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# **Phosphorus Removal in Extended Aeration Systems by Chemical Precipitation**

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Report to the Division of Water Pollution Control  
Massachusetts Water Resources Commission  
Department of Environmental Quality Engineering  
Contract Number 76-10(1)



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AMHERST, MASSACHUSETTS

PHOSPHORUS REMOVAL IN EXTENDED  
AERATION SYSTEMS BY CHEMICAL PRECIPITATION

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## PREFACE

This report represents the combined results of many studies on phosphorus removal in extended aeration systems conducted at the University of Massachusetts Wastewater Pilot Plant by Environmental Engineering Program graduate students. Robert M. Burke (12) conducted the first study with alum and concluded that there was insufficient alkalinity in Amherst wastewater to ensure pH values compatible with biological treatment. Alan J. Roy (13) examined the effect of alum addition on sludge accumulation and determined that a dosage of 200 mg/ℓ would triple the sludge accumulation rate. Raymond A. Noga (8) tried a lower alum dose (100 mg/ℓ) but pH was still depressed and sludge production again tripled. Finally, a study was conducted inhouse by Mr. C. James Martel, Research Associate, and Robert E. Pariseau, Research Chemist, during which lime was added for pH control. Most of the data on alum addition presented in this report is the result of this latter study. The sodium aluminate study was performed by Mr. Peter Spawn (7).

## ABSTRACT

Although chemical precipitation of phosphorus has been thoroughly investigated in conventional activated sludge systems, little work has been done relative to extended aeration plants. Contrary to conventional systems, extended aeration plants are designed to operate in the endogenous respiration phase of the bacterial growth curve where net growth is minimal. However, when chemicals are added for phosphorus removal, the precipitates formed will drastically increase sludge production. The amount of this increase and its effect on sludge handling are critical factors which must be considered when modifying existing and designing future extended aeration facilities. Also of concern is the effect of nitrification, a common occurrence in extended aeration plants, on system pH during chemical addition.

In a year long study conducted at the University of Massachusetts Wastewater Pilot Plant Facility, sodium aluminate and alum were compared for phosphorus removal effectiveness in an extended aeration unit with a capacity of 8775 gal/day (33217  $\ell$ /day). The effect of these chemicals on overall treatment efficiency, the solids accumulation rate and the dewaterability of the sludges produced were also investigated. A preliminary study indicated that the optimum point for sodium aluminate addition was at the end of the aeration basin. Alum was added in the influent well to the clarifier. The unit was fed raw wastewater containing 4 to 8 mg/ $\ell$  as P total phosphorus. Approximately 23 percent of the total phosphorus was removed by the unit without chemical addition.

The results of this study demonstrated that both chemicals were capable of providing greater than 90 percent phosphorus removal. Mean effluent concentrations of total phosphorus were reduced to 0.5 mg/l as P or less by both chemicals. However, the optimum Al:P<sub>filt</sub> weight ratio for sodium aluminate was 1.8:1 while alum required only 1:1. The likely cause of this difference was the fact that during alum addition, pH was maintained within the optimum range for phosphorus precipitation (5.5 to 6.5). To maintain pH, 230 to 460 lb/mil gal of lime (Ca(OH)<sub>2</sub>) were required to offset the alkalinity consumed by alum and nitrification. During sodium aluminate addition, system pH stabilized above the optimum range. Nitrification provided some measure of pH control by consuming much of the alkalinity introduced by the addition of caustic sodium aluminate.

Both chemicals improved the overall treatment efficiency of the unit. Mean effluent concentrations of BOD<sub>5</sub>, COD, suspended solids, turbidity and ammonia were significantly lower during the sodium aluminate and alum addition periods compared to periods without chemical addition.

As expected, both chemicals produced dramatic changes in sludge characteristics and accumulation rate. Mixed liquor volatile suspended solids (MLVSS) content decreased from 70 to 80 percent to the 50 to 65 percent range after chemical addition. Mean values of sludge volume index (SVI) were reduced from 62 before chemical addition to 52 and 54 during sodium aluminate and alum addition. Total sludge production ranged between 670 and 970 lb/mil gal which was two to three times the normal sludge production rate for the pilot plant unit.

A series of bench scale tests were conducted to evaluate a wedge wire bed as a means of dewatering sludge produced by extended aeration plants using alum or aluminate for phosphorus removal. Undigested sludge solids broke through the screen and appeared in the drainage water. Laboratory tests conducted with three different anionic polymers indicated that 250 mg/l of Calgon WT 2640 could effectively coagulate aerobically digested sludge and thus reduced solids breakthrough. After addition of this polymer, typical sludges containing 2 to 3 percent solids were effectively dewatered to 9 to 12 percent after 24 hours. No odor problems were encountered during the 24 hour dewatering tests.

The addition of sodium aluminate or alum for phosphorus removal will substantially increase the cost of treatment by extended aeration processes. The main item causing the increased costs are chemicals, storage and feeding equipment and larger sludge handling facilities. Estimates based on pilot plant results indicate that the additional cost of treatment for a 1 MGD plant using sodium aluminate would be 8.2¢/1000 gal while alum treatment would be less than 7.0¢/1000 gal.

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## INTRODUCTION

### Background

Many small communities rely on the extended aeration modification of the activated sludge process for efficient and economical wastewater treatment. According to EPA estimates (1), approximately 55 percent of the operational facilities with flows less than 1.0 mgd in the New England Region are of the "activated sludge" type. Presumably, most of these facilities operate as extended aeration plants. Also, because many small communities are presently without treatment facilities, more of these plants will probably be constructed in the future.

Although the volume of wastewater treated by extended aeration plants is usually small, the phosphorus in the final effluent may still cause eutrophication problems in downstream receiving waters. Many plants are located in remote areas where the effluent is discharged into nearby streams which eventually flow into lakes and impoundments. Unless phosphorus is removed, algal growth will be stimulated and eutrophication will result. This could adversely affect the area's recreational appeal upon which much of the local income may depend.

For small treatment facilities like extended aeration plants, tertiary treatment methods for phosphorus removal would be complicated and expensive. A more reasonable alternative may be chemical precipitation with metal salts such as alum or sodium aluminate. This method is capable of high phosphorus removal efficiencies and is simple to operate. Chemicals can be fed by automatic feeders directly into existing unit processes. Ease of operation is especially important to small communities who can ill afford the higher cost of skilled manpower required by other phosphorus removal techniques.

Although chemical precipitation with alum and aluminate has already been thoroughly investigated in conventional activated sludge systems, little research has been done relative to extended aeration plants. Extended aeration differs from conventional activated sludge in two important respects. First, the extended aeration process is designed to operate in the endogenous phase of the bacterial growth curve where net sludge growth rate is minimal. However, if chemicals are added for phosphorus removal, the precipitates formed will accumulate in the system causing sludge production to increase. The magnitude of this increase and its effect on sludge handling are critical factors which must be considered when upgrading existing or designing new extended aeration facilities.

Secondly, nitrification often occurs in extended aeration plants because of the long sludge age of the basin solids. Theoretically, the nitrification reaction consumes 7.14 pounds of total alkalinity per pound of ammonia nitrogen oxidized. In low alkalinity wastewaters such as those found in New England, nitrification can be a problem because it could cause pH to drop below the normal operating range for biological treatment. If alum, an acidic chemical, is added for phosphorus removal further pH reductions can be expected. Conversely, the addition of caustic sodium aluminate may offset nitrification and stabilize pH. The combined effect of nitrification and chemical addition on system pH is of special interest in this study since optimum phosphorus removal occurs within a pH range of 5.5 to 6.5.

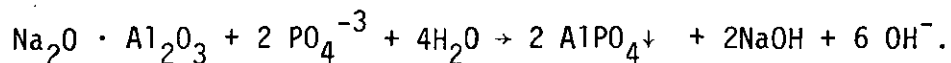
#### Phosphorus Precipitation with Aluminum

Raw sewage contains phosphorus in three forms: organic, condensed and orthophosphate. During biological treatment most of the organic and

condensed phosphorus present is converted to orthophosphate, which is the easiest form to precipitate with aluminum compounds such as alum or sodium aluminate. The aluminum ion in these two chemicals combines with the orthophosphate ion to produce aluminum phosphate ( $\text{AlPO}_4$ ) precipitate. Also, some of the aluminum ions combine with hydroxide ions to form aluminum hydroxide ( $\text{Al}(\text{OH})_3$ ) precipitate. In actual practice, the precipitate formed is probably an amorphous combination of  $\text{AlPO}_4$  and  $\text{Al}(\text{OH})_3$  (4).

To optimize the formation of  $\text{AlPO}_4$  precipitate, the EPA Process Design Manual for Phosphorus Removal (2) recommends that the pH of the system be maintained between 5.5 and 6.5. If system pH is allowed to rise above 6.5 some phosphorus removal will occur but more of the aluminum ions will be lost to the formation of  $\text{Al}(\text{OH})_3$ . Because of this competing hydroxide reaction, aluminum concentrations above stoichiometric amounts are needed for effective phosphorus removal. Laboratory and field investigations have shown that Al:P mole ratios of 1.5 to 3.0 are normally required to reduce effluent total phosphorus concentrations below 1.0 mg/l as P (3).

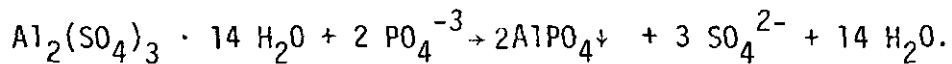
When sodium aluminate ( $\text{Na}_2\text{Al}_2\text{O}_4$ ) is used as the principle source of aluminum, it reacts with the phosphate present as follows:



Because sodium aluminate is a strong alkali, a rise in pH may be expected upon addition to wastewater. If the resulting pH is above 6.5, much of the aluminum will be lost to the hydroxide ion. Thus, sodium aluminate is often less effective than alum for phosphorus removal. In their comparison of sodium aluminate and alum, Long and Nesbitt (6) observed that the total phosphorus concentration in the filtered effluent was 70 percent higher using

sodium aluminate than alum.

In contrast to sodium aluminate, alum is an acidic chemical and tends to lower pH. The extent of pH reduction will depend on the alkalinity of the wastewater at the point of chemical addition. In most activated sludge systems, the pH depression caused by alum will be minimal. However, in extended aeration systems where nitrification often occurs, the alkalinity at the dosing point may be insufficient to buffer the alum dose. An alkaline chemical such as lime, sodium hydroxide, or soda ash may be necessary to supplement the alkalinity and restore the pH within the optimum range for phosphorus removal. The chemical reaction of alum with the phosphate present in wastewater may be expressed as follows:



#### Scope of Research

This study was conducted at the University of Massachusetts Wastewater Pilot Plant. Since this facility has only one extended aeration unit, parallel studies comparing sodium aluminate and alum were impossible. However, each chemical was used long enough (approximately 6 months) so that indirect comparisons can be made. Also, the intent of this study was not to determine which chemical was superior but to demonstrate how each of these chemicals can be used for phosphorus removal in extended aeration units.

Because the study involves separate investigations of each chemical, this report is divided into two parts. Part I presents the results of the sodium aluminate investigation which was conducted from May 6, 1975 to August 22, 1975 and again from May 6, 1976 to June 17, 1976. Part II reports

the results of the alum addition period which began on September 9, 1975 and terminated on April 26, 1976.

Altogether over 220 composite samples of the influent and effluent were analyzed during this study (100 during sodium aluminate addition and 122 during alum addition). During sodium aluminate addition, influent and effluent samples were taken every two hours by automatic samplers and composited according to flowrate. During the alum feed period, the automatic samplers were not available and a composite sample was made by taking grab samples at 9, 10, 11 AM and 1, 2, 3 PM.

Each influent and effluent sample was analyzed for pH, alkalinity, suspended solids, BOD<sub>5</sub>, COD, turbidity, NH<sub>3</sub>-N, total P, and filterable P. Operational parameters measured include dissolved oxygen, settleability, MLSS, MLVSS, SVI and temperature. Sample preservation methods and analytical techniques are discussed in Appendix I.

### Study Objectives

The main objectives of this study were to:

- 1) Determine the optimum dosage of sodium aluminate and alum for maximum phosphorus removal.
- 2) Analyze the effect of alum and sodium aluminate on the normal treatment efficiency of the unit.
- 3) Measure the solids accumulation rate as a result of chemical precipitation.
- 4) Evaluate the dewaterability of the sludge wasted from the process.
- 5) Compare the cost of using either sodium aluminate or alum for phosphorus removal.

## PILOT PLANT DESCRIPTION AND OPERATION

The extended aeration unit used in this study was originally a DAVCO<sup>1</sup> package plant. Pictures of the unit are shown in Figure 1. The aeration basin and clarifier have design capacities of 7000 and 1800 gal respectively. Two positive displacement blowers provided a continuous supply of air to the aeration basin. The dissolved oxygen (DO) level was maintained at 2.0 mg/l minimum. The blowers also supplied the air lift sludge recycle system and the surface skimmer. The circular clarifier was equipped with a sludge scraper and a peripheral weir overflow.

The raw wastewater feed for the pilot plant was obtained from the neighboring Amherst Sewage Treatment Plant. Prior to entering the aeration basin, the raw wastewater was pumped over a Bauer<sup>2</sup> hydrasieve which removed garbage and other large solid matter. The flowrate was regulated by a preset timer which controlled a solenoid valve in the raw wastewater supply line. When open, the solenoid valve allowed a flow of 9 gpm to enter the aeration tank. By adjusting the time interval when the solenoid valve was kept open a diurnal flow pattern was simulated. The flow pattern used during this study is shown in Figure 2. Total daily flow was 8775 gal which resulted in an average flowrate of 6 gpm and a sewage detention time of 19 hours. The surface loading rate to the clarifier was approximately 450 gal/day/sq ft.

Mixed liquor solids which settled to the bottom of the clarifier were recycled back to the head of the aeration basin. The recycle flowrate

<sup>1</sup>DAVCO Manufacturing Company, Thomasville, Georgia.

<sup>2</sup>The Bauer Brothers Company, a subsidiary of Combustion Engineering, Springfield, Ohio.



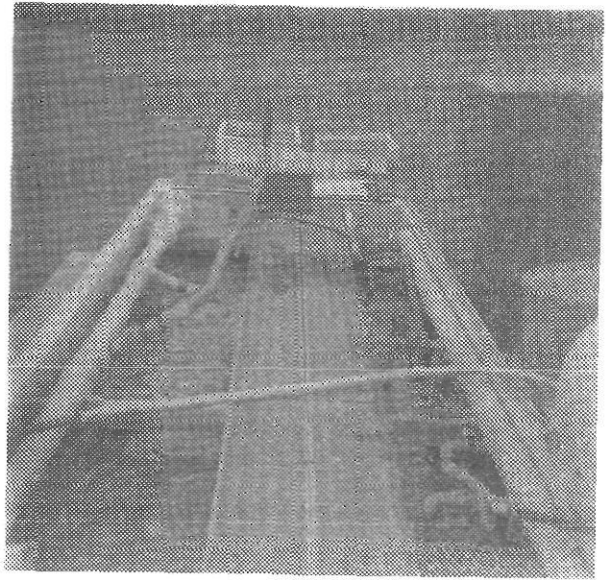
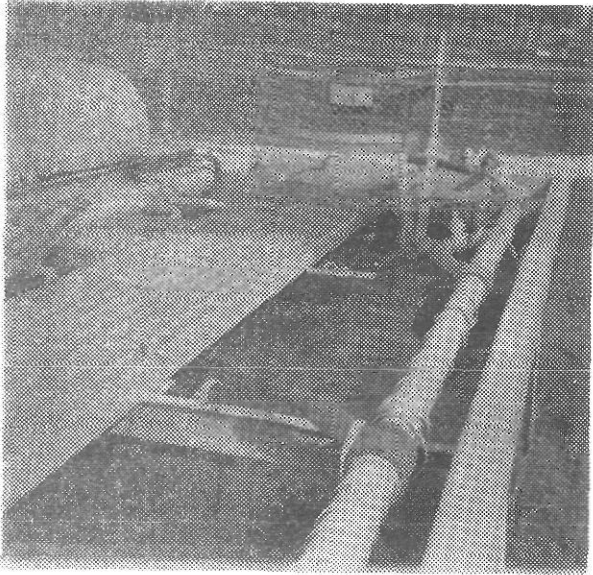


Figure 1. UMASS Wastewater Pilot Plant Extended Aeration Unit.

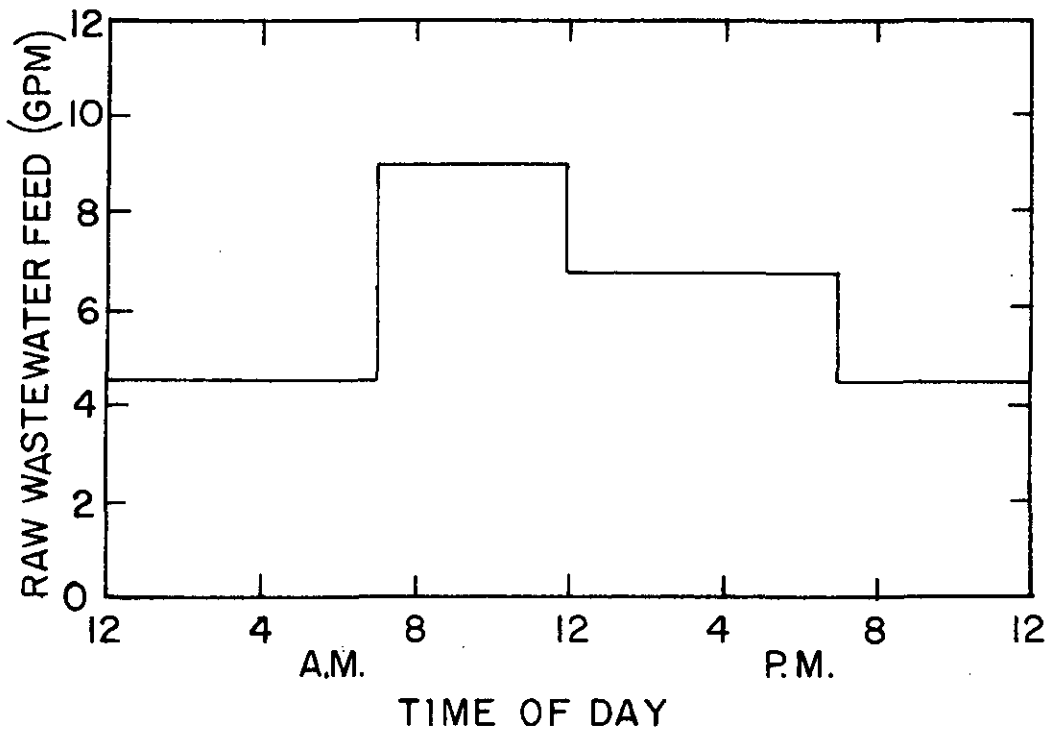


Figure 2. Diurnal Flow Pattern Used in Pilot Plant Studies.

was approximately 9 gpm or 150 percent of the average influent flowrate. Sludge was wasted from the recycle line whenever it became apparent that excess solids were being washed out in the effluent. Normally this occurred when the mixed liquor suspended solids (MLSS) concentration approached 7000 mg/ℓ. The sludge wasting procedure consisted of wasting return sludge until the MLSS concentration in the aeration basin was reduced to approximately 3000 mg/ℓ.

The dosing point selected during sodium aluminate addition was located 1 ft from the end of the aeration basin. Preliminary studies comparing dosing points at the head and the end of the aeration basin showed no significant differences in overall treatment efficiency. However, slightly better removals of non-filterable phosphorus were noted when dosing at the end of the basin.

The dosing point selected for the alum study was located in the influent pipe to the clarifier. Dosing at this point provided adequate mixing time, and confined the immediate pH depression effects of alum to the influent pipe. Nevertheless it was necessary to supplement the buffering capacity of the system by daily additions of hydrated lime ( $\text{Ca}(\text{OH})_2$ ). The amounts and method used will be discussed in a later section.

A Sigmamotor<sup>1</sup> Finger Pump was used to control the amount of alum and sodium aluminate dosed. This pump was also connected to the same timer that regulated the raw wastewater flow. Thus, chemical addition

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<sup>1</sup>Sigmamotor Incorporated, Middleport, New York.

occurred only when wastewater was flowing into the unit. The dosage was not adjusted to match diurnal changes in influent phosphorus concentration.

The commercial-grade liquid alum used in this study was supplied by Holland Company<sup>1</sup>. This solution has a specific gravity of 1.33 and contains 5.4 lbs of dry alum per gallon. Approximately 9 percent by weight of the dry alum is aluminum. Prior to dosing, alum was diluted 1:10 with tap water and stored in a covered 55 gallon plastic tank.

The liquid sodium aluminate used during the study was NALCO 8750<sup>2</sup> which has a specific gravity of 1.45 and contains approximately 10 percent aluminum. Liquid sodium aluminate was diluted 1:20 prior to dosing.

#### TREATMENT EFFECTIVENESS WITHOUT CHEMICAL ADDITION

The treatment effectiveness of the extended aeration unit without chemical addition is shown in Table 1. This data was obtained from "baseline" investigations of plant performance conducted by Spawn (7) Noga (8) and the Pilot Plant staff. A total of 60 observations were made over a two year period.

Without the aid of phosphate precipitating chemicals, approximately 23 percent of the influent total phosphorus was removed by the pilot plant unit. Filterable phosphorus removal was only 7 percent which indicates that most of the total phosphorus removed was organic. Therefore, the phosphorus removal efficiency of the unit without chemical addition depended largely on the amount of suspended solids in the effluent. This

<sup>1</sup>Holland Company, North Adams, Massachusetts

<sup>2</sup>NALCO Chemical Company, Chicago, Illinois

Table 1. Treatment Effectiveness of Extended Aeration Process Without Chemical Addition

<u>Parameter</u>	<u>Mean Influent</u>	<u>Mean Effluent</u>	<u>Effluent Standard Deviation</u>	<u>% Removal</u>
Total P (mg/ℓ as P)	6.5	5.0	1.0	23
Filterable P (mg/ℓ as P)	4.2	3.9	0.72	7
BOD <sub>5</sub> (mg/ℓ)	199	28	12.6	86
COD (mg/ℓ)	425	75	45	82
Suspended Solids (mg/ℓ)	152	34	18	78
Turbidity (JTU)	69	19	9	72
NH <sub>3</sub> (mg/ℓ as N)	29	6.1	6.6	71
pH	7.1	5.9	1.0	--
Alkalinity (mg/ℓ as CaCO <sub>3</sub> )	119	39	15.0	--

agrees with data obtained by Long and Nesbitt (6) which shows a high degree of correlation between effluent suspended solids and effluent insoluble phosphorus.

As shown in Table 1, BOD<sub>5</sub>, COD, and suspended solids concentrations were 28, 75 and 34 mg/l respectively. Based on secondary treatment standards (9), these effluent concentrations were only marginally acceptable. The reason for the poor performance was the cyclic behavior of the nitrification reaction. At the beginning of the cycle, nitrification was minimal and the effluent quality was excellent. As the rate of nitrification increased, alkalinity consumption also increased and pH began to drop. When nitrification reached its peak, the pH in the aeration basin dropped below 5.0. Continued operation at this low pH caused sludge bulking and the effluent quality deteriorated. After approximately one week, nitrification would cease, the pH would gradually increase, and normal treatment efficiency would be restored. Nitrification would then resume and the pH depression cycle would be repeated. This cyclic phenomenon was observed several times and in each case the effluent quality deteriorated. Evidence of the nitrification reaction causing a drop in pH can be seen in Figure 3.

#### PART I. SODIUM ALUMINATE ADDITION

##### Jar Tests

Before initiating pilot plant testing of sodium aluminate addition, a series of jar tests were conducted to determine the approximate dosage necessary for effective phosphorus removal. Mixed liquor samples taken from the aeration basin were used in these tests. After the desired dose of aluminate was added, each sample was mixed for one minute at 100 rpm,

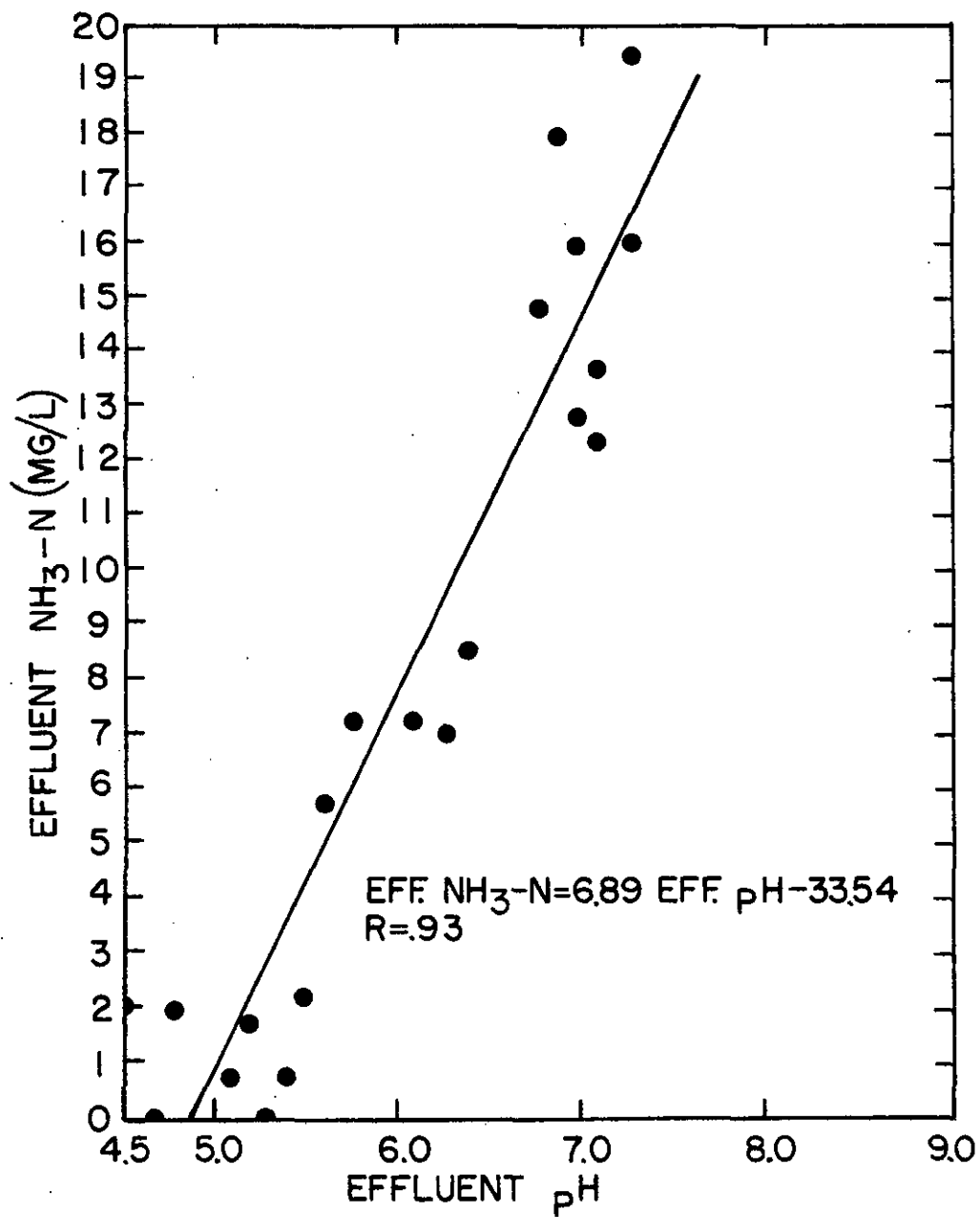


Figure 3. Effluent NH<sub>3</sub>-N Concentration vs. pH During Periods of No Chemical Addition.

flocculated for 15 minutes at 20-25 rpm and then allowed to settle for 30 minutes. The supernatant was analyzed for both total and filterable phosphorus, pH and alkalinity. The aluminum to total phosphorus mole ratio ( $Al:P_{tot}$ ) was calculated based on the sodium aluminate dose and the total phosphorus content of the control sample.

The results of the jar tests are shown in Figure 4. Generally, both total and filtered phosphorus concentrations decreased as the sodium aluminate dose or the  $Al:P_{tot}$  mole ratio increased. A line of best fit was drawn through the data points to show the approximate relationship between residual phosphorus concentration and  $Al:P_{tot}$  mole ratio. At the highest  $Al:P_{tot}$  mole ratio (4:1) residual total phosphorus was only reduced to 1.7 mg/ℓ. However residual filtered phosphorus concentrations were reduced to 0.3 mg/ℓ as P. In an attempt to improve the removal of total phosphorus, an anionic polymer (NALCO #7763) was added in doses ranging from 0.01 to 1.0 mg/ℓ. However, total phosphorus residuals remained high which indicated that the non-filterable or suspended fraction of phosphorus was not being removed. These results were not surprising considering the inadequacy of the jar test procedure to match the suspended solids removal capability of actual treatment systems.

Because of the high total phosphorus residuals predicted by the jar tests, selection of the initial dose for pilot plant studies was based on filtered phosphorus removal. From Figure 4 it can be seen that an  $Al:P_{tot}$  mole ratio of approximately 3:1 was sufficient to produce an average filterable phosphorus concentration of 0.5 mg/ℓ as P. Assuming that the extended aeration unit would remove all but 0.5 mg/ℓ non-filterable



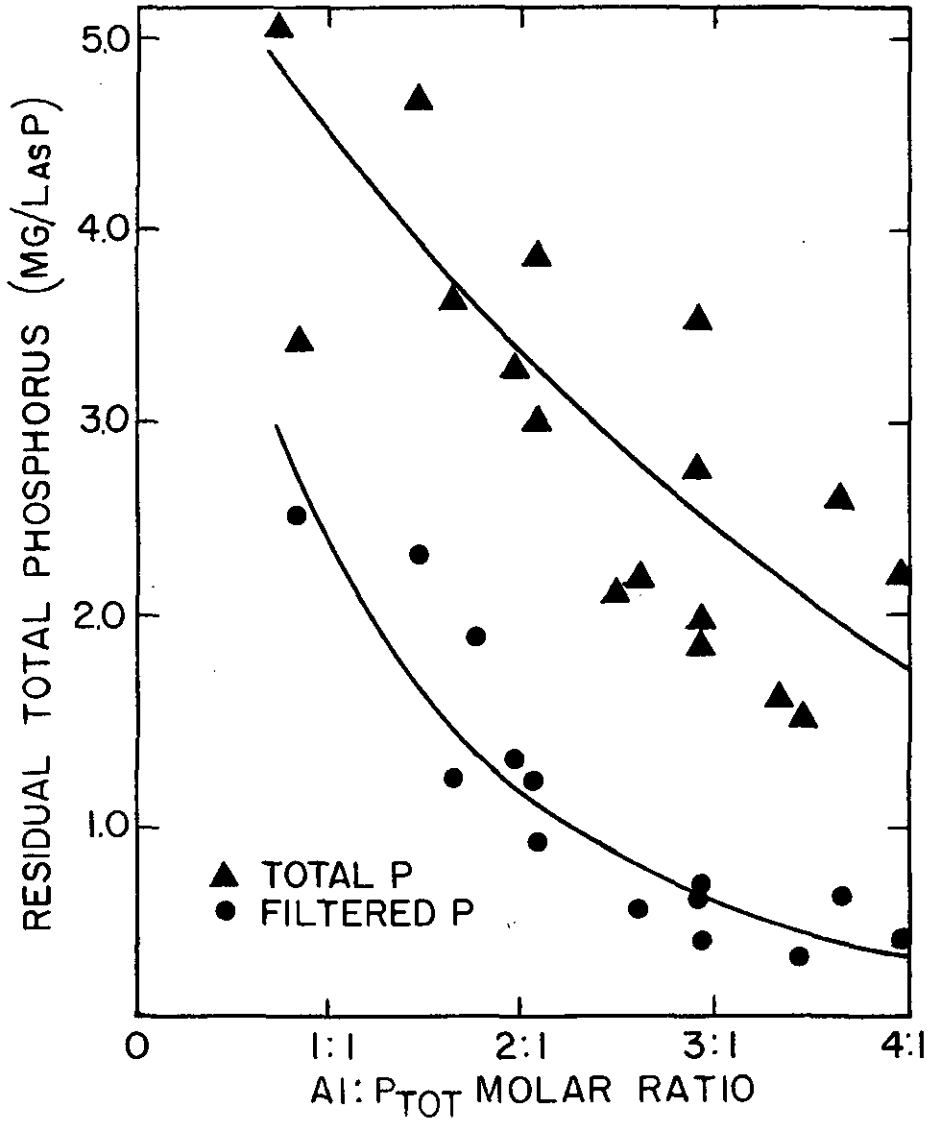


Figure 4. Results of Jar Tests With Sodium Aluminate.

phosphorus, the total phosphorus concentration in the effluent should not exceed 1.0 mg/ℓ as P. Thus, with an influent total phosphorus concentration of approximately 6.0 mg/ℓ and an Al:P<sub>tot</sub> mole ratio of 3:1 the aluminum dose needed for effective phosphorus removal is 15 mg/ℓ (45 mg/ℓ of sodium aluminate).

#### Evaluation of Dosing Point

The point of chemical addition must be carefully selected to insure proper mixing. Although the precipitation reactions occur almost instantaneously, adequate mixing is necessary to disperse the chemical so that aluminum ion contact with the orthophosphate ion is assured. Mixing may be more critical when adding sodium aluminate than alum because less aluminate is needed to satisfy a given Al:P ratio. In the extended aeration process, the logical area for chemical addition is the aeration basin where mixing already occurs. However, the most effective point within the basin may vary depending on the type of aerators used and whether the aerators are operated continuously or intermittently. Only by testing different locations will the most effective dosing point be found.

In the pilot plant study, two dosing points were evaluated. The first dosing point was located at the head of the aeration basin and 3 ft below the surface. This point provided the most mixing time and the greatest opportunity for aluminum and orthophosphate ion contact. The second dosing point was located 1 ft from the end of the aeration basin and 4 ft below the surface. This placed the chemical addition point directly in front of the clarifier influent pipe where the general flow

pattern was toward the clarifier. By dosing at the end of the aeration basin, excessive agitation and floc destruction could be avoided and hopefully, sufficient detention time would be available for the precipitation reaction to occur. Each point was evaluated over a two week period using a sodium aluminate dose of 45 mg/l. Because the strength of the influent wastewater was similar during each evaluation period, a valid comparison of the effectiveness of each dosing point can be made.

The result of the dosing point comparison is shown in Table 2. Both dosing points produced the same residual total phosphorus of 1.2 mg/l as P. However, better removals of filterable phosphorus were obtained by dosing at the head of the basin. This suggests that a longer mixing time is needed for effective precipitation. Conversely, better removals of non-filterable phosphorus were achieved when aluminate was dosed at the end of the basin. The addition of aluminate at the end of the aeration tank may allow better floc aggregation and thus better non-filterable phosphorus removals. Overall treatment efficiency, as indicated by BOD<sub>5</sub> and suspended solids removal, did not seem to be affected by dosing point.

As a result of this study, it appears that the point of sodium aluminate addition is not critical for effective total phosphorus removals. However, dosing at the end of the basin provided significantly better removals of non-filterable phosphorus, which is often the most difficult fraction to remove. Also, other investigators (3,4,6) confirm that better removals were obtained when dosing just before final solid-liquid separation. Consequently, the end of the aeration basin was selected as the dosing point for subsequent pilot plant investigations.

Table 2. Summary of Data for Dosing Point Comparison

Parameter	Dosing at Head of Aeration Basin April 16 to 27, 1975			Dosing at End of Aeration Basin May 16 to 27, 1975		
	Infl.	Effl.	% R	Infl.	Effl.	% R
Total P (mg/ℓ as P)	6.11	1.22	80	6.41	1.23	81
Filterable P (mg/ℓ as P)	3.77	0.44	83	4.09	0.92	78
Non-Filterable P (mg/ℓ as P)	2.34	0.78	67	2.32	0.31	87
pH	7.13	7.17	--	6.91	7.38	--
Alkalinity (mg/ℓ as CaCO <sub>3</sub> )	131	118	--	117	147	--
NH <sub>3</sub> -N (mg/ℓ)	21	15	27	22	20	9.1
BOD <sub>5</sub> (mg/ℓ)	230	30	87	265	27	90
S.S. (mg/ℓ)	228	33	86	211	37	83

### Phosphorus Removal

Using the end of the aeration basin as the dosing point, pilot plant studies were continued in order to evaluate the long term effectiveness of sodium aluminate addition. Six different dosages, ranging from 6 to 42 mg/ℓ as  $\text{Na}_2\text{Al}_2\text{O}_4$  were tested. The initial dose tested was 42 mg/ℓ as  $\text{Na}_2\text{Al}_2\text{O}_4$  which was selected on the basis of the jar test results. This dosage was later reduced as it became apparent that lesser dosages could provide satisfactory phosphorus removal. Table 3 shows the dosing schedule used during the sodium aluminate study.

The effect of each dose on phosphorus removal is shown in Table 4. This data indicates that aluminate dosages above 24 mg/ℓ will produce little improvement in phosphorus removal. Also, total phosphorus removal was noticeably greater in the pilot plant tests than in the jar tests. The mean effluent total phosphorus was easily reduced to 1.0 mg/ℓ or less using dosages of 15, 24, 30 and 42 mg/ℓ as  $\text{Na}_2\text{Al}_2\text{O}_4$ . Improved total phosphorus removal was probably due to the excellent settling characteristics of the mixed liquor.

To determine the optimum sodium aluminate dose, effluent filtered phosphorus was plotted against the applied  $\text{Al}:\text{P}_{\text{filt}}$  weight ratio. This data, and the regression equations for the lines of best fit are shown in Figure 5. Filtered, rather than total phosphorus was used in this analysis because it eliminated the need to consider background phosphorus removals. As shown earlier (see section on Treatment Effectiveness Without Chemical Addition) filtered phosphorus removal was negligible without chemical addition. A weight ratio was selected because it was easier to use in day to day calculations.

Table 3. Dosing Schedule Used During Sodium Aluminate Study

<u>Inclusive Dates of Continuous Operation</u>	<u>Number of Observations*</u>	<u>Sodium Aluminate Dose (mg/l)</u>	<u>Equivalent Aluminum Dose mg/l Al<sup>3+</sup></u>
6/12/75-6/27/75	14	42	14
6/28/75-7/11/75	10	30	10
7/11/75-8/2/75	14	24	8
8/3/75-8/22/75	15	15	5
5/6/76-5/27/76	14	15	5
6/2/76-6/9/76	6	9	3
6/10/76-6/17/76	6	6	2

\* Each observation represents a 24-hour composite sample.

Table 4 . Effect of Sodium Aluminate Dosage  
on Phosphorus Removal

Parameter	Sodium Aluminate Dosage mg/ℓ						
	6.0	9.0	15.0	15.0	24.0	30.0	42.0
Mean Influent Total P(mg/ℓ)	6.4	6.3	6.8	4.8	4.8	6.3	6.5
Mean Influent Filterable P (mg/ℓ)	4.3	4.6	4.7	2.9	2.5	3.6	3.4
Mean Effluent Total P (mg/ℓ)	2.9	2.6	2.4	0.9	0.4	0.7	0.7
Mean Effluent Filterable P (mg/ℓ)	2.7	2.2	1.8	0.4	0.09	0.16	0.17
% Removal Total P	55	59	65	81	92	89	89
Mean Effluent pH	5.9	5.8	6.2	6.3	6.8	6.7	6.7

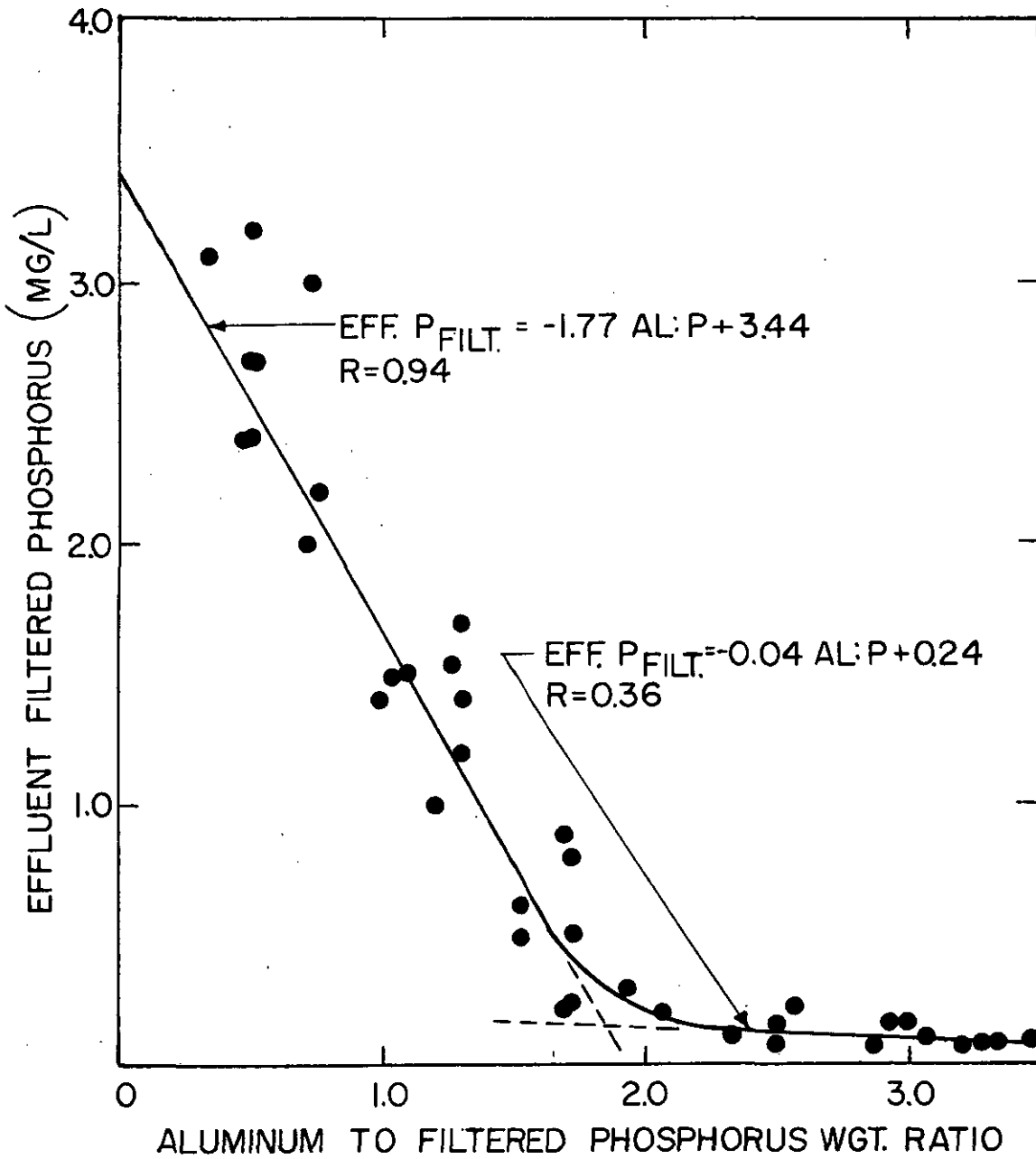


Figure 5. Effluent Filtered Phosphorus Concentration vs. Al:P<sub>filt.</sub> Weight Ratio During Sodium Aluminate Addition.



As shown in Figure 5, an Al:P<sub>filt</sub> weight ratio of approximately 1.8:1 reduced filtered phosphorus to a minimum concentration of 0.3 mg/ℓ as P. Weight ratios above 1.8:1 did not produce further significant reductions. Therefore, it can be concluded that the optimum Al:P<sub>filt</sub> weight ratio using sodium aluminate was 1.8:1. The equivalent Al:P<sub>filt</sub> mole ratio is 2:1. In terms of sodium aluminate concentration, the optimum dosage based on a mean influent P<sub>filt</sub> concentration of 4.2 mg/ℓ (see Table 1) was 23 mg/ℓ as Na<sub>2</sub>Al<sub>2</sub>O<sub>4</sub>. This is approximately one-half the dosage predicted by the jar tests.

#### General Treatment Efficiency

General treatment efficiency improved significantly during the sodium aluminate dosing period. As shown in Table 5, BOD<sub>5</sub>, suspended solids, turbidity and ammonia removals were 94, 91, 86 and 97 percent, respectively. Without chemical addition (see Table 1), the removal efficiencies of these same parameters were only 86, 78, 72 and 71 percent. There was no discernible trend of effluent quality being a function of dosage applied.

The improved treatment by the unit after sodium aluminate addition was probably due to coagulation of colloidal organics and stabilization of pH. It is well known that aluminate can coagulate colloidal organics and thus significantly improve secondary clarifier performance (15). Also, after sodium aluminate addition, system pH stabilized between 5.8 to 6.8 which is more compatible with biological treatment. As noted earlier, without chemical addition effluent pH often dropped below 5.0 and sludge bulking was observed. A drop in pH was caused by the alkalinity

Table 5. Treatment Effectiveness of Extended Aeration Process During Sodium Aluminate Addition

<u>Parameter</u>	<u>Mean Influent</u>	<u>Mean Effluent</u>	<u>Effluent Std. Deviation</u>	<u>% Removal</u>
BOD <sub>5</sub> (mg/ℓ)	195	11	4	94
Suspended Solids (mg/ℓ)	163	15	6.7	91
Turbidity (JTU)	57	8	2.3	86
NH <sub>3</sub> (mg/ℓ as N)	15.3	.43	.9	97

consuming nitrification reaction. Apparently, the alkalinity introduced by caustic sodium aluminate was enough to offset the alkalinity consumed by nitrification. Barth et al. (10) also noted the stabilizing effect of sodium aluminate on system pH when nitrification was occurring.

## PART II. ALUM ADDITION

### Dosing Schedule and Point of Addition

Because of the limited success of the jar tests during the sodium aluminate study, it was decided that the alum study should begin directly with pilot plant testing. As in the sodium aluminate study, a series of alum dosages were applied to the extended aeration unit. No attempt was made to match the alum dosages with equivalent aluminate dosages. Table 6 shows the alum dosing schedule used during this study.

Alum was added to the influent pipe of the clarifier. By adding alum at this point, pH depression effects were isolated from the aeration basin and potential floc destruction was avoided. Based on calculations using pipe dimensions and flow rate, the mixing time in the pipe was approximately three minutes. Because the precipitation reactions occur almost instantaneously, this mixing time was considered to be sufficient.

### pH Control Using Lime

In earlier tests performed with alum (8), it was observed that pH was severely depressed to 4.5 and below. Since the desired pH range for phosphate precipitation is 5.5 to 6.5, the phosphorus removal efficiency of the unit was greatly reduced. Also, low pH severely affected the activated sludge biota in the unit. A microscopic examination after alum addition revealed a noticeable absence of protozoa and rotifers. Burke (12) and Roy (13) noted similar problems when alum was added.

The severe pH depression observed when alum was added to the extended aeration unit was not surprising considering the low alkalinity of Amherst wastewater and the nitrification reaction occurring within the unit. As discussed earlier, even without chemical addition, nitrification

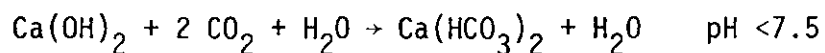
Table 6. Dosing Schedule Used During Alum Study

<u>Inclusive Dates of Continuous Operation</u>	<u>Number of Observations*</u>	<u>Alum Dose mg/l</u>	<u>Equivalent Aluminum Dose mg/l</u>
10/8/75-10/17/75	6	14	1.3
10/20/75-10/31/75	10	22	2.0
11/3/75-12/5/75	20	30	2.6
3/10/76-4/26/76	26	56	5.0
1/5/76-3/8/76	39	90	8.0

\*Each observation represents a 24-hour composite sample.

consumed most of the alkalinity available in the system. The addition of alum, an acidic chemical, depleted the remaining alkalinity and this resulted in the observed low pH. Therefore, the alkalinity lost by nitrification and alum addition, must be replaced in order to restore the pH to the optimum range for phosphorus removal. If nitrification were not occurring or the influent wastewater alkalinity was higher, supplemental alkalinity would not be necessary.

The addition of hydrated lime ( $\text{Ca}(\text{OH})_2$ ) will produce bicarbonate alkalinity ( $\text{HCO}_3^-$ ) as follows:

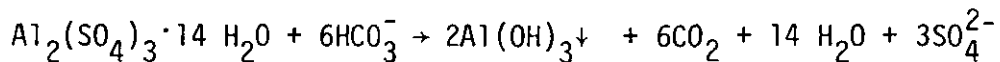


Based on this equation 1.35 pounds of alkalinity are produced per pound of lime added (assuming that the total alkalinity is equal to the bicarbonate alkalinity). The amount of lime required for pH control can be estimated from the alkalinity needed to restore pH to the desired range of 5.5 to 6.5. This amount can be calculated by developing a mass balance relationship which takes into consideration the influent alkalinity, the alkalinity consumed by nitrification and alum, and the effluent alkalinity required at pH 5.5 to 6.5. A detailed explanation of these calculations is shown in Appendix II.

During the pilot plant study, lime additions ranged between 2 to 4 pounds per day (230 to 460 lb/mil gal). The lime was not continuously fed into the unit but added on a batch basis to the aeration basin. The mixing action in the aeration basin quickly dispersed the lime so that no large increases in pH were noted. The actual amount of lime added varied

from day to day depending on the value of the effluent pH. If the effluent pH began to decrease slightly, more lime was added. Conversely, if the effluent pH increased, the lime dosage was decreased. Although this method relied on operator discretion, it proved to be successful in maintaining the effluent pH in the optimum range for phosphorus removal throughout the study period.

It should be noted that the amount of lime needed for pH control can be minimized by controlling the alum feed so that overdosing is avoided. Excess alum not used to precipitate phosphorus consumes alkalinity ( $\text{HCO}_3^-$ ) according to the relationship;



Calculations indicate that 0.5 pounds of alkalinity are consumed for every pound of alum added in excess of that required for phosphorus precipitation. In extended aeration systems, the most likely opportunity for an alum overdose would be at night or during periods of excessive stormwater infiltration. Smaller daytime variations in flow may not be a problem because of the equalization effect provided by the long detention time in the unit. Preventing alum overdoses may be accomplished by manually reducing the alum feedrate at night and during periods of higher infiltration. In the pilot plant unit, overdosing was not a problem because both influent wastewater flowrate and alum feedrate were controlled.

#### Phosphorus Removal

The phosphorus removal effectiveness of alum is shown in Table 7. A gradual increase in percent phosphorus removal was noted for each increase in alum dosage. However, only a two percent increase in phosphorus removal efficiency and a 0.2 mg/l reduction in mean effluent total phosphorus

Table 7. Effect of Alum Dosage on Phosphorus Removal

Parameter	Alum Dosage (mg/l)				
	14	22	30	56	90
Mean Influent Total P (mg/l)	7.9	6.4	6.9	6.7	6.0
Mean Influent Filterable P (mg/l)	5.2	4.1	4.1	4.6	4.0
Mean Effluent Total P (mg/l)	3.8	2.5	2.0	0.7	0.5
Mean Effluent Filterable P (mg/l)	3.2	2.1	1.6	0.2	0.1
% Removal of Total P	52	61	71	90	92
Mean Effluent pH*	6.9	6.1	6.1	6.3	6.3

\* Effluent pH was controlled by adding lime ( $\text{Ca(OH)}_2$ )



concentration was gained by increasing the alum dose from 56 to 90 mg/l. This indicates that the optimum alum dose had been exceeded and that much of the alum was being wasted on  $\text{Al}(\text{OH})_3$  formation. As discussed in the previous section, an increase in  $\text{Al}(\text{OH})_3$  formation causes an increase in the lime requirement for pH control. Consequently, overdosing with alum wastes both alum and lime, thus resulting in higher chemical costs.

As in the sodium aluminate studies, daily effluent filtered phosphorus was plotted against the applied  $\text{Al}:\text{P}_{\text{filt}}$  weight ratio as shown in Figure 6. At weight ratios less than one, effluent filtered phosphorus concentrations were strongly dependent on aluminum dosage. However,  $\text{Al}:\text{P}_{\text{filt}}$  weight ratios greater than one did not produce a further significant decrease in effluent filtered phosphorus. Based on these results, the optimum  $\text{Al}:\text{P}_{\text{filt}}$  weight ratio is approximately 1:1 ( $\text{Al}:\text{P}_{\text{filt}}$  mole ratio = 1.15:1). With a mean influent filtered phosphorus concentration of 4.2 mg/l as P (see Table 1), the optimum alum dose for phosphorus removal in the pilot plant unit was 50 mg/l.

A lower  $\text{Al}:\text{P}_{\text{filt}}$  weight ratio was required when alum was used as the aluminum source rather than sodium aluminate. The optimum  $\text{Al}:\text{P}_{\text{filt}}$  weight ratio using sodium aluminate was 1.8:1 while alum required only 1:1. Other investigators (6,11) also reported lower Al:P ratios when using alum. The greater effectiveness of alum at lower Al:P ratios was probably due to the fact that during the alum addition, pH was maintained closer to the optimum range for phosphorus removal. As shown in Table 7, the mean effluent pH was in the optimum range (5.5 to 6.5) for all alum dosages except the 14 mg/l dose. On the other hand, during sodium aluminate addition,

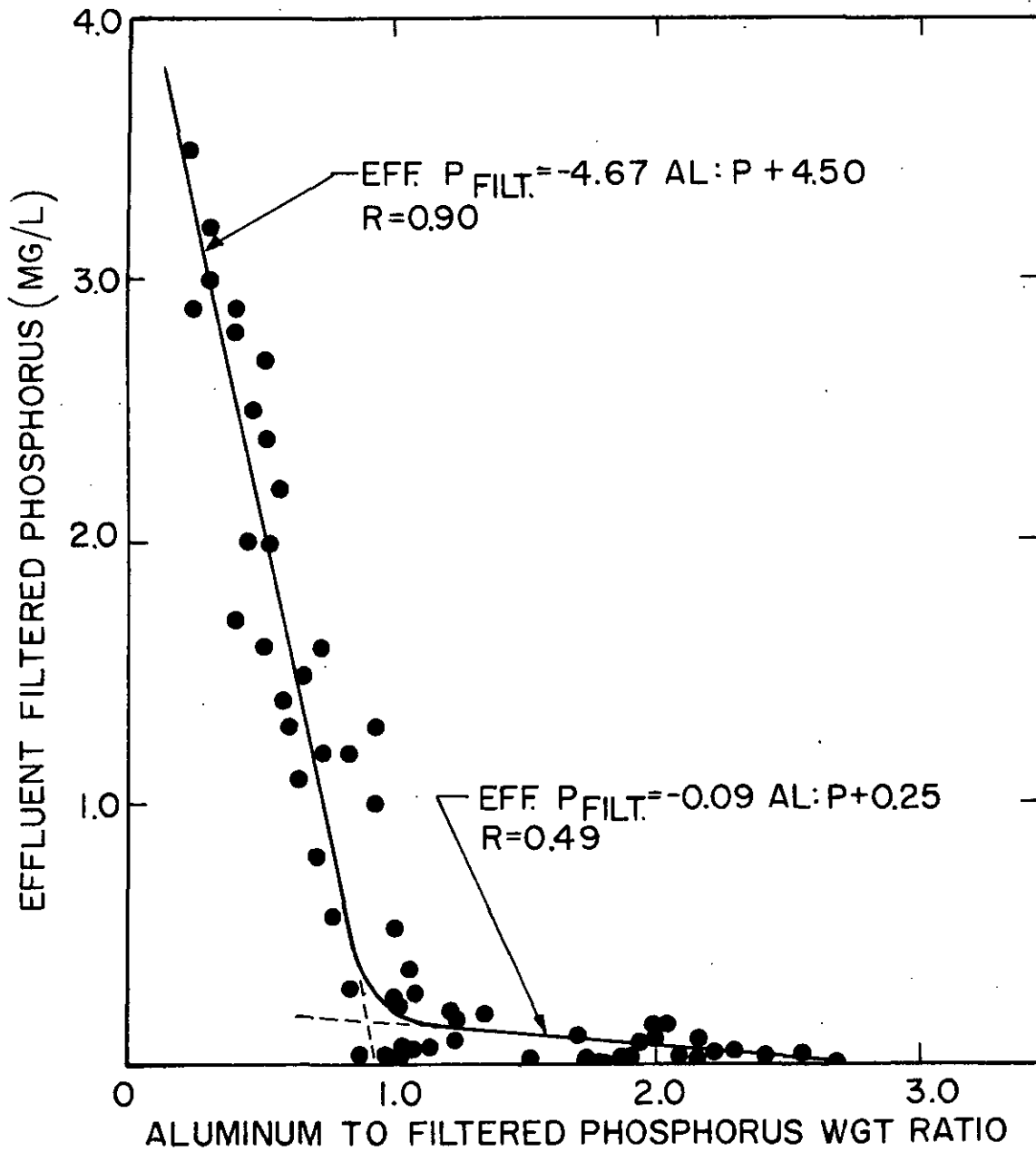


Figure 6. Effluent Filtered Phosphorus Concentration vs. Al:P<sub>filt</sub> Weight Ratio During Alum Addition

mean effluent pH was often greater than 6.5 (see Table 4). Although these differences in pH seem minor, studies by Bowen (14) indicate that relatively minor pH variations (greater than  $\pm 0.5$  pH units) result in large reductions in phosphorus removal efficiency.

Phosphorus precipitation by lime added for pH control rather than alum is unlikely. Studies by Jenkins *et al.* (4) have shown that calcium phosphate solids nucleate and grow very slowly at neutral pH. At a pH of 7.6, approximately 50 hrs of contact time was needed before lime had any effect on phosphorus removal. However, in these pilot plant studies, the average detention time in the aeration basin was only 19 hours and the pH was maintained near 6.0. Also, the fact that pH control was maintained by the lime additions is good evidence of lime being used as an alkalinity source and not as a phosphate precipitating chemical.

#### General Treatment Efficiency

The general treatment efficiency of the extended aeration unit was excellent throughout the alum study. As shown in Table 8, the mean effluent concentrations of BOD<sub>5</sub>, COD, suspended solids, turbidity, and ammonia were 6.8 mg/l, 25 mg/l, 16 mg/l, 5 JTU and 1.3 mg/l as N respectively. Comparing these concentrations with those produced without alum addition (see Table 1) indicates that a definite improvement in effluent quality can be expected when alum is added for phosphorus removal. As concluded in the sodium aluminate study, the improved treatment performance during alum addition was probably due to coagulation of colloidal organics and stabilization of system pH.

Table 8. Treatment Effectiveness of Extended Aeration Process During Alum Addition

<u>Parameter</u>	<u>Mean Influent</u>	<u>Mean Effluent</u>	<u>Effluent Std. Deviation</u>	<u>Percent Removal</u>
BOD <sub>5</sub> (mg/ℓ)	180	6.8	3.4	96
COD (mg/ℓ)	312	25	9.6	92
Suspended Solids (mg/ℓ)	131	16	12	88
Turbidity (JTU)	52	5	1.6	90
NH <sub>3</sub> (mg/ℓ as N)	19.9	1.3	1.5	93

Comparing the data in Table 5 and 8, it is impossible to say whether alum or sodium aluminate will provide better treatment efficiency. Each study was conducted separately and with different influent wastewater concentrations. Clearly, either chemical is capable of improving the effluent quality of extended aeration units to at least secondary treatment levels.

#### SLUDGE PRODUCTION RATE

Theoretically, the net production of sludge in the extended aeration process is zero and no sludge wasting is required (16). However, in actual systems, solids accumulation does occur and some sludge must be wasted if the extended aeration unit is to operate effectively. Usually the amount wasted is small and only periodic wasting is required. Earlier studies at the UMASS Pilot Plant (7,8,12,13) have shown that approximately 300 lb /mil gal will be produced. Of this amount, 71 percent, or 210 lb/mil gal is volatile and the remaining 29 percent or 90 lb/mil gal is fixed or inorganic solids. Sludge was wasted approximately every three months when, in the judgment of the operator, the sludge blanket level was getting too high and solids were being washed out with the effluent.

When chemicals such as alum or sodium aluminate are added for phosphorus removal, a significant increase in sludge production can be expected. Long and Nesbitt (6) reported that total solid production doubled and volatile solids increased by 50 percent when alum was added. Minton and Carlson (3) concluded that the addition of 10 to 30 mg/l Al would result in a doubling of the sludge mass. Zenz and Pivnicka (17) also reported increases in the volume of waste sludge when alum was added.

During this pilot plant study, sludge production rates were determined by measuring the increase in MLSS and MLVSS concentration with time. A typical plot showing the change in MLSS and MLVSS during the 90 mg/l alum dosing period is shown in Figure 7. A least squares fit of this data was used to calculate the rate of solids production in mg/l/day. For the dosing period shown, the MLSS and MLVSS accumulation rates were 80 and 52 mg/l/day respectively. The accumulation rate of the inorganic fraction was therefore 28 mg/l/day.

The volatile, inorganic and total solids production rates expressed in lb/mil gal for two periods of sodium aluminate and alum addition are shown in Table 9. Volatile solids production rate doubled after chemical addition, ranging between 430 to 460 lb/mil gal. To determine whether volatilization of bound water during the standard solids analysis test was responsible for this increase, sludge samples were acidified to pH 2 before filtration as suggested by Humenick et al. (18). This procedure causes chemical sludges to dissolve and bound water to be released. The results of these tests indicated that chemically bound water was insignificant. Longer residence times provided in extended aeration plants may allow for completion of the precipitation reaction and a reduction in the bound water content. The presence of bound water would also be evident if higher chemical doses increased volatile solids production. However, there was almost no difference in volatile solids production rate for each chemical dosage applied. Instead of volatilization of chemically bound water, it appears that capture of colloidal organics by chemical coagulation with subsequent biological degradation is causing most of the increase in volatile solids production.

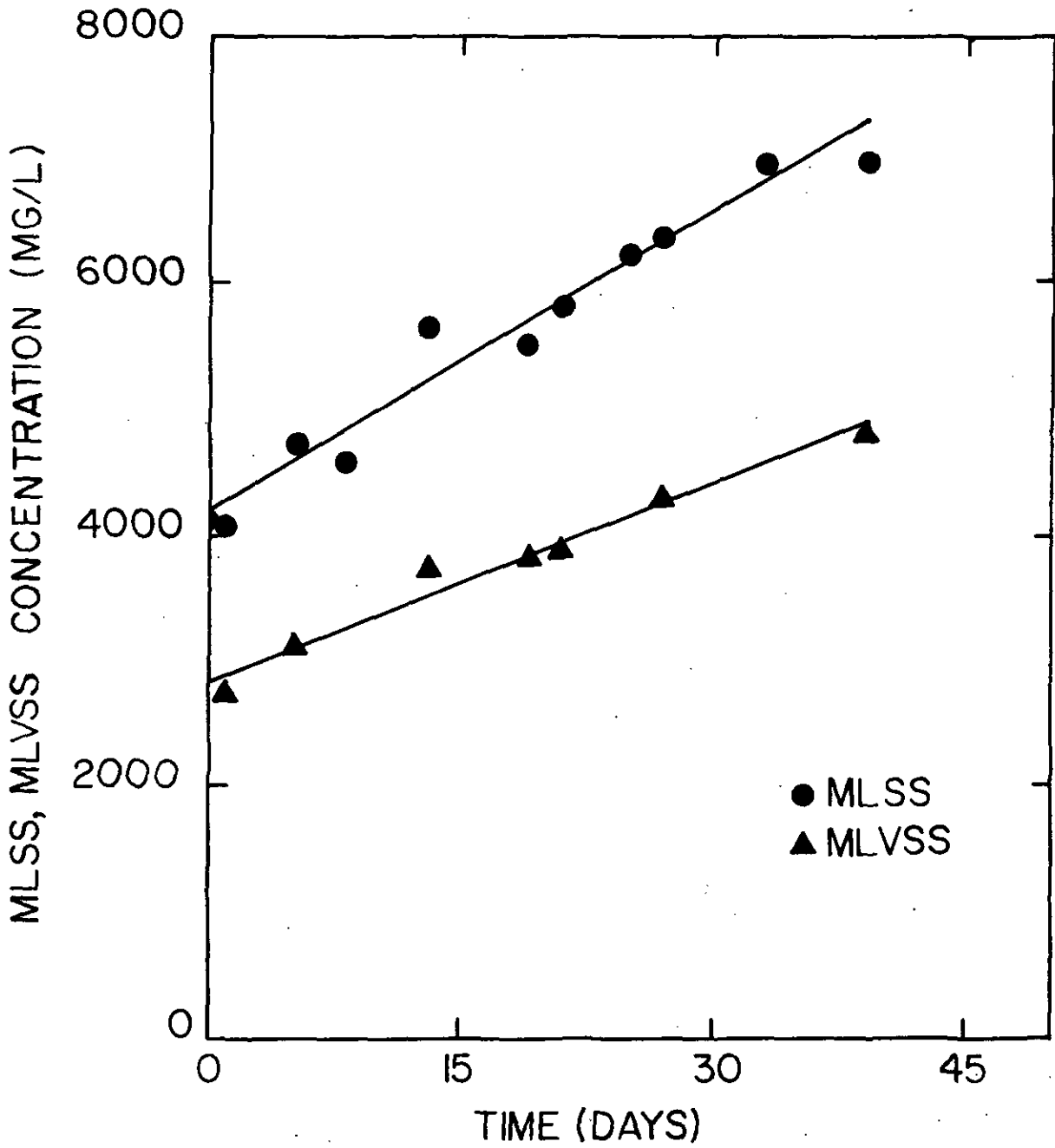


Figure 7. MLSS and MLVSS Concentrations During 90 mg/& Alum Dosing Period.

Table 9. Sludge Production Rates During Sodium Aluminate and Alum Addition

<u>Chemical Added</u>	<u>Average Dosage mg/ℓ Al</u>	<u>Volatile Solids lb/mil gal</u>	<u>Inorganic Solids lb/mil gal</u>	<u>Total Solids lb/mil gal</u>
None	0	210	90	300
Sodium Aluminate	12	460	510	970
Sodium Aluminate	6.5	450	420	870
Alum*	8.0	430	240	670
Alum	5.0	460	250	710

\*Primary effluent was used as influent to the extended aeration unit during this alum addition period.



As shown in Table 9, inorganic sludge production increased substantially when sodium aluminate and alum were added. During two periods of sodium aluminate addition the inorganic solids production was 510 and 420 lb/ mil gal. Alum addition periods produced 240 and 250 lb/mil gal. Increases in inorganic solids production were caused by improved suspended solids removal and the accumulation of phosphate and hydroxide precipitate. Improved suspended solids removal was noted during both sodium aluminate and alum studies. The accumulation of phosphate and hydroxide precipitate will depend on the amount of aluminum added. These amounts can be estimated by using stoichiometric relationships as given in the EPA Process Design Manual for Phosphorus Removal (2). Inorganic sludge production can be controlled by adjusting the aluminum dose so that phosphorus removal requirements are met while the loss of aluminum to  $Al(OH)_3$  formation is minimized.

Alum addition periods produced only one-half the amount of inorganic sludge produced during sodium aluminate addition. This suggests that alum addition will cause less inorganic sludge production than sodium aluminate. However, direct comparison of results is difficult because the sodium aluminate and alum studies were not conducted in parallel. In general the sodium aluminate study period was characterized by higher aluminum doses and greater influent suspended solids concentrations which could account for the difference in sludge production. Since both sodium aluminate and alum form the same chemical precipitates when added to wastewater, large differences in chemical sludge production should not occur if operating conditions are similar.

As shown in Table 9, total sludge production (volatile plus non-volatile solids) ranged between 670 and 970 lb/mil gal, which is two to three times that normally expected without chemical addition. However, no attempt was made to reduce sludge production rate by controlling the aluminum dose in order to minimize  $Al(OH)_3$  formation. Also, these increases may be slightly inflated because of the below-normal treatment efficiency of the unit without chemical addition. Nevertheless, sludge production will increase substantially with chemical addition, thus increasing the cost of sludge handling and disposal.

#### CHANGE IN PERCENT VOLATILE SUSPENDED SOLIDS (MLVSS)

With the addition of alum or sodium aluminate, the percent MLVSS will decrease due to the accumulation of inorganic  $AlPO_4$  and  $Al(OH)_3$  precipitates. In laboratory activated sludge studies, Grigoropoulos *et al.* (19) observed that the addition of sodium aluminate and alum caused the volatile fraction to decrease from 80 to about 50 percent. Although there have been no reported cases of a lessening of treatment efficiency due to a reduction in percent volatile solids, some investigators (3,20) have suggested that MLVSS rather than MLSS should be used to measure the biomass concentration. As the percent volatiles decreases, a higher MLSS must be carried in the aeration basin to provide an equivalent MLVSS concentration. After sludge wasting, the MLVSS must be sufficient to maintain effective biological treatment.

A definite decrease in percent volatile solids was noted after alum and sodium aluminate addition. Prior to chemical addition, percent volatile solids were typically in the 70 to 80 percent range. After

chemical addition this ratio was reduced to the 50 to 65 percent range. A reduction in percent volatile solids can be minimized by controlling the amount of  $Al(OH)_3$  formed. Formation of aluminum hydroxide precipitate can be controlled by eliminating periods of aluminum overdosing and by maintaining the pH in the desired range for phosphorus removal.

The final percent volatile solids after prolonged (steady state) operation will vary depending on the relative rates of organic and inorganic sludge accumulation. This can be shown by assuming that increases in MLSS and MLVSS are linear with time:

$$X_1 = m_1 t + b_1 \quad (6)$$

$$X_2 = m_2 t + b_2 \quad (7)$$

where  $X_1$  = MLSS concentration  
 $X_2$  = MLVSS concentration  
 $b_1$  = initial MLSS  
 $b_2$  = initial MLVSS  
 $m_1$  = rate of MLSS accumulation  
 $m_2$  = rate of MLVSS accumulation  
 $t$  = days of operation

The percent MLVSS, is the ratio of MLVSS to MLSS or  $X_2/X_1$ , and thus:

$$\text{percent MLVSS} = \frac{X_2}{X_1} \cdot 100 = \frac{1 + b_2/m_2 t}{m_1/m_2 + b_1/m_2 t}$$

As time increases, the terms  $b_2/m_2 t$  and  $b_1/m_2 t$  approach zero and the final percent MLVSS,  $X_2/X_1$ , approaches  $m_2/m_1$ . From this analysis it can

be seen that the percent MLVSS will never be zero as long as volatile solids growth continues. For the solids growth period shown in Figure 7, the volatile solids content after continued operation would be expected to stabilize at approximately 65 percent, which is within the range observed during these pilot plant tests.

#### SLUDGE SETTLEABILITY

The settleability of the mixed liquor improved slightly as a result of sodium aluminate or alum addition. As shown in Table 10, the mean values of sludge volume index (SVI) were reduced from 62 when no chemicals were added to 52 and 54, when sodium aluminate and alum were added. Chemical addition also seemed to stabilize SVI as indicated by the lower standard deviations. Based on the small difference between sodium aluminate and alum SVI values, there appears to be no reason to expect better settling performance from one chemical over the other. This is in conflict with the findings of Long and Nesbitt (6), who found that sodium aluminate produced a significantly lower SVI (64 for alum and 25 for sodium aluminate).

#### EVALUATION OF WEDGE WIRE DEWATERING DEVICE

As discussed previously, the addition of sodium aluminate or alum for phosphorus removal will double or triple sludge production. In many extended aeration plants, the existing sludge drying beds would be inadequate for such a large increase in sludge production. Instead of increasing the area of sludge drying facilities, a new device called a wedge wire drying bed may be used. This device has been used successfully in England, Florida and Rollingsford, New Hampshire. The New Hampshire plant reports that its wedge wire bed dewateres activated sludge, conditioned with polymers, from two percent solids to a liftable condition in four hours (21).

Table 10. Comparison of Mean Sludge Volume Index (SVI) Values

	<u>Mean SVI</u>	<u>Standard Deviation</u>	<u>Number of Observations</u>
Without chemical addition	62	14	24
With sodium aluminate addition	52	11	47
With alum addition	54	8	34

A cross section of a wedge wire drying bed is shown in Figure 8. The procedure for using this device begins with placing one in. of support water over the wedge wire. Thickened sludge is then conditioned with polymers if needed and carefully applied to a splash plate resting on the wedgewire. The water is withdrawn at a controlled rate to prevent solids from breaking through. When dry, the sludge can be removed by mechanically tilting the entire bed.

To evaluate wedge wire beds a series of tests were conducted using a bench scale model. Manufactured by Hendrick Screen Company<sup>1</sup>, this device has an area of one sq ft and a capacity of approximately 4 gallons. Only sludges produced during the alum addition period were used in these tests. Significant differences in dewatering characteristics between alum and aluminate sludges are not expected because both sludges contain the same major organic and inorganic constituents.

Initial tests indicated that undigested sludges would easily dewater with this device. However, when digested sludges were applied, many particles dropped through the screen and appeared in the drainage water. The loss of sludge through the wedge wire screen was probably due to the smaller size of the aerobically digested floc particles. Numerous polymer conditioning tests were performed to improve the dewaterability of aerobically digested sludge. Three cationic polymers supplied by Calgon Corporation<sup>2</sup> were tried; CAT FLOC B, WT 2640 and E 207L. A six paddle

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<sup>1</sup>Hendrick Screen Company, Owensboro, Kentucky.

<sup>2</sup>Calgon Corporation, Pittsburg, Pennsylvania.

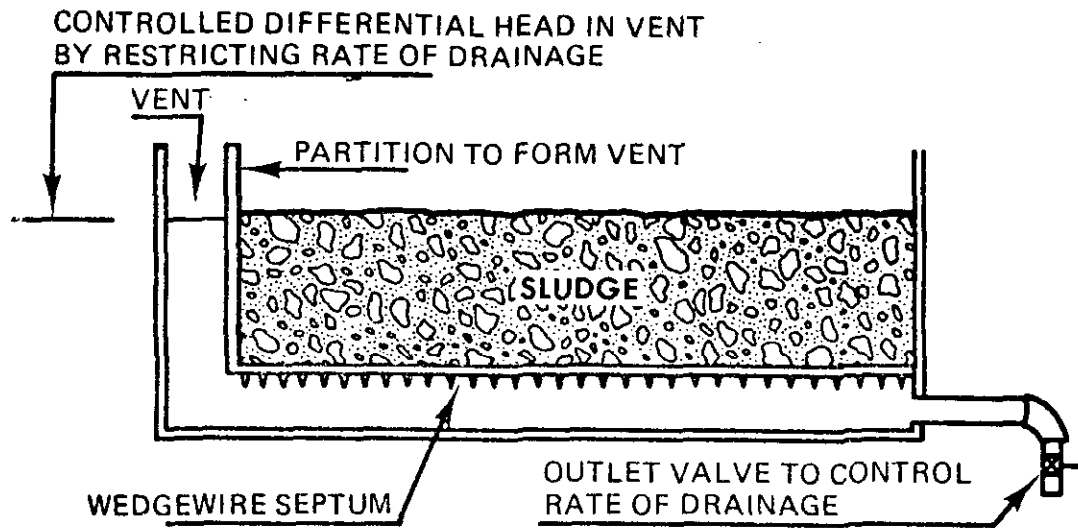


Figure 8. Cross Section of a Wedge Wire Dewatering Bed (22).

variable speed, gang stirring device was used for rapid mixing and flocculation of the sludge samples. Dosages ranging from 50 to 1000 mg/ℓ were tried. The effects of polymer addition were evaluated by noting changes in floc particle size and reductions in settled volume compared to a control sample. The results indicated that 250 mg/ℓ of #WT 2640 produced the greatest reduction in settled sludge volume (40 percent). Polymer E-207L was less effective with a maximum of only 26 percent reduction at a dosage of 500 mg/ℓ. CAT FLOC B produced only a 7 percent reduction for dosages ranging between 200 to 800 mg/ℓ.

As a result of the polymer conditioning tests, 250 mg/ℓ of Calgon WT 2640 were added to aerobically digested sludge samples prior to application over the wedge wire. Visual observations of the drainage water clarity confirmed that the polymer definitely improves solids capture by the wedge wire screen. Typical sludges containing 2 to 3 percent solids were effectively dewatered to 9 to 12 percent solids after 24 hours. Considering the ease in which the sludge was lifted from the surface of the wedge wire, the dischargeability of the sludge cake should be excellent. The results of several wedge wire dewatering tests using both digested and undigested sludges are shown in Table 11.

The effectiveness of the wedge wire device in dewatering undigested, chemical-biological sludge suggests that direct disposal could result in substantial cost savings. If permitted by regulatory agencies, undigested sludge could be landfilled and aerobic digestion facilities and polymer conditioning chemicals would not be needed. Odors normally associated with undigested sludge should not be a problem if the sludge is covered immediately.



Table 11. Results of Wedge Wire Dewatering Tests on Waste Extended Aeration Sludge Produced During Alum Addition

<u>Sludge Type</u>	<u>Polymer Applied</u>	<u>Feed Solids %</u>	<u>Cake Solids %</u>	<u>Time Interval(hrs)</u>
Undigested	None	1.8	9.0	24
	None	2.0	9.8	21
	None	3.0	9.1	24
Aerobically Digested	300 mg/l Calgon WT 2640	2.1	11.5	21
	250 mg/l Calgon WT 2640	2.4	12.0	26
	250 mg/l Calgon WT 2640	2.5	9.1	24

No odor problems were encountered during the 24 hour dewatering tests.

#### COST OF PHOSPHORUS REMOVAL IN EXTENDED AERATION SYSTEMS

The addition of sodium aluminate or alum for phosphorus removal will substantially increase the cost of treatment by extended aeration processes. Chemical storage and feeding equipment, and the greater capacity required for sludge handling facilities are the major cost factors. Additional personnel costs may also be incurred for time spent on checking chemical feeders, handling the increased solids load and performing the laboratory analyses necessary for process control.

Under the present pricing structure alum is less costly than sodium aluminate. Also, as demonstrated by this study, less aluminum (as alum) was needed for optimum phosphorus removal (Optimum Al:P<sub>filt</sub> weight ratio for sodium aluminate = 1.8:1; for alum = 1:1). If lime is necessary for pH control when alum is added, then the cost advantage of using alum is reduced somewhat. Nevertheless, for most applications alum appears to be less expensive than sodium aluminate for equivalent phosphorus removal.

The cost of chemical storage facilities and feeding equipment for both alum and sodium aluminate should be approximately the same. If lime is required for pH control, additional storage facilities and feeding equipment may be required. However, these pilot plant studies demonstrated that lime could be added on a batch basis and thus, special feeding equipment would be unnecessary. The EPA Process Design Manual for Phosphorus Removal (2) is an excellent source of information on the storage and feeding of these chemicals.

Expanded sludge handling facilities may be required to accommodate the increased sludge production resulting from phosphorus removal. Pilot plant studies indicated that two to three times more sludge can be expected. If present sludge handling capacities are inadequate; a wedge wire dewatering device may provide a solution. The cost of this device may be partially offset by eliminating the need for aerobic digestion prior to dewatering; at least during colder weather. Pilot plant studies demonstrated that undigested sludge can be dewatered to a liftable condition in 24 hours.

The total impact of phosphorus removal on the cost of treatment by extended aeration is difficult to assess because each site varies as to the degree of treatment required and the extent of existing facilities. However, if the present cost of treatment is known, the total cost may be estimated by adding the cost of only those chemicals and facilities needed for phosphorus removal. Table 12 shows the estimated cost of phosphorus removal in a 1.0 mgd extended aeration plant based on pilot plant results. The additional cost of treatment using sodium aluminate was estimated to be 8.2¢/1000 gal while alum treatment would cost less than 7.0¢/1000 gal.

#### CONCLUSIONS

Pilot plant studies on phosphorus removal in extended aeration systems using sodium aluminate and alum have shown that:

1. Both chemicals are equally effective in removing phosphorus.

However, a lower  $Al:P_{filt}$  weight ratio is required when alum is used as the aluminum source. The optimum  $Al:P_{filt}$  weight ratio using sodium aluminate was 1.8:1 while alum required only 1:1.

Table 12. Additional Cost of Treatment Using Sodium Aluminate or Alum for Phosphorus Removal in a 1 MGD Extended Aeration Plant

	<u>Sodium Aluminate</u> ¢/1000 gallons	<u>Alum</u> ¢/ 1000 gallons
Chemical Costs <sup>1</sup>	4.0	1.9
Lime <sup>2</sup> 42 mg/ℓ	0	0.8
Chemical Feed Equipment <sup>3</sup>	0.9	0.9
Wedge Wire Dewatering Screen <sup>4</sup>		
Capital Cost (7% for 20 years)	2.0	2.0
Operating Cost	<u>1.3</u>	<u>1.3</u>
TOTAL COST	8.2	6.9

<sup>1</sup>Based on unit costs of \$0.07/lb of Nalco #8750 sodium aluminate and \$0.05/lb of dry alum. Optimum Al:P<sub>filt</sub> weight ratio for sodium aluminate = 1.8:1; for alum = 1:1.

<sup>2</sup>Based on lime costs of \$0.03/lb (Ca(OH)<sub>2</sub>)

<sup>3</sup>From EPA Process Design Manual for Phosphorus Removal (2).

<sup>4</sup>Capital and operating cost information from personal communication with Allen I. Barry, President, Barry & Associates, Incorporated, Milton, Maine 02186

2. The addition of either chemical can improve the overall treatment efficiency of the unit. Mean effluent concentrations of BOD<sub>5</sub>, COD, suspended solids, turbidity and ammonia were significantly lower during both sodium aluminate and alum addition periods as compared to periods without chemical addition. The improved treatment performance was probably due to chemical coagulation of colloidal organics and stabilization of pH.
3. With addition of sodium aluminate, pH is self-regulating if nitrification also occurs. During pilot plant studies, a balance was maintained where the alkalinity depletion by nitrification was offset by the addition of alkaline sodium aluminate.
4. With alum addition, severe pH depression occurs unless lime is added. During the pilot plant studies 230 to 460 lb/mil gal of lime were needed to restore pH to the optimum range for phosphorus removal.
5. Sludge production will increase dramatically when sodium aluminate or alum are added for phosphorus removal. The total sludge production during the pilot plant studies ranged between 670 and 970 lb/mil gal, which is two to three times the normal sludge production rate.
6. A definite decrease in percent mixed liquor volatile suspended solids (MLVSS) can be expected after sodium aluminate or alum addition. This decrease is caused by the accumulation of inorganic AlPO<sub>4</sub> and Al(OH)<sub>3</sub> precipitates. As a result, a higher mixed liquor suspended solids concentration (MLSS) must be carried in the aeration basin to insure effective organic removal.

7. The settleability of the mixed liquor will improve slightly as a result of sodium aluminate or alum addition. During pilot plant studies, mean values of sludge volume index (SVI) were reduced from 62, when no chemicals were added, to 52 and 54 when sodium aluminate and alum were added.
8. Dewatering larger quantities of sludge produced during alum or sodium aluminate addition may be accomplished with a wedge wire drying bed. Pilot plant studies demonstrated that both undigested and digested (with polymer) sludges can be dewatered to a manageable 9 to 12 percent solids within 24 hours.
9. The addition of sodium aluminate or alum for phosphorus removal will substantially increase the cost of treatment by extended aeration processes. Chemicals, storage and feeding equipment and larger sludge handling facilities are major cost factors. Based on pilot plant results, the additional cost of treatment using sodium aluminate would be 8.2¢/1000 gal while alum treatment would add less than 7.0¢/1000 gal.

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APPENDIX I  
ANALYTICAL METHODS AND TECHNIQUES

All analyses were performed in accordance with the 13th Edition of Standard Methods for the Examination of Water and Wastewater (23) and Methods for Chemical Analysis of Water and Wastes (24). Most samples were analyzed immediately after sampling, but when preservation was necessary, it was done according to EPA guidelines.

Phosphorus - Total phosphorus was determined according to the EPA single reagent method. Dilutions were made as necessary. The persulfate digestion was used and colorimetric determinations were carried out with a Bausch and Lomb Spectronic 20.

At least two standards and a reagent blank were analyzed with every set of samples. Glassware was washed with hot 1 + 1 hydrochloric acid, and filled with distilled water until used.

Soluble phosphorus was determined by immediate filtration through a 0.45 micron membrane filter prior to analysis.

Alkalinity - Alkalinity was measured by titrating each sample with .01 N  $H_2SO_4$  to the respective endpoints of 4.5 for total alkalinity and 8.3 for phenolphthalein alkalinity. Electrometric titrations were carried out on a Radiometer model 28B pH meter and results expressed in mg/l as  $CaCO_3$ .

Chemical Oxygen Demand (COD) - The samples including a blank were refluxed for two hours and titrated with standardized .01 N ferrous ammonium sulfate.

Biochemical Oxygen Demand (BOD)<sub>5</sub> - BOD<sub>5</sub> was determined by the standard dilution technique and the modified Winkler dissolved oxygen method.

Turbidity - Turbidity measurements were obtained using a Hach Model 2100A Turbidimeter. The meter was standardized before each use and the data was expressed in Jackson Turbidity Units (JTU).

Ammonia (NH<sub>3</sub>-N) - Ammonia nitrogen concentrations were measured using a specific ion electrode.

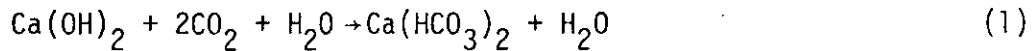
To monitor the accumulation and composition of the aeration basin solids, daily grab samples were analyzed gravimetrically for mixed-liquor suspended solids (MLSS) and mixed-liquor volatile suspended solids (MLSS). Sludge volume index (SVI) was calculated from the settled volume of a one liter sample and the MLSS.

Routine measurements were made of aeration basin dissolved oxygen levels. This allowed adjustment of the compressed air supply to ensure adequate DO levels in the basin.

APPENDIX II

CALCULATION OF LIME REQUIRED FOR pH CONTROL  
WHEN USING ALUM FOR PHOSPHORUS REMOVAL

The quantity of lime required for pH control may be calculated by determining the amount of supplemental alkalinity needed to maintain system pH in the optimum range for phosphorus removal. When lime ( $\text{Ca(OH)}_2$ ) is added to wastewater (pH between 5.5 to 6.5), bicarbonate alkalinity ( $\text{HCO}_3^-$ ) is produced according to the reaction,



From this relationship it can be seen that 1.0 pound of lime as  $\text{Ca(OH)}_2$  will produce 1.35 pounds of alkalinity. Thus, the amount of lime needed in pounds/day can be calculated as shown below:

$$\text{Ca(OH)}_2 = 6.2 (Q) (\text{Alk}_d) \quad (2)$$

where  $Q$  = flowrate, mil gal/day

$\text{Alk}_d$  = alkalinity deficit, mg/l as  $\text{CaCO}_3$

The alkalinity deficit ( $\text{Alk}_d$ ) can be determined by the conservation of mass principle. Assuming that the only alkalinity inputs are from lime and influent wastewater, and the alkalinity losses are through nitrification,  $\text{Al(OH)}_3$  formation, and effluent discharge, the alkalinity deficit can be calculated as follows:

$$\text{Alk}_d = \text{Alk}_n + \text{Alk}_a + \text{Alk}_e - \text{Alk}_i \quad (3)$$

where  $\text{Alk}_n$  = alkalinity consumed by nitrification, mg/l as  $\text{CaCO}_3$

$\text{Alk}_a$  = alkalinity consumed by  $\text{Al(OH)}_3$  formation, mg/l as  $\text{CaCO}_3$

$\text{Alk}_e$  = effluent alkalinity needed to maintain pH in the range  
from 5.5 to 6.5, mg/l as  $\text{CaCO}_3$

$\text{Alk}_i$  = influent alkalinity, mg/l as  $\text{CaCO}_3$

The influent alkalinity ( $Alk_i$ ) can be determined by averaging the influent alkalinity concentrations. The effluent alkalinity needed to maintain pH in the 5.5 to 6.5 range ( $Alk_e$ ) could be obtained by jar tests or by plotting effluent pH vs alkalinity as shown in Figure II-1. During the pilot plant study, an effluent alkalinity concentration of approximately 8 mg/ℓ as  $CaCO_3$  was needed to maintain pH at 6.0.

Alkalinity Consumption by Nitrification ( $Alk_n$ )

The alkalinity consumed by nitrification can be calculated according to the relationship

$$Alk_n = ACR(N_o - N_e) \quad (4)$$

where ACR = alkalinity consumption rate, mg Alk as  $CaCO_3$ /mg of ammonia removed

$N_o$  = influent ammonia concentration, mg/ℓ  $NH_3$ -N

$N_e$  = effluent ammonia concentration, mg/ℓ  $NH_3$ -N

The average influent and effluent ammonia concentrations can be determined from existing plant data or design calculations. The alkalinity consumption rate (ACR) can be calculated by the method of Sherrard (25) which takes into account the sludge age and  $BOD_5:N:P$  ratio of the nitrifying activated sludge system. Alternatively, the theoretical ACR of 7.14 mg Alk as  $CaCO_3$ /mg  $NH_3$ -N removed can be used for engineering approximations (26). Substituting the theoretical value of ACR into Equation 4, the alkalinity consumed by nitrification can be calculated as follows:

$$Alk_n = 7.14 (N_o - N_e) \quad (5)$$

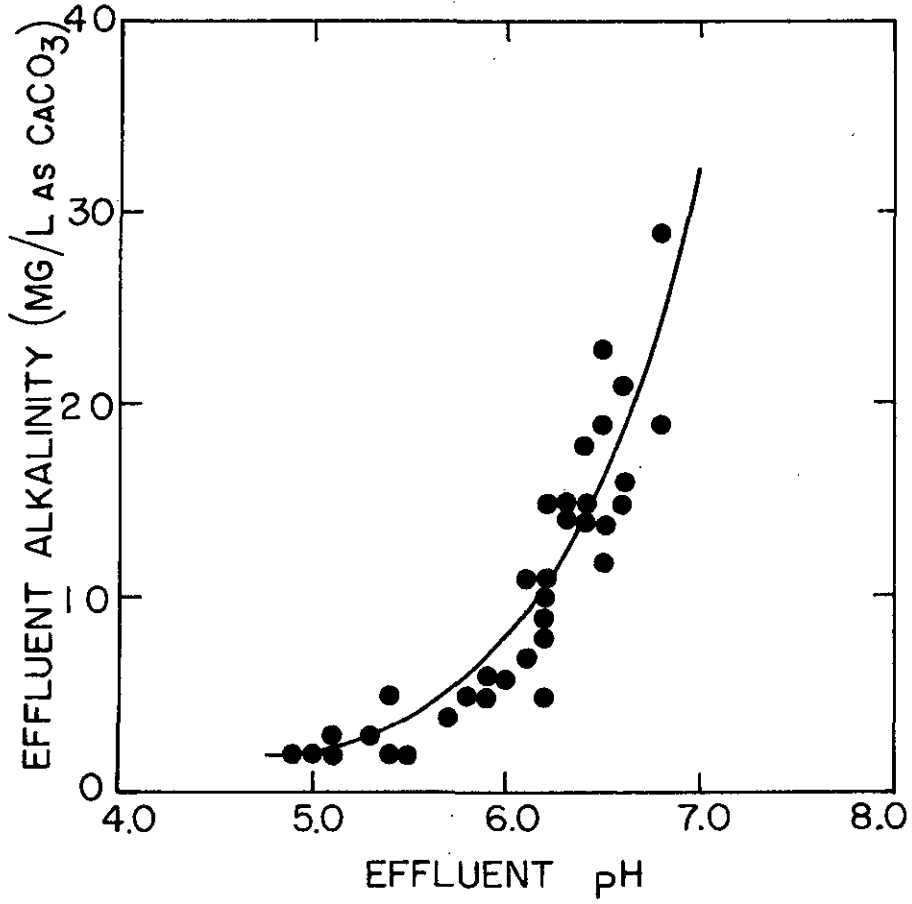


Figure II-1. Observed Effluent pH vs. Alkalinity During Alum Addition.

### Alkalinity Consumption by $Al(OH)_3$ Formation

In wastewater containing  $PO_4$ , it is assumed that only excess alum not used in precipitating  $PO_4^{3-}$  is available for  $Al(OH)_3$  formation. According to stoichiometric calculations, 9.6 mg of alum are used per mg of phosphorus removed. Also, 0.5 mg of alkalinity as  $CaCO_3$  will be consumed per mg of excess alum available. Therefore, the alkalinity consumed by alum addition ( $Alk_a$ ) can be calculated as follows:

$$Alk_a = 0.5 [Alum_f - 9.6 (P_o - P_b - P_e)] \quad (6)$$

where  $Alum_f$  = alum feed concentration, mg/l

$P_o$  = influent total phosphorus, mg/l as P

$P_b$  = background phosphorus removal, mg/l as P

$P_e$  = effluent total phosphorus, mg/l as P.

Substituting Equations 5 and 6 into Equation 3, the alkalinity deficit ( $Alk_d$ ) for the system is calculated as shown below:

$$Alk_d = 7.14 (N_o - N_e) + 0.5 [Alum_f - 9.6 (P_o - P_b - P_e)] + Alk_e - Alk_i \quad (7)$$

Once the alkalinity deficit is determined, the amount of lime needed for pH control can be determined using Equation 2.

### Calculation of Lime Required During Pilot Plant Study Using Alum

To provide an example of how the approximate lime requirement for pH control can be calculated, the above procedure was applied to the pilot plant unit. During the 90 mg/l alum dosing period, the average ammonia, phosphorus and alkalinity data was reported as follows:

$$N_o = 17.0 \text{ mg/l as N}$$

$$N_e = 1.8 \text{ mg/l as N}$$

$$P_o = 6.0 \text{ mg/l as P}$$

$$P_b = 23 \text{ percent} = 1.4 \text{ mg/l as P}$$

$$P_e = 0.5 \text{ mg/l as P}$$

$$\text{Alk}_i = 100 \text{ mg/l as CaCO}_3$$

$$\text{Alk}_e = 8 \text{ mg/l as CaCO}_3$$

$$Q = 8775 \times 10^{-6} \text{ mil gal/day}$$

From Equation 7, the alkalinity deficit ( $\text{Alk}_d$ ) was calculated to be 42 mg/l as  $\text{CaCO}_3$ . Using Equation 2, the lime required to offset the alkalinity deficit and maintain pH control is 2.3 lb/day or 260 lb/mil gal.