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DISPOSAL OF SLUDGE AND WASTEWATERS FROM WATER TREATMENT PLANT

THE ONTARIO WATER RESOURCES COMMISSION

DISPOSAL OF SLUDGE AND WASTEWATERS

FROM WATER TREATMENT PLANTS

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SUMMARY

This report, based on a literature survey and personal experience, presents a review of the current methods and some problems associated with the treatment and disposal of sludge and other waste by-products generated by municipal waterworks including those which employ diatomite filtration, iron removal and water softening processes. The main emphasis is, however, directed to the handling of sludge and filter washings derived from chemical coagulation plants.

Over 90 percent of the waterworks utilizing chemical coagulation in Canada and the United States disposed of their wastes by discharging directly into the nearest stream of a large body of water without any kind of treatment whatsoever. The literature has revealed some examples of water quality impairment, pollution, silting, unsightly conditions and other nuisance problems developing in the receiving streams as a result of this practice.

Alternative methods of sludge disposal were lagooning, landfill, discharging to municipal sewers, pumping out to sea, recirculation for re-use and recovery of alum. Of these, lagooning was found to be the most popular and the cheapest method. Unfortunately, the land available in large metropolitan areas has become too expensive for sludge disposal. Furthermore, land used as a disposal site for alum sludge becomes sterilized and worthless for agricultural purposes.

The most widely used method of thickening waterworks sludge was by sedimentation in lagoons or in holding tanks where the solids were allowed to settle by gravity and the supernatant was removed by decantation. Other methods reported to be in use were sludge drying beds, wedge-wire filtration and filter pressing. Vacuum filtration and centrifuging have also been considered for sludge dewatering but their application has been limited so far only to laboratory and pilot studies.

Alum sludge was considered to be one of the most difficult of all sludges to handle. Several methods were reportedly employed to condition the sludge in order to improve its dewatering and settling characteristics. This involved one of the following methods:

(a) chemical conditioning with one of the following: aluminium chlorohydrate, lime or polyelectrolyte consisting of high molecular weight polymers,

(b) heat treatment,

(c) freezing and thawing techniques.

Sludge conditioning was usually used in the preparation of sludge just prior to one of the mechanical dewatering processes.

TABLE OF CONTENTS

Page No.

1.0 INTRODUCTION

To date, the disposal of sludge and wastewaters produced in the purification of municipal water supplies has not been regarded as a serious problem in Ontario. However, with the increased growth of industrialization and urbanization, many municipalities are confronted with the task of supplying greater volumes of water than ever before. In some cases, it has become necessary to utilize more water of inferior quality and thus requiring a much greater degree of treatment. In addition, today's consumer is more conscious of water quality and he will not hesitate to voice his complaints if it does not measure up to the acceptable standards of aesthetic quality.

In order to satisfy this ever-increasing demand for clean water, many new waterworks are being constructed and some of the existing plants are being enlarged and modernized to provide more elaborate methods of water purification which will involve greater utilization of chemicals. This will result in the production of increased volumes of sludge and wastewaters that must be disposed of from these plants.

The purpose of this study is to review the published information in the literature and outline the various methods employed in the disposal of waterworks sludge and their attendant problems. The disposal of wastes from other purification processes such as diatomite filtration, iron removal and water softening will be mentioned briefly, but the main discussion will be directed to the disposal of sludge and filter washings from waterworks utilizing alum coagulation as nearly all of the municipal water supplies in Ontario are treated in this manner.

2.0 PURIFICATION WASTES AND THEIR METHODS OF DISPOSAL

2.1 Classification

In the purification of water, waste products in the form of sludge are derived from the impurities removed and chemicals used in the treatment. Most of the sludge accumulates in the sedimentation tanks and a lesser amount on top of the filters during the treatment process. The discharge of sludge is usually intermittent from the filters and ion-exchange filter units but it may be either intermittent or continuous from the sedimentation tanks depending on the design of the equipment employed (1) (2).

The type of sludge and wash water produced by water treatment plants may vary from plant to plant and is governed by the treatment process, impurities removed and the chemicals added. In general, they can be classified into the following categories:

(a) wastes from chemical coagulation plants

  (i) sludge from sedimentation basins
  (ii) wash water from filters

(b) sludges from lime and lime-soda softening plants

(c) brine wastes from sodium zeolite softeners

(d) wash water from other types of filtration plants

  (i) diatomite
  (ii) iron and manganese removal

2.2 Wastes from Chemical Coagulation Plants

Depending upon its design, wastes may originate at three different points in water treatment plants which employ chemical coagulation and filtration. At some plants, coarse sand, heavy particles and other large debris are settled out and removed from the raw water and collected separately in the pretreatment basins. In the majority of cases, most of the very finely dispersed clay, colour colloids, algae and other suspended matter in the water are coagulated with the aid of chemicals into floc particles which settle out and accumulate as sludge in the sedimentation basins. The main bulk of the sludge consists of hydroxide or oxides of aluminium or iron depending on the coagulant chemical used. In addition, small quantities of activated carbon or any other substances added in the treatment process may be found in the sludge.

Sludge can also be collected in the filter wash water obtained during the backwashing operations. This consists mainly of very fine floc particles and other impurities that have remained in the water after sedimentation but removed by filtration.

In general, the largest quantity of solids removed from the water during the purification process is collected as sludge in the sedimentation basin. However, the actual volume of sludge discharged from the basins depends on the amount of impurities in the raw water, chemical dosages and the frequency of cleaning. Although there are no data available to show the amount of sludge collected in the pretreatment basins, it has been reported that the volume of sludge discharged from sedimentation basins may vary from 0.5 percent to well over 5 percent of the treated water production (1). It should be noted that a large number of waterworks do not have any pretreatment basin facilities.

The wash water requirements for the cleaning of filters may vary from 0.5 to 2.5 percent of total water production depending on the design of the filters and the efficiency of the sedimentation basins (1).

The literature survey shows that there are a number of methods employed in the handling and disposal of sludge and filter wash water from these plants. The selection of the method is based on quality and quantity of wastes to be handled, local conditions, ultimate effects resulting from the disposal and economic considerations.

Nearly all of the waterworks in Ontario utilize aluminium sulphate (alum) as the primary coagulant in the purification process. Therefore, only the problems and methods related to the disposal of alum sludge will be considered and the details given later.

2.3 Sludges from Lime Softening Plants (2, 3, 4)

The sludges produced from lime and lime-soda softening plants consists principally of calcium carbonate, along with varying amounts of calcium and magnesium hydroxide, aluminium hydroxide, coagulant chemicals and impurities removed from raw water.

If the plant is located on a small stream or in a locality where impounding facilities are not readily available, then the disposal of this sludge becomes a problem. If dumped into a stream during periods of low flows, it may not be carried away immediately and therefore it may become a public nuisance.

In practice, disposal of wastes from lime and lime-soda softening plants is handled in the following manner:

(a) impounding in lagoons where excess water is removed by skimming or evaporation,

(b) controlled discharge of wet sludge into a large stream,

(c) sludge is dewatered partially in a lagoon and then dried completely in a "flash" drying process. The dried material is used for agriculture or as a filler in the manufacture of roofing materials, plastic, rubber, paints, millboard and a variety of other products,

(d) sludge is dried and calcined for re-use.

2.4 Wastes from Sodium Zeolite Softeners (2, 5, 6)

Wastes from sodium zeolite softeners consist of backwash and rinse waters produced during the regeneration cycle and may vary from 3 to 10 percent of the volume of water treated. They contain very high concentrations of chlorides of calcium and magnesium together with unused sodium chloride and small quantities of iron and manganese.

The following are some of the problems that may result from the disposal of brine wastes:

(a) Significant increases in chlorides, sodium, calcium, magnesium and other dissolved solids can be expected if dumped into a stream not having sufficient dilution water.

(b) The addition of constituents that cannot be removed readily by ordinary water purification methods.

(c) If discharged into municipal sewers, the high salt content may corrode sewer mains and pumping equipment at the sewage plant and also have detrimental effects on the biological process.

(d) Fish and other aquatic life in the receiving streams may be adversely affected.

(e) Water contaminated with brine cannot be used for agricultural purposes.

(f) There is always a potential hazard of ground water contamination.

In general, brine wastes are disposed of by the following methods:

(a) evaporation ponds,
(b) discharge into municipal sewers,
(c) discharge into streams using controlled dilution techniques,
(d) brine disposal wells.

Haney (5) (6) concluded that the controlled dilution technique was the only method applicable to most situations provided that there was ample dilution water available at the time of discharge. Evaporation ponds and brine disposal wells often do not offer a practicable solution to this problem.

Unless the difficulties associated with the disposal of brine wastes can be resolved, the use of sodium zeolite softeners for large municipalities should be discouraged.

2.5 Wastes from Diatomite Filtration Plants

The wastes produced by diatomite filtration plants consist of spent diatomaceous earth (diatomite) filter-aid and the impurities removed from the water.

The filter-aid is a finely divided powder consisting of skeletal remains of diatoms and microscopic crustaceans. It is chemically inert and practically insoluble. Its constituents are made up approximately 70 percent silica with the remainder consisting of alumina and oxides of calcium, magnesium, iron and other alkali substances.

Depending on the water quality, the total requirement of filter-aid may range from 50 to 200 lbs per million gal of water filtered with an average of 100 lbs per million gal. The wash water requirement is estimated to be about 1 to 2 percent of the total throughput (7).

There are approximately 75 diatomite filtration plants that are being utilized for the purification of potable water supplies in Canada and the United States (7). There is no published information with regards to the methods being employed in the disposal of spent diatomite from these plants. However, a Task Group Report (8) suggested that no spent diatomite filter-aid should be discharged to sanitary or storm sewers. It also recommended that a separate lagoon or another filter unit should be provided to dewater the spent diatomite wastes.

2.6 Wastes from Iron Removal Plants

Wastes from iron removal plants consist of wash water obtained during the backwashing of the contact beds or the filtration units. Sludge in the wash water is composed of insoluble iron oxide or hydroxide that has been removed from the iron-bearing water. Discharge of this sludge into a stream is undesirable because it can create unsightly conditions and impair water quality. In Ontario, most of the iron-bearing waters are derived from wells and the wastes from many of these plants can be discharged without any difficulty into nearby lagoons.

3.0 CHARACTERISTICS OF ALUM SLUDGE

Sludges collected from the sedimentation basins usually have very high moisture contents. A typical sample may show an analysis of 2 to 5 percent solids and the remainder as moisture. If allowed to settle, it will gradually compact into a semi-solid mass and establish a clear boundary between the supernatant and settled particles. It is free flowing and can be pumped without any great difficulty (1) (9).

Its colour may vary from light brown to dark brown or black depending upon its content of organic matter and age. The use of powdered carbon or any other substance in the treatment process will obviously influence its colour.

Normally, fresh alum sludges do not give off any appreciable odours other than those emitted by the certain species of algae and other impurities already present in the raw water. However, if the sludge is allowed to remain in the sedimentation basin for any length of time, it may undergo putrefaction and develop very objectionable odours. This condition occurs more frequently during the summer months with warmer water temperatures.

Depending upon the water supply, the sludge will contain varying amounts of organic matter in the form of algae, colour colloids and vegetable matter removed from the water. Its BOD values will vary in accordance with its organic content. A survey of the literature has revealed that only limited data related to BOD values for waterworks sludges are available. Almquist (10) found BOD values in the range of 38 to 1,100 ppm with an average of 337 ppm in the samples of basin sludge containing solids varying from 0.05 to 4.2 percent with an average of 1.3 percent. These samples are collected from 13 rapid-sand filtration plants in Connecticut. In another case (11), it was reported that samples of sludge with 1 percent solids had BOD values in the range of 109 to 232 ppm with an average of 150 ppm. These were obtained from two waterworks plants which treated water from Lake Ontario in upflow solids contact clarifier units.

Sludge derived from the clarification of turbid waters may contain large amounts of clay and silt and those obtained from the treatment of highly coloured waters may have a mixture of organic matter and iron compounds.

The main ingredient in the waterworks sludge consists of metal hydroxide precipitated chemically from coagulant chemicals during the water treatment process. Metal hydroxides have certain properties that make them difficult to dewater. Physically, they are very light and flocculant, gelatinous, compressible and readily deformed. Aluminium hydroxide, a main constituent of alum sludge, is said to be the most difficult of all the metallic hydroxides to handle (9). This aspect of alum sludge will be discussed in more detail under "SLUDGE DEWATERING METHODS".

4.0 METHODS OF SLUDGE DISPOSAL

4.1 Discharges into Streams

A review of the literature indicated that there were several methods employed in the disposal of sludge and filter wash water from waterworks utilizing chemical coagulation. It is apparent that the wastes from an overwhelming majority of the plants were simply dumped into the nearest stream. This has been confirmed by a questionnaire survey conducted by Dean (12) on his study of the sludge disposal methods employed by water purification plants in the United States, Hawaii and Alaska. The data from this survey are presented in the tables below.

Table 1

DISPOSAL OF BASIN SLUDGE

Discharged Into	Plants Reporting Number	Plants Reporting Percent
Streams or lakes	1,414	92.42
Storm sewers or surface drains	53	3.46
Sanitary sewers	4	0.26
City reservoirs	2	0.13
Irrigation ditches	1	0.07
Dry creeks	3	0.20
Sludge Beds or low ground	47	3.07
Impounding basins (discharged into rivers at high water levels)	6	0.39
Total	1,530	100.00

Table 2

DISPOSAL OF FILTER WASHINGS

Place or Method of Disposal	Plants Reporting Number	Percent
To stream or lake	1,404	82.64
To storm sewers or surface drains	181	10.65
To sanitary sewers	42	2.48
To lagoons without solids removal	32	1.88
Impounded and discharged to streams at high levels	4	0.24
Recycled through plants	6	0.36
To city reservoirs	2	0.12
To irrigation canal	1	0.06
To roadside ditches	5	0.284
To drainage ditches	5	0.284
To low ground	2	0.12
To dry creeks	13	0.77
To beds from which sludge is removed	2	0.12
Total	1,699	100.00

The data in Table 1 indicate that sludges from approximately 96 percent of the plants surveyed were eventually discharged either directly or through storm sewers and surface drains into receiving streams without any kind of treatment. It can be seen from Table 2 that filter washings from about 95 percent of the plants are also disposed of in the similar manner.

It is believed that nearly all waterworks utilizing chemical treatment in Ontario discharge their wastes directly into the lakes and streams from which they draw the water. The wastes are usually released in the river downstream from the waterworks or at some point in the watercourse where they will not create any nuisance in the water being drawn into the plant.

According to the literature, the filter wash water from most plants is discharged directly into the nearest stream during the backwashing operation. The sludge from the sedimentation and coagulation basins is released slowly and discharged into the stream during the cleaning operation. At some plants, the sludge is transferred from the basins and impounded in a large holding tank or lagoon. The supernatant liquid is decanted and the sludge discharged at times of high water levels in the receiving streams or carted away to another disposal site. According to Hall (13), this method of disposal was not a standard practice in the United States but it was adopted at some plants which were compelled to do so by complaints.

4.2 Disposal with Domestic Sewage (14)

The data presented in the above tables indicate that a very small percentage of the plants in the survey discharged their wastes to the municipal sewers. Although this method of disposal requires no treatment whatsoever it merely transfers the problem to the sewage treatment plant operator (11) (15).

Dumping these wastes into sanitary sewers may involve the release of several thousands of gallons of sludge within a matter of a few hours. The volume would depend upon the size of the basin and the interval between cleanings. These are some of the problems that may result from this practice:

(a) overloading at the sewage treatment plant if the facilities are not adequate to handle large flows.

(b) silting due to deposition of sludge in the sewers.

(c) assimilation of waterworks sludge with sewage.

None of these problems are considered to be too serious. They can be overcome by cleaning out the basin during the periods of minimum flows at the sewage plant and by restricting the sludge discharges to 30-minute intervals. Waterworks sludge do not contain any substances considered to be harmful to the sewers nor to the biological process in the sewage plant. Silting problems can be avoided if the sewer mains are of adequate size and have been installed with proper grades.

4.3 Lagooning

Lagooning is a popular method of sludge disposal employed by waterworks that are restricted from discharging their wastes into the streams. This is a common practice in Britain (15).

Sludge and filter washings are collected and accumulated in one place and then pumped directly to the disposal area. The latter is selected so that it will not be located too far from the waterworks. The impounding area may consist of a ditch, lagoon, pond or a low-lying area surrounded by dykes. The wet sludge is pumped to the lagoon and then allowed to dry. The usual practice is to apply the sludge in layers at different intervals - each layer of sludge is dried before the next application (12).

If the space for disposal is limited, the dried sludge is dug out and eventually carted away to another area. In some cases, the impounding area is divided in several sections or ponds. Sludge is poured into some sections while others are being dried. Dean (12) reported that, at one plant, the dried sludge was removed by means of a bulldozer and then the hollow area was filled in with wet sludge. At another plant, the sludge was allowed to dry. The dried sludge was removed to another area for final disposal.

If sufficient land is available, lagooning is considered to be the cheapest method of disposal. However, there are some problems created by dumping alum sludge in lagoons or using it as landfill. Practically all of the land and the area surrounding the disposal site is sterilized and becomes worthless for agricultural purposes. The soil in the area will not support any vegetation and as a result, the land will take on a very barren and desolate appearance. The sludge used as landfill tends to remain fluid and soft and this may present a potential hazard for many years to come (12) (15) (16) (27).

4.4 Pumping Sludge Out to the Sea

This is one of the methods employed in the disposal of sewage sludge at a number of coastal cities in the British Isles and the United States. The sludge, after thickening, is transported by pipelines or barges out to the sea and then dumped (17) (18). Its suitability depends on the local conditions and the distance between the treatment plant and disposal site.

An example of a waterworks sludge being disposed of in this manner was reported by Ash (19). He found that pumping thickened sludge (with about 15 percent solids) over a distance of four miles out to the sea was considered to be less expensive in comparison to lagooning and centrifuging.

4.5 Re-use of Sludge and Filter Wash Water

Some attempts have been made to utilize sludge as a coagulant aid. The sludge drawn from the sedimentation basin is recirculated with the incoming raw water. It is suggested that the sludge particles will help to improve coagulation by providing turbidity to the raw water and thereby adding some weight to the newly formed floc in order to enhance its settling characteristics. An example of this practice reported by Marshall (20) was at Kansas City, Mo., where the sludge from the secondary basin was recirculated with 60 percent being returned to the primary basin and 30 percent to the secondary flocculation zone and remaining 10 percent was dumped into the sewers.

The re-use of basin sludge means that the sludge returned to the plant may have to be handled several times before it is finally disposed of. Hence, there appears to be very little advantage in this practice unless a substantial reduction in the chemical consumption can be achieved (12).

A literature survey revealed that the practice of re-using basin sludge in the plant was very rare and almost non-existent. However, it was found that the filter wash water was frequently recycled and mixed with the incoming raw water (1)(12)(21). In some cases, the suspended solids removed in the wash water recovery tanks and the clarified water was returned to the plant (9)(22)(23). Scott (24) cited examples where the provisions had been made to reclaim filter wash water as a conservation measure during periods of water shortage and at another plant, this practice helped to eliminate the need for constructing a large sewer main to get rid of large volumes of wash water.

4.6 Recovery of Alum for Re-use

The feasibility of alum recovery from sludge for re-use in water purification has been investigated by a number of research workers in Britain and the United States (9) (15) (25) (26) (27) (28) (29). The basic principle of the process is quite simple. It consists of a chemical reaction between aluminium hydroxide in the sludge and concentrated sulphuric acid to form aluminium sulphate (alum) as indicated in the following equation:

$$2Al(OH)_3 + 3H_2SO_4 \longrightarrow Al_2(SO_4)_3 + 6H_2O$$

However, in actual practice, this process becomes more complicated and difficult due to the presence of organic and other extraneous matter in the sludge. Some of the impurities such as colour colloids and iron compounds, have a tendency to redissolve when the sludge is subjected to acid treatment.

For an economical feasibility of this process, the sludge must be thickened or partially dried prior to treatment with acid. Much of the published information related to alum recovery has been devoted to this aspect of the process. The use of dried sludge was the first to receive any serious attention. Experiments by Palin (15) indicated that substantial alum recovery can be achieved if the dried sludge was charred at temperatures of 750°F first and then its residue dissolved in a suitable quantity of concentrated sulphuric acid and water. He reported that he was able to obtain a yield of approximately 2 tons of alum cake (14% Al_2O_3) from four tons of air-dried sludge with 25 percent solids treated with 0.9 tons of 98 percent sulphuric acid. Satisfactory yields were reported by others (9) who conducted similar experiments on sludges that had been dewatered by use of other methods such as freezing and air-drying on wire mesh screens but heated only to temperatures of 480°F. In another study, the use of high ignition temperatures resulted in decreased amounts of alum being recovered and therefore it was suggested that the temperature should not exceed that required for self-combustion.

In another set of experiments, Palin (15) investigated the possibility of bleaching and oxidizing the colour colloids and other impurities in the liquors resulting from the acid treatment of alum sludge. He found that by treating the acid extracts with a high dosage of chlorine, the colour could be reduced and the resulting solution could be used to reduce the dosage of fresh alum required in the coagulation process. Although a substantial saving was achieved in the consumption of alum, the cost of the chemicals required did not justify the cost of alum saved.

Vahidi (27) (28) reported that the results obtained from his laboratory experiments showed that raw alum sludge subjected to anaerobic digestion prior to acid treatment helped to improve the recovery of alum.

Isaac and Vahidi (29) stated that one of the major problems experienced in the recovery of alum was the colour resulting from the iron and organic matter in the raw water. They found that by lowering the pH below 3, there was a slight increase in the alum recovery as well as an increase in colour.

Based on their laboratory and pilot plant studies carried out at Tampa, Florida, Roberts and Roddy (25) stated that the alum recovery from a thickened sludge containing one percent solids was economically feasible in a large plant operation. In their process, the settled sludge is drawn from the sedimentation basins and collected in a thickener. The thickened sludge is pumped into a reaction tank where concentrated sulphuric acid is fed and regulated by means of a pH control system. The pH is maintained between 1.5 and 2.5 for very high and low alkaline waters, respectively. From the reaction tank, the recovered alum is returned to the point of application for re-use. They reported that the savings in alum costs of approximately 70 percent could be realized by this method.

Similar studies were also conducted by Webster (26) at Daer Water Treatment Works, Scotland, which, as a result of improved coagulation techniques, was faced with the problems of handling increased volumes of sludge. The latter was obtained from the treatment of peaty water with a low alkalinity in an upflow solids contact sedimentaion basin.

After some extensive laboratory and pilot plant tests, he proposed a scheme for an alum recovery plant which involved the treatment of 0.5 percent solids sludge with sulphuric acid in a special acid treatment tank and then sludge dewatering by employing freezing and thawing techniques.

He reported that substantial recovery of alum was achieved with a considerable savings in chemical costs. The disposal of acidified sludge did not present any serious problems.

5.0 POLLUTIONAL EFFECTS OF WATERWORKS SLUDGE

As noted in a recent survey (12), it is apparent that sludge and filter washings from over 90 percent of the water treatment plants using chemical coagulation in the United States are eventually discharged into the receiving streams without any kind of treatment. This situation is also applicable to the disposal of purification wastes from nearly all of the waterworks in Ontario. Heretofore, this practice has not been regarded as being a potential source of pollution mainly because of the fact that none of these wastes contained any substances considered to be pollutants other than the impurities originally present in the raw water along with the spent chemicals used in the treatment process.

In the purification process, all of the undesirable constituents in the water are removed by chemical coagulation and accumulated in a more concentrated form as sludge in the sedimentation basins or as filter wash water. At the time of discharge, these wastes may become laden with suspended solids in the range of 50,000 to 100,000 ppm (30). Although the volume of these wastes may constitute only but a small percentage of the total water production and chemically, they may be considered completely harmless, nevertheless, sudden discharges even at infrequent intervals are liable to create some adverse conditions in the receiving streams. This is particularly true in cases where the lake or river does not have sufficient dilution water for good waste assimilation or adequate flow capacity to carry away the wastes solids from the point of discharge.

The following are some of the nuisance problems that have been reported and attributed to the dumping of these wastes into the receiving streams.

(1) Deposits of muck, silting problems and formation of mudbanks near the point of discharge appear to be one of the most common complaints (10)(12)(14)(30)(31).

(2) Sludge stored in basins for any length of time emits very disagreeable odours and may create some nuisance conditions in the stream. It was reported in one case that the cattle refused to touch the water which came from a river with sludge dumped into it (10)(13).

(3) Unsightly conditions may result in streams where the sludge is not carried away by the flow of water (10) (14) (30) (31).

(4) Sludge with high organic content could exert deleterious effects on the stream quality in the same manner as domestic sewage if the stream does not have an adequate capacity for self-purification (10) (13). Values of BOD reported in the literature are given on page 8.

(5) Greater use of powdered activated carbon has manifested itself on some bathing beaches located in the area where filter wash water has been discharged (10) (30) (31).

(6) Sludge consists of impurities removed from the raw water but present in much greater concentrations. When discharged improperly over a short period of time, it could impart turbidity and other undesirable constituents to the water and create some detrimental effects on the stream quality for its downstream users (10) (12) (13) (30) (31).

Filter washings usually contain only very small quantities of suspended solids and turbidity but according to the values reported in the literature, they may be as high as 1,000 ppm (30) and 500 units (12) respectively. Because of chlorination, the bacterial quality of wash water is usually better than that of the raw water (30) (31). Dean (12) stated that discharge of filter wash water to the stream would not be very objectionable. This opinion was also shared by others (10) (30) (31), while it was generally agreed that the sudden discharges of basin sludge in large volumes to the stream was considered undesirable.

6.0 SLUDGE DEWATERING METHODS

6.1 General

Water treatment plants that are unable to get rid of their purification wastes by discharging directly into a suitable watercourse or a nearby lagoon may be faced with some difficulty particularly if large volumes are involved. In such cases, it is considered more practical to reduce the overall volume of the wastes by sludge dewatering. This will help to facilitate the handling of sludge, especially if it must be transported over any distance to its final destination.

The sludge dewatering process involves the removal of water or the thickening of solids in a liquid system containing a very low percentage of suspended solids. This must be accomplished at the lowest possible cost.

A review of the literature has shown that nearly all of the published information related to the handling and treatment of waterworks sludge has appeared within the past ten years. In Britain, the disposal of waterworks sludge has become a growing problem. Consequently, this has stimulated considerable interest and research on various methods for reducing alum consumption, dewatering of sludge and recovery of alum (15).

Briefly, these are some of the methods that have been studied and considered practical for dewatering waterworks sludge:

(a) Natural Dewatering Methods

- (i) sedimentation in holding tanks, lagoons, ponds and reservoirs,
- (ii) drainage in sludge drying beds and wedge-wire filtration beds
- (iii) evaporation in drying beds.

(b) Mechanical Dewatering Methods

- (i) filter pressing
- (ii) vacuum filtration
- (iii) centrifuging

(c) Sludge Conditioning

(i) chemical
(ii) freezing and thawing
(iii) heat treatment

The selection of the method for a particular application depends on the character and the quantity of sludge to be handled, local conditions and the final disposal of sludge.

Many of the dewatering methods in practice are designed to take advantage of natural physical processes such as sedimentation, evaporation and natural drainage because they are considered to be the least expensive. However, these methods have certain limitations with respect to the thickness or the solids concentrations that can be attained and land requirements. Mechanical dewatering methods, though slightly costlier, are becoming more and more popular in municipalities where disposal sites are scarce and the cost of transportation has become an important consideration.

Waterworks sludges are by nature difficult to dewater. In order to improve the dewaterability, filterability and settling properties of the sludge, some changes must be made in its physical characteristics. This is called "sludge conditioning" and it is a technique that is used as a preliminary step in the preparation of the sludge for other methods of dewatering.

It is interesting to note that many of the methods and problems associated with the dewatering of waterworks sludges are also applied in the treatment and disposal of sewage sludges. The subject of dewatering sewage sludges has been thoroughly reviewed by others (17)(32)(33). Although both sludges bear very little resemblance to each other chemically, nevertheless their solids are colloidal and gelatinous in nature and for these reasons, many of the problems experienced in the dewatering processes are similar.

6.2 Factors Which Influence Sludge Dewatering

A comprehensive study was undertaken by Gauntlett (9) on the principal factors which determined the dewatering characteristics of waterworks sludges. He stated that alum sludge was perhaps the most difficult of all the waterworks sludges to handle for dewatering.

In order to confirm his findings, he made a detailed examination of all types of sludge that were collected from some 30 waterworks plants in England (34). He concluded that the particle size and the gelatinous metal hydroxide content were the two most important factors that determined the ease with which a sludge can be dewatered by drainage or pressure filtration.

The size of the floc particles was governed by the water treatment process and therefore could not be changed once the sludge was already formed. Smaller particles seemed to hinder settling rates and increase settled volumes and therefore they had a tendency to make dewatering of sludge more difficult by any method. Although the settling rates could be improved with the use of larger coagulant dosages, there was also a tendency to increase the volume of sludge produced and thus affect the dewatering process.

Coagulant chemicals employed in the purification of water produce very light voluminous floc particles which are gelatinous precipitate consisting of metal hydroxides. Gauntlett stated that these metal hydroxides, by their very nature, have a great affinity for water and therefore it would be impossible to remove very much water by ordinary physical methods. He concluded that any method for dewatering sludges must comply with the inherent nature of these metal hydroxides and therefore must be based on the removal or destruction of the hydroxide itself.

6.3 Sludge Dewatering by Sedimentation

Sedimentation is one of the most widely used methods for sludge dewatering. Its application can be found in the handling and disposal of sludges of many sewage and industrial wastes. It plays an important role in the pretreatment or the preliminary preparation of waterworks sludge for subsequent thickening processes.

In practice, the sludge from the sedimentation basin and filter washings are collected and impounded in holding tanks, lagoons or reservoirs where the suspended solids are allowed to settle out under the influence of gravity and the supernatant is decanted. At some waterworks, the filter wash water is handled separately. The solids are removed by sedimentation and then disposed of with the basin sludge. The clarified water may be then discharged directly to the stream or returned to the plant (1) (19) (21) (22) (23) (24).

Based on their studies, several authors (9) (16) (26) (35) (36) have reported that sludge thickening by sedimentation could be hastened by gentle stirring. It is apparent that this action helps to bring about the aggregation of the particulate matter, prevents the arching of the solids in the sludge and releases any liquid that may be entrapped in the floc particles. This, in turn, results in a smaller volume of sludge.

Data obtained from Webster's experiments and presented in Table 3 show dramatically the beneficial effects of gentle agitation on sludge thickening (26).

Table 3

EFFECTS OF GENTLE STIRRING ON SLUDGE THICKENING

	Solid Analyses in Percent	
Settling Tests with	Stirred	Not Stirred
(a) 0.60 percent sludge		
After 48 hrs	1.08	0.68
72	1.28	0.76
(b) 0.43 percent sludge		
After 48 hrs	1.00	0.71
72	1.08	0.73
172	1.57	0.85

In order to study the effects of slow stirring, Doe (35) designed a special apparatus which consisted of a small cylindrical tank with a conical base fitted on the inside with a set of four paddles. The latter was comprised of a number of 1/8-inch diameter steel rods placed vertically at 1 1/4-inch diameter centres and connected to an electric motor through a reduction gear assembly.

He conducted experiments to check the effects of stirring at different speeds on the thickening of solids in the wash water. He found that regardless of the initial solids concentrations in the sludge, the effects of small variations in stirring speeds tended to become equalized after a long period of stirring. He concluded that wash water sludge could be thickened economically by slow stirring in a relatively short time to about 5 to 6 percent solids.

6.4 Sludge Drying Beds

Sludge drying beds are commonly used for the dewatering of digested sewage sludges. The removal of water is effected by evaporation or natural drainage or by a combination of both. They are usually found in small to medium-sized plants because the high cost of labour involved in the removal of dried sludge would make them uneconomical for handling large volumes of sludge. Their effectiveness is governed by the climatic conditions in the locality. If the area is humid and has a great deal of rainfall, the drying time in the bed will be greatly lengthened (17)(32).

The literature indicates that only a very limited use has been made of sand drying beds for drying waterworks sludge.

A recent report (11) gives some details of an experimental study related to the drying of alum sludge in sand drying beds. It was found that a sample of sludge with one percent solids could be thickened to a concentration of over 20 percent total solids content in about 100 hours with a loading rate of approximately 0.8 lb per sq ft. The tests were conducted on a small bench model consisting of a bed bed made of 6- to 9-inch layers of 0.3 to 0.5 mm sand placed on an underdrain system comprising of 1/8- to 1/4-inch graded gravel bed varying in depth from 6 to 12 inches.

6.5 Wedge-Wire Filtration

The use of a wedge-wire filtration bed has been developed recently in Britain for dewatering sewage sludges, industrial wastes and waterworks sludges that are very difficult to handle (37). This consists of a drying bed having a bottom fitted with a specially woven fine wire mesh with the apertures in the range of 0.125 to 0.25 mm. The wet sludge is placed on the bed at a depth of 6 to 12 inches and the water is removed by natural drainage and evaporation.

According to its suppliers, wedge-wire filtration offers several advantages over the conventional type of drying bed:

(a) lower cost of installation
(b) rapid initial drainage
(c) increased capacity due to faster drying time
(d) economy of operation

Sankey (16) conducted some experiments on dewatering waterworks sludge with wedge-wire filtration. He found that great care was required in applying the sludge to the bed and the control of the initial draining was extremely critical in order to prevent a breakthrough of floc particles through the wedge-wire. It was claimed that sludge can be thickened from 2 percent solids to 25 percent, in a 21-day cycle under proper conditions.

6.6 Mechanical Dewatering Methods

Mechanical devices, such as filter presses, vacuum filters and centrifuges, are employed extensively in the handling and treatment of sludges derived from sewage treatment and industrial wastes. Only a limited number of these are actually found in the application to the disposal of waterworks sludge. Most of these have been reported in British publications and involve the use of filter presses. The application of vacuum filters and centrifuges to the dewatering of waterwork sludge has been limited to laboratory and pilot studies. A review of published information related to filter presses and vacuum filters is presented in the following sections.

6.6.1 Filter Presses

Filter presses have been used quite extensively in England and on the continent for dewatering chemically treated sewage sludges. Because of their high costs of initial outlay, labour, filter media and conditioning chemicals, they have not been widely accepted in the United States. It is doubtful if any of those filter presses installed for dewatering sewage sludge some years ago are in use today (32).

Recent English publications give details of experiments conducted by various authors to investigate the applicability of filter presses for dewatering waterworks sludge. Palin (15) reported that alum sludge derived from the coagulation of slightly alkaline peaty waters at Whittle Dene Waterworks at Newcastle could not be treated satisfactorily in filter presses.

Doe (35) was interested in improving this technique of filter pressing so that it could be used in conjunction with his sludge freezing process. His concern was the length of time required in the production of a dry cake.

The results of his study indicated that preliminary thickening of the sludge by slow stirring prior to filter pressing helped to produce a far better cake. By filter pressing at moderate pressures, sludge cakes with about 25 percent solids could be produced without any difficulty but the centre of the cake remained sloppy. The wet cakes presented some problems in the disposal. However, this could be overcome by longer pressing time or by the use of chemical conditioners such as aluminium chlorohydrate.

The major advantage of filter pressing was the lower capital cost of the plant, but this may be offset by the necessity of providing space to stack the cakes to dry and by the frequent replacements of new filter cloth.

Sankey (16) conducted similar experiments to evaluate the effectiveness of chemical conditioners prior to filter pressing. He found that hydrated lime yielded the best results. However, the main disadvantage of utilizing lime or any other chemical as a conditioner was that it might constitute a substantial proportion of the sludge cake. This, in effect, reduced the output of the plant and increased the weight of the material that had to be removed from the plant. He suggested that the use of other conditioners such as aluminium chlorohydrate or polyelectrolytes which require a dosage of only a few ppm may be more practical.

6.6.2 Vacuum Filtration

Vacuum filtration is another method of mechanical dewatering which is used very widely in the handling of sewage sludges. Some laboratory and pilot tests have been conducted by Doe (35) and Sankey (16) in Britain to investigate its application to waterworks sludge. It was also considered in a recent study conducted by New York State Department of Health (11).

Doe (35), in his investigations to find ways of improving the performance of his filter presses, felt that vacuum filtration offered some attractive possibilities. With this in mind, he undertook a few tests in a small rotary vacuum filter devised with a porous bronze surface but he found that it becomes clogged very rapidly at pressures of only 10 psi. After several tests, he could obtain yields of only 0.14 lb dry solids per hr even with pressures increased to 100 psi in comparison to a minimum yield of 2 lb dry solids per sq ft per hr, which is considered to be economical for a vacuum filter. Therefore, he concluded that the sludge from his waterworks was not amenable for vacuum filtration.

Sankey (16) conducted his tests on a small pilot rotary vacuum filter with a filtering area of 10 sq ft. He reported that he could not dewater sludge even with 2 percent solids by direct application on a conventional type of filter cloth. However, with diatomaceous earth applied as a precoat on the filter cloth, he achieved varying degrees of success. He concluded that the settled sludge was not amenable to direct vacuum filtration unless it could be done with the use of a precoat. He suggested that the sludge should be subjected to some form of pretreatment or conditioning prior to filtration. In his experiments, a sample of sludge treated with 2 percent hydrated lime produced a filter cake with 15 percent solids at a filtration rate of 4 gph and this was hardly dry enough for direct disposal on the land.

In another study (11), results of laboratory experiments indicated that a filter cake with 20 percent cake could be produced by vacuum filtration of a clarifier sludge containing 1 percent solids. A precoat of diatomite was applied on the filter and the sludge was treated with lime prior to filtration.

6.6.3 Effectiveness of Various Dewatering Methods

It has been reported that waterworks sludges can be compacted to thickness of approximately 14 and 20 percent solids by sedimentation in earth lagoons after three years (11) (12). Experimental data obtained from underdrained systems which utilize evaporation and natural drainage showed that a sludge with one percent solids can be concentrated to about 20 percent within 100 hrs (11) and 2 percent sludge can be dried to 25 percent by wedge-wire filtration in a 21-day cycle (16).

By the use of filter presses, it is possible to obtain sludge cakes with up to 25 percent solids depending upon the pressure applied (9) (35).

Various results have been reported for rotary vacuum filters using a precoat. In one case, using a 1/2-inch thick precoat of Kieselguhr, deposited on the filter cloth, a filter cake containing 8 percent moisture was produced (9) and the results of another study showed that a filter cake containing 20 percent solids (11) could be produced.

A report of one study indicated that by centrifuging, sludge could not be concentrated to any more than 12 percent solids even with the use of polyelectrolytes and lime (11).

7.0 SLUDGE CONDITIONING

7.1 General

Most sludges are difficult to dewater and cannot be very easily filtered. By conditioning the sludge, it is possible to effect some changes in the physical and chemical characteristics of the sludge solids so that they become more filterable and made to separate more easily from the liquid.

Sludge conditioning is a technique commonly used in the treatment of sewage sludges as a preliminary step to mechanical dewatering. This is done by the addition of chemicals such as ferric chloride, either with or without lime and is known as "chemical conditioning".

In recent years, some experimental and pilot plant studies have been conducted by a number of research workers to investigate the feasibility of sludge conditioning techniques involving heat treatment and freezing and thawing. The details of these studies are discussed on the following pages.

7.2 Chemical Conditioning

In the treatment of sewage sludges, it is a common practice to treat the sludge solids with certain substances such as alum, ferric chloride, lime or polyelectrolytes as a preliminary step immediately prior to mechanical dewatering. These chemicals are known as "conditioning agents" which are added and mixed with the sludge in definite proportions based on the weight of dried solids fraction in the sludge (38). Their main purpose is to change the characteristics of the sludge solids by a complex mechanism somewhat similar to chemical coagulation so that they can be more easily separated from the liquid (36). As a result of conditioning, the colloids and other finely divided particles dispersed in the sludge begin to coalesce and form large particles which, in turn, improve its filterability and drainage characteristics.

Much of the work related to chemical conditioning of waterworks sludge reported in the literature has dealt with the pretreatment of sludge for further dewatering by filter pressing and vacuum filtration.

For the treatment of waterworks sludge, lime, aluminium chlorohydrate and polyelectrolytes are the chemicals frequently mentioned. Sankey (16) reported that sludge conditioned with hydrated lime produced excellent results when subjected to filter pressing and vacuum filtration. He pointed out that the use of lime or any other similar conditioning chemical added in some weight proportion of the sludge to be treated, had a tendency to give extra weight and become a portion of the filter cake thereby reducing the output of the plant. In another case, the addition of lime to the sludge obtained from the upflow solids contact unit helped significantly in vacuum filtration (11).

In his work, Doe (35) found that the use of aluminium chlorohydrate prior to filter pressing helped to give more uniformly dried cakes that peeled off easily from the filter cloth.

7.3 Polyelectrolytes

During the recent years, there has been a growing interest in the application of polyelectrolytes for sludge conditioning (39) (40). Polyelectrolytes are a class of synthetic organic compounds that are water-soluble and characterized by a polymer-type of structure. They have very high molecular weights that may be in the range of a few thousand up to well over one million. They are used quite extensively for many applications such as conditioning agents for soils and in sewage treatment, as thickening agents in the sedimentation of clays and finely divided mineral ores and also as coagulant aids in the purification of water and industrial wastes.

A review of the literature indicated that there is only limited information available on the use of polyelectrolytes in the treatment of waterworks sludge. Sankey (16) mentioned that polyelectrolytes may yield better results in dewatering sludge by vacuum filtration but its cost did not justify its use. Benson and Thomas (39) found that polyelectrolytes were more effective in conditioning sludges which did not respond to treatment with lime while in another case, it was reported (11) that they did not improve the filterability of alum sludge as well as lime. Doe (35) suggested that polyelectrolytes might be used to an advantage prior to freezing.

Gauntlett (40) conducted an extensive series of laboratory experiments on a wide range of commercially available polyelectrolytes. He found that the most effective types of polyelectrolytes for dewatering alum sludge consisted of polyacrylamides and their derivatives. They seemed to enhance the drainage and settling characteristics of the sludge and with proper usage, improved its filterability. He concluded that polyelectrolytes should have minimum molecular weights of at least one million in order to yield satisfactory results. For the treatment of any particular sludge, the dosage and the type of chemical should be determined by experimentation.

7.4 Heat Treatment

Heat treatment is another method which has been studied as an aid to sludge dewatering. A number of sewage treatment plants in Britain have reportedly adopted the Porteous method as a prelude to the filtration of sewage sludges (15) (18) (41). In this process, the raw sludge is heated to 360°F with steam in a heat exchanger for a period of 30 to 45 minutes. This helps to break down the gel structure in the sludge and destroy some of its affinity for water. After treatment, the sludge is discharged to decanting vessels where the solids settle out very quickly and supernatant water is removed by decantation. The settled sludge is further thickened by means of filter presses.

Palin (15) conducted some experiments on alum sludges using this method of treatment. He found that heat treatment improved the settleability of the sludge and its effect was dependent on the steam pressure. He concluded that the cost of an extensive plant utilizing this type of treatment would be fairly expensive but with the use of heat restricted to sludge conditioning and decantation, it may be worthy of consideration.

7.5 Freezing and Thawing

When subjected to slow freezing, alum sludge undergoes physical changes and loses its gelatinous characteristics. Upon thawing, the solid particles, in the sludge, become more friable and settle out more readily.

The first experiments involving freezing and thawing techniques were carried out on dewatering sewage sludges but Palin (15) applied the same principles to the treatment of alum sludge derived from the waterworks at Whittle Dene and found some very startling results. He noted that there was a marked improvement in the filtrability and settleability of the solids in samples treated in this manner. When subjected to freezing tests, he found that the solids in the alum sludge settled out very rapidly to about 16.7 percent of the original volume in a matter of two or three minutes and a clear supernatant was produced while in the untreated sample, the solids settled to a final volume of 69 percent after 48 hrs.

After freezing and thawing, the solids in the sludge become more friable and more easily filterable. Palin reported that filtration was almost instantaneous using a vacuum filtration. He was able to obtain a filter cake having a solids content of 33.9 percent from a settled sludge with 20.2 percent solids.

A detailed investigation was also carried out by Doe (35) on the application of freezing techniques for dewatering waterworks sludge. These were some of his conclusions based on the results of his laboratory experiments.

(1) Freezing changes the gelatinous characteristics of the sludge and renders it more filterable when thawed out.

(2) Freezing time was critical. Rapid freezing produced very little change in the colloidal character of the sludge. Best results were obtained with a thawed sludge that has been frozen very slowly over a 2-hr period.

(3) The minimum time that the sludge remains in the frozen state prior to thawing is extremely important. Sludge, thawed immediately after freezing, produced very poor results and therefore a minimum holding time of 15 minutes was suggested.

(4) Methods applied in thawing had no significant effect on the ultimate filtrability of the sludge.

(5) Initial concentrations of solids in the sludge had no bearing on the freezing process nor on its filtrability.

Because the results of Doe's experiments were encouraging and indicated definite promise, a full scale plant was finally built to handle 4,800 gpd of sludge and then later extended to 11,000 gpd. This is described by Doe et al (42) and it consists of three separate stages; preliminary thickening by slow stirring, retention for further sedimentation and then final dewatering by freezing.

The sludge and wash water from the water treatment plant are collected in specially designed 30-ft diameter octagonal tanks which are equipped with slow-stirrers. Here, the sludge is thickened from 0.5 percent solids to about 2.0 percent solids. In the second stage, the sludge is further thickened to 2.4 percent solids by settling for a 24-hr period in another tank. In the final stage, thickened sludge is transferred to a special freezing cell where it is frozen. The freezing cell is equipped with a liquid ammonia refrigeration system.

Each cell is designed to handle 150 gals of sludge and is equipped with a series of vertical freezing tubes. The process consists of two cycles, consisting of 45-minute freezing and then 45-minutes of thawing. After the sludge is frozen, the flow of ammonia through the tubes is reversed and this causes the frozen sludge to melt. After thawing, the supernatant is decanted from the sedimentation tank and discharged into the river.

The authors were convinced that the freezing technique was a feasible method of dewatering sludge at Stocks Filtration Plant.

As mentioned previously, Webster (26) suggested the use of freezing techniques as a final step in his proposed alum recovery plant to reduce the volume of the acidified sludge before disposal.

8.0 CONCLUSIONS

Sludge and other purification wastes derived from over 90 percent of the chemical coagulation plants in Canada and the United States are discarded by simply dumping into the nearest streams or watercourses without any kind of treatment. Although most of the constituents in these wastes are considered to be innocuous, large volumes of sludge discharged suddenly into a receiving stream may have some far-reaching and significant effects, cause nuisance problems and jeopardize the water quality for its downstream users.

With the future prospects for steadily increasing volumes of wastes being generated from water treatment plants, present practice of waste disposal will no longer be considered as a satisfactory method particularly where the water quality becomes adversely affected for its downstream users.

If sufficient land is available near the waterworks plants, lagooning is considered to be one of the cheapest method of sludge disposal. Unfortunately, most of the land in the vicinity of large population centres is becoming depleted and too valuable to use for this purpose.

It is expected that liquid wastes will be dried and transported to another locality for ultimate disposal as landfill. Therefore, techniques involving sludge conditioning and sludge dewatering will become an important part of handling and disposal of waterworks sludge.

Polyelectrolytes, particularly polymers with high molecular weights, appear to offer some interesting possibilities because they require only very small dosages. Their selection, however, should be made only after a thorough experimentation.

Sludge conditioning with heat treatment would not likely be considered economically feasible at the present time. The application of freezing and thawing techniques would be somewhat more expensive than chemical conditioning, but this method offers some interesting possibilities, particularly for use in conjunction with an alum recovery process.

The feasibility of reclaiming alum from waterworks sludge for re-use in water treatment would be rather difficult to justify at most plants in Ontario because of the low cost of fresh alum. The savings in chemical costs achieved by alum recovery must be weighed against the costs of the necessary equipment and operation.

The disposal of sludge will assume a role of greater importance with those who are actively engaged in pollution control activities and those who are concerned with the design and operation of waterworks.

9.0 RECOMMENDATIONS

Serious consideration should be given to include and incorporate sludge disposal as an integral part of the water treatment process. It is therefore recommended that some provisions be made in the design of any new water treatment plants for the installation of suitable facilities for the proper disposal and treatment of wastes by-products derived from water purification.

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