COMBINED DISPOSAL OF WATER SOFTENING AND SEWAGE SLUDGES

by

MILTON D. LARSEN

B.S., Kansas State University, 1973

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1975

Approved by:

Lawrence A. Schmid

Major Professor

ACKNOWLEDGMENTS

I wish to thank Dr. Lawrence A. Schmid for his assistance and patience. I would also like to thank Dr. Jerome J. Zovne, Dr. Robert R. Snell, and Dr. Jason C. Annis for serving on the review committee. I am appreciative of the assistance provided by the staffs of the water softening and sewage treatment plants in Junction City and for the information provided by Allyn Moore of Caspar Engineering.

Financial support for this project was provided by Junction City and for this I am thankful. I will be ever grateful for the support and understanding provided by my family and friends.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

For years water treatment plants have disposed of their sludges by the most convenient and economical means available. In most cases, this meant that the sludge was discharged into the river or lake that had been the treatment plant's source of raw water. In 1949, Black (2) surveyed 21 states and 371 lime or lime-soda ash water softening plants. He found that 58.4 percent of the water softening plants surveyed discharged their waste sludges into a watercourse. A 1953 survey of approximately 1600 water treatment plants revealed that 92 percent of the plants studied discharged their sludges into a stream or a lake (30).

Public Law 92-500 was enacted in October 1972 due to the growing public concern over water pollution. This law considered water softening sludges as industrial wastes and a pollutant when discharged into a watercourse. The discharge of these sludges is legal at this time if a permit has been granted, but it will have to be discontinued by July 1, 1977.

The water softening plant in Junction City, Kansas is currently discharging the waste softening sludges and backwash water into the Republican River under a temporary discharge permit granted by the Kansas Department of Health and Environment. One alternative method for the disposal of these sludges that is currently being studied is to transport them to the Junction City Waste Treatment Plant where they may be disposed of along with the sewage sludges.

The Junction City Waste Treatment Plant is currently being upgraded from primary treatment to include secondary treatment in order to meet the 1977 "best practicable control technology available" provisions of PL 92-500. In the upgraded waste treatment plant, the raw primary sludge will be taken from the primary clarifier and blended with thickened waste activated sludge before vacuum filtration. If the lime softening sludges are added to the sewage sludges it will occur when the primary and activated sludges are blended. Final disposal will be to a landfill.

Since the primary sludge will not be digested, it must be stabilized in some way before disposal. The primary purposes in stabilizing the sludge are to destroy the pathogenic organisms and to avoid offensive odors. Lime stabilization was the method selected to stabilize the waste sludges. Lime is added to the sludge in order to create a high pH condition which is lethal to most pathogens and greatly reduces the offensive odors. It was hoped that the addition of softening sludges to the waste treatment plant's sludge would raise the sludge pH enough to reduce the required lime dose.

LITERATURE REVIEW

SOFTENING SLUDGE DISPOSAL TO SEWAGE TREATMENT PLANTS

There have been a relatively small number of cases in which water softening sludges were disposed of by discharge to the waste treatment plant. In Black's (2) 1949 survey of 371 lime and lime-soda ash water softening plants, it was determined that only 8.6 percent of the plants discharged their sludges to a storm drain, sanitary sewer, or directly to a sewage treatment plant. In a 1969 study of approximately 80 large water treatment plants, 6 were found to have disposed of their softening sludges by means of a storm or sanitary sewer (5, 30).

Several problems have been encountered with this means of disposal. Lime softening sludges have been known to settle out and plug sewers (14). In order to avoid this problem, an adequate flow must be maintained along with high velocities. This should dilute the sludge and keep the sewers scoured out.

There have been a number of reports in which lime softening sludges were blamed for causing problems in anaerobic digesters (2, 5, 14). Krasauskas and Streicher (14) mentioned that it was possible that the problems occurring within the digesters could be due to a disproportionate build up of softening sludge which inhibits biological action. Black (2) reported a case in Lebanon, Indiana, where the softening sludge stopped digestion and plugged the anaerobic digesters. This treatment scheme was abandoned and the sewage and softening sludges were lagooned together. Black reported that the combined sludge was relatively stable with no fly or odor problems. Russell and Russell (26) reported on a case in Daytona, Florida where sludge digestion was not included in the treatment process because of the addition of lime softening sludge. They noted in a pilot study that the lime softening sludge greatly inhibited the decomposition of sewage.

The waste treatment plant in Daytona was designed to take advantage of the lime softening sludge's properties in the joint treatment of sewage and softening sludge (2, 21, 26, 37). Williamson (37) reported that the softening sludge would be used as the coagulant for the sewage in an upflow clarifier. The plant achieved a 45 percent reduction in BOD and a 75 percent suspended solids removal with a much smaller clarifier than is normally required in conventional primary sedimentation. Russell and Russell (26) mentioned that there were some odor problems because the sewage was often septic when it reached the plant.

Shortly after the construction of the waste treatment plant in Daytona, a similar plant was built in Ocala, Florida (20). It was in use until 1961 when it was abandoned due to poor maintenance. In 1968, Black and Veatch (3) finished a design report for a waste treatment plant in Dallas, Texas. The plant was to use lime softening sludge to treat overflows from the sanitary sewer during periods of high infiltration. O'Brien and Moore (21) studied the use of softening sludge with sewage in an upflow clarifier employing solids recycling. They found that it could remove 83 percent of the BOD, 81 percent of the suspended solids, and 45 percent of the phosphorous.

Culp and Culp (7) reported that at Lake Tahoe it was difficult and expensive to centrifuge mixtures of raw primary, waste activated, and lime clarification sludges. The sludges dewatered much better when the chemical and sewage sludges were centrifuged separately. Culp and Culp did note that there was some evidence that mixtures of chemical and sewage sludges from hard water areas did dewater much more readily than those from soft water areas.

LIME DISINFECTION AND STABILIZATION

For years lime has been used in a number of different ways in water supply and waste treatment. Lime has long been used to reduce the fly and odor problems around latrines (33). Lime has been used at numerous waste treatment plants to condition sludge for vacuum filtration (28). Farrell, et al. (9) reported that lime stabilization of sewage sludges precipitated by alum or iron decreased the specific resistance by a factor of 4 and doubled the filter yield. Much of the early knowledge gained on the disinfecting power of elevated pHs came from the water softening plants.

In 1912, Dr. Houston (12), a chemist for the Metropolitan Water Board in London, England, noticed the destruction of bacteria in lime treated water and proposed the use of excess lime treatment to sterilize water. The following year, Hoover and Scott (11) reported that when the free and half-bound carbonic acid was precipitated along with the magnesium by lime addition, the bacteria belonging to the colon and typhoid groups were killed within 48 hours if the water did not contain a large amount of organic matter. It took from 4 to 24 hours to disinfect the water if an excess of 1/2 to 1 grain of lime per gallon was added over the amount required to reduce the carbonate hardness to its minimum value. Hoover and Scott also mentioned that the disinfecting action of the excess lime destroyed the pathogenic bacteria while allowing certain nonpathogenic bacteria to live.

Streeter (29) reported on U.S. Public Health experiments which showed that the bactericidal efficiency of excess lime in the treatment of water is directly related to the degree of causticity.

Wattie and Chambers (36) studied the effects of lime addition to water containing Escherichia coli and the pathogens Eberthella typhosa and Shigella dysenteriae. They found that at room temperature and a pH ranging from 10.51 to 11.00 it took 10 hours to completely destroy E. coli, while pH 11.01 to 11.50 took 5 hours to achieve a 100 percent kill. A 100 percent kill of Eberthella typhosa required 4 hours at pH 10.51 to 11.00 and 2 hours at pH 11.01 to 11.50. Shigella dysenteriae was completely destroyed in 2 to 3 hours at pH 10.51 to 11.00 while pH 11.01 to 11.50 required 75 minutes. Wattie and Chambers also found that if the temperature was decreased, the survival times of the bacteria increased.

In 1952, Riehl, et al. (24) published a paper on the survival of bacteria at varying pHs, temperatures, and water qualities. They determined that E. coli could be destroyed in 30 minutes in distilled water at pH 11.7 and 5°C, at pH 11.4 and 15°C, and at pH 10.3 and 25°C. In soft water, a pH of 9.5 or greater killed all of the E. coli within 8 hours. E. coli kills were often less than 100 percent at the end of the 10-hour study period for hard and turbid waters. In distilled water at pH 11.0, S. Montivideo was completely destroyed in 2 hours at 2°C and in 30 minutes at 12°C. S. typhosa survived for 1 hour at 2°C and 30 minutes at 12°C in distilled water at pH 11.5. In clear river water, S. typhosa survived for 5 hours at 12°C and pH 11.6 while at 2°C and pH 11.5 it survived 8 hours. The authors concluded that at 15°C a 4 hour plus detention time with a pH in the range of 11.0 to 11.5 should kill many of the bacteria that they tested.

In a later paper, Riehl, et al. (25) reviewed the disinfecting powers of lime as used in water softening. In the Mahoning Valley Sanitary District, the water was limed to a pH of 10.6 to 10.9. After a 3 1/2 hour detention period, the coliform index of the settled water was 1 percent of that found in the raw water. Riehl, et al. also reported that the St. Louis Water Company lime softens Missouri River water, raising the pH from 8.0 to 10.2. After a 3 1/2 hour detention period, there was an 83.5 percent reduction in the number of coliforms and an agar count reduction of 93 percent. Lab tests were run on the same water in which it was mixed with lime for an hour and settled for an hour. At pH 11.2 the reduction in the total count neared 100 percent, and at pH 11.4 the coliforms were completely destroyed.

Berg (1) reported that water at pH 11 and 25°C would destroy S. typhosa and 99 percent of the E. coli within 2 hours. Berg also found that at pH 9.6 and 25°C, 99 percent of the polio virus I is killed within 36 hours.

After their review of the literature and research, Thayer and Sproul (31) felt that many of the animal viruses are inactivated to a large degree by high pHs such as those found in water softening.

In 1936, McCulloch and Costigan (16) studied the effects of temperature and the presence of organic matter on the disinfecting powers of several bactericides. They found that at 2° and 20°C it took roughly double the amount of sodium hydroxide to produce a kill in fecal suspensions that was equal to the kill in those not containing feces. When the temperature was raised to 40°C, there was a smaller difference between the kills in the different mediums. They found that the disinfecting power of lye varied only slightly between 2° and 20°C, but there was a large increase between 20° and 40°C.

In 1923, Winslow and Falk (38) reported that bacteria possess the ability to lower the pH of an alkaline solution. A few years later, Watkins and Winslow (35) determined that the bacterial concentration was important to the bacteria's survival in alkaline solutions. They reasoned that as the bacteria concentration increased, so would the concentration of buffering agents. Lange (15) found that the presence of dead bacterial cells in a medium would also tend to protect the surviving bacteria.

Using lime as a flotation flocculant for humus tank effluent in a flocculation/flotation system, van Vuuren, et al. (32) found that excellent E. coli and Poliovirus reductions were obtained when the pH in the flotator was 11.4.

Grabow, et al. (10) also worked with a flocculation/flotation system for humus tank effluent, and they noted that all the previous studies on the disinfecting power of lime had dealt only with Gram-negative bacteria. They determined that the Gram-positive and acid-fast bacteria were more resistant to an elevated pH than the Gram-negative bacteria. It was reported that when the humus tank effluent was maintained at pH 11.5 for 60 minutes, 99 percent of the bacterial population was destroyed including all of the Gram-negative bacteria. Most of the surviving population was made up of bacterial spores.

According to Mitchell (17), the most important pathogenic bacteria that contaminate water supplies are of the genera Salmonella, Shigella, and Vibrio comma. These bacteria are Gram-negative, non-spore formers.

Buzzell and Sawyer (4) found that when raw wastewater was limed to pH 10.9 or greater for 1 hour or more, the coliform kill was always greater than 99 percent and the median kill was greater than 99.9 percent. When sludge was placed in an air tight container from 4 to 7 days, they found that sludge with a pH below 11.0 became highly odorous, while sludge with a pH over 11.0 exhibited no odor problems.

Humble (13) studied lime disinfection of raw sewage at low temperatures. He found that the coliform kills at pH 10.0 and 10.5 were insufficient. At pH 11.0 the kills were improved, but a long contact time was required for satisfactory kills. Rapid coliform kills were obtained at pH 11.5 and 12.0, and the total and fecal coliforms were reduced to about 10 per ml in both the precipitated solids and the effluent after 90 minutes contact time. At pH 11.0 or lower, the total coliforms exhibited much better survival in the precipitated sewage solids than in the effluent. At pH 11.5, total coliform survival in the solids was slightly better than in the effluent, while at pH 12.0 the kills were practically the same. Humble also noted that the fecal coliforms had less tolerance for high pH conditions than did the total coliforms.

Farrell, et al. (9) used lime to stabilize chemically precipitated primary sludges at Lebanon, Ohio. A lime slurry was gradually air mixed with the sludge until pH 11.5 was reached. The sludge was maintained at pH 11.5 and mixed for another 30 minutes before being discharged to sand beds. A downward drift was observed in the pH shortly after lime addition; however, if the pH was raised to 11.5 the pH quickly dropped to just above 11, but failed to drop below pH 11 within 24 hours.

Farrell, et al. determined during their preliminary studies that it took approximately 200 pounds $Ca(OH)_2$ per ton of raw primary sludge to reach pH 11.5. The alum and iron precipitated sludges took 800 pounds and 540 pounds $Ca(OH)_2$ per ton of solids respectively. During the plant scale studies it was observed that the lime demand had diminished and the alum sludge required 550 pounds $Ca(OH)_2$ per ton of solids while the iron sludge required 230 pounds $Ca(OH)_2$ per ton of solids.

Obnoxious odors were present when the sludge was first mixed with air. After lime addition ammonia was stripped from the sludge masking the obnoxious odors. The ammonia odor quickly diminished and after a short period of storage on the drying beds only a humus like odor remained.

The sludge was stored on the sand beds for one month before bacterial testing. It was determined that Salmonella sp. and P. aeruginosa had been destroyed, while the total aerobic count was somewhat reduced. The surviving bacteria appeared to be non-pathogenic, spore formers.

Farrell, et al. carried out further bacteriological studies on an iron precipitated primary sludge. The sludge was limed to pH 10.5, 11.5, and 12.5 before mixing for 0.5 hours. A pH of 10.5 was found to be unsatisfactory for killing pathogens. At pH 11.5 there was a slight indication of P. aeruginosa at 0.5 hours, but it was not detected at

24 hours. Salmonella sp. was not detected at either 0.5 or 24 hours. No pathogenic bacteria was detected at pH 12.5.

Farrell, et al. also tested several filter cakes at pH 11.5 for pathogenic bacteria. At 0.5 hour contact time, the pathogens were found to be below detectable levels. There was a deterioration of the bacterial quality of the filter cake at 24 hours with P. aeruginosa reappearing. This was attributed to the short two minute conditioning time with lime before filtration.

It was determined that higher organisms such as Ascaris ova could survive pH 11.5 for a 24 hour contact period, but Farrell, et al. concluded that the hazard from these organisms is no more than in a well digested sludge, while the bacterial and virus hazard is much less.

Doyle (8) investigated the survival of Salmonella typhosa and coliforms at high pHs in raw sewage filter cakes. He determined that filter cakes with a pH of 12.2 or higher completely destroyed S. typhosa in less than 2 hours. If the pH of the filter cake could be maintained at pH 11.0 or higher for 24 hours, S. typhosa was completely killed. Doyle found the coliform to be much more resistant to elevated pHs than S. typhosa and it was his opinion that the coliform "...should not be used as the criterion for judging the safety of sludge for disposal purposes." Doyle reported that a considerable downward drift occurred in all the filter cake pHs below 12.2. At pH 12.2 or higher, the pH was found to drop 0.2 pH units or less in 24 hours.

In a study conducted for the EPA, Courts and Schuckrow (6) reported that sewage sludge must be limed from pH 12.2 to 12.4 and maintained above pH 11.0 for over 2 weeks in order to insure stabilization. Paulsrud and Eikum (23) agreed with the above findings and estimated that it takes from 200 to 300 pounds $Ca(OH)_2$ per ton of primary sludge and 600 to 1000 pounds $Ca(OH)_2$ per ton of biological sludge to keep the pH over 11.0 for at least 2 weeks.

It must be realized that lime stabilization never chemically stabilizes the sludge (9, 22). Even with extremely high lime doses chemical or biological action will eventually bring the pH down and surviving bacteria may regrow under favorable conditions.

RESULTS AND DISCUSSION

SOFTENING SLUDGE AND BACKWASH

Since Junction City must soon discontinue the discharge of lime softening sludge into the Republican River, it was decided to investigate the possibility of transporting the softening sludge to the waste treatment plant which might be able to economically dispose of the sludge. In order to evaluate if this was a feasible means of disposal, it was first necessary to determine the weight and volume of softening sludge produced each day along with its composition and properties. It was important to determine the volume of softening sludge produced each day in order to assess the transportation requirements. The softening sludge and backwash water volumes were also important because they determine the size of the catch basin. The quantities of softening sludge produced and its properties could influence the dewatering process and would determine if the softening sludge could raise the pH of the sewage sludge to the extent that it would reduce the amount of lime required for lime stabilization.

Calculated Softening Sludge Quantities

The quantity of softening sludge produced in an average day was determined by running a chemical balance on the raw and finished water. Junction City is currently obtaining its raw water from eight wells that are located adjacent to the water softening plant along the Republican River. The pumping rate of each well and the total hardness of the raw water is listed in Table 1.

TABLE 1

Well Pumping Rates and Raw Water Hardness

Well #	Q in gpm	Total Hardness in mg/l as $CaCO_3$
2	50	194
3	555	224
4	538	254
5	250	194
6	527	318
7	1000	222
8	555	318
9	1000	222

The daily flow rate, hours each well was pumped, and finished water hardness were taken from the daily log at the Junction City Water Softening Plant for three days in June, four days in July, one day in August, and eight days in November in order to assist in determining the sludge quantities produced. The total hardness removed from the water was found to average 127 mg/l as $CaCO_3$, as shown in Table 2. The average daily flow rate for 1974 was estimated to be 2.4 MGD (18). At the year's end, it was determined that the average daily flow rate was actually 2.28 MGD as shown in Table 3.

TABLE 2

Total Hardness as mg/l $CaCO_3$ Precipitated From the Raw Water

Day	Raw Water	Finished Water	Hardness Removed
6/03/74	244	116	128
6/13/74	253	122	131
6/23/74	237	113	124
7/03/74	251	110	141
7/18/74	252	118	134
7/23/74	257	115	142
7/24/74	259	121	138
8/26/74	254	128	126
11/01/74	253	153	100
11/02/74	254	153	101
11/03/74	277	151	126
11/04/74	279	142	137
11/05/74	279	161	118
11/06/74	278	154	124
11/07/74	269	147	122
11/08/74	289	146	143

TABLE 3

Flow Through Water Softening Plant During 1974

Month	Q (million gallons)
Jan.	68.4
Feb.	55.0
March	60.8
April	61.1
May	68.5
June	84.9
July	124.9
Aug.	87.8
Sept.	63.8
Oct.	54.3
Nov.	47.6
Dec.	56.7
Total	833.8

Q average day = 833.8/365 = 2.28 MGD

After the raw water enters the water softening plant, it is pumped to a tray aerator to remove the carbon dioxide. The water then flows into the rapid mix chamber for lime addition. Water samples could not be obtained between the aerator and the rapid mix for CO_2 analysis; therefore, it was assumed that 10 mg/l CO_2 remained in the water after aeration.

In lime softening, the CO_2 and hardness are precipitated from the water by the following reactions (34):

(1) $CO_2 + Ca(OH)_2 \rightleftharpoons \underline{CaCO_3} + H_2O$

(2) $Ca(HCO_3)_2 + Ca(OH)_2 \rightleftharpoons \underline{2CaCO_3} + 2H_2O$

(3) $Mg(HCO_3)_2 + Ca(OH)_2 \rightleftharpoons \underline{CaCO_3} + MgCO_3 + 2H_2O$

(4) $MgCO_3 + Ca(OH)_2 \rightleftharpoons \underline{CaCO_3} + \underline{Mg(OH)_2}$

(5) $2Na\ HCO_3 + Ca(OH)_2 \rightleftharpoons \underline{CaCO_3} + Na_2CO_3 + 2H_2O$

(6) $MgSO_4 + Ca(OH)_2 \rightleftharpoons \underline{Mg(OH)_2} + CaSO_4$

The alkalinity of Junction City's raw water normally runs around 253 mg/l as $CaCO_3$ (18). If an average of 127 mg/l of the total hardness is precipitated from the water, then approximately one-half of the alkalinity will be consumed. Since only one-half of the carbonate hardness is precipitated, reactions 5 and 6 will not occur. $Mg(OH)_2$ is precipitated when excess lime is added to the water and the pH in the water softening basin is 10.8 or higher (27). Very little if any $Mg(OH)_2$ will precipitate since no excess lime is added to the water and the pH is kept at 10.6 (18). It can be expected that the first two reactions will predominate.

The sludge production on an average day due to CO_2 removal is computed as follows:

$$(10\ \text{mg/l})\left(\frac{50\ \text{mg/meq}}{22\ \text{mg/meq}}\right)(2.28\ \text{MGD})(8.34\ \text{lb/gal}) = 430\ \text{lb/day as } CaCO_3$$

The average daily sludge production due to carbonate hardness precipitation is as follows:

$$(127\ \text{mg/l} \times 2)(2.28\ \text{MGD})(8.34\ \text{lb/gal}) = 4830\ \text{lb/day as } CaCO_3$$

This results in an average daily sludge production of 5260 pounds of $CaCO_3$. For the purposes of the laboratory investigation it was estimated that the mean lime softening sludge production was 5500 pounds per day using an average daily flow of 2.4 MGD. It was also assumed that the production of softening sludge would increase at the same rate as the population of Junction City.

Measured Softening Sludge Quantities

The quantity of lime softening sludge that was discharged from the water softening plant was measured on several occasions for comparison with the amount that was calculated for the previous day. The sludge was normally discharged around 10 A.M. and samples were taken at the outlet of the corrugated metal pipe that discharges the sludge into a gulley leading to the river. The quantity of $CaCO_3$ and $Mg(OH)_2$ in the sludge samples were measured and then multiplied by the volume of sludge discharged to determine the total quantities discharged.

A rectangular weir was placed in the gulley leading from the sludge discharge tube to the Republican River to measure the volume of sludge that was discharged and the backwash water. The weir was a sharp-crested contracted rectangular weir cut from a 4' x 8' sheet of 3/4-inch particle board with a weir crest that was four feet long and two feet high. The weir was sandbagged into the channel about 40 feet below the outfall.

Several operational problems were encountered while the weir was in use. During the backwash the weir was bowed somewhat so that the weir face was no longer a plane surface and the effective crest length was reduced. The second problem was that the approach channel filled in with softening sludge in a very short period of time.

The measured lime softening sludge quantities that were discharged into the river are listed in Table 4. Problems associated with the weir operation are not the only source of the observed discrepancies between the calculated and measured volumes of lime softening sludge. One rather obvious source is that the plant operator determines how much sludge to waste by visually inspecting the clarifier blow off. When the wasted sludge thins down to the point that it looks about right, the operator closes the valve. This makes it impossible for the plant operator to waste the exact amount of sludge that was produced in the previous

24 hours. A second large source of error between the measured and calculated sludge quantities occurs when the softening sludge is carried out of the upflow clarifiers and settles in the secondary sedimentation basin or on the filters. The secondary sedimentation basin has a volume of 237,300 gallons and is 16 feet deep. It is normally emptied twice a year and when it was emptied during the summer of 1974, it reportedly had approximately 5 feet of sludge in the bottom (18). This corresponds to a total of 74,000 gallons of softening sludge. It is estimated that a mean of 1100 pounds per day of sludge is deposited in the secondary sedimentation basin at 26 to 28 percent solids.

TABLE 4

Softening Sludge Quantities Measured by the Weir and Calculated From Chemical Balances

Date	lbs Sludge Measured	lbs Sludge Calculated	% Measured/Calculated	Gallons Sludge Measured
6/04/74	10,760	6670	161	12,060
6/14/74	4350	5700	76	1220
6/24/74	6170	7470	83	6170
7/19/74	4880	12,170	40	5370

During the backwash, water is discharged from two sources. The largest source by far is the backwash and the smaller source is a leaky intake valve for the filter beds. Normally, the filters are backwashed for five minutes and then the backwash is shut off for another five munites in order to build up head and to allow the plant operator time to wash the filter media's surface with a fire hose. After this delay, the filters are backwashed a second time until the backwash water is clean by visual inspection. During the period of time that the backwash is shut off, there is still a continual discharge due to the leaky valve. Backwashing the filters normally takes from 30,000 to 50,000 gallons per filter as in Table 5. In order to determine the quantity of softening sludge suspended in the backwash, it was assumed that there was 150 mg/l as $CaCO_3$ of total hardness in the water, which is the softening plant's finished water quality goal. Therefore, it is estimated that there were 200 to 600 pounds of softening sludge in the backwash (Table 5).

TABLE 5

Backwash Volume and Sludge Quantities in the Backwash

Date	Filter Run (hrs.)	Backwash Volume (gallons)	Sludge in Backwash (pounds)
5/31/74	--	30,600	460
6/04/74	64	34,400	190
6/14/74	108.5	50,100	580
6/14/74	--	44,900	260

Samples of the wasted lime softening sludge were allowed to settle for one hour in a 1000 ml graduated cylinder in order to get an approximation of the volume to which it could be thickened. The sludge that was initially tapped from the bottom of the clarifier tended to settle to a higher solids content in one hour than the sludge that was discharged near the end of the blow off. After one hour of settling the softening sludge ranged from a low of 14 percent solids to a high of 45 percent solids. The sludge settled to a median value of 26 to 28 percent solids.

The softening sludge was analyzed to determine the relative quantities of calcium carbonate and magnesium hydroxide present in the sludge. The other constituents of the sludge that may have been present due to impurities in the lime were not considered in this analysis. In order to analyze the sludge, it was pipetted into a volumetric flask, dissolved with concentrated hydrochloric acid, and diluted with distilled water. The calcium carbonate content was determined by adding 8N potassium hydroxide to a 10 ml sample of the solution until a pH in the range of 11 to 12 was obtained. The sample was then titrated with EDTA using CalVer II* as an indicator. The total hardness of the solution was obtained by buffering a 10 ml sample with Hardness I Solution* to a pH of 10.0. Then ManVer II* was added to act as an indicator and the sample was titrated with EDTA. The magnesium hydroxide content in the sludge was expressed in mg/l as $CaCO_3$ and determined by subtracting the calcium hardness from the total hardness.

Through the spring and summer of 1974 it was determined that a mean of 92.4 percent of the softening sludge was $CaCO_3$. The remaining 7.6 percent of the sludge was $Mg(OH)_2$ expressed

---

*Hach Chemical Company Trade Name

as $CaCO_3$. From late 1974 to April 1975 the softening sludge was found to average 95.2 percent $CaCO_3$. It had been expected that the sludge would be composed of close to 100 percent $CaCO_3$ since the pH in the upflow clarifier was maintained near 10.6 and much of the alkalinity had not been removed. According to Sawyer and McCarthy (27) excess lime and a pH of 10.8 is required to precipitate $Mg(OH)_2$. One possible explanation for the presence of the $Mg(OH)_2$ in the softening sludge is that it could have been introduced through impurities in the quick lime. The relatively high amounts of $Mg(OH)_2$ in the sludge during the earlier parts of 1974 might also be due to the water softening plant's staff adding higher lime doses to the water at that time. Junction City was later instructed by the Kansas Department of Health and Environment to cut back on the lime used in establishing a goal of 150 mg/l total hardness in the finished water.

The lime softening sludge pH was found to vary from a low of 9.0 to a high of 10.7. The majority of the time, the softening sludge was found to have a pH of 10.0 or greater. Since the pH of the softening sludge was not always measured on the day that the sludge was collected, it is possible that some of the lower pHs could be due to carbon dioxide absorption and neutralization of part of the hydroxile ions.

PRIMARY SLUDGE PRODUCTION

Since the softening sludge is to be blended with the waste sludges at the sewage treatment plant, the daily production of each sludge must be determined in order to mix the different sludges in the proper ratio for the laboratory work. The properties of the primary sludge are important because they affect the quantity of lime required to stabilize the combined sludge and its dewatering characteristics.

Currently, the waste treatment in Junction City is strictly primary sedimentation with vacuum filtration of the raw primary sludge. The filter cake is then disposed of by burial in a landfill. The waste treatment plant has one Eimco rotary belt vacuum filter which meets all the plant's needs by operating a few hours two or three times a week.

Moore (19) has estimated that the design primary solids production will be approximately 4900 pounds per day at 5 percent solids. The upgraded waste treatment plant is being designed for a population of 36,000 and with the current population of Junction City in the neighborhood of 22,000, it is estimated that the current primary solids production averages around 3000 pounds per day.

Since a gravity thickener hasn't been included in the design of the upgraded waste treatment plant, the concentration of the solids that are discharged from the primary sedimentation basin is extremely important. It was not until the later stages of this study that an attempt was made to measure the discharge concentration of the primary sludge. The primary sludge was found to range from a high of 3.76 percent solids to a low of 2.70 percent solids.

The mean concentration was 3.35 percent solids. Often a great deal of very thin sludge had to be bled off the bottom of the clarifier before the thicker sludge was discharged. The concentration of this sludge was not measured, and it would further tend to dilute the sludge. It is quite possible that the primary sludge might thicken to the desired 5 percent solids if allowed to remain in the primary clarifier longer. For the laboratory work, the primary sludge was gravity thickened to the design value of 5 percent solids.

The pH of the sludge that was taken from the primary basin sump ranged from pH 6.0 to 6.9. The mean pH was 6.4. These pHs are much higher than those that were found in the sludge holding tank earlier in the investigation.

ACTIVATED SLUDGE PRODUCTION

In the upgraded Junction City waste treatment plant, the activated sludge is to be aerobically digested and thickened by dissolved air flotation before blending with the primary sludge. It is also possible that softening sludge will be combined with these.

Activated sludge is known to have several undesirable effects on the dewatering process. When dewatering activated sludge, the filter loadings tend to be low and the cake discharge is often poor even when the activated sludge is blended with other sludges. In addition, the solids capture is usually poor, and the filter cake moisture content is high. It was noted by Paulsrud and Eikum (23) that biological sludges take much larger amounts of lime to stabilize the sludge than do primary sludges.

Moore (19) estimates that there will be approximately 4600 pounds per day of aerobically digested waste activated sludge in the design year. Taking into account Junction City's current and design populations, it is estimated that if the upgraded waste treatment plant was operational at this time, 2800 pounds of waste activated sludge would be produced each day. After the waste activated sludge is aerobically digested, it will be thickened to a minimum of 4 percent solids by dissolved air flotation (19).

For the purposes of the laboratory work, activated sludge was taken from an extended aeration treatment plant at the Walnut Grove Mobile Home Park near Manhattan, Kansas. This sludge was gravity thickened to a laboratory design value of 2.50 percent solids and aerated overnight. Quite often the activated sludge couldn't be thickened to 2.50 percent solids so the primary sludge was thickened over 5 percent solids to compensate. The activated sludge that was used for this study had a pH range of 7.5 to 8.05 and a mean pH of 7.8.

COMBINED SLUDGES

The properties of the combined sewage and lime softening sludges are extremely important. The solids concentration and the relative amount of each sludge present in the combined sludge each have a pronounced effect on the dewatering process.

The ease with which the combined sludge can be stabilized with lime depends mostly upon the relative quantities of the different sludges present and also upon the initial sludge pH.

For the laboratory work the primary, activated and lime softening sludges were blended at 5 percent solids, 2.5 percent solids, and 32 percent solids (400 gm/liter) respectively. The experiments were based on an average daily production of 5500 pounds of lime softening sludge although it was later determined that the average daily production would be 5260 pounds. When the primary and activated sludges were combined at the above stated concentrations, the combined sludge had a solids concentration of 3.37 percent solids. When the softening sludge was blended in, the resulting sludge was 5.97 percent solids.

It is expected that under actual conditions there will normally be around 3000 pounds primary sludge at 5 percent solids, 2800 pounds activated sludge at 4 percent solids, and 5260 pounds lime softening sludge at 32 percent solids in an average day. When the primary and activated sludge is combined the sludge will have 4.46 percent solids, and if the softening sludge is added the resulting sludge will have 7.56 percent solids.

When the primary and activated sludges were mixed in the laboratory, the pH of the combined sludge ranged from 6.5 to 6.85 with an average pH of 6.7, when the primary sludge was fresh. When septic primary sludge was mixed with the activated sludge the resulting pH was around 5.7. When the lime softening sludge was mixed with fresh primary and activated sludge, the pH ranged from a low of 7.1 to a high of 8.0. The average pH was 7.6. From this it can be seen that the softening sludge will raise the combined sludge pH on the average from pH 6.7 to pH 7.6. The actual change in the hydroxyl ion concentration at this range on the pH scale is relatively minor.

The lime softening sludge appeared to have a slight flocculating effect on the combined sewage sludge. It also increased the density of the combined sludge so that it settled faster and to a smaller volume than the sewage sludges without the lime sludge.

LIME REQUIREMENTS FOR COMBINED SLUDGE STABILIZATION

The purpose of lime stabilization is to destroy or greatly reduce the number of pathogens in a sewage sludge and to eliminate odor problems. Lime stabilization will not cause a reduction in the volatile solids content, as will anaerobic digestion. The Environmental Protection Agency requires the disinfection of all raw primary sludges that are disposed of in sanitary landfills. One such way is lime stabilization. The EPA originally wanted Junction City to raise the pH of the sludge filter cakes to 12 for 60 days. They later reduced this requirement to maintaining a pH of 11 for 60 days. Moore (19) feels that it will be acceptable if the filter cake pH is at or above 11 at the time of burial.

It was necessary to determine the lime doses that would raise the combined sludge to pH 11.0 and pH 12.0 for the purpose of stabilizing the sludge. The lime requirements were determined by first mixing 1.0 gram of hydrated lime per liter of combined sludge. At the end of a 10-minute reaction period the pH of the sludge was recorded. Lime was then added at 0.2 gram per liter doses every 10 minutes until the sludge reached pH 12.0. This procedure was adopted because shortly after the lime had been added and the pH initially increased, it began a rapid and continual drop. The method allows for the objective comparison of lime requirements for different sludge combinations. It was observed that the pH did not drop nearly as rapidly once it had been raised into the upper 11s.

The combined primary and activated sludges required approximately 80 pounds of hydrated lime per ton of dry solids to raise the sludge pH to 11.0. This corresponds to approximately 230 pounds of hydrated lime per day at the current estimated solids production or 380 pounds per day at design solids production. The same sludge required 146 pounds of hydrated lime per ton of dry solids to reach pH 12.0. This is equal to 420 pounds of hydrated lime per day at the current estimated sludge production and 690 pounds per day in the design year. See Table 6. It should be noted that the current lime requirements were made assuming that the activated sludge process was in operation.

TABLE 6

Hydrated Lime Requirements to Raise Primary and Activated Sludge to pH 11 and 12

pH	mean lb lime / ton dry solids	range lb lime / ton dry solids	lime required at current solids prod. (lb/day)	lime required at design solids prod. (lb/day)
11	80	80-81	230	380
12	146	135-163	420	690

If 100 percent of the average daily softening sludge production is added to the primary and waste activated sludges, it is estimated that it will require 89 pounds of hydrated lime per ton of dry sewage solids to raise the combined sludge to pH 11.0. At the current estimated sludge production, 260 pounds of hydrated lime will be required each day to raise the sludge pH to 11.0, and in the design year 420 pounds of hydrated lime per day will be needed. If the sludge is to be raised to pH 12.0, 154 pounds of hydrated lime per ton of dry sewage solids is required. The corresponding daily lime requirements are 450 pounds at the current solids production and 720 pounds at design capacity. See Table 7.

If only 50 percent of the daily softening sludge production is added to the primary and activated sludges instead of 100 percent of the mean daily softening sludge production, then the hydrated lime requirements should decrease by approximately 20 pounds per day at pH 11.0 and by 30 pounds per day at pH 12.0. If 200 percent of the average day softening sludge production is added to the combined sludge then the hydrated lime requirements will increase by 40 pounds per day at pH 11.0 and 40 pounds per day at pH 12.0.

TABLE 7

Hydrated Lime Requirements to Raise Primary, Activated, and Average Day Softening Sludge Production to pH 11 and 12

pH	mean lb lime / ton dry sewage solids	range lb lime / ton dry sewage solids	lime required at current solids prod. (lb/day)	lime required at design solids prod. (lb/day)
11	89	59-116	260	420
12	154	128-185	450	720

Despite the fact that the softening sludge raised the pH of the sewage sludges, it was determined that the combination of the softening, activated, and primary sludges would comsume more lime on a daily basis (less on a pound per ton of dry solids basis) than the combined primary and activated sludges in order to raise the pH to either 11 or 12. This can be traced to the fact that the pH of the softening sludge is below pH 11; therefore, additional lime must be added for the softening sludge.

SLUDGE DEWATERING

In order for the waste sludges to be disposed of in a sanitary landfill they must first be dewatered from a slurry form to a solid form. Junction City will dewater its combined sludges on a vacuum filter before trucking them to the sanitary landfill. The resulting filter cake must have a low enough moisture content that it will be easy to handle and will dry rapidly to reduce leachate and to slow bacterial regrowth.

The purpose of the dewatering studies is to find the proper combination of filter media, polymer, and polymer dose. The dewatering studies should also yield information as to filter loading rates, solids capture, moisture content, and cake discharge.

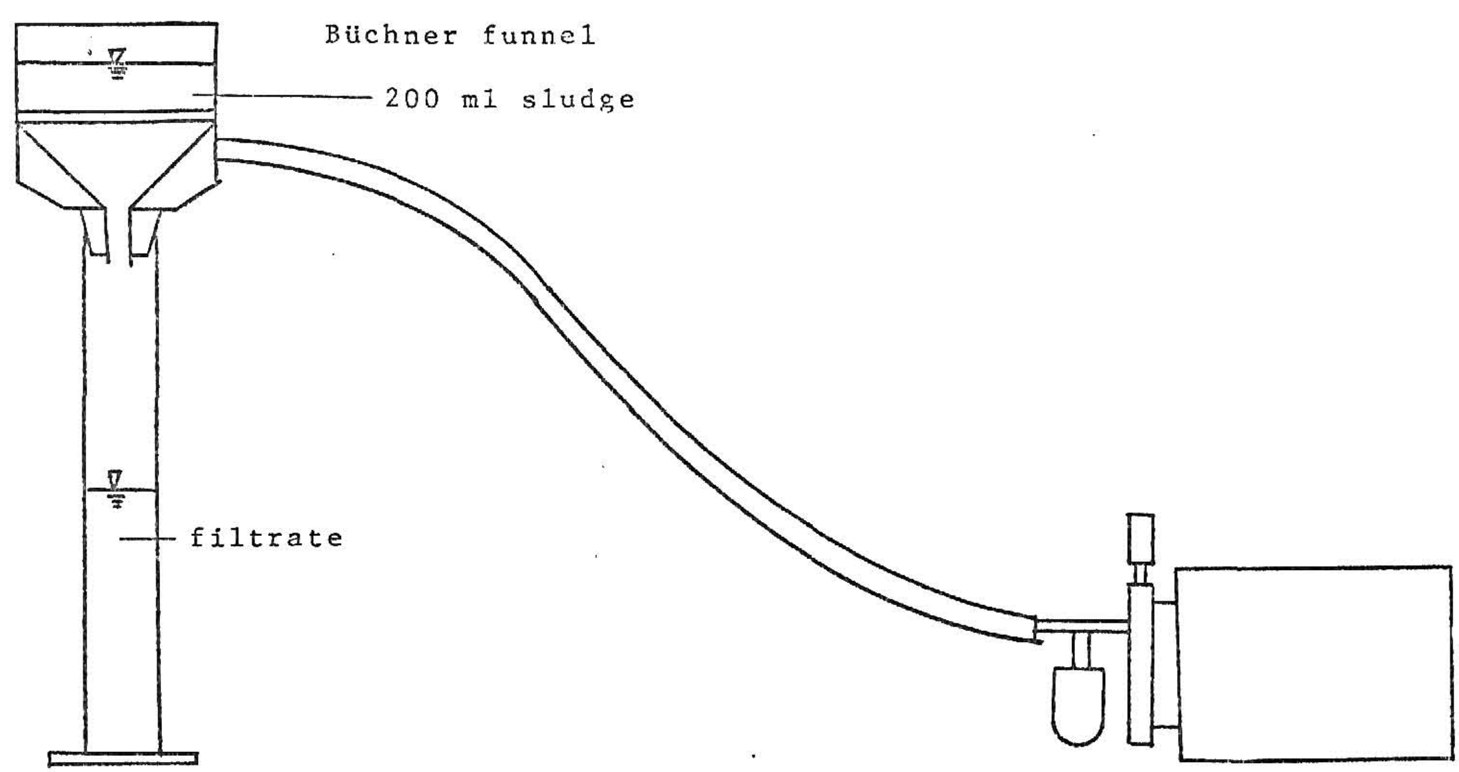
Büchner Funnel Tests

The Büchner funnel is used as a screening process to determine which polyelectrolytes will satisfactorily condition the sludge before dewatering. In the past, the Büchner funnel has been used to determine filter loading rates, but it is not as accurate as the filter leaf for such determinations.

For these tests a 10.5 cm Büchner funnel was used along with Whatman #40 filter paper. See Figure 1. A 200 ml sample of the sludge to be tested was conditioned with hydrated lime approximately 10 minutes before testing. One minute before testing the polymer was added. A constant vacuum was applied to the sludge and the filtrate volume was recorded every 20 seconds for 2 minutes. In order to determine if a particular polymer or dosage merited further study, it was compared to the filtration rates of a like sludge sample conditioned only with lime and to the filtration rates obtained by other polymers. During the early Büchner funnel tests Versa TL #700, Purifloc A23, and Magnifloc 835A were found to give the best filtration rates. When Magnifloc 521C was tested near the end of the study it was found to be superior to the other polyelectrolytes.

FIGURE 1

Büchner Funnel Test



In the laboratory investigation, 20 ml of Magnifloc 521C was diluted to one liter with distilled water. For a combined activated and primary sludge of 3.25 percent solids, the apparent polymer dose was found to be 100 ml of the diluted polymer per liter of sludge. This corresponds to 140 pounds of Magnifloc 521C per ton of dry solids. It was later determined during the more reliable filter leaf tests that this dosage was much higher than was actually needed. The polymer dose can be decreased by a factor of four and quite likely even more.

Filter Leaf Tests

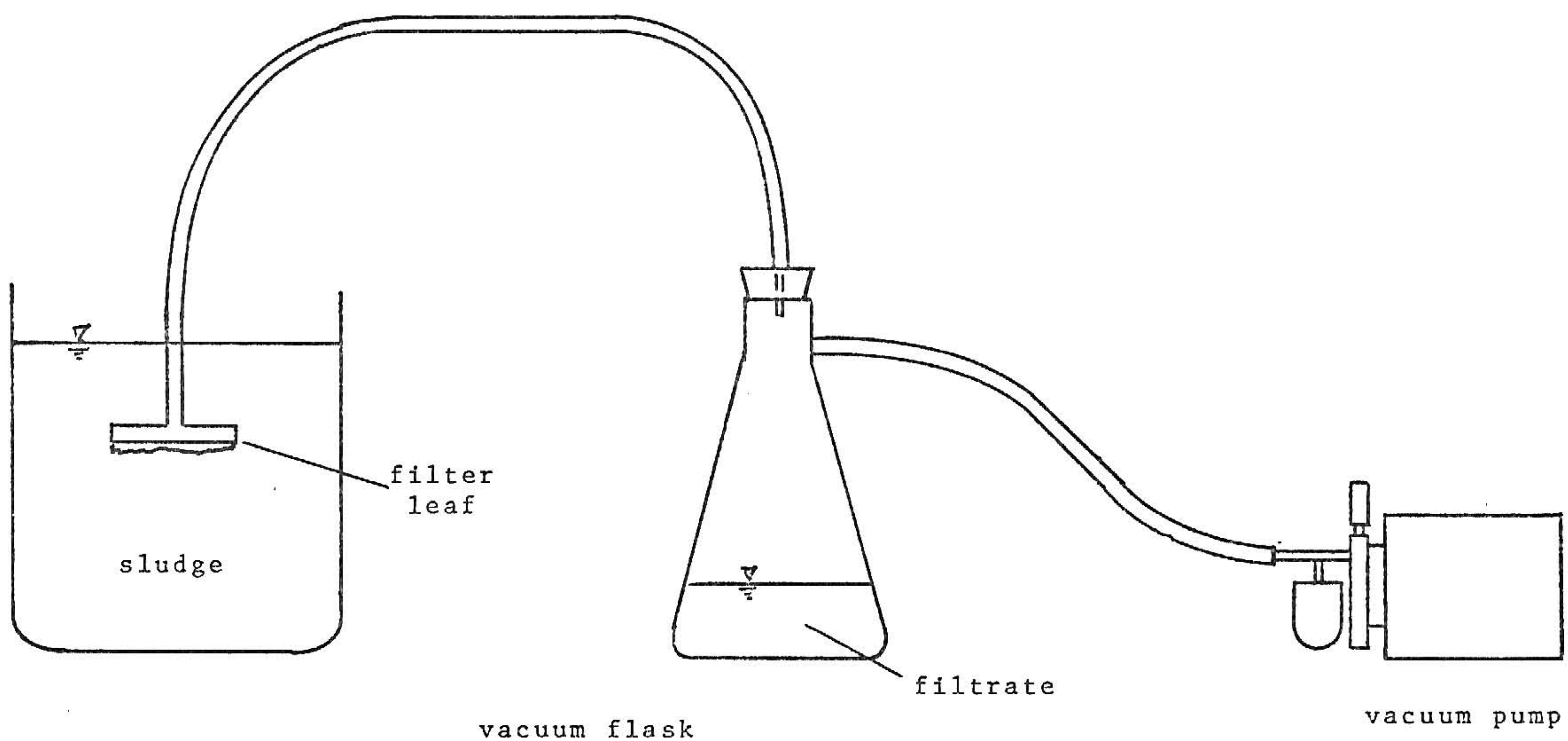
The filter leaf can be used in the laboratory to simulate the actual operation of a vacuum filter. The filter leaf can be used to test the actual filter media that will be used in the field.

An Eimco filter leaf with a filter surface area of 0.1 ft^2 was used for the filter leaf tests. An initial vacuum of 20 inches mercury was applied to the filter leaf, but it dropped considerably toward the end of the dry time. No attempt was made to optimize the cycle time, but rather for the laboratory work the cycle time was divided into a one-minute form time and a two-minute dry time.

The different filter medias were studied to determine the cake discharge characteristics, filter loading rates, filtrate loading rates, solids capture, moisture content of the filter cake, and whether the media tended to plug. When a new filter media was initially used, the first several filter runs were normally discarded, but with many of the media it

FIGURE 2

Filter Leaf Test



could be determined after one or two tests that they were inappropriate for this particular sludge. The mos common problems were plugging of the filter media and poor cake discharge. When the filter media began to plug, the filter loading rates dropped, the filter cakes dewatered very poorly and were very sticky. After every filter run, the filter media was washed to simulate the actual conditions in the vacuum filter and reduce the plugging.

The two best filter medias tested were Eimco POPR-907 and NY-415. See Table 8. When the combined activated and primary sludge was filtered by either of these medias without polymer addition there was always some binding of the sludge to the filter media, which resulted in a poor filter cake discharge. NY-415 usually discharged the filter cake better than POPR-907, but the solids capture for NY-415 was much lower than with POPR-907, especially without polymer addition.

TABLE 8

Filter Media and Their Properties

Media	POPR-907	NY-415
Weave	2/2 Twill	1/1 Plain
Yarn	12 Mil Mono-Filament	Mono-Filament
Thread Count	68 x 29	40 x 40
Weight (oz/sq. yd.)	8.30	5.70
Air Flow (cfm/sq. ft.)	300	----
Finish	Calendered	Stabilized

It was determined during the filter runs that the addition of lime softening sludge to the sewage sludge aided the dewatering process. When the softening sludge was added to the primary and activated sludges the combined sludge dewatered to a lower moisture content. The lower moisture content of the filter cake allows the sludge to dry out faster and thus makes it less hospitable for bacteria regrowth and odor production. The softening sludge increased the filter loading rate and the solids capture. This was somewhat to be expected because the addition of the softening sludge increased the solids content which is conducive to higher filter loadings. One of the greatest advantages in adding softening sludge to the sewage sludges is that the filter cake discharges much better and plugs the filter media less. This might be due to the coagulant properties of the lime softening sludge.

When Magnifloc 521C was added to the combined activated and primary sludge the filter loading increased, the moisture content dropped, the solids capture improved, and the cake discharge improved. See Table 9. When Magnifloc 521C was added to the combined primary, activated, and lime softening sludge the filter loading, solids capture, and cake discharge improved while the moisture content remained constant. See Table 10.

The solids concentration in the field is expected to be higher than in the laboratory, which would tend to increase the filter loading.

TABLE 9

Combined Primary and Activated Sludge Filter Leaf Tests

filter media	POPR-907	POPR-907	POPR-907	POPR-907	POPR-907	NY-415	NY-415
lb Magnifloc 521C / ton dry solids	0	0	35	35	136	0	35
lb hydrated lime / ton dry sewage solids	83-87	347	87	347	83	77	347
mean filter loading ($lb/ft^2/hr$)	1.4	2.05	2.4	2.95	2.7	1.3	2.95
range of filter loading ($lb/ft^2/hr$)	1.3-1.5						
mean moisture content (%)	87	87	85	85.5	82	84	85
range of moisture content (%)	87-87.5						
mean solids capture (%)	81.5	83	88	86	87	75	83
range of solids capture (%)	81-82						
cake discharge	poor to very poor	poor	poor	poor	poor	poor	good

TABLE 10

Combined Primary, Activated and Softening Sludge Filter Leaf Test

filter media	POPR-907	POPR-907	POPR-907	POPR-907	POPR-907	NY-415
lb Magnifloc 521C / ton dry solids	0	0	0	0	19	0
lb hydrated lime / ton dry sewage solids	90-92	184	276	367	90	90-96
mean filter loading ($lb/ft^2/hr$)	2.85	3.3	3.9	3.7	4.8	2.6
range of filter loading ($lb/ft^2/hr$)	2.4-3.35					1.9-3.0
mean moisture content (%)	76	78	76	73	77	70
range of moisture content (%)	71-80.5					67-73
mean solids capture (%)	88	90	90	90	90.5	75
range of solids capture (%)	85-90.5					70-80
cake discharge	fair to poor	fair	fair	good	good	fair to good

The sludge was normally conditioned with 1.4 grams of hydrated lime per liter of sludge (90 to 100 pounds per ton of dry sewage solids) about 20 minutes before the filter leaf tests began. This was usually sufficient to raise the pH up to a range of 11.5 to 11.8. The filter leaf test often took in the neighborhood of five hours to complete, and at the end of the tests the sludge pH had often dropped to a range of 10.7 to 11.15. When the lime dosage was increased to 5.6 grams of hydrated lime per liter of sludge (350 to 375 pounds per ton of dry sewage solids), the initial pH was around 12.5 and it dropped much slower while the filter loading increased.

LIME STABILIZATION OF FILTER CAKES

The method used in this investigation to determine the filter cake's pH was developed by Doyle (8) for his work. The filter cake was suspended in a volume of distilled water that was equivalent to twice the sludge cake's initial wet weight and then the pH was measured. If the sludge cake had dried out it was very difficult to suspend in the distilled water even when a Waring Blender was used. From these studies it was determined that for the combined primary, activated, and softening sludge that 200 pounds of hydrated lime per ton of dry solids or 370 pounds of hydrated lime per ton of sewage solids would keep the pH above 11 for at least 24 hours. See Table 11. Approximately 350 pounds of hydrated lime per ton of dry solids would keep the pH of a primary-activated sludge filter cake above 11 for 24 hours. See Table 12.

TABLE 11

Filter Cake pH vs. Time
(Primary, Activated, & Softening Sludge)

lb lime / ton sewage solids	lb lime / ton solids	initial pH	final pH	time (hrs.)
93	48	11.7	10.1	4
94	48	11.45	10.0	4
93	48	11.6	8.8	20
92	47	11.8	8.6	37
90	46	11.35	8.6	48
90	46	11.6	8.7	62
179	92	12.15	10.25	14
201	104	12.35	10.1	14
184	95	12.4	9.5	36
179	92	12.15	9.1	42
179	92	12.15	9.0	60
179	92	12.15	8.85	152
269	138	12.5	10.7	12
276	142	12.5	9.95	38
276	142	12.5	9.05	132
367	189	12.6	11.05	37
367	189	12.6	9.1	132

TABLE 12

Filter Cake pHs vs. Time
(Primary and Activated Sludge Only)

lb lime / ton dry solids	initial pH	final pH	time (hrs.)
347	12.5	12.3	18
345	12.55	9.55	89
347	12.5	9.6	90
347	12.5	9.15	90

SUMMARY

If the upgrading additions to the waste treatment plant in Junction City were operational at this time the following sludge quantities could be expected to be produced in an average day: 3000 pounds of primary sludge at 5 percent solids, 2800 pounds of activated sludge at 4 percent solids, and 5260 pounds of lime softening sludge at 32 percent solids. It is expected that there will be 4900 pounds per day of primary solids and 4600 pounds per day of waste activated sludge in the design year, but the future softening sludge quantities are unknown because the future status of the present water plant is not yet resolved.

If the softening sludge is not added to the primary and activated sludges, the NY-415 filter media should probably be used because of its better discharge characteristics. With this media, a hydrated lime dose of 350 lb/ton of solids, and a polymer dose of 35 lb Magnifloc 521C/ton of solids, the filter loading rates, moisture content, and solids capture should be around 3.9 $lb/ft^2/hr.$, 85 percent, and 83 percent, respectively. If a higher solids capture is desired, the POPR-907 filter media could be used, but the cake discharge will be poor. The filter loading and moisture content will remain the same, but the solids capture should be about 86 percent.

If the softening sludge is added to the primary and activated sludges, all phases of the dewatering operation should improve.

With the softening sludge addition the POPR-907 filter media should be used. At a polymer dose of 19 lb Magnifloc 521C/ton of solids and a hydrated lime dosage of 90 lb/ton sewage solids the filter loading, moisture content, and solids capture should be 6.1 $lb/ft^2/hr.$, 77 percent, and 90.5 percent, respectively. The cake discharge should also be good. At higher lime dosages which are likely to occur due to lime stabilization requirements, the filter loadings should be even larger. At the lime dosages in the neighborhood of 90 lb/ton of sewage solids it was observed that the combined sludge with softening sludge had a filter loading that was approximately double the filter loading of the combined sludge without the softening sludge. If this holds true at the higher lime doses, it would require no additional filters nor any additional filtration time to dispose of the softening sludge.

In order to stabilize the filter cake, it was determined that it would take nearly the same quantity of hydrated lime for a sludge that contained the softening sludge as for a waste sludge that did not. It will take from 350 to 370 pounds of hydrated lime to keep the pH of one ton of dry sewage solids over 11 for over 24 hours. The initial pH resulting from this lime dose should be about 12.5 and remain near that level for quite awhile.

CONCLUSIONS

1) Lime softening sludge will raise the pH of the combined primary and activated sludge. The pH is likely to be increased from 6.7 to 7.6.

2) The addition of the lime softening sludge will increase the lime requirements slightly on a daily weight basis.

3) The lime softening sludge will improve the cake discharge, increase the filter loading and the solids capture, and reduce the filter cake's moisture content.

4) The pH of the limed filter cake was found to drop rapidly. It will probably take 200 pounds of hydrated lime per ton of dry primary and activated sludge solids to keep the filter cake pH over 11 for 24 hours. It will take around 350 pounds of hydrated lime per ton of dry combined primary, activated, and softening sludge to keep the filter cake pH over 11 for 24 hours. Therefore, the initial sludge pH should be well over 12 in both cases.

5) The filter loading rates that occur in the actual operation of the vacuum filter should be higher than those that were found in the laboratory due to the higher initial solids concentration expected.

6) Magnifloc 521C was found to be the most effective polyelectrolyte of those tested.

7) The lime softening sludge can be disposed of at the water treatment plant with little additional cost other than the cost involved in transporting the softening sludge to the waste treatment plant. The disposal of the combined chemical and sewage sludges should not require any additional vacuum filters nor any additional filtration time.

REFERENCES

1. Berg, G., "The Virus Hazard in Water Supplies," Journal, New England Water Works Association, Vol. 78, June, 1974, cited in: Doyle, C. B., "Effectiveness of High pH for Destruction of Pathogens in Raw Sludge Filter Cake," Journal of the Water Pollution Control Federation, Vol. 39, No. 8, Aug., 1967, pp. 1403-1409.

2. Black, A. P., "Lime and Lime Soda Sludge Disposal," Disposal of Softening Plant Wastes Committee Report, Journal of the American Water Works Association, Vol. 49, No. 9, Sept., 1949, pp. 819-829.

3. Black and Veatch Design Report, "Bachman Creek Stormwater Overflow Treatment Plant - Dallas, Texas," 1968, cited in: Neubauer, W. K. and Proudfit, D. P., "Disposal of Wastes from Water Treatment Plants - Part 1 - Status Report on Engineering," American Water Works Association Research Foundation Report, Journal of the American Water Works Association, Vol. 61, No. 10, Oct., 1969, pp. 551-561.

4. Buzzell, J. C., Jr. and Sawyer, C. N., "Removal of Algal Nutrients from Raw Wastewater with Lime," Journal of the Water Pollution Control Federation, Vol. 39, No. 10, Part 2, Oct., 1967, pp. R16-R24.

5. Committee Report, "Disposal of Water-Treatment-Plant Wastes," Journal of the American Water Works Association, Vol. 64, No. 12, Dec., 1972, pp. 814-820.

6. Courts, C. A. and Schuckrow, A. J., "Design, Development, and Evaluation of a Lime Stabilization System to Prepare Municipal Sewage Sludge for Land Disposal," Report for the Environmental Protection Agency, 1974, cited in: Black, Crow, and Eidness, "Process Design Manual for Sludge Treatment and Disposal," 1974.

7. Culp, R. L. and Culp, G. L., Advanced Wastewater Treatment, Van Nostrand Reinhold Company, New York, 1971.

8. Doyle, C. B., "Effectiveness of High pH for Destruction of Pathogens in Raw Sludge Filter Cake," Journal of Water Pollution Control Federation, Vol. 39, No. 8, Aug., 1967, pp. 1403-1409.

9. Farrell, J. B., et al., "Lime Stabilization of Primary Sludges," Journal of the Water Pollution Control Federation, Vol. 46, No. 1, Jan., 1974, pp. 113-122.

10. Grabow, W. Q. K., Grabow, N. A., and Burger, J. S., "The Bactericidal Effect of Lime Flocculation Flotation as a Primary Unit Process in a Multiple System for the Advanced Purification of Sewage Works Effluent," Water Research, Vol. 3, No. 12, Dec., 1969, pp. 943-953.

11. Hoover, C. P. and Scott, R. D., "Lime Sterilization of Water," Engineering Record, Vol. 68, No. 10, Sept., 1913, pp. 257-259.

12. Houston, A. C., "Eighth Research Report of the Metropolitan Water Board," London, England, cited in: Riehl, M. L., Hartung, H. O., and Taylor, F. S., "Effects of Lime Softening," Journal of the American Water Works Association, Vol. 46, No. 5, May, 1954, pp. 493-498.

13. Humble, D. E., "Lime Disinfection of Sewage Bacteria at Cold Temperature," thesis presented to Colorado State University at Fort Collins, Colorado, in 1973, in partial fulfillment of the requirements for the degree of Master of Science.

14. Krasauskas, J. W. and Streichner, L., "Disposal of Wastes from Water Treatment Plants - Part 2 - Status Report on Plant Operation," American Water Works Association Research Foundation Report, Journal of the American Water Works Association, Vol. 61, No. 11, Nov. 1969, pp. 621-626.

15. Lange, B., Zeitschr. f. Hygiene, Vol. 96, 1922, pp. 92-117, cited in: Watkins, J. H. and Winslow, C.-E.A., "Factors Determining the Rate of Mortality of Bacteria Exposed to Alkalinity and Heat," Journal of Bacteriology, Vol. 24, No. 3, Sept., 1932, pp. 243-265.

16. McCulloch, E. C. and Costigan, S., "A Comparison of the Efficiency of Phenol, Liquor Cresolis, Formaldehyde, Sodium Hypochlorite and Sodium Hydroxide Against Eberthella Typhia at Various Temperatures," Journal of Infectious Diseases, Vol. 59, No. 3, 1936, pp. 281-284.

17. Mitchell, R., Introduction to Environmental Biology, Prentice-Hall, Englewood Cliffs, New Jersey, 1974.

18. Mock, R., personal communication, 1975.

19. Moore, A., personal communication, 1974.

20. Neubauer, W. K. and Proudfit, D. P., "Disposal of Wastes from Water Treatment Plants - Part 1 - Status Report on Engineering," American Water Works Association Research Foundation Report, Journal of the American Water Works Association, Vol. 61, No. 10, Oct., 1969, pp. 551-561.

21. O'Brien, W. J. and Moore, J. A., "Use of Water Softening Sludge in Sewage Treatment," Kansas University, Lawrence, Kansas, 1972.

22. Paulsrud, B., personal communication, 1973, cited in: Vesilind, P. A., Treatment and Disposal of Wastewater Sludges, Ann Arbor Science Publishers, Ann Arbor, Michigan, 1974.

23. Paulsrud, B. and Eikum, A. S., personal communication, April, 1974, cited in: Black, Crow, and Eidness, "Process Design Manual for Sludge Treatment and Disposal," 1974.

24. Riehl, M. L., Weiser, H. H., and Rheins, B. T., "Effects of Lime-Treated Water Upon Bacteria," Journal of the American Water Works Association, Vol. 44, No. 5, May, 1952, pp. 466-470.

25. Riehl, M. L., Hartung, H. O., and Taylor, F. S., "Effects of Lime Softening," Journal of the American Water Works Association, Vol. 46, No. 5, May, 1954, pp. 493-498.

26. Russell, G. D. and Russell, G. S., "The Disposal of Sludge from a Lime-Soda Softening Plant as Industrial Waste," Proceedings, 9th Industrial Waste Conference, Purdue University Engineering Extension Series Bulletin 87, March, 1955, pp. 201-216.

27. Sawyer, C. N. and McCarty, P. L., Chemistry for Sanitary Engineers, 2nd ed., McGraw-Hill Book Company, New York, 1967.

28. Sontheimer, H., "Effects of Sludge Conditioning with Lime on Dewatering," Proceedings, 3rd International Conference Water Pollution Research, Munich, 1966, In Advances in Water Pollution Research, Vol. 2, 1967, pp. 165-179.

29. Streeter, H. W., "The Bacterial Efficiency of the Excess-Lime Method of Water Purification," Public Works, Vol. 64, No. 8, Aug., 1933, p. 17.

30. Streicher, L., "Use of Organic Polymers and Sludge Volume Reduction," Proceedings, American Water Works Association, Minimizing and Recycling Water Plant Sludge, May, 1973, pp. II-1 to II-15.

31. Thayer, S. E. and Sproul, O. J., "Virus Inactivation in Water Softening Precipitation Process, "Journal of the American Water Works Association, Vol. 58, No. 8, Aug., 1966, pp. 1063-1074.

32. van Vuuren, L. R. J., et al., "Advanced Purification of Sewage Works Effluent Using a Combined System of Lime Softening and Flotation," Water Research, Vol. 1, No. 7, July, 1967, pp. 463-474.

33. Vesilind, P. A., Treatment and Disposal of Wastewater Sludges, Ann Arbor Science Publishers, Ann Arbor, Michigan, 1974.

34. Water Treatment Plant Design, American Water Works Association, New York, 1969.

35. Watkins, J. H. and Winslow, C.-E.A., "Factors Determining the Rate of Mortality of Bacteria Exposed to Alkalinity and Heat," Journal of Bacteriology, Vol. 24, No. 3, Sept., 1932, pp. 243-265.

36. Wattie, E. and Chambers, C. W., "Relative Resistance of Coliform Organisms and Certain Enteric Pathogens to Excess-Lime Treatment," Journal of the American Water Works Association, Vol. 35, No. 6, June, 1943, pp. 709-720.

37. Williamson, J., Jr., "Something New in Sewage Treatment," Water and Sewage Works, Vol. 96, No. 4, 1949, p. 159.

38. Winslow, C.-E.A. and Falk, I. S., "Studies on Salt Action VIII - The Influence of Calcium and Sodium Salts at Various Hydrogen Ion Concentrations Upon the Viability of Bacterium Coli." Journal of Bacteriology, Vol. 8, No. 3, May 1923, pp. 215-236.

COMBINED DISPOSAL OF WATER SOFTENING
AND SEWAGE SLUDGES

by

MILTON D. LARSEN

B.S., Kansas State University, 1973

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1975

ABSTRACT

This research investigated the possibility of disposing of the water softening sludges of Junction City, Kansas to its wastewater treatment plant.

Measurements were made of the quantities of softening sludge, primary sludge, and activated sludge that were produced. Measurements were also made of the lime quantities required for lime stabilization of the combined sludges. Büchner funnel and filter leaf tests were run to determine the effects of different polyelectrolytes, polyelectrolyte dosages, and filter medias.

It was determined that the softening sludge could be feasibly disposed of at the sewage treatment plant with little extra cost other than the cost involved in transporting the softening sludge from the water softening plant to the waste treatment plant. The softening sludge improved the filter cake discharge, moisture content, filter loading rate, and solids capture in the dewatering process. It was determined that the addition of lime softening sludges to the sewage sludges increased the lime requirements for lime stabilization only slightly.