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The Effectiveness of Removal of Bacteria by Various Concentrations of Lime and Alum Floc

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THE EFFECTIVENESS OF REMOVAL OF BACTERIA BY VARIOUS CONCENTRATIONS OF LIME AND ALUM FLOC

by

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TABLE OF CONTENTS

The modern development of water purification started in the seventeenth century with the application of steam power for water works. Also about this time the English scientist, Cavendish (1) removed the calcareous substance from London well water by adding lime, thus precipitating the calcium and magnesium as carbonates. Softening on a plant scale was first proposed by Thomas Hardy (2) about 1800, but it was not until 1841 that softening on a large scale was tried by Thomas Clark (3) of Aberdeen Scotland. Forty-seven years later a municipal softening plant was built in America in 1901 at Winnepeg Canada, followed by a plant which attracted much attention at Oberlin, Ohio in 1903. In 1908 water softening was attempted on a large scale at Columbus Ohio.

By this time softening had obtained a foothold although for many years the advantages were offset by the disadvantages such as clogging sand filters, excess causticity, and lag of chemical reactions in cold dilute solutions. The latter disadvantage proved to be the greatest problem until it became known that prolonged stirring shortened the reaction time. It has been a common practice for many years to use a four hour reaction period.

Bacterial purification of water has been effected primarily by sedimentation, filtration, and chemical disinfection. Where the softening process is not a part of the purification system sedimentation is induced by alum coagulation in settling chambers. Both alum and lime treatment remove 90 percent or more of the bacteria in the water, the percentage removal being dependent largely on the density of the bacterial population and the dosage of reagents.

Lime treatment not only removes the bacteria by sedimentation but actual kill of the organisms may also occur. Hoover (4) working with several Ohio water softening plants found that one grain per gallon (gpg) excess lime killed 99.93 percent of the coliform organisms in the water. When 20-25 p.p.m. causticity was maintained in the lime treatment at Ironton, Ohio, Edwards (5) found a decided reduction of micro-organisms. Scott and McClure (6) studying the effect of hydrogen ion concentration of bacteria of the colon-typhoid group found in municipal supplies that there was an effective removal if pH values were kept above 9.5.

Wattie and Chambers (7) carried out an extensive study on the bactericidal efficiency of lime treatment at various pH values using several pathogens as well as coliform organisms. Their findings show that the pathogen death rate is higher than the nonpathogen at similar pH values. They found that at pH range 10.1-10.5 complete kill of organisms was not obtained at the end of a four hour contact period, an exposure of eight hours for pathogens and ten hours for nonpathogens being necessary. In order to obtain 100 percent kill of these organisms within the four hour exposure period pH values of 10.5-11.0 for pathogens and 11.01-11.5 for nonpathogens had to be maintained. Temperature influenced the rate of kill, neither pathogen nor nonpathogen being 100 percent killed at 0° C. at pH 10.01-10.5 in a ten hour test period.

Bayliss (8) stated in 1930 that an alum floc could be used for the removal of turbidity, color and micro-organisms. He believed that the removal of turbidity, color and micro-organisms was an adsorption action. Calvert (9) using 10-30 p.p.m. alum as a coagulant obtained an 89 percent

removal of micro-organisms in 15 minutes. Streeter (10) demonstrated that an increasing bacterial removal was obtained by increasing rates of application of alum. Flinn, Weston and Bogart (11) came to about the same conclusions using water of a low turbidity and color. A study was made by Gehm (12) to compare methods of bacterial removal in sewage. He found that by using an excess of ferric chloride (60 p.p.m.) 97 percent of the total bacteria and 70 percent of the Escherichia coli were removed.

Spaulding (13) developed a method of softening water by utilizing the accumulated sludge to speed the chemical reactions. This process utilized a unit called the Precipitator designed as a combination mixing, coagulation and settling tank which brings the unstable lime treated water into equilibrium quickly by retaining previously precipitated carbonates and hydroxides in contact with the flowing water. The process is reported to give complete treatment in one hour instead of four hours in the conventional process.

The studies presented in this thesis were instituted to investigate the effectiveness of the Spaulding Precipitator in the removal of bacteria in comparison to the conventional four hour treatment. The Precipitator and the conventional type tank were tested on both lime treatment and in water clarification using alum.

Inasmuch as there has been a very limited amount of work reported on the removal of bacteria by flocs, it seemed advisable to make a laboratory survey to ascertain if more extensive studies on a pilot plant scale would be worthwhile. Furthermore glass cylinder tests were a more convenient means of evaluating the influence of various concentrations and various types of sludge in bacterial removal. Under such laboratory con-

ditions all variables were controlled which is impossible in a pilot plant installation. Sampling methods and plating techniques were worked out so that discrepancies would be minimized. Finally, although these studies were initiated primarily for the reason given above, certain data on the comparative value of the two processes namely the Precipitator and the conventional settling tank were obtained.

Seven liter Pyrex glass cylinders were used for testing. For stirring purposes glass rods were bent at 90° angles in a zig-zag fashion, these being attached to wooden pulleys by means of a chuck. Belts connected each pulley, the entire assembly being driven by an electric stirrer. In this manner all sludge concentrations were agitated at the same velocity.

In this study various types of sludges have been tried, these being alum, lime, lime-alum, and lime ferric hydroxide. However as the alum and lime-alum flocs are used more extensively in practical operation than the other two mentioned, more comprehensive investigations were made with these flocs. The heavy concentrations of alum sludge (over 500 p.p.m.) were preformed, the floc being accumulated in the following manner. After optimum chemical dosage and proper pH for maximum flocculation had been determined, the chemical was added to six liters of distilled water. The mixture was stirred while pH adjustment was made and then the stirrers were removed. The floc was permitted to settle for several days. After this period, the filtrate was decanted and the settled sludge was added to previously accumulated sludge.

Escherichia coli was used as the test organism primarily because this organism is the standard for measuring water purity. This organism was also selected because its growth requirements as to temperature, pH, and nutrients are wide and it adapted itself well to these studies. Twenty-four hour broth cultures or saline washing from 24 hour agar slants were used, the latter being used when heavier inoculations were desired than could be obtained with broth.

Part I - Studies with Settling Sludge Blanket

For the test six liters of accumulated sludge plus tap water were used, the sludge concentrations varying from 17 to 3500 p.p.m. Larger amounts of floc were not included due to the slow settling rate. PH adjustments where necessary, were made with N/1 sodium hydroxide and N/1 hydrochloric acid unless otherwise designated. Four to six glass cylinders containing various amounts of sludge and a raw water control comprised each run.

Sludge concentrations and pH adjustments were made prior to each trial to comply with the desired testing conditions. The _E. coli_ culture was added while the stirrers were operating so that an immediate mixing would occur. Mixing was continued for approximately one hour. During this period samples were withdrawn from the top of the cylinders to determine the initial inoculum of cells. After the termination of mixing the agitators were removed to allow settling. Samples were taken at intervals of 30 minutes, 1, 2, 3, and 4 hours.

The point of sampling at the various time intervals was questioned on the basis that the bacteria in the supernatant might decrease at the surface during the four hour settling period. Accordingly samples were collected at three levels in the supernatant. The data are presented in Table 1. The results are comparable, being well within the experimental errors inherent to plant counts.

Table 1. The number of bacteria at various levels in the supernatant liquid above the settling sludge blanket

Levels above the settling sludge in inches	No. of bacteria per ml.
2	21,000
6	23,000
Water surface	21,000

At the completion of each run, the supernatant fluid was decanted and fresh tap water added preparatory to the next trial. In this manner the same sludge blanket could be used repeatedly. Five trials were made for each set of experiments in order to minimize variances due to experimental error in settling rates, sampling, and plating.

Several sampling techniques were investigated as early exploratory tests demonstrated that 1 ml. samples were not always consistent and representative of the number of bacteria present. It was felt that a larger sample might give a more representative sample, as the number of bacteria adsorbed on the floc particles might vary considerably. Accordingly a comparative sampling was made using 1, 10, and 100 ml. portions. The 10 and 100 ml. portions were shaken prior to plating in appropriate dilutions. The 100 ml. portions gave the most consistent results so that in later tests these portions were collected.

The glass cylinder tests made it possible to obtain comparative figures on the effects of sludge concentrations on bacterial removal because it is possible to run a series of varying concentrations with a constant bacterial content simultaneously. This eliminates many variables which would affect the results if tests on the various concentration were run at different times in a pilot plant. Accordingly four concentrations were tested, namely 3500, 2400, 1200, and 500 p.p.m. at pH values of 7.6 and 9.0 respectively. The data presented in Tables 2 and 3 demonstrated that the heaviest floc concentrations gave the most effective removal. There was little difference in the removal of bacteria in the concentrations of 1200, 2400, and 3500 p.p.m. although the 3500 p.p.m. gave the best results.

Table 2. A comparison of varying concentrations of alum sludge at pH 7.8 in the removal of *Esch. coli.*

Settling time in hours	Percentage - reduction of bacteria				
	Sludge concentrations in p.p.m.				Control
	3500	2400	1200	500	
1	98	92	91	43	12
2	99	90	94	44	4
3	99	93	96	64	7
4	99	91	96	50	6

Table 3 - A comparison of varying concentrations of alum sludge at pH 9.0 in the removal of *Esch. coli.*

Settling Time in Hours	Percentage - reduction of bacteria				
	Sludge concentration in p.p.m.				Control
	3500	2400	1200	500	
1	93	92	90	86	29
2	98	88	91	93	39
3	97	91	99	89	26
4	95	93	94	88	29

Because there was little difference in the heavy concentrations, lighter concentrations were included in the next series. Sampling in this series was made only at 30 minute and 4 hour settling intervals. The 30 minute period was selected to determine if there were possible variations in the early stages of settling with the various concentrations of sludge. In this series presented in Table 4, sludge concentrations of 17, 34, 600, 1200, 2400, and 3500 p.p.m. were used.

The data for the 30 minute settling period are extremely interesting. It can be seen that 30 minutes was not a sufficient settling period for 3500 p.p.m. of floc. However, with the exception of trial 1, the three other concentrations of heavy sludge removed organisms effectively in 30 minutes. The light concentrations of sludge (17 and 34 p.p.m.) even with a 4 hour settling period were from 30 to 50 percent less efficient than were the heavy sludges after 30 minutes settling.

In the tests cited, an alum sludge was used. In the next series, the effectiveness of an alum-calcium hydroxide floc was tested in removing bacteria. In these tests bacterial removal was checked in 30 minutes, 1, 2, 3, and 4 settling periods. In this series of tests an attempt was made to reduce the hardness of the water to 85 p.p.m. and maintain a pH of 10. As the same sludge was used for all runs, it was impossible to maintain a pH of 10 and a hardness of 85 p.p.m. in all runs therefore two series of tests were made, one with a constant hardness of 85 p.p.m. with a varying pH and a second with a constant pH of 10 and a varying hardness. As before 5 trials were made with each set of conditions and an average bacterial removal expressed in percentage-reduction which is reported in the accompanying tables. The concentrations of sludge used were 5000, 2500, 1200 and 700 p.p.m.

Table 4 - A comparison of varying concentrations of alum sludge at pH 6.5 in removal of *Esch. coli.* at 0.5 and 4 hours settling periods.

Trial No.	Settling Time in Hours	Percentage - reduction of bacteria Sludge concentrations in p.p.m. 3500	2400	1200	600	34	17	Control
1	0.5	0	59	33	41	30	13	35
	4.0	96	99	80	88	52	46	50
2	0.5	27	99	97	97	0	1	0
	4.0	99	99	99	98	65	21	0
3	0.5	62	99	91	90	19	0	13
	4.0	100	99	99	99	71	36	13
4	0.5	0	98	72	73	39	13	17
	4.0	9.6%	99	98	99	71	69	20
5	0.5	44	95	74	77	22	8	0
	4.0	98	99	98	99	62	51	0

The results obtained with a constant pH of 10 and a varying hardness of 50-110 p.p.m. are presented in Table 5. An examination of the table reveals that the percentage-reduction of bacteria in 30 minutes was the same as that obtained after 1, 2, 3, and 4 hours settling. The greater the concentration of the sludge blanket up to 2500 p.p.m. the greater the percentage-reduction bacteria, although the difference was only an increase of 2 percent between 1200 and 2500 p.p.m.

With a constant hardness of 85 p.p.m. and a pH varying from 8.5 to 10, the results were comparable to those obtained with a constant pH and a varying hardness, except 5000 p.p.m. removed 99 percent of the bacteria whereas 2400 p.p.m. removed 98 percent. The results are presented in Table 6. In general the bacterial removal was not as great. This may be due to the difficulty in adjusting the sludge concentration which involved breaking up and reforming the floc several times in order to obtain the desired hardness.

The data obtained in the cylinder tests indicate that there is a definite relationship between sludge concentration and bacterial removal. The results demonstrated that when the concentration of sludge is in excess of 1200 p.p.m. marked removal of bacteria occurred with a one hour settling period. Increasing the concentration above 1200 p.p.m. gave increasingly better results as long as the sludge would settle within the allotted time. However, these percentage reductions were not marked inasmuch as lower concentrations removed approximately 97 percent of the bacteria. The rate of removal of the heavy concentrations of sludge was greater than the lighter concentrations, the former showing as much as a 50 percent better result in 30 minutes settling time than the latter after 4 hours settling. The data obtained in the cylinder tests where

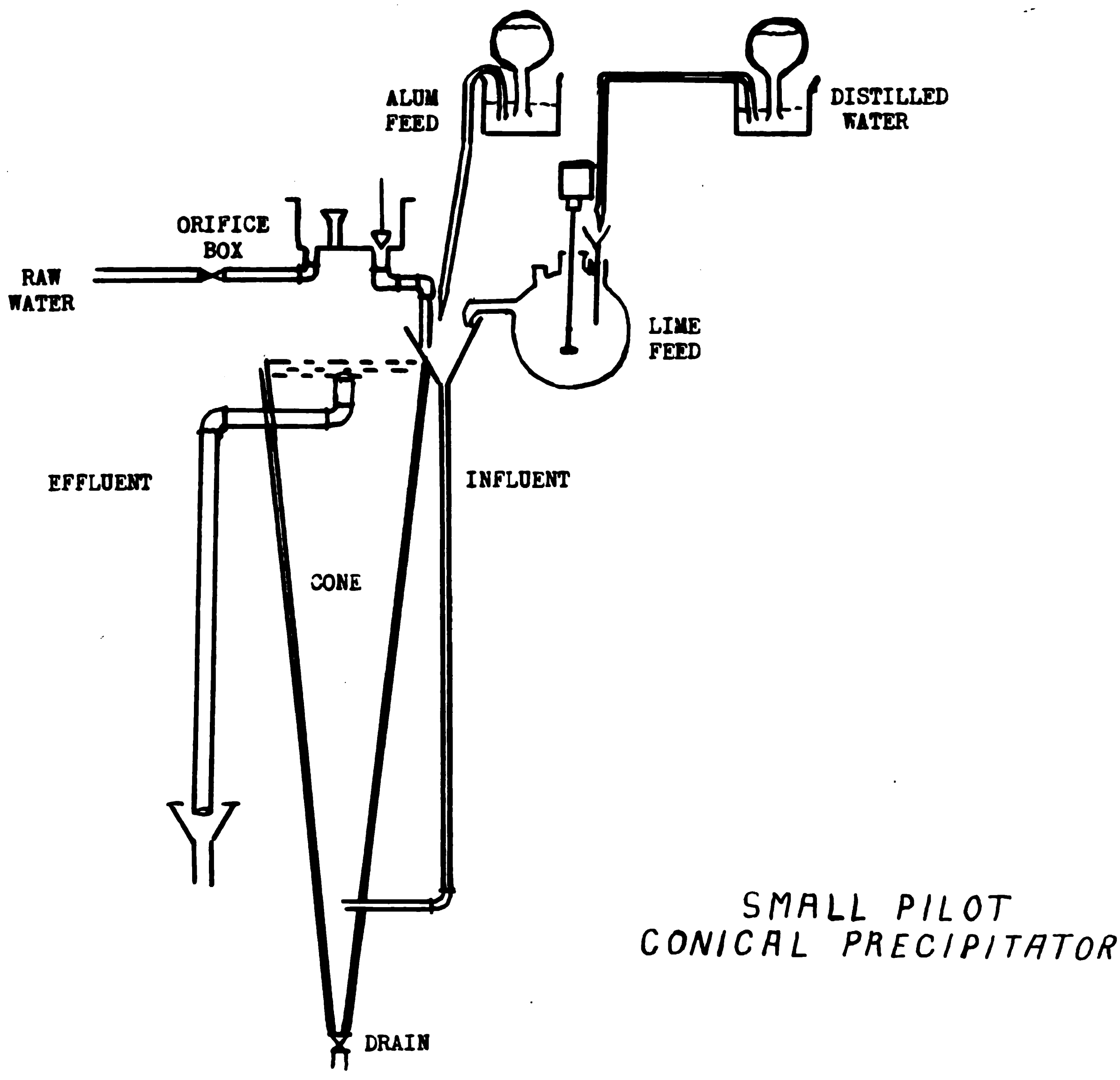
Table 5 - A comparison of varying concentrations of lime-alum floc at a constant pH 10 with hardness varying from 50 to 110 p.p.m. in removal of Esch. coli.

Settling Time in Hours	Percentage- reduction of bacteria Sludge concentration in p.p.m.				Control
	5000	2500	1200	700	
0.5	99	99	97	75	0
1.0	99	99	97	75	0
2.0	99	99	97	75	7
3.0	99	99	97	74	20
4.0	99	99	97	85	53

Table 6. A comparison of varying concentrations of lime-alum floc at a constant hardness of 85 p.p.m. with a pH varying from 8.5 to 10 in removal of *Esch. coli.*

Settling time in hours	Percentage - reduction of bacteria Sludge Concentration in p.p.m. 5000	2400	1200	700	Control
0.5	99	98	95	93	22
1.0	99	98	90	90	29
2.0	99	98	91	92	31
3.0	99	98	90	96	41
4.0	99	97	92	93	46

Fig. 1. Cone Precipitator with orifice box and chemical feed beakers.



ALUM
FEED
DISTILLED
WATER
ORIFICE
BOX
RAW
WATER
LIME
FEED
EFFLUENT
INFLUENT
CONE
DRAIN
SMALL PILOT
CONICAL PRECIPITATOR

Fig. 1

no disturbance occurs due to water flow, as would occur under practical conditions, definitely show the value of heavy sludge concentrations in removal of bacteria. The data warranted further studies wherein a continuous flow system is used.

Part II - Studies with Cone Precipitator

The results obtained with the cylinders definitely show that sludge concentrations, comparable to those used in practice with a Spaulding Precipitator, remove bacteria from the treated water effectively. However as these results were obtained with an undisturbed settling sludge and because in the Spaulding Precipiator the water passes up through the sludge, the second phase of this study was undertaken using an inverted cone such as Spaulding used in his early work. In such a cone, raw water and chemicals enter at the bottom, ascend through the previously accumulated sludge blanket and finished water is taken off at the top.

The cone experiments were instituted primarily to determine whether the expense of a pilot plant would be justified and also to obtain further data using an apparatus in which various short experiments could be made.

The cone precipitator unit consisted of the following pieces of equipment: The cone, constructed of sheet metal was 6 ft. high, the top having a diameter of 10 in. which tapered to an apex at the bottom. A drawing of the unit is present in Figure I. An angle iron standard supported the cone 2 ft. from the floor in an upright position. Four stopcocks were located at various levels for sampling with a valve at the apex for draining. An intake pipe (5/8 in.) was soldered into the cone on the outside at a tangent about 12 in. from the apex. A vertical pipe with a funnel attached to its top was connected at right angles to the intake pipe. Raw water and chemicals were fed into this pipe. The outlet pipe orifice was located in the center of the cone about one inch from the top. The cone had a capacity of 33 liters.

Raw water flow was controlled by an orifice box which was located above the water intake funnel. An alum solution was fed into the water intake funnel from a constant head beaker, the amount being regulated by a stopcock. The lime hydrate was added in a suspended state from a 2 liter, 3 neck boiling flask which had a spout attached to its side. A motor driven stirrer was used to mix the material and keep the lime in suspension. Distilled water was added to the lime flask from a constant head beaker to assure a steady flow of lime water into the water intake funnel. A charge of dry hydrate lime was added to the flask every 30 minutes to maintain a constant concentration of lime.

In order to duplicate conditions of softening plant operation, raw water from the Red Cedar River was used. This also supplied a varied bacterial flora representative of a sewage polluted water. Previous tests had showed the bacterial flora to be abundant in this water even at low temperatures. Hardness of the water varied somewhat necessitating operational changes several times a day. The pH of the effluent was maintained below 10.3 at all times as previous work had showed that higher values were bactericidal. For this reason the treatment was not always as complete as might be desired.

The cone was used first for determining the effectiveness of the Spaulding Precipitator with a water detention period of one hour and the conventional type of softening without sludge blanket and a detention period of four hours.

The bacteriological procedure followed in full the recommended procedures of "Standard Methods for the Examination of Water and Sewage"(14). Tests were made for both total counts and colon indices. Colon indices were determined by planting the decimal dilutions in triplicate and reporting the colon indices by the most probable number. In order to eliminate discrepancies in variable plate counts each 100 ml. sample was plated in 8 replicate. Four platings were made by placing 1 ml. of the sample in 4 sets of saline dilution blanks and making appropriate dilution plates from each and four platings were made in a similar manner starting with 10 ml. of the sample in saline dilution blanks. By average the counts of the eight separate platings, discrepancies due to the plating technic and sampling were largely eliminated. Plates and tubes were incubated for 48 hours at 37° C. Inasmuch as past experience had demonstrated that gas production was always due to coliform organisms, the presumptive test was considered positive if gas appeared in the fermentation tubes within 48 hours. In practically all cases gas was evident at the end of 24 hours incubation. Forty eight hour readings on the agar plates were used because it was desired to obtain the maximum numbers of bacteria present in the water.

Samples were collected at two points, the raw water from the orifice box at 3 and 4 hour intervals depending upon the rate of flow and the finished water from the final effluent at hourly intervals. Lack of change in the number of organisms in the raw water did not warrant sampling every hour. Twenty samples were taken in most cases; each sample was either set up for bacteriological test immediately or refrigerated for not more than 8 hours.

Lime-Alum Experiments

As previously stated in this thesis, the objective of the study was a comparison of the Spaulding Precipitator using a sludge blanket and the conventional settling tank without a sludge blanket, therefore the cone was used in the first test as a Precipitator unit and, in the second test, as a conventional settling tank.

The detention period in the first series was one hour with a flow rate of 8 gallons per hour. A carbonate hydroxide sludge blanket was built up in the cone to a level of 15 in. from the surface in conformity to Precipitator operation. It took 3 days to accumulate sufficient sludge. To maintain a constant sludge level of 15 in. sludge was drawn off from the apex valve every hour during operation.

In the second series, when the cone was used as a conventional settling tank, a 4 hour detention period was used to conform to practical operation. With this detention period the flow rate was decreased to 2 gal. per hour with the chemical feeds adjusted proportionally. As no sludge blanket is used in this type of softening, accumulated sludge was drawn off at hourly intervals.

The operating data, when the cone was used as a Precipitator unit, are presented in Table 7. These data show the degree of variation encountered in the operation of the unit. An examination of the table shows that the alkalinity and pH were fairly constant. A turbidity of 5 to 8 was maintained except for a period of 4 hours when the turbidity was nearly as high as the raw water. The sludge levels varied from 11 to 22 in. with an average of 16 in.

Table 7 - Operating Data when the cone was used as a Spaulding Precipitator with a 1 hour detention.

Time of Sampling	Flow Rate ml/min.	Effluent					Raw Water			Sludge		Bacterial Sample No.
		Phenolth Alk.	M.O. Alk.	Hard.	pH	Tur.	M.O. Alk.	Hard.	Tur.	Level	% Settling 10 min. C#3	
10:00 AM	510							246				
12:00	505	40	120		10.0	20						
1:00 PM		38	90		10:15					11"		
1:30	510	38	81		10:25	8					37	
2:00		38	80		10:25	8				15"		
3:00		35	88	88	10.1	7						
4:00		37	80		10.25	6-7				15"	35	
5:00	505	36	80		10.25	5-6				16"		
6:00		37	76(F)		10.3	5-6						
7:00		37	74		10.3	6-7				15"		1
8:00		38	74		10.3	6				16"		2
9:00		27	51(F)		10.3	5				16"		3
10:30 AM	505									13"		
12:00	505	33	65(F)		10.3					15"		
12:30 PM		34	68		10.25	7				15"		4
1:30	505	35	69(F)		10.3							5
2:30		30	57(F)		10.3	7				15"	29	6
3:30		28	57		10.25	6					31	7
4:30	500	27	52(F)		10.25	6				20"		8
5:30		26	47		10.3	5-6		208		19"		9
6:30		25	50		10.2					20"		10

Table 7 -
Sheet 2.

Sampling	Flow Rate ml/min.	Effluent					Raw Water			Sludge		Bacterial Sample No.
		Phenolth Alk.	M.O. Alk.	Hard.	pH	Tur.	M.O. Alk.	Hard.	Tur.	Level	% Settling 10 min. C#3	
9:00 AM	505	31	65		10.25		182		12			
10:00 AM	495-505	36	56(F)							22"		
11:00	495-505	39	57(F)			10-15	181				37	
12:00		29	54(F)		10.4	10-12			15-18	21"		11
01:00 PM	500	32	62(F)			10-15					36	12
2:00		30	61(F)		10.3	10-12						13
3:00	515-505	29	58(F)		10.2	10-15			15	18"		14
4:00		28	60(F)		10.3					18"		15
5:00	495	27	56(F)			6-7					34	16
6:00	495	26	53(F)	107	10.15	6-7				17"		17
7:00	505	27	52(F)		10.2	6						18
8:00	505	26	53(F)		10.15	5-6						19
9:00		25	51(F)			5-6					39	20

NOTES:

1. F= Filtered Sample
2. C#3 = Cock #3
3. Sludge drawn off 2000 cc at a time at 2-3 hr. intervals
4. Raw Water - 52° - 54° F.
5. Feeds - cut lime 13% at 11:00 A.M. 1/1/46.

The operating data, when the cone was used as a conventional settling tank are presented in Table 8. The alkalinity and pH were fairly constant and compared to that obtained with the Precipitator tests. The turbidity during the early part of the run was approximately 15 in the final effluent and in the latter part of the run it was 10 during the last 3 hours, 7 to 8. The raw water had a turbidity of 5 to 8. Thus in this case the final effluent had a turbidity throughout the experiment higher than the raw water. This was unavoidable because the cone did not adapt itself satisfactorily as a conventional settling tank.

The bacteriological data for the two series of tests are presented in Table 9. It will be observed that the hourly samples vary both in total count and colon indices. This would be expected in individual samples so that in evaluating the data, it is necessary to use averages of repeated tests. The data show that with a sludge blanket and 1 hour detention the colon index was reduced from 11,900 to 1194, a reduction of 90 percent. In the case of the 4 hour detention period without a sludge blanket the colon index fell from 4500 to 1233, a reduction of 73 percent.

The results attained in the reduction of total bacterial counts are similar to those obtained for the colon indices. The reduction in total count for the 1 hour detention period with a sludge blanket was 95 percent whereas only a reduction of 39 percent was obtained with the 4 hour detention period without the sludge blanket.

As previously stated the cone, when operated with a 1 hour detention period and a sludge blanket, gave a final effluent with a turbidity of approximately 7 to 8 while the cone operated as a conventional type

TABLE 8 - Operating Data When the Cone was Used as Conventional Softener with a 4 Hr. Detention

Date	Time	Flow Rate ml/min.	Effluent Phenolth Alk.	Effluent M.O. Alk.	Effluent Hard.	Effluent pH	Effluent Turbidity	Raw Water M.O. Alk.	Raw Water Hard.	Raw Water Tur.	Bacteria Sample No.
1/3/46	2:00 P.M.	118-122	36	61						8	
	3:00	120-128	26	76				230			
	4:00	120-128	13	52		9.77					
	5:00	122-133	18	56		10.00	20				
	6:00	140-126	19	64		9.85		232			
	7:00	130	19	60		9.95	15				
	8:00	127	20	64		9.95	15				
	9:00	130	21	63		10.0	15				
	10:00	125	22	65		10.0	15				
	11:00	125	21	65		10.0	15				
	12:00	124	21	58		10.1	12-15				
1/4/46	1:00 A.M.	127	20	55		10.1	12-15				
	2:00	126	22	54		10.2	12	232		5	
	3:00	118-127	22	51		10.2	12				
	4:00	127	23	50		10.25	12				
	5:00	128	24	48	121	10.3	12-15				
	6:00	126	23	49		10.27	12-15				

TABLE 9 - A comparison of the data of the Lime-alum sludge blanket with 1 hour detention and that without sludge blanket and 4 hour detention in bacterial removal at pH 10.3

	Sludge Blanket			Without Sludge Blanket		
Hourly Samples	Raw Water Colon Index	Effluent Colon Index	% Reduction Total Count	Raw Water Colon Index	Effluent Colon Index	% Reduction Total Count
1	11,000	45	95	4,500	4,500	76
2		450	87		4,500	53
3		450	96		14,000	38
4	11,000	450	87	4,500	4,500	56
5		450	96		4,500	59
6		250	95		150	0
7		450	95		4,500	24
8		950	88		450	70
9		2,500	90		450	23
10		2,500	99		70	10
11	14,000	4,500	99	4,500	450	39
12		2,500	98		2,500	50
13		4,500	99		140	24
14		4,500	98		2,500	50
15		4,500	99		140	24
16		2,500	98		950	96
17		2,500	98		2,500	77
18		750	99		950	49
19		2,500	99		2,500	91
20		2,500	95		2,500	94
Log Average	11,900	1,194	95	4,500	1,233	39

softening unit yielded an effluent with a turbidity of approximately 15, which was higher than the influent. The bacteriological results obtained with the cone operated as a conventional type softening unit reflect the turbidity data in that marked variability was obtained both in total count and colon indices. This is shown in Table 10. These data show that the cone operated with a flow rate of 2 gal. per hour cannot be operated satisfactorily and that the cone is not designed to act as conventional settling basin. The data, as a whole demonstrate that a sludge blanket helps materially in the removal of bacteria, but do not necessarily demonstrate the inefficiency of the conventional water softening process in the removal of bacteria. The data however, do show a marked difference in bacterial removal which is so marked that the data cannot be ignored. The results are similar to those obtained with the cylinder tests which further confirm the data obtained in the cone studies.

Coagulation Experiment with Alum

For the coagulation test with alum, the cone was first used as a Precipitator and second as a conventional tank without a sludge blanket. The cone was changed slightly. A 4 in. intake pipe replaced the 3/8 in. pipe in order to have sufficient area for carbon dioxide, which collected in the pipe, to escape. It was necessary to prevent the gas from entering the cone as it would carry the floc to the top of the cone hindering blanket formation. Preliminary beaker tests had shown the optimum pH for coagulation to be 6. To obtain the desired clarification it was necessary to use 30 p.p.m. of alum. Sulphuric acid (N/1) was added from a

Table 10 - Relationship of turbidity of effluent and bacterial removal with and without a lime-alum sludge blanket

Sample No.	Sludge Blanket			Without Sludge Blanket		
	% Removal Total Count	Colon Index	Turbidity	% Removal Total Count	Colon Index	Turbidity
1	95	45	7	76	4,500	15
2	87	450	7	53	4,500	15
3	96	450	3	38	14,000	12
4	87	450	9	56	4,500	12
5	96	450	6	59	4,500	12
6	95	250	6	0	150	12
7	95	450	4	24	4,500	12
8	88	950	4	70	450	15
9	90	2,500	7	23	450	15
10	99	2,500	7	10	70	13

constant head beaker to adjust the pH of the water. To give the floc weight, clay was fed from a three neck boiling flask into the intake funnel in the same manner that lime had been added in the preceding softening experiments.

Again comparative tests with and without the sludge blanket were made. Twenty samples of the treated effluent were taken in each series of experiments. Total bacterial counts and colon indices were made as before.

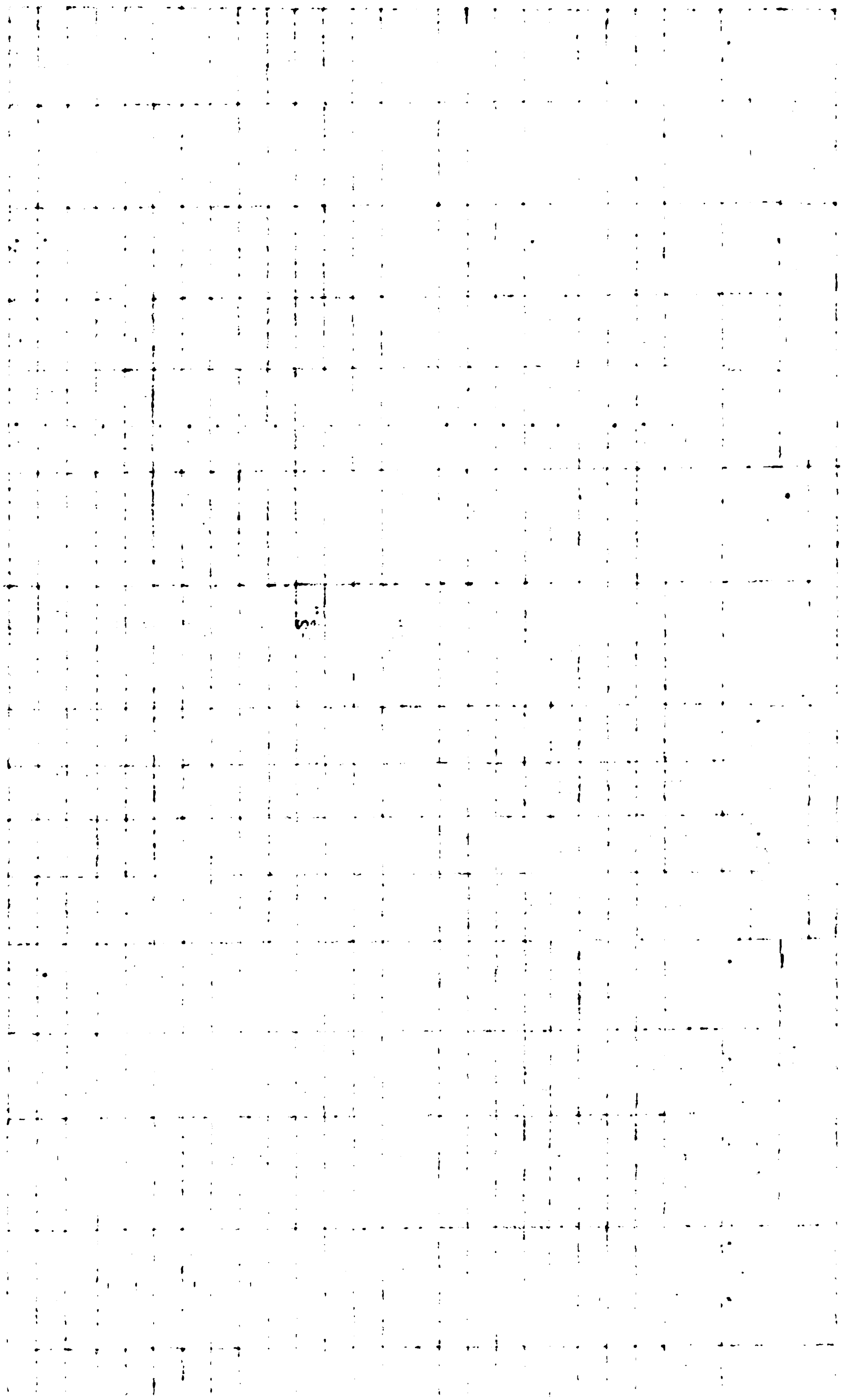
The operating data for the experiments on alum coagulation with a sludge blanket and one hour detention period are presented in Table 11. During the period of sampling the turbidity averaged approximately 6 in the effluent and ranged from 14 to 50 in the raw water. The pH was slightly under 6. The sludge level was approximately 17 inches from the surface of the water.

The operating data for the experiments with alum without a sludge blanket and a four hour detention period are presented in Table 12. The turbidity ranged from 3 to 4 in the effluent and from 10 to 14 in the raw water. It will be noted that the turbidity without a sludge blanket was lower than that obtained with a sludge blanket. The pH was approximately 6.2 which is, at least, 0.2 higher than that obtained in the experiments with a sludge blanket. The pH was approximately 6.2 which is, at least, 0.2 higher than that obtained in the experiments with a sludge blanket.

The bacteriological tests for these experiments are reported in Table 13. With a sludge blanket the average percentage reduction of coliform organisms was 98.6 for the 3 successive days of the experiment. The total average bacterial removal as represented by the percentage reduction

Table 11 - Operating Data when the cone was used as a Precipitator for Coagulation with an Alum Sludge Blanket and 1 hr. detention

Time	Flow Rate ml/min.	Raw Water			Sludge						Effluent			Samples for Bacteria	
		M.O. Alk.	Tur.	C° Temp.	% Sett. 10 Min. C#1	C#2	C#3	C#4	Sludge Level	ml. Sludge Blown	pH	Tur.	C° Temp.	Raw	Eff.
3/2/46 8:00 AM	500	136	20		13	20	No				5.2	15			
1:00 PM	500		40		14	26	No		21"		5.8	7			
2:00	500										5.9	7		1	1
4:00	500		25								5.7	7		2	2
5:00	500	134				32	15	No	14"	200	5.7	5			3
6:15	505		14		18						5.7	9	14.5°	3	4
7:15	510		50			33	30	No	14"	200	5.9	6			5
8:15	500						31	No	13"	100	5.9	6			6
9:15	502										5.8	4			7
3/4/46 9:40 AM	505	76			52	49			14"	200	5.9	4		4	
11:00	500	75	25								6.0	7			8
12:00	508			12							6.0	7	13		9
1:00 PM	508		25				45		11½"	200	5.95	5		5	10
2:00	500		20	12							5.95	4			11
3:00	480-500	76	25						9"		5.95	4			12
4:00	520	77	30	15							6.00	4	13	6	13
5:00	490-500		30		33	55	47		7½"	300	6.00	3			14
6:00	500	80	25	10.5							5.92	2-3	13		15
7:00	480-510		25	9.5					7"		5.90	2-3	12	7	16
8:00	480-510								5"		5.90	3			17
9:00	505		20				46		6"	600	6.00	4			18
10:00	505	85	20	11.0			47	29	5½"	800	6.00	4	11.5	8	19
11:00	505		20				43	25	5½"	500	6.00	2-3	11.5		20



NOTES ON TABLE 11.

1. After sludge stood overnight, it was agitated 15 minutes to break up lumps.

2. Raw water color approx. 50-60 on 3/4.

3. Settling times in 20 min.
   9:40 A.M. C.#2- 40% C#3 -38%
   2:00 A.M. C.#1 -33% C#2 44%, C#3- 42%

4. Where effluent shows pH 5.9 - 6.0 actual coagulation took place at pH 5.7-5.8. pH increased in passing outlet pipe due to aeration.

5. Dosages - Alum $3-3\frac{1}{2}$ grs., clay $2-2\frac{1}{2}$ grs. Acid to ph Adjustment.

Table 12 - Operating Data when the cone was used as a conventional Coagulator with Alum without a sludge blanket and a 4 hour detention

Time	Flow Rate ml./min.	Raw Water M.O.	Raw Water Tur.	Raw Water Temp. O. B.	Sludge Temp. Inlet	Sludge Ml. Blown	Sludge % Sett. 10 min.	Effluent pH	Effluent Tur.	Effluent Temp.	Samples for Bacteria Raw	Samples for Bacteria Eff.
3/7/46 8:30 AM	128							5.8			1	
9:30	128	109	13			100	20	5.9				
10:30	130				14	100	25	6.3	3	18.5		
11:30	126	112	12		14	110	20	6.4	4	17.5		
12:30 PM	130		14		14	180	15	6.35	4	16.7	2	1
1:30	126		10		15	120	25	6.3	3	16.5		2
2:30	122-131		12		13	120	21	6.2	3-4	16.5		3
3:30	128	115	12		14.5	90	28	6.2	3-4	16.5		4
4:30	130	115	12		15	100	28	6.1	3	16.8	3	5
5:30	134-127				15	120	27	6.1	4	16.7		6
6:30	124-130				15	110	50	6.15	4	16.5		7
7:30	128		14	11.5	15			6.2	3	16.0		8
8:30	120-130	118	13	15.5	15.5	125	36	6.15	3	16.5	4	9
9:30	128			22.0	22.0	100	60	6.05	3	16.5		10
10:30	126			20.5	20.5	150	32	6.15	3	17.0		11
11:30	123-126		12	18	19	115	40	6.2	3	18.0		12
3/8/46 12:30 AM	135-128	122	13	18	18	150	14	6.3	3-4	18.2	5	13
1:30	125		13	19	19.5	90	26	6.25	4	18.7		14
2:30	126			20	19.5	85	30	6.35	3-4	19.0		15
3:30	122-130			18	17.5	100	20	6.2	4	18.7		16
4:30	132-128	125	12	19	19	100	30	6.2	3	18.7	6	17
5:30	127			19.5	19.5	100	40	6.15	3-4	19.0		18
6:30	130			20	20	125	30	6.2	4	19.5		19
7:30	128	122	10	19.5				6.25	3	19.5		20

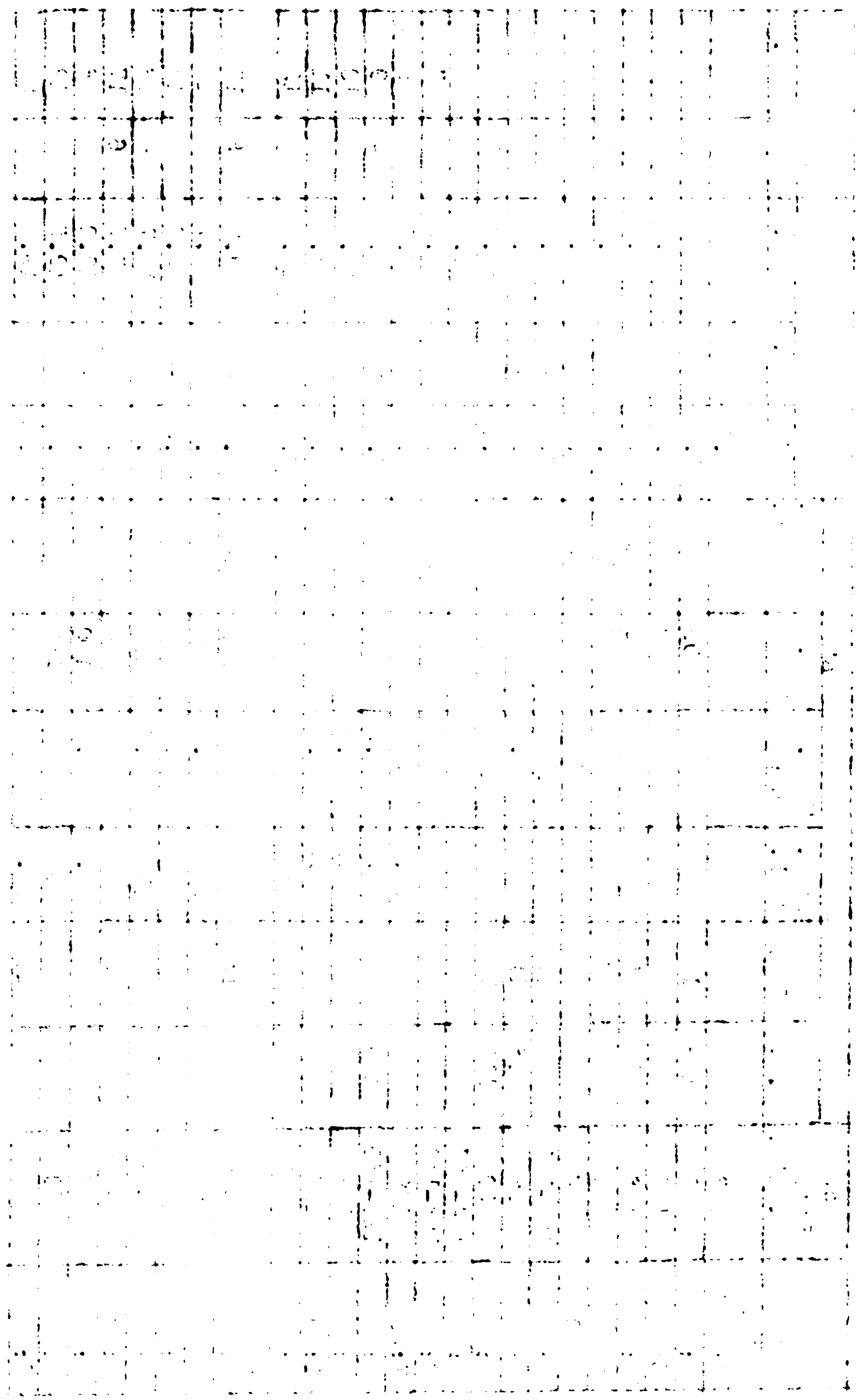


TABLE 13 - A comparison of the data of the alum sludge blanket 1 hour detention and that without sludge blanket and 4 hour detention in bacterial removal at pH 6.0

	Sludge Blanket			Without Sludge Blanket		
Hourly Samples	Raw Water Colon Index	Effluent Colon Index	% Reduction Total Count	Raw Water Colon Index	Effluent Colon Index	% Reduction Total Count
1	7,700	75	90	8,750	15	87
2		45	95		95	81
3		45	93		95	84
4		95	90		95	87
5		95	93		75	78
6		95	96		25	89
7		95	97		45	84
8	12,500	450	99	1,350	45	86
9		250	94		75	89
10		150	90		45	80
11		95	93		150	93
12		150	92		450	92
13		250	91		950	91
14	5,975	250	97	2,475	250	91
15		40	96		95	89
16		45	97		95	85
17		450	90		45	86
18		75	92		75	86
19		250	89		95	81
20		95	92		25	89
Log Average	8,299	117	92	3,076	81	86

in total count was 92. Without a sludge blanket, the total average of the percentage reduction of coliform organisms was 97.4 for the 3 days and percentage reduction in bacterial counts at 86..

These data indicate that the average reduction of both colon indices and total count was only slightly higher for the sludge blanket tests using one hour detention period than that obtained without a sludge blanket and a detention of 4 hours.

In these experiments the cone worked fairly satisfactory as a conventional settling basin with a detention period of 4 hours. It is rather interesting to note that although the turbidity of the effluent was greater in the experiments with a sludge blanket, still the bacterial reduction was slightly more effective.

Pilot Plant Studies

The results obtained with cylinder tests and the cone precipitator appeared to warrant an installation of pilot plants of both the Spaulding Precipitator and a conventional type installation so that they could be operated simultaneously. In this manner all variables such as water temperature, hardness of the water and bacterial content could be eliminated and the only variable would be the differences in operation characteristic of each installation. The plants could be made large enough so that they would simulate actual plant operation.

For the past several years Precipitator design has been altered to meet the needs of each job and to utilize existing equipment in the plants until today there are four types of units in use. The types are (1) round Precipitator, (2) square Precipitator, (3) double deck Precipitator, and (4) rectangular Precipitator. With the round and rectangular softeners raw water and chemicals enter the center of the unit near the top, pass downward through the mixing zone until the port is reached and then ascend outside the mixer through the sludge blanket to the effluent discharge. The double deck and the square Precipitators have raw water, chemicals and sludge mixed in a section outside the inflow filter zone with the results that the ascending treated water is inside the mixing zone.

The unit used in these studies, although a round tank, utilized the latter method of water passage through the Precipitator. It is shown in Figure 3. The outside jacket of the Precipitator was 3 ft. in diameter and 8 ft. in height. Inside of this tank a cone was hung about 12 in. from the bottom of the tank. The mixing zone was in the section between the cone and the Precipitator tank. The sludge concentrator, attached to the inside of the cone at the bottom, was extended upward about 2.5 ft. Stilling baffles were welded to the outside of the cone in the mixing zone. Sampling cocks, a blow-off, a blow-back, and a drain were located at proper levels on the side of the tank. The incoming mixture of raw water and chemicals entered the tank at the 5.25 ft. level and descended through the mixing zone to the port. The finished effluent was taken off the top by 5/16 in. orifices into a collection trough. Accumulated sludge was kept suspended and also mixed with incoming water-chemical mixture by agitator arms located in the lower mixing zone. Agitators in both units were driven by a $\frac{1}{2}$ H.P. motor with a gear reducing the rotation of the agitators to 16 R.P.M. for each unit. Automatic sludge blow-

Fig. 2. Shows general plan of the pilot plant with Precipitator, conventional settling tank, chemical mixing tank and feed tanks.

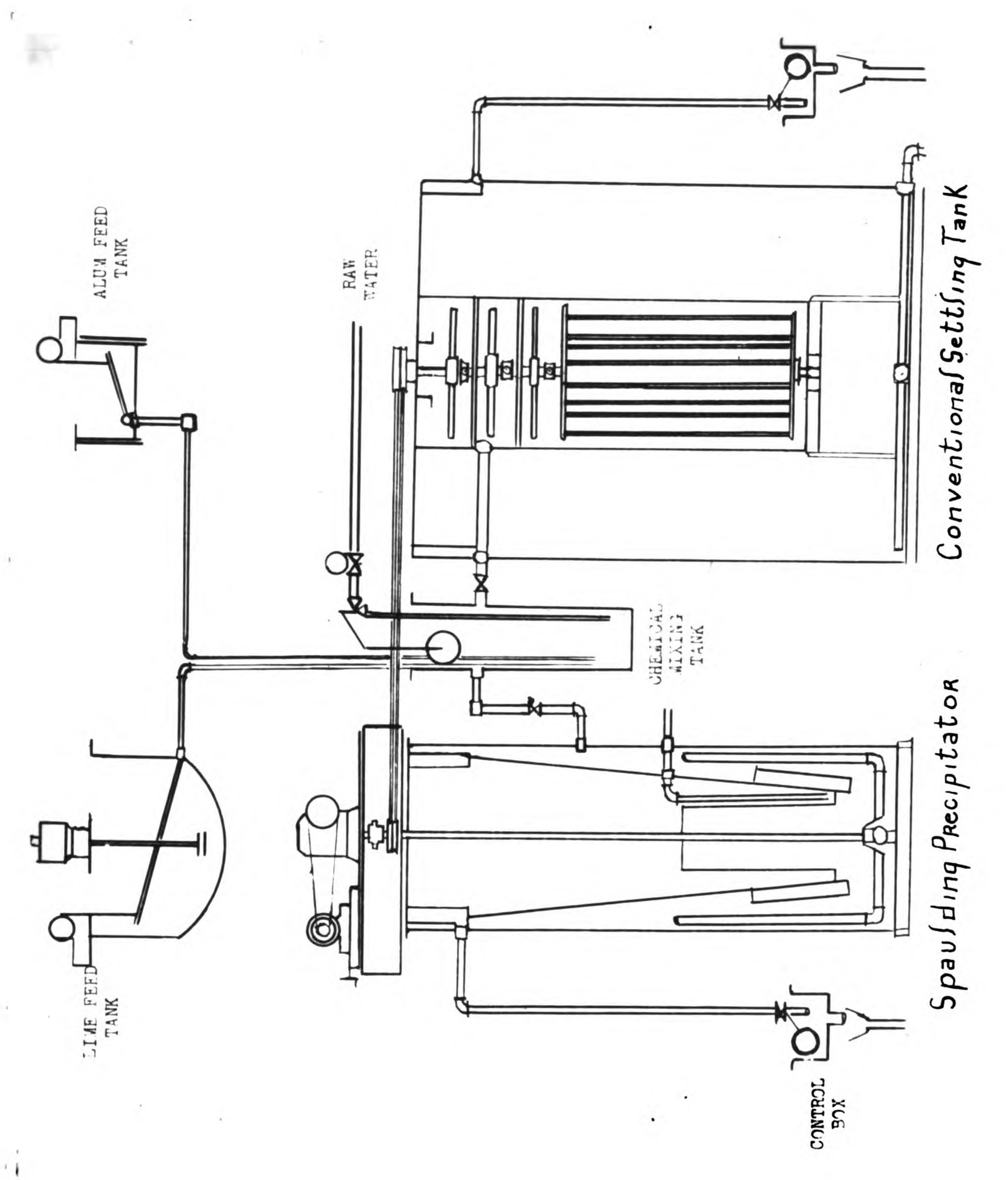
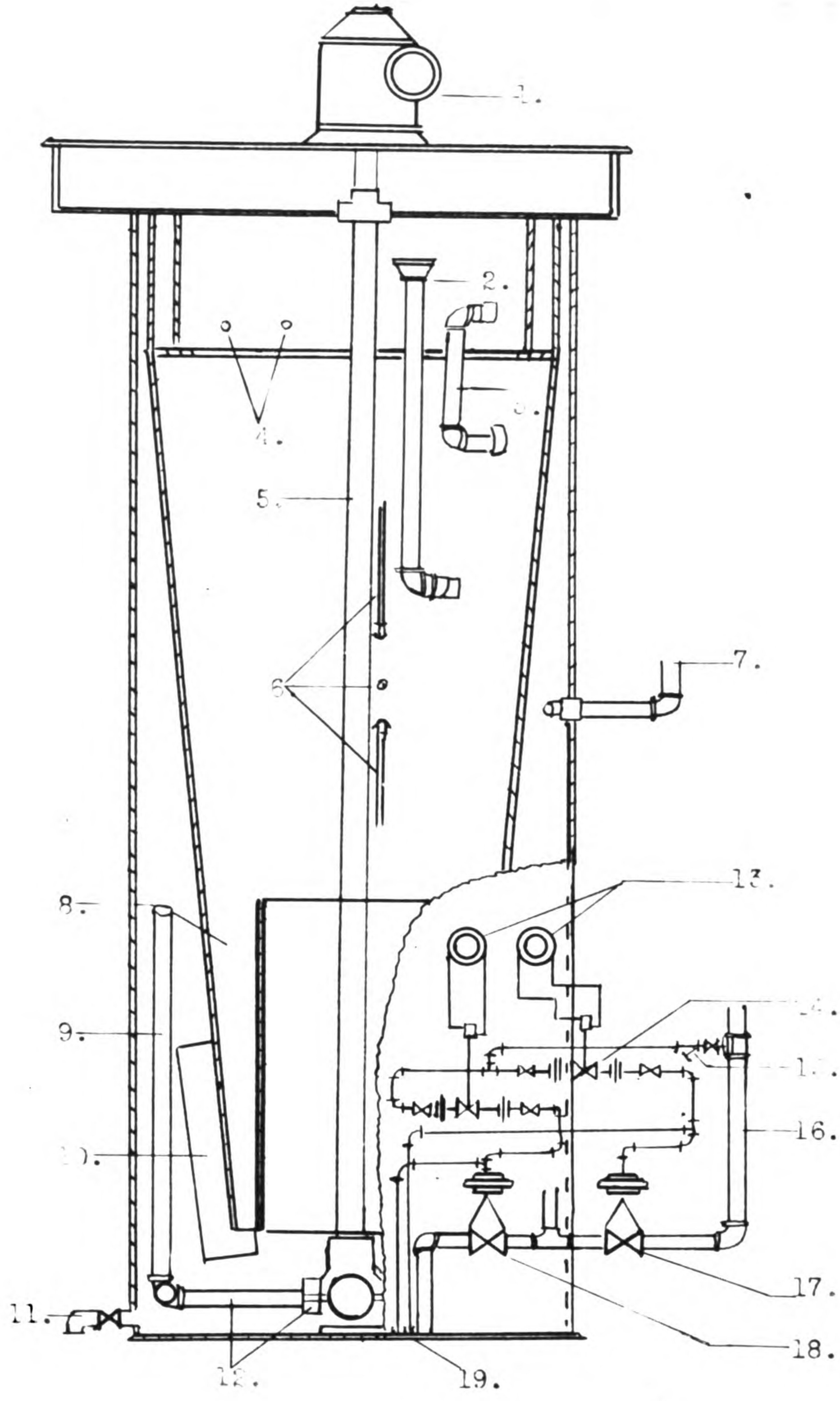

ALUM FEED TANK
RAW WATER
CHEMICAL MIXING TANK
LIME FEED TANK
CONTROL BOX
Conventional Settling Tank
Spaulding Precipitator

Fig. 2

Fig. 3 - Detailed drawing of Spaulding Precipitator

1. Speed reducer attach to ½ H.P. motor
2. Overflow pipe
3. Outlet
4. Orifices in collector ring
5. Shaft attached to agitators
6. Sampling cocks
7. Inlet pipe from mixing tank
8. Sludge concentration
9. Agitators
10. Stilling baffles
11. Drain pipe
12. Agitator assembly
13. 20 minute time clocks
14. Solenoid valves
15. Strainer
16. Flushback supply line
17. Flushback diaphram valves
18. Concentrator blowoff diaphram valve
19. Bleeder lines from diaphram valves



SPAULDING PRECIPITATOR

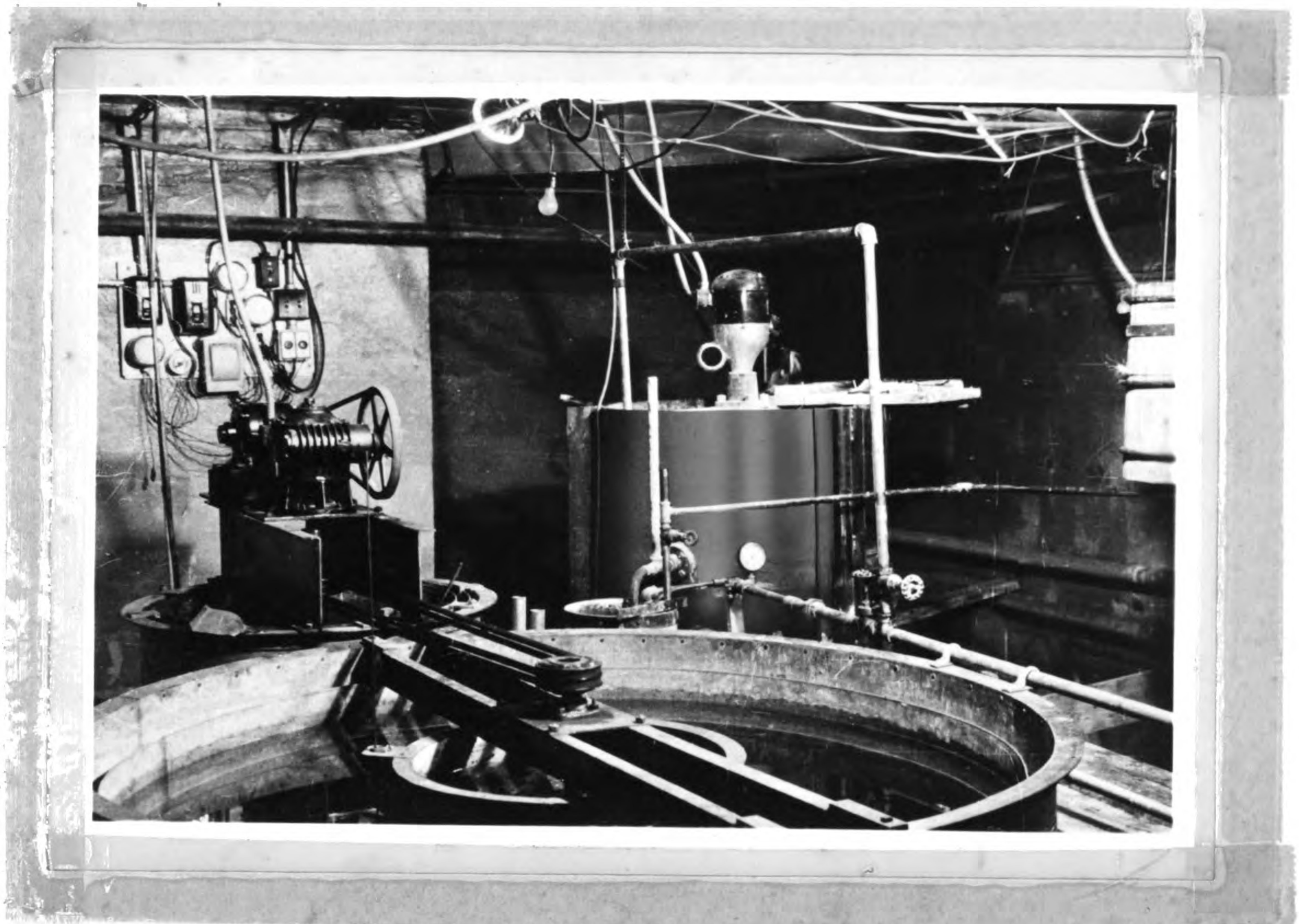
Fig. 5

offs and blow backs were controlled by 20 minute time clocks which released solenoid valves which in turn opened disphragm valves into the Precipitator.

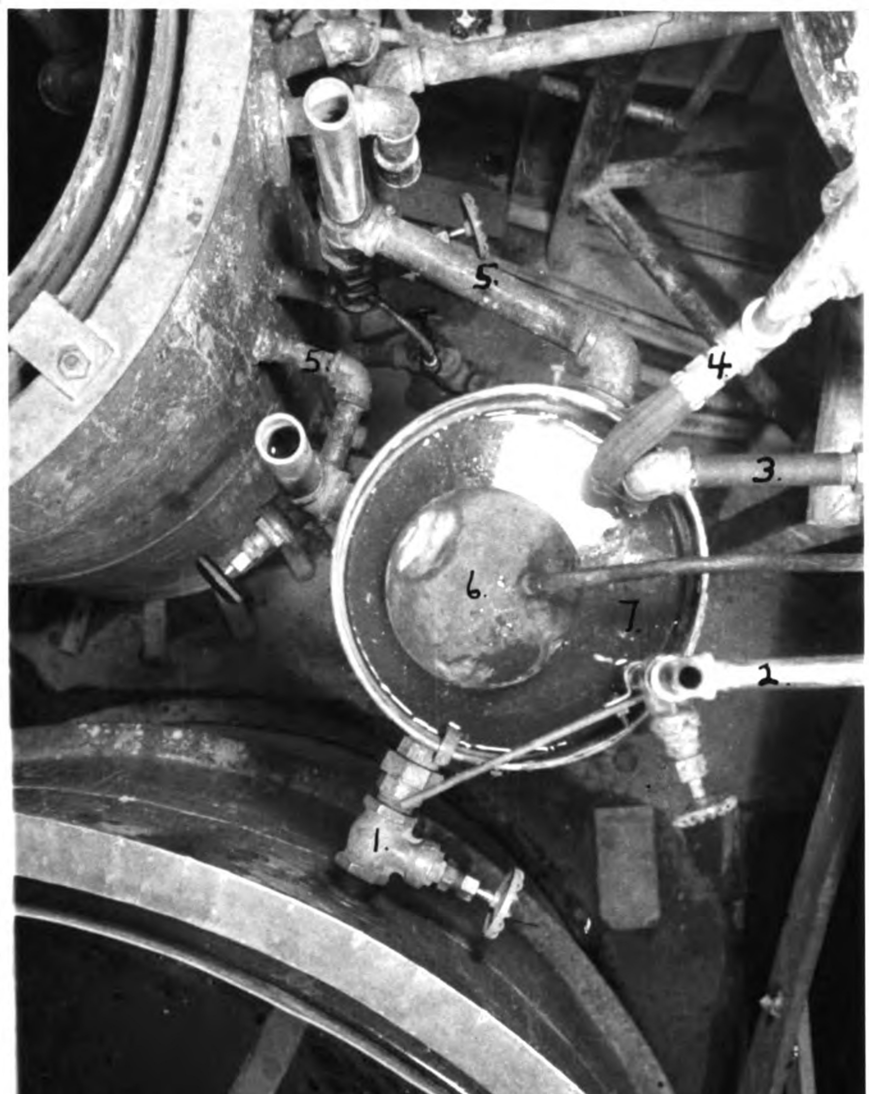
The conventional type settling tank was constructed of 18 gauge steel with a diameter of 6 ft. and a height of 8 ft. The mixer, which had a diameter of 24 in. and a height of 6.75 ft. was set 12 in. off of the bottom of the tank. Stators and agitators blades were attached to a shaft in the mixer. The influent from the mixing tank entered the mixer 13 in. from the top and descended through the mixing zone. After mixing, sludge was allowed to settle and the treated water ascended through the settling area to the ½ in. effluent orifices and to a collector ring at the top of the tank. Accumulated sludge was drawn hourly from this unit by a grid lying on the bottom of the tank which assured an even pull of sludge from the entire area during the blow-off. Draining was done by a valve in the bottom of the tank.

The Precipitator and the conventional settling tank were placed next to each other with a mixing tank (1 ft. diameter and 3.5 ft. high) located between the units. Lead-in pipes 16 in. from the top of the mixer fed each tank the lime-alum water mixture. Chemicals were fed into the mixer from a steel lime tank and a wooden alum tank by electro-chemical feeders. Charges were added periodically to these feed tanks. Raw river water was also fed into the mixer, its rate being regulated by a float valve. Equal rates through both units were regulated by control boxes on the side of each tank. In these boxes a butterfly valve regulated a float held at a constant head over the orifice. The arrangement of the tank is shown in Fig. 2 and Photographs 1 and 2.

Photograph 1. Pilot plant showing softening units and feed tanks.



Photograph 1.



Photograph 2

Photograph 2 - Shows piping into and out of
Central Mixing Tank.

1. Inlet pipe into conventional settling tank.

2. Pipe from alum tank.

3. Raw water pipe line

4. Pipe from lime tank

5. Inlet pipes into Precipitator

6. Float regulating raw water flow

7. Mixing tank.

With continuous operation, it was found satisfactory to charge the feed tanks every 12 hours, using raw water as the suspending medium. The electro-chemical feeders were set to deliver the proper dosage of chemicals. The flow-rate through each tank was 6.5 gal. per min. giving the desired detention time of one hour in the Precipitator and four hours in the settling tank. During bacteriological testing the following tests were made hourly, pH, alkalinity, turbidities, and settling rates of Precipitator sludge. Hardness was determined daily. About every 10 days the settling tank was drained and flushed out to prevent a gradual accumulation of sludge. In addition sludge samples were collected every 12 hours for bacteriological testing. Occasionally sludge samples were taken from the settling tank when sludge was drawn. A daily operation sheet, typical of a run is presented in Table 14. Bacteriological testing was done as previously described.

Red Cedar River water was selected for these tests as the bacterial population is high during the summer months. The water is slightly sewage-polluted so the colon index is generally high. The bacterial count usually runs between 25,000 and 50,000 during the summer months but this year Michigan had an exceptionally dry season and because there was little or no run-off water the population was unusually low. One series of tests was made using the low count river water and a second run was made wherein coliform organisms were fed into the water to produce a high count water. For the latter series, *Escherichia coli* was fed from a tank with a small injector pump into the river water line about 200 ft. ahead of the units. The organisms were grown in nutrient broth and were added to the feed tank twice daily.

Table 14 - Operational data of a typical days run with a lime-alum treatment at pH 9.7-10.0

Time	Water Vol. Prec. GPM	Water Vol. CTST GPM	Feed Data Lime in.	Feed Data Alum in.	Precip-Sludge up Mix	Precip-Sludge Low Mix	Sludge Body #2cock	Sludge Level	Raw Water MO	Raw Water TH	Raw Water pH	Raw Water T.	Raw Water C° Temp.	Raw Water Bact.	Prec. Eff. P	Prec. Eff. MO	Prec. Eff. TH	Prec. Eff. pH	Prec. Eff. T.	Prec. Eff. C° Temp.	Prec. Eff. Bact.	CTST Eff. P Alk.	CTST Eff. MO Alk.	CTST Eff. TH	CTST Eff. pH	CTST Eff. T.	CTST Eff. Temp.	CTST Eff. Bact.	Precip. C ST Aut. Sec. Blow	Precip. C ST Sec. Blow	Remarks
1AM	6.5	6.5	11	5-3/8	2		18.5%	31"	244		8.2	7	19.5					9.64		19.5					9.83		19.5		13		Chnges.Alum 5-3/8 Lime 11"
2						26	20	32"										9.72							9.82				13	10	
3	6.5	6.5					19	31"										9.80							9.80				13		
4							20	31"										9.62							9.77				13	10	Lime incr. at 3:50AM 2%
5	6.5	6.5				20	20	33"	246		8.2	7	19	R44				9.72	5	19					9.73	7	19		13	15	Lime incr. at 5:05AM 1%
6							19	33"						R45				9.82	5		P44				9.80	6			8	15	
7	6.5	6.5				25	22	32"						R46				9.96	5		P45				9.87	6			8	15	
8							19.5	30"						R47				9.86	5		P46				9.90	6			18	15	
9	6.5	6.5				23	21	30"					19	R48	13	40		9.90	5	19	P47	19	58		9.90	6		C44	18	15	
10							20	32"	248		8.2	7		R49				9.80	5		P48				9.95	6		C45	18	15	
11	6.5	6.5				23	20	32"						R50				9.90	5		P49				10.0	7		C46	14	15	
12N			11	7¼			20	31"					19	R51	14	40	112	99.88	5	19	P50	20	60		9.98	6	19	C47	19.5	15	Chrged. Alum 7¼" Lime 11"
1PM	6.5	6.5				19	20	33"										9.90	5		P51				10.0	6		C48	19.5	15	
2							17	34"										9.80	6						9.93	7		C49	12	15	
3	6.5	6.5				19	16	34"					20					9.81	5						9.92	6		C50	12	15	
4						20	17	34"	246	290					11	42	110	9.75	6	20		17	57	140	9.92	7	20	C51	12		Charged Lime 3"
5	6.5	6.5						35"																					11	30	
6																													11		
7	6.5	6.5																											11	30	
8																													11		
9	6.5	6.5																											11	30	
10																													11		
11	6.5	6.5																											11	30	
12M																													11		

Date 9/28/46 Total gals. 24 hrs. 18,720 # lime/in 1.58 # alum/in 0.34 #Clay in____ ppm acid____

3:50 A.M. - 1.61
5;00 A.M. - 1.62

Lime - 250 p.p.m.

Precip. = Precipitator
CTST= convent. type sett. tank
Data in sludge body #2 cock are percent settling in 5 minutes.

Lime-Alum Studies

In the first series of tests, lime-alum water softening procedure was used. With Red Cedar River water, complete treatment resulted at a pH of 10.3 to 10.5. Because bactericidal action may result to some extent at pH values above 10, it was decided to make two runs, one at 10.5 and the other at 9.7 to 10 where bactericidal action would not occur. Bacteriological tests were made on the river flora at pH 8.3, 10 and 10.25 at exposure periods of 1 and 4 hours to determine bactericidal activity. No reduction occurred at pH of 8.3 and 10, but some reduction occurred at 10.25. When the water was treated at 9.7 to 10, undertreatment occurred. It was necessary to keep the pH above 9.7 in these tests because the lime-alum floc became very fine and light at this pH causing a considerable carry-over of the sludge with the effluent. These latter testing conditions showed the effect of organisms removal by sludge blanket without the variable of bactericidal action due to alkalinity which might occur in tests at a pH above 10.

The first series of tests were made at pH 10.5 with complete treatment. The units were operated continuously for these studies for five days. Usually samplings were made hourly each day over an eight hour period. The raw water sample preceeded the Precipitator sample by 1 hour and the settling tank by four hours. This was done so that the sampling of influent and effluents represent the same water in all cases. This procedure was done in all experiments in the pilot plant testing. Space does not permit presentations of all tests. In all cases, the plants were operated until daily sampling gave approximately the same bacteriological pictures. In Table 15 is presented a typical daily run, showing the bacterial reductions, expressed in total counts and colon indices for

TABLE 15 - A typical pilot plant run using lime-alum treatment at pH 10.5 showing comparative bacterial reduction in the Precipitator and the conventional type settling tank

	Raw Water			Precipitation effluent			Settling tank effluent		
Hourly Sample	Bacteria Count	Colon Index	Turbidity	Bacteria Count	Colon Index	Turbidity	Bacteria Count	Colon Index	Turbidity
1	1,500	950	8	20	0	5	100	95	6
2	1,600	2,500		24	30	5-	110	450	6
3	1,500	4,500		17	0	5-	72	250	7
4	1,700	750		19	4	5-	62	15	7
5	1,500	4,500		17	25	5	47	45	7
6	1,800	950		21	4	5	170	25	7
7	2,000	950		12	4	5-	61	25	8
8	1,300	950		20	9	5-	33	25	7
Log Average	1,585	1,532		18	5		72	57	
Percent Reduction				98.9	99.8		95.5	97.0	

an 8 hour period. In this series, the turbidities were maintained at a level lower than the influent. It will be noted in this series that the turbidities were higher in the settling tank than those obtained in the Precipitator. The raw water counts were fairly constant throughout the run, averaging 1585 bacteria per ml. The colon indices varied considerably. This variation was characteristic of all sampling of raw water from the Red Cedar River through the entire study. The total count of the Precipitator effluent averaged 18 bacteria per ml. and the colon index of 57 with reductions of 95.5 and 97.0 percent respectively. These data show a lower bacterial reduction for the Precipitator.

In all of the studies, the turbidity was always lower in the Precipitator than in the settling tank. It was impossible to maintain the same turbidities in both tanks because identical treatment of the water resulted in a lower turbidity in the Precipitator. Because the turbidity was always higher in the settling tank it might follow that more bacteria were being carried over in the effluent. It could be argued that the differences in efficiencies in bacterial removal were due to this factor and not due to the effectiveness of the sludge blanket. Accordingly, a second series of tests was made wherein the turbidities were raised and comparable turbidities were obtained by disturbing the sludge blanket in the Precipitator to obtain a greater carry-over of sludge particles into the effluent. Again daily runs were made and daily sampling followed. In Table 16, is presented a typical daily run. In this run, there was an average reduction in total count of 94.7 percent, and in colon index of 97.5 for the Precipitator and an average reduction in total count of 92.2 percent and in colon index of 95.2 percent for the settling tank.

Table 16 - A typical pilot plant run using lime-alum treatment at pH 10.5 showing comparative bacterial reduction in the Precipitator and the conventional type settling tank when the same turbidities were maintained in both pilot plants

Hourly Samples	Raw Water			Precipitator effluent			Settling tank effluent		
	Bacteria Count	Colon Index	Turbidity	Bacteria Count	Colon Index	Turbidity	Bacteria Count	Colon Index	Turbidity
1	2,100	2,500	8	68	250	8	100	450	11
2	1,900	9,500		50	450	10	63	450	11
3	1,900	43,000		49	450	12	130	1,500	11
4	1,100	9,500		90	45	11	150	450	11
5	1,200	45,000		94	2,500	10	140	2,500	11
6	1,400	4,500		100	250	10	130	250	11
7	1,400	9,500		96	450	11	180	450	11
8	2,100	4,500		180	250	11	140	750	11
Log Average	1,585	13,100		83	335		123	640	
Percent Reduction				94.7	97.5		92.2	95.2	

These data show that where the turbidites were maintained at the same point, the reductions in total count and colon indices were still lower in the Precipitator. These data thus indicate that the Precipitator with a sludge blanket is more effective in removing bacteria and that the higher turbidity obtained in most of the studies in the settling tank does not account for the higher bacterial populations in the effluent.

The two series presented show the results obtained with lime-alum treatment of a water with moderate bacterial populations. To obtain further data where unusually heavy bacterial populations were present, Esch. coli. was fed into the river water line in excessive doses. Considerable difficulty was encountered in obtaining a constant seeding of the tanks, however this difficulty was finally overcome. Several runs were discarded because of the marked variability in the coliform organism content of the raw water. Three comparable daily runs were obtained. One of these is presented in Table 17. The average colon index of the raw water was 959,400. The average colon index of the Precipitator effluent was 19,410 with a percentage reduction of 97. In all runs the colon index was slightly higher in the settling tank effluent.

These data show that in a water with excessive colon indices, the Precipitator with a 1 hour detention period gave a slightly better reduction in colon index than did the settling tank with a 4 hour detention period.

To eliminate the possibility of bactericidal activity of high pH in the reduction of the bacteria which might have played a part in the tests presented, a series was made using pH 9.7-10 in the final effluent. A typical run is presented in Table 18. The Precipitator gave a reduction

Table 17 - A typical pilot plant run using lime-alum at pH 10.5 with river water seeded with Esch. coli. showing comparative reduction in colon indices in the Precipitator and the conventional type settling tank.

Hourly Samples	Raw Water Colon Index	Raw Water Turbidity	Precipitator Efflu. Colon Index	Precipitator Efflu. Turbidity	Sett. Tank Effluent Colon Index	Sett. Tank Effluent Turbidity	
1	2,500,000	6	25,000	16	25,000	19	
2	950,000		45,000	18	25,000	19	
3	950,000		45,000	18	95,000	19	
4	950,000		9,500	16	25,000	19	
5	950,000	5	45,000	17	9,500	19	
6	950,000		25,000	17	45,000	19	
7	450,000		4,500	17	9,500	19	
8	950,000	5-	25,000	16	45,000	19	
9	450,000		9,500	16	111,000	19	
10	250,000		25,000	12	25,000	19	
11	4,500,000		4,500	12	25,000	19	
12	1,500,000	5-	45,000	12	45,000	19	
Log Average	959,400		19,410		29,450		
Percent Reduction			98.0		97.0		

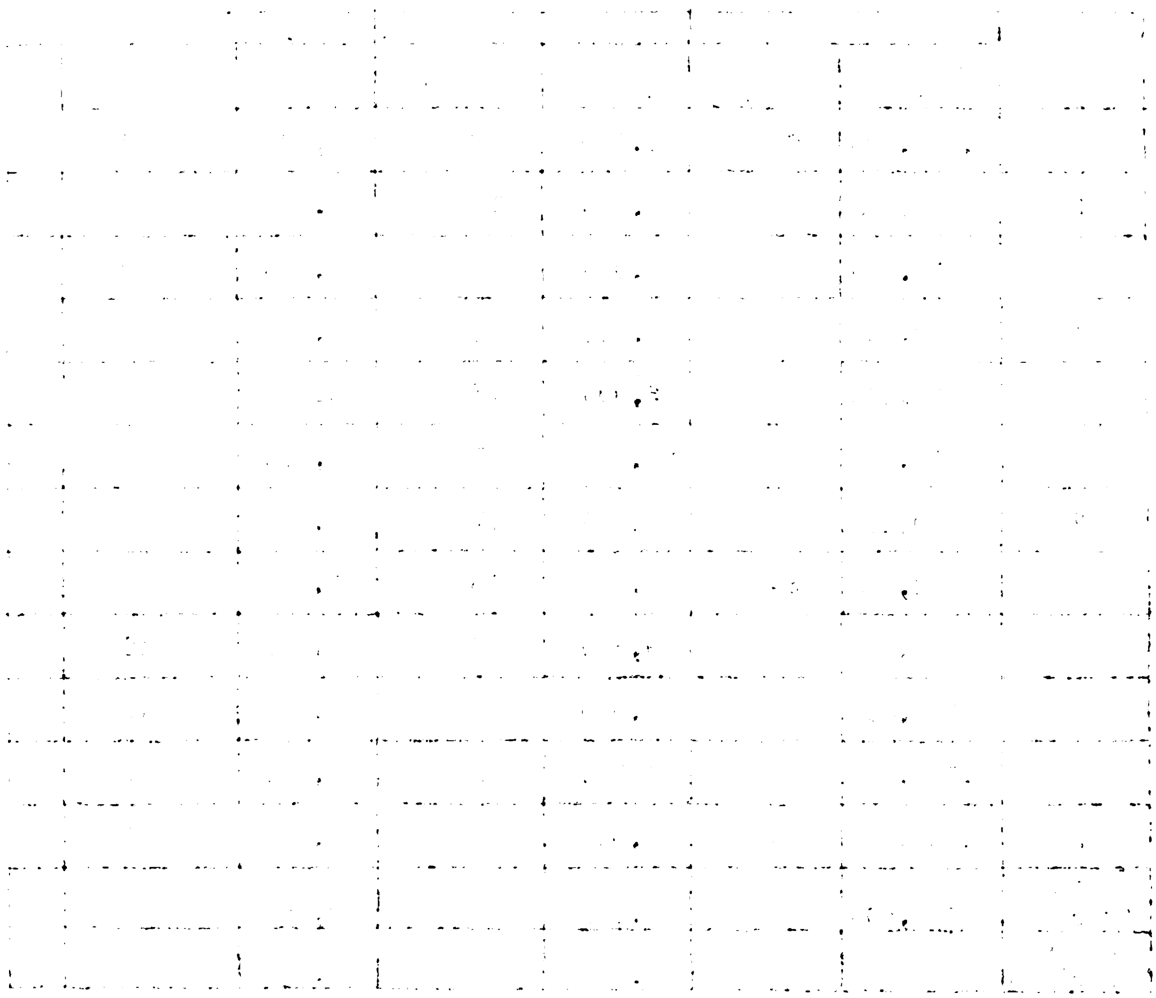


TABLE 18 - A typical pilot plant run using lime-alum at pH 9.7-10.0 showing comparative bacterial reduction in the Precipitator and the conventional type settling tank

Hourly Samples	Raw Water			Precipitator Effluent			Settling Tank Effluent		
	Bacterial Count	Colon Index	Turbidity	Bacterial Count	Colon Index	Turbidity	Bacterial Count	Colon Index	Turbidity
1	1,100	7,500	7	130	450	5	540	450	6
2	1,200	2,500		190	450	5	310	2,500	6
3	950	4,500		110	250	5	260	450	7
4	1,500	9,500		80	250	5	290	950	6
5	1,200	4,500		190	450	5-6	250	950	6
6	2,100	4,500		260	250	5	270	1,500	7
7	1,600	4,500		180	250	5	300	950	6
8	1,800	9,500		100	250	5	290	450	7
Log Average	1,384	5,358		153	511		300	855	
Percent Reduction				89.0	94.2		78.4	84.3	

of 89 percent in total count and 94.2 percent in colon index and the settling tank a reduction of 78.4 percent in total count and 84.3 percent in colon index. These data present the same general picture as that presented in the studies using higher pH values. The relative relationships of the Precipitator and settling tank were the same as in previously cited experiments but the percentage-reduction was less. This difference is likely due to bactericidal activity at the higher pH values. It is also possible that the greater differences shown between the two systems at pH 9.7 - 10 might be due to some bactericidal activity in the settling tank due to the longer detention period. The fact that the Precipitator still shows a greater percentage-reduction than does the settling tank could be attributed to the greater efficiency of the sludge blanket in actual mechanical removal of the bacteria.

Coagulation Experiments with Alum

The results obtained with the cone used as a conventional coagulation tank were not entirely satisfactory due to the fact that the cone was designed to simulate the action of the Precipitator. The data, however, showed that the Precipitator gave a better removal of bacteria but this could have been due to the fact that the tests were not comparable. Because the Precipitator has been used as a coagulator for water treatment, it seemed advisable to run tests with the pilot plants where design made possible the testing with one variable, namely one hour detention without sludge blanket in the conventional tank.

In the first series, raw Red Cedar River water was used so that bacterial tests could be made with the natural water flora. No pH adjustments were necessary during these tests as a good coagulation was obtained at the resulting pH 7.6. The alum dosage was 2½ grains with clay being added also at the rate of $2\frac{1}{2}$ grains to induce better settling. Sampling and testing was done as in previous pilot plant operations. The results of a typical days run are presented in Table 19. The raw water count averaged 1675 for this run with an average colon index of 5945. The Precipitator gave an average reduction of 65.8 percent with an average count of 572. The colon index was reduced to 794, an average percentage reduction of 86.7. The conventional tank without sludge blanket gave an average reduction of 60.7 percent with an average count of 659. The colon index was reduced to 1437, an average percentage reduction of 74.2. These data indicate that the Precipitator with a sludge blanket in one hour detention gives a better bacterial removal both in total count and colon index than does the conventional type tank with a four hour detention period.

In the second series, Esch. coli was added as in previous experiments with lime-alum treatment to give an exceedingly high colon index. This was done to see if the sludge blanket could cope with heavy bacterial populations. These tests were run at pH 7.6 with the same dosages of alum and clay. Only colon indices were checked in this series of tests. In Table 20 are presented a typical days run. An examination of the table reveals that the raw water had an average colon index of 2,500,000. The Precipitator reduced the colon index to 385,000 which gives a percentage-reduction of 84.6. The conventional tank gave a colon index of 467,000 a percentage reduction of 81.4. Here again, the Precipitator with a heavy bacterial population gave a greater bacterial reduction.

Inasmuch as the sludge blanket represents, in part, sludge which has been adsorbing bacteria from the water for some time, a check of the sludge

Table 19 - A typical pilot plant run using alum sludge at pH 7.6 showing comparative bacterial reduction in the Precipitator and the conventional settling tank

Hourly Sample	Raw Water			Precipitator Effluent			Settling Tank Effluent		
	Bacteria Count	Colon Index	Turbidity	Bacteria Count	Colon Index	Turbidity	Bacteria Count	Colon Index	Turbidity
1	1,600	9,500	8	410	450	5-	700	950	5-
2	1,400	4,500		640	2,500	5-	790	2,500	5-
3	1,700	9,500		820	950	5-	1,050	950	5-
4	1,300	4,500		1,050	1,500	5-	500	950	5-
5	1,500	4,500		600	450	5-	650	1,500	5-
6	1,600	9,500		540	250	5-	580	950	5-
7	3,200	4,500		490	950	5-	560	2,500	5-
8	2,300	4,500		390	950	5-	600	1,439	5-
Log Average	1,675	5,945		572	794		659	1,439	
Percent Reduction				65.8	86.7		60.7	74.2	

Table 20 - A typical pilot plant run using alum-clay at pH 7.6 with river water seeded with E. coli showing comparative reduction in colon indices in the Precipitator and the conventional settling tank.

Hourly Samples	Raw River Water Colon Index	Precipitator Effluent Colon Index	Settling Tank Effluent Colon Index
1	25,500,000	300,000	950,000
2	450,000	95,000	450,000
3	4,500,000	450,000	250,000
4	2,500,000	950,000	950,000
5	2,500,000	950,000	450,000
6	2,500,000	450,000	450,000
7	2,500,000	200,600	450,000
8	2,500,000	450,000	250,000
Log Average	2,500,000	385,000	467,000
Percent Reduction		84.6	81.4

was made to determine the bacteria content. In these tests, sludge samples were collected over a period of 9 days of operation to determine whether an increase of bacteria occurred particularly when a water with a heavy bacterial population was used. Both lime-alum and alum-clay sludges were tested both with light and heavy bacterial populations. In Table 21 are presented data using a lime-alum sludge blanket. With both heavy and light bacterial populations, no increase in population of the sludge occurred in 8 days of operation. In Table 22, are presented the data using an alum-clay sludge blanket. Here again there was no change in bacterial population over 9 days operation.

It is apparent from these data that the draw off of sludge to retain a constant level carries off sufficient used sludge so that the bacterial population remains constant.

Discussion

The results presented in this comparative study of the two types of water softening are extremely interesting in that they show the possibility of bacterial removal in pilot plants. Inasmuch as both plants were operated simultaneously with the same water and identical chemical treatment, the results are definitely comparable. It would be expected that bacteria would be removed but the data show definitely that a sludge blanket removes more bacteria than a settling procedure. It is also interesting to note that a sludge blanket removes more bacteria in an hour detention period than that obtained in a four hour detention period in the absence of a sludge blanket.

In the softening of a sewage polluted water supply, any process that will remove more bacteria, although the softening process is not necessarily a bacterial removal procedure, is significant from a public health

Table 21 - The Bacterial population of sludge in the Precipitator when lime-alum treatment was used during 8 days of operation

Sample Date	With influent bacterial Count of 20,000 organisms/ml.		Sample Date	With Influent bacterial Count of 1500 organisms/ ml.	
	Bacterial Counts	pH		Bacterial Counts	pH
11/8	20,600*	10.4	9/13	6,700	10.5
11/9	8,140	10.5	9/14	7,550	10.5
11/10	22,200	10.6	9/15	4,600	10.4
11/11	15,400	10.4	9/16	6,500	10.4
11/12	25,800	10.6	9/17	7,000	10.5
11/13	Spreaders	10.5	9/18	7,700	10.4
11/14	20,200	10.5	9/19	1,050	10.7
11/15	19,000	10.4	9/20	6,470	10.4

*Sludge plate count corrected to 30% settling 5 minutes.

Table 22 - The bacterial population of sludge in the Precipitator when alum-clay treatment was used during 9 day-operation

Sample Date	With influent bacterial Count of 25,000 organisms/ml.		Sample Date	With influent bacterial Count of 1,000 organisms/ ml.	
	Bacterial Counts	pH		Bacterial Counts	pH
10/29	677,000 *	7.6	10/6	14,000	7.6
10/30	534,000	7.5	10/7	13,000	7.6
10/31	403,000	7.4	10/8	10,800	7.6
11/1	277,000	7.4	10/10	15,500	7.6
11/2	359,000	7.6	10/11	11,100	7.6
11/3	419,000	7.6	10/13	3,000	7.4
11/4	300,000	7.6	10/14	16,200	7.5
11/5	253,000	7.6	10/16	6,700	7.6
11/6	210,000	7.7	10/17	12,000	7.6

*Sludge plate counts corrected to 10% settling 5 minutes.

standpoint. The greater the removal of bacteria in each step of the purification process, prior to post-chlorination the less responsibility is placed on the post chlorination to assure a water free of health hazard.

If it is possible to obtain more complete water softening in a sludge blanket Precipitator in one hour detention period than that obtained in a four hour detention conventional water softener and at the same time greater bacterial removal is also obtained than the process has a marked advantage.

The studies on the clarification of water by alum treatment also gave similar results in bacterial removal. This is particularly significant because in these studies, bactericidal action of high alkalinity was not encountered. The sludge blanket treatment for clarification has been used in small installation in bottling plants but the data presented in these pilot plant studies would indicate a useful application in municipal water supplies where polluted water is used.

It is particularly interesting to note that in the three methods of testing, namely cylinder tests, and laboratory cone Precipitator and pilot plant operations, the sludge blanket treatment gave the best results. It is apparent that in passing the water through a blanket of sludge floc the bacteria are in closer contact to the floc and hence bacteria are removed more rapidly and more effectively.

At the start of the studies, it was thought that the holding of used sludge in the tank might serve to recontaminate the water because the sludge could conceivably be heavily laden with bacteria. However in the studies it was found that the bacterial population of the sludge blanket rapidly reaches a constant in keeping with population of the effluent. In earlier laboratory tests, sludges with populations as high as 11,000,000 still effectively removed bacteria introduced by the effluent.

Conclusion

(1) In the lime-alum treatment for softening water, the sludge blanket treatment for one hour removed more bacteria than that obtained with the conventional treatment without sludge blanket for four hours.

(2) Experiments made in cylinders in laboratory experiments, and in pilot plant operations with a small experimental cone Precipitator and practical pilot plants were in agreement in results attained.

(3) In the alum-clay treatment for clarification of water, the sludge blanket treatment for one hour removed more bacteria than that obtained with the conventional treatment without sludge blanket for one hour.

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