencing	2,000.00
Berm Stabilization	1,500.00
Roadways	1,000.00
Property	5,000.00
Engineering and Contingencies	3,000.00
Miscellaneous Appurtenances	1,000.00
	$ 25,000.00
Annual Operating Cost	
Sludge Pumping	$ 3,600.00
Supernatant Decanting	800.00
Sludge Removal	1,900.00
Maintenance	1,200.00
	$ 7,500.00
Unit Costs	
Capital - per ton of sludge	$ 55.00
- per capita	8.33
Operating - per ton of sludge	16.50
per capita per year	2.50
Annual Capital (per capita) (based on 30 year amortization 6% per annum interest	1.60
Annual per capita overall	4.10
Overall per ton of sludge (same amortization)	48.10

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* Costs are adjusted to reflect increased Alaskan construction costs of approximately 150 percent of U. S. average.

TABLE 5. COMPARISON OF ESTIMATED COSTS OF VARIOUS ALTERNATIVES*

Installation	Per Ton Handled
Lagoons (Freeze-Thaw)	$ 48.00
Vacuum Filtration (with filter aids)	$ 54.00 - 72.00
Sand Drying Beds (covered)	$ 87.00 - 115.00
Centrifugation	$ 53.00 - 70.00
Incineration	$ 60.00 - 75.00

* Costs are adjusted to reflect increased Alaskan construction cost of approximately 150 percent of U. S. average.

sludge should receive the maximum degree of treatment technically possible, and that the residue should be discharged to the less sensitive element of the environment. The cost of this activity will be small compared to the total costs of maintaining the environment."

SUMMARY AND CONCLUSIONS

The use of natural refrigeration for conditioning waste activated sludge by the freeze-thaw method was found to be very effective. Freezing of the sludge substantially improved its settleability and dewatering characteristics. In general, slow freezing was more beneficial than fast freezing, and improved efficiency of the process was obtained with thinner sludge having a solids content of one to two percent. The sludge handling characteristics were greatly improved, the sludge being granular and earthy with little to no odor.

Design of a prototype operation should consider two operational phases, including summertime conventional lagoon drying and wintertime lagoon freezing.

Depth of sludge to be frozen is dependent on the local climatology. Increased depth will result in reduced area requirements; however, a longer period of retention will be needed for thawing during spring warmup. For the College, Alaska locale the maximum depth for freezing could be as much as three to four feet if an external heat source, such as heat tapes, is provided to reduce the time of thawing. Because of large land areas required to use this sludge conditioning technique, utilization will be limited to relatively small facilities having sufficient land in close proximity to the treatment plant. Estimated costs for the process, based on a depth of 12 inches for freezing, compare favorably with the alternatives available for sludge dewatering. Capital and operating costs are estimated at approximately $50 per ton of sludge processed, as compared with $70 per ton using vacuum filtration, centrifugation or incineration, and $100+ per ton for sand drying beds.

Provisions should be made for the collection of the leachate from the process. The leachate analyzed during this study exhibited properties two to three times the strength of domestic sewage. Ultimate disposal of the freeze-thaw conditioned sludge can be accomplished through conventional methods. Waste activated sludge from extended aeration processes can be directly discharged to a sanitary landfill following freeze-thawing and dewatering.

The process seems well suited for arctic and subarctic areas, where an abundance of natural refrigeration is available. Furthermore, the freeze-thaw technique appears to merit consideration for use by small treatment facilities in many of the northern states. Nevertheless, the process needs further evaluation on a full-scale basis.

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APPENDICES

APPENDIX A

FREEZE - THAW CONDITIONING OF BIOTREATMENT PLANT SLUDGE
in
SUB-ARCTIC ALASKA

A

Thesis

Presented to the Faculty of The
University of Alaska in Partial Fulfillment
of the Requirement
for the Degree of
Master of Science

By
Larry Eugene Garinger, B.Sc. (C.E.)
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May, 1972

FREEZE - THAW CONDITIONING OF BIOTREATMENT PLANT SLUDGE
in
SUB-ARCTIC ALASKA

Larry Eugene Garinger, M.S.

ABSTRACT

The literature was searched for papers reporting research work done on freezing water, wastewater effluent, water treatment plant sludge and sewage treatment plant sludge. An experiment was conducted to determine the effect of freezing, provided naturally, as a conditioning step prior to the dewatering of sewage sludge. The sludge was drawn from a biological waste treatment plant located near Fairbanks in sub-Arctic Alaska. The analytical results and physical observations showed that freezing greatly enhanced the settling and dewatering characteristics of this sludge. A prototype design suggested the use of a pair of identical lagoons in which sludge would be poured to a maximum depth of 12 inches. Freezing would be effected during the winter months, thawing would occur in the spring and drying would be carried on during the summer and early fall. A peripheral cost estimate and simple logistics indicated that lagoons would compete very favorably with alternative methods of sludge dewatering.

October, 1971

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APPENDIX B

PRESENTED AT: 27th Annual Purdue Industrial Waste Conference, Purdue University, Lafayette, Indiana, May 1972.

FREEZE CONDITIONING OF WASTE ACTIVATED SLUDGE

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ABSTRACT

A study was conducted to evaluate a sludge disposal process consisting of modified sand drying beds in combination with the freeze-thaw technique utilizing natural refrigeration. Special consideration was directed at designing a process that was simple to operate and easy to maintain.

The purpose of freeze-thawing of sewage sludge is principally to condition the sludge such that it is readily dewaterable and, subsequently, results in a reduced volume of solids to be further processed.

Research on freezing of sewage sludge dates back as early as 1929. More recent studies indicate that artificial freezing and thawing of sewage sludge cannot economically compete with the more established methods currently available for sludge conditioning. Some investigators have suggested the use of natural freezing as a sludge conditioning process, however it has been rarely used. Alaska, having an abundance of natural refrigeration, is an ideal location for evaluating this mode of sludge conditioning.

The study consisted of three separate evaluations using three model drying beds for each respective run. Two of the beds were studies at sludge depths of six inches, and the third bed was evaluated at an eighteen-inch sludge depth. Settled activated sludge for placement on the model beds was obtained from the sedimentation tank of a local activated sludge plant. Field evaluations were conducted from February to June, 1971.

The use of natural refrigeration for conditioning waste activated sludge by the freeze-thaw method was found to be very effective. Freez-

ing of the sludge substantially improved its settleability and dewatering characteristics. In general, slow freezing was more beneficial than fast freezing, and improved efficiency of the process was obtained with thinner sludge having a solids content ranging from one to two percent. The sludge handling characteristics were greatly improved, the sludge being granular and earthy with little to no odor.

Design of a prototype operation should consider two operational phases including summertime conventional sand drying and wintertime lagoon freezing. The depth of the sludge to be frozen is dependent on the local climatology. Increased depth will result in reduced area requirements; however, a longer period of retention will be needed for thawing during spring warmup. For the College, Alaska locale, the maximum depth for freezing could be as much as three to four feet if an external heat source, such as heat tapes, is provided to reduce the time of thawing. Because of large land areas required to use this sludge conditioning technique, utilization will be limited to relatively small facilities having sufficient land in close proximity to the treatment plant. Estimated costs for the process, based on a depth of 12 inches for freezing, compare favorably with the alternatives available for sludge dewatering. Capital and operating costs are estimated at approximately $50 per ton of sludge processed as compared to $70 per ton using vacuum filtration, centrifugation or incineration and $100+ per ton for sand drying beds.

Provisions should be made for collection of leachate from the process. Leachate analyzed during this study exhibited properties two to three times the strength of domestic sewage. Ultimate disposal of the freeze-thaw conditioned sludge can be accomplished through conventional methods. Waste activated sludge from extended aeration processes can be directly discharged to a sanitary landfill following freeze-thawing and dewatering.

The process seems well suited for arctic and subarctic areas, where an abundance of natural refrigeration is available. Furthermore, the freeze-thaw technique appears to merit consideration for use by small treatment facilities in many of the northern states. Nevertheless, the process needs further evaluation on a full-scale basis.