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NITRIFICATION IN HIGH RATE
TRICKLING FILTERS

by

Dennis Eston Harman

A Thesis
Presented to the Graduate Committee
of Lehigh University
in Candidacy for the Degree of
Master of Science
in
Civil Engineering

Lehigh University
1971

CERTIFICATE OF APPROVAL

This research report is accepted and approved in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering.

Jan 7, 1972
(date)

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LIST OF ABBREVIATIONS

NOD	Nitrogenous Oxygen Demand
BOD	5 day 20°C Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
TOD	Total Oxygen Demand
BOD _L	Ultimate Biochemical Oxygen Demand
gpd/sq ft	gallons per day per square foot
ft	Feet
gpm	gallons per minute
MGAD	Million Gallons Per Acre Daily
mg/l	milligrams per liter
ml	milliliter
MGD	million gallons per day
ptcfd	pounds per thousand cubic feet per day

ABSTRACT

This study attempted to increase the rate of nitrification by a pilot scale high rate trickling filter operated at the Bethlehem Sewage Treatment Plant. The pH of the pilot scale trickling filter influent was increased to approximately 8.5 which is the optimum range for the growth of Nitrosomonas and Nitrobacter, the two major nitrifying bacteria.

Test results indicate that the adjustment of the sewage pH did increase the degree of nitrification. However, the magnitude of the increase was not significant enough to warrant the procedure on a plant scale basis.

The major cause of low nitrification with or without the pH adjustment was the high organic loading due to the actual trickling filter influent of the Bethlehem facility. Pilot scale trickling filter operation at slightly lower organic loadings indicate that further reduction of the organic loading will be required before nitrification can be achieved.

Occasional high concentrations of cyanide in the wastewater during the study probably inhibited the nitrification to an appreciable degree. Additional verification of this problem is needed at the Bethlehem facilities.

INTRODUCTION

Nitrification of wastewaters is the oxidation of ammonia nitrogen to the nitrate form via nitrite. This oxidation occurs naturally in soils and streams as a result of autotrophic bacterial metabolism. Autotrophic bacteria synthesize new cell protoplasm, most using inorganic chemical sources and a few using sunlight as the energy source. Carbon dioxide serves as the carbon source although carbon monoxide can also be a carbon source (13).

A typical effluent from conventional secondary sewage treatment facilities will contain 10 to 20 mg/l ammonia nitrogen (10). In the receiving waters, nitrifying bacteria will oxidize this ammonia first to nitrite and then to nitrate. A limited amount of ammonia is used directly by other organisms in their metabolism. Under favorable environmental conditions ammonia oxidation will proceed rapidly and may reduce the dissolved oxygen of the stream or lake to near zero, resulting in a possible fish kill.

The oxygen demand exerted by nitrification has been termed the NOD. The NOD will be most critical for low flow streams which receive relatively large quantities of secondary sewage effluent. The most critical period is during the summer when warm temperatures and low stream flows create favorable environmental conditions for nitrification (10).

Nitrogen in the ammonia, nitrite, and nitrate forms is also an important nutrient for cultural eutrophication. Eutrophication is

a natural process involving an increase in biological activity and productivity in a stream or lake as a result of natural nutrient enrichment. When man increases the nutrient level of the body of water, the natural eutrophication process is accelerated and the process is known as cultural eutrophication (11).

The most practical method of reducing cultural eutrophication is by reducing the amount of nitrogen and/or phosphorus discharged to the receiving water. Denitrification is the process of reducing nitrate to molecular nitrogen or nitrous oxide which are given off as gas. However, in order to denitrify an effluent, the sewage must first be nitrified. Nitrification, then, is a necessity not only for reducing the effluent's oxygen demand in a stream, but also for removing nitrogen from the sewage effluent via the denitrification process.

In the past, the major concern for the dissolved oxygen in a stream was considered to be the oxygen demand exerted by the microorganisms which assimilate the carbonaceous organic material in the sewage effluent. This oxygen demand, measured by the five day, 20°C BOD test (15), was used as the basic parameter in the evaluation of sewage plants with design based on attaining certain levels of BOD in the treated effluent. When the effects of nitrification on receiving waters were recognized, regulatory agencies began setting more stringent effluent requirements. Effluent standards are beginning to be defined in terms of the TOD. In Pennsylvania, the Department of Environmental Resources has defined the TOD as:

$$\text{TOD} = 1.5 (\text{BOD}) + 4.6 (\text{NH}_3) \quad (1)$$

The 1.5 factor is used to transform the five day 20°C BOD to the ultimate BOD_L. The 4.6 factor is the stoichiometric amount of oxygen needed to oxidize one unit of ammonia to nitrate, both expressed as N. The TOD thus requires more than six times the amount of oxygen as indicated by the BOD. As a result, new plants are being designed to consider the TOD of the sewage.

Existing plants are faced with a very real problem in meeting present and future effluent quality standards which require a greater degree of nitrification. Increased nitrification might be obtained by adding biological nitrifying units, but the cost of additional units could be quite high. A desirable alternative would be to increase nitrification in the existing secondary treatment units.

The following example using TOD as the effluent quality criteria will illustrate the additional degree of treatment required. Suppose a secondary treatment plant is removing 90% of the influent BOD which averages 250 mg/l. The plant is also removing a quite respectable 50% of the influent ammonia which is approximately 30 mg/l. The following values for TOD would then exist:

$$\text{TOD}_{\text{inf}} = 1.5 (250) + 4.6 (30) = 513 \text{ mg/l}$$

$$\text{TOD}_{\text{eff}} = 1.5 (25) + 4.6 (15) = 106.5 \text{ mg/l}$$

The plant efficiency for TOD removal is only 79%. In order to meet an effluent standard of 90% TOD removal, the plant would have to produce an effluent with a TOD of 46 mg/l. This means that the current TOD of the plant effluent would have to be reduced about 60%. An increase in

plant facilities of this magnitude is quite costly.

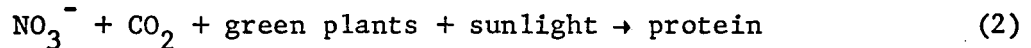
Wild et al. (18) have shown that by adjusting the pH of sewage increased nitrification could be achieved in activated sludge units. They adjusted the pH to approximately 8.0 to 8.5, the optimum for the growth of nitrifying bacteria. Since the nitrifying bacteria increased the rate and extent of ammonia oxidation at this pH in activated sludge units, then this pattern should hold true in high rate trickling filters. The objective of this research was to determine the increase in nitrification corresponding to an increase in the pH of the filter influent to these optimum levels.

By significantly increasing nitrification in high rate trickling filters, the existing plants could save on the cost of additional nitrifying units. Instead of building new units the plants would only have to install a chemical feed system to adjust the pH of the sewage. The only additional costs would be for the chemicals and the chemical feed equipment.

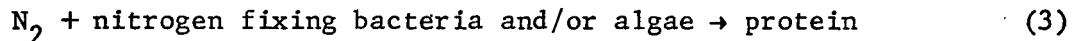
LITERATURE REVIEW

Nitrogen is an important ingredient in all life functions. A general composition of biological protoplasm is $C_5H_7O_2N$, indicating that 0.13 pounds of nitrogen are required for each pound of bacterial cells synthesized (8). The earth's atmosphere is approximately 78% molecular nitrogen, which is unusable by most living organisms. Through electrical discharge, molecular nitrogen is converted to the nitrate form, the first step in the nitrogen cycle depicted in Fig. 1 (15).

Nitrate is utilized by green plants in their photosynthesis to produce protein.



Nitrogen-fixing bacteria and some forms of algae are able to convert molecular nitrogen directly to protein.



The protein becomes the source of nitrogen for humans, animals, and some plants that are unable to use nitrate directly. Nitrogen in the form of protein is used in the body for growth and muscle repair.

This nitrogen from the proteins is continuously released by humans and other animals as waste products. Nitrogen compounds are also released upon the death of plants and animals. About 85 to 90% of the nitrogen released is in the form of ammonia or an organic compound easily broken down into ammonia. A common form is urea, which

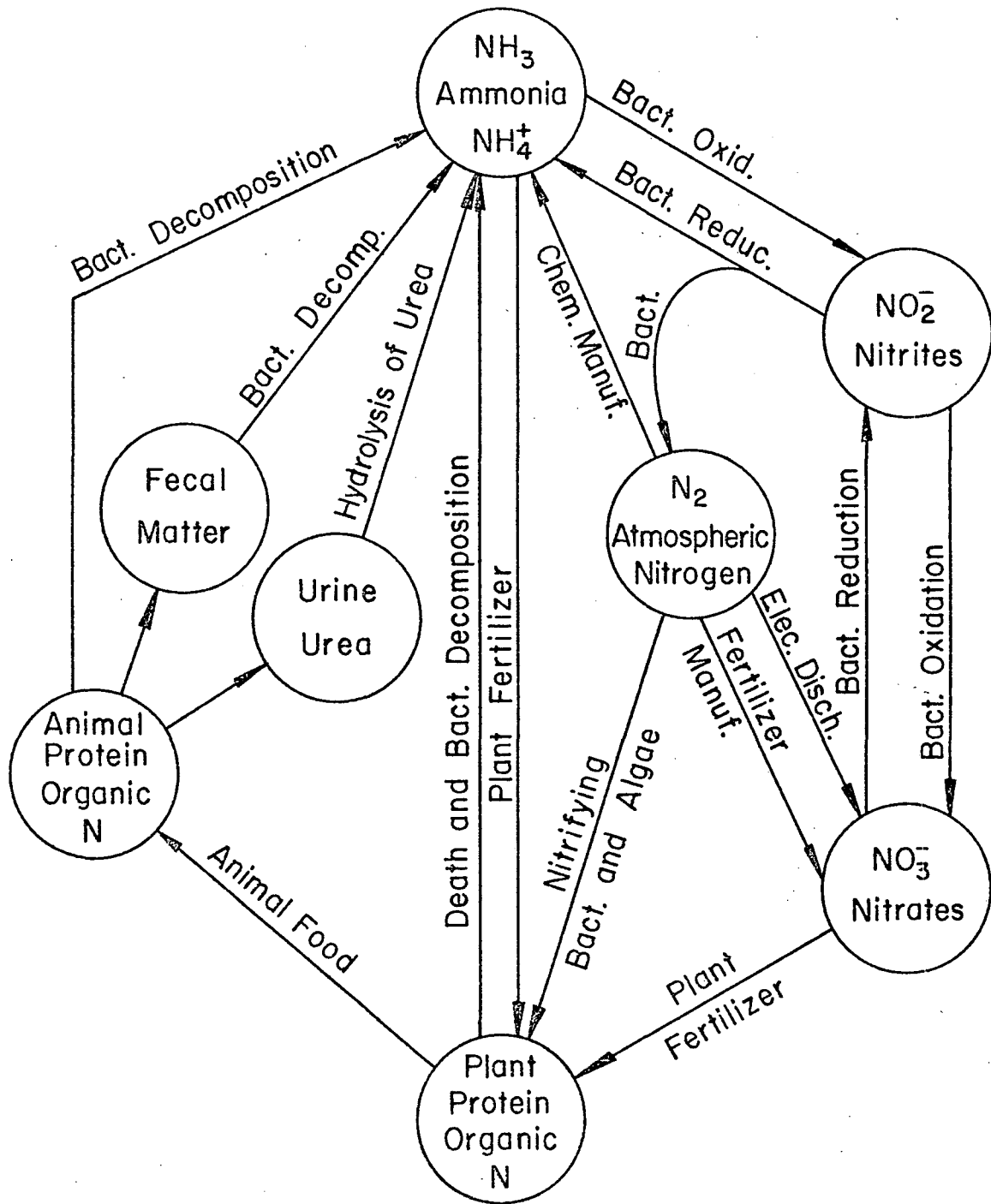
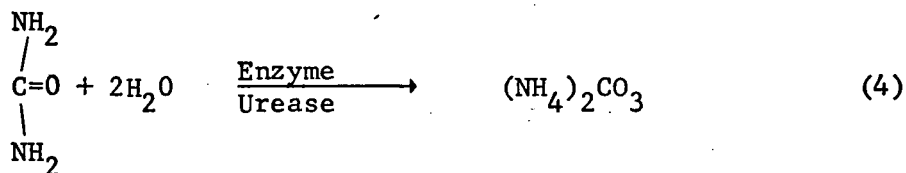


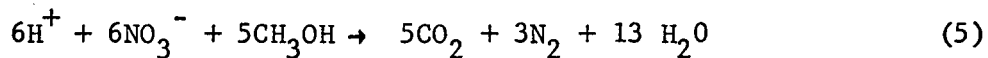
Fig. 1 Nitrogen Cycle

is hydrolyzed by the enzyme urease to ammonium carbonate (15).



Ammonia is further converted to nitrite and nitrate by autotrophic bacteria. The nitrogen in the nitrate form once again becomes an important nutrient for plant growth.

The nitrogen in the nitrate form can be converted to one of two different forms. As previously mentioned, nitrate may be converted to protein by green plants, or may be reduced to molecular nitrogen by microbial activity according to the following equation (8):



Unlike nitrification, there are many denitrifying species of bacteria capable of reducing nitrate to molecular nitrogen or, in some cases, to nitrous oxide. Anaerobic conditions are required along with a supply of organic carbon (8).

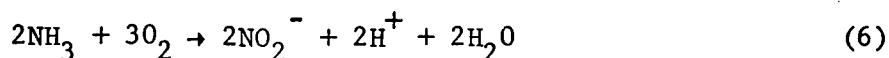
The current research was concerned with a portion of the nitrogen cycle--the oxidation of ammonia to the nitrate ion via nitrite. As previously stated, herein lies one portion of the water pollution problem. The natural bacterial oxidation reduces the dissolved oxygen level in the receiving body of water which can lead to deleterious effects on fish and other aquatic life.

The solution to the problem of reduced dissolved oxygen in the receiving water due to the NOD is to oxidize the ammonia prior to

discharge from the sewage plant. The current method of ammonia reduction is the biological oxidation to the nitrate form using autotrophic bacteria termed nitrifiers.

Autotrophic microorganisms which derive energy by oxidizing inorganic compounds such as ammonia or nitrite and which use carbon dioxide as a carbon source are termed chemolithotrophic bacteria (6). Only a small number of organisms are capable of ammonia or nitrite oxidation, among which are the Nitroso- and the Nitro-bacteria.

The Nitroso-bacteria include Nitrosomonas, Nitrosococcus, Nitrosocystis, Nitrosogloea, and Nitrosopira. These bacteria oxidize ammonia to nitrite, with Nitrosomonas being by far the most abundant (15). The equation for the oxidative process is:



The equation indicates that the only chemical reactants needed are oxygen and ammonia, but carbon dioxide is also required by the Nitroso-bacteria as a carbon source for new cell synthesis. The products of the overall reaction include nitrite, water, hydrogen ions and new Nitroso-bacteria cells (2).

The Nitro-bacteria on the other hand, include only Nitrobacter and Nitrocystis, which oxidize the nitrite to the nitrate form. Nitrobacter is the more prevalent. The equation for this oxidation is similar to that for Nitrosomonas.



Nitrite and oxygen are the reactants, along with carbon dioxide as a carbon source, yielding nitrate and new Nitrobacter cells as end products (5).

The usual growth rate for these autotrophs is quite slow, taking about a week for a new generation of the bacteria to be produced. In order to increase the nitrification in trickling filters, the growth and metabolism rate of Nitrosomonas and Nitrobacter must be increased.

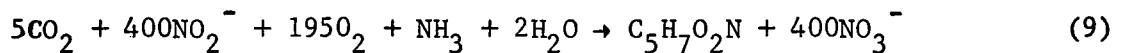
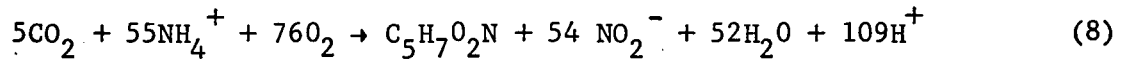
Additional nutrients, such as phosphorous, magnesium, and iron, are required in small quantities for growth of Nitrosomonas and Nitrobacter (13). Nitrosomonas also requires calcium and copper in small amounts.

It has been determined (2) that the rate of nitrification is independent of the ammonia concentration when it is greater than 3 mg/l as N. Another study (18) found no inhibitory effects on Nitrosomonas when the ammonia concentration reached 60 mg/l. A typical raw sewage will contain about 25 to 40 mg/l ammonia. All of the other nutrients are usually found in substantial amounts in sewage except for the nitrite ions, which are supplied by the Nitrosomonas bacterial metabolism (14).

Nitrosomonas and Nitrobacter tend to adhere to solid surfaces. In fact, for Nitrosomonas a solid surface is almost a necessity for growth, although the reason is not certain (13). The trickling filter media provides an excellent surface onto which the nitrifiers can adhere.

Oxygen is needed in abundant amounts for nitrification.

The stoichiometric oxygen requirements for oxidation of ammonia and nitrite has been determined to be 3.22 mg/l oxygen per mg/l ammonia as N oxidized to nitrite and 1.11 mg/l oxygen per mg/l nitrite as N oxidized to nitrate (12,15). The equations for this oxygen consumption are (15):



The total oxygen use is 4.33 mg/l oxygen for each mg/l ammonia nitrogen converted to nitrate.

How then does the state of Pennsylvania arrive at its 4.6 mg/l oxygen for the TOD in Eq. 1? The answer lies in the realization that synthesis of the bacteria ends not only in the oxidized products of nitrate and energy, but also in an increased number of bacteria. These bacteria will in turn eventually die and the cell protoplasm will exert a demand on oxygen, thereby increasing the 4.33 mg/l to approximately the stoichiometric 4.6 mg/l oxygen value.

Long periods without oxygen are not lethal to the nitrifying bacteria, as they merely become dormant. Heavy metals such as nickel, chromium, and zinc in concentrations of about 0.25 mg/l are toxic to the bacteria, along with cyanide in smaller concentrations (7).

The effect of organic material on nitrification has not been clearly established. Several sources (6,15,17) indicate that certain organic substances (including mannose, dextrose, and pentose) inhibit

the growth of the nitrifiers, but do not affect the ability of already formed cells to oxidize the ammonia. An indirect effect seems to be the reduction of the oxygen levels in both filters and activated sludge units by the microorganisms metabolizing the organic material (18). This reduces the oxygen available for nitrification. Wild et al. (4) indicate that a BOD concentration in excess of 40 to 50 mg/l will retard the growth of nitrifiers.

According to several sources (4,6,18), the temperature and the pH of the sewage are also important variables in the growth rate of the bacteria. Although the temperature and pH affect the nitrification, the reasons for this phenomenon have not been indicated. The optimum temperature for nitrification appears to be from 30 to 35°C. One study (18) indicates that below 5°C, there is little or no nitrification. Thus, nitrification will be severely inhibited in the northern parts of the United States during the winter months due to low temperatures in the sewage.

Meyerhof (6) has found that optimum growth will occur at a pH of about 8.5 to 8.8 for *Nitrosomonas* and at a pH of about 8.3 to 9.3 for *Nitrobacter*. Thus, by adjusting the pH and the temperature, the nitrification in waste water can theoretically be maximized.

DESCRIPTION OF RESEARCH

Research was conducted on a pilot trickling filter constructed and operated at the Bethlehem Sewage Treatment Plant in Bethlehem, Pennsylvania. The purpose of the research was to study the effect of increased pH on the nitrification of the sewage in high rate trickling filters.

There were five separate stages of research. Phase I consisted of pilot filter operation at a hydraulic loading of 407 gpd/sq ft, using the same wastewater as the plant trickling filters. This phase was to determine if the treatment efficiency of the pilot filter was comparable with the results of the plant filters.

Phase II maintained the same hydraulic loading and influent wastewater as Phase I, but the influent wastewater pH was increased to the optimum for nitrification. In Phase III, the flow rate was reduced from 407 to 203 gpd/sq ft with the rest of the flow scheme unaltered from Phase II.

Phase IV was conducted with the flow rate increased from 203 to 326 gpd/sq ft. To reduce the organic loading, the flow scheme was altered so that the plant trickling filter effluent was the pilot influent. Phase V was a continuation of Phase IV, but the chemical feed was discontinued and the pH of the pilot filter influent was allowed to return to its normal level. Throughout the research, the pH of the sewage was increased by using sodium hydroxide.

PILOT PLANT DESCRIPTION

The pilot trickling filter was a three ft diameter galvanized steel tank. The height was approximately five ft, with a media depth of four ft, the same as the plant trickling filters. The pilot filter media was four to six inch rock, removed from the existing plant trickling filters.

The influent wastewater distribution system consisted of a 3/4 inch polyvinyl chloride pipe which divided the flow into four approximately equal streams through a system of tee sections as shown in Fig. 2. Each of the four streams flowed through a 90° elbow directing the sewage onto the filter. The flow distribution achieved nearly equal flow to all areas of the filter.

The pilot filter rested on a steel grate, in turn resting on two steel beams which spanned a control box. The control box influent was from the primary settling tanks and included the recirculation flow to the trickling filters. The effluent from the pilot filter was channeled to a sampling point prior to flowing back into the control box.

Influent wastewater to the pilot trickling filter was taken from two different sources during the research. First, the pilot filter influent was taken from the control box just as was the plant trickling filter influent. The second influent source for the pilot filters was the effluent from the plant trickling filters. A centrifugal pump and rate control valve¹ supplied the pilot trickling filter

¹Manufactured by the Dole Valve Company

Suction
Line 1/2" PVC

Pilot
Filter

Rate
Control

Pump

NaOH

Discharge
Line 3/4" PVC

Tee Sections

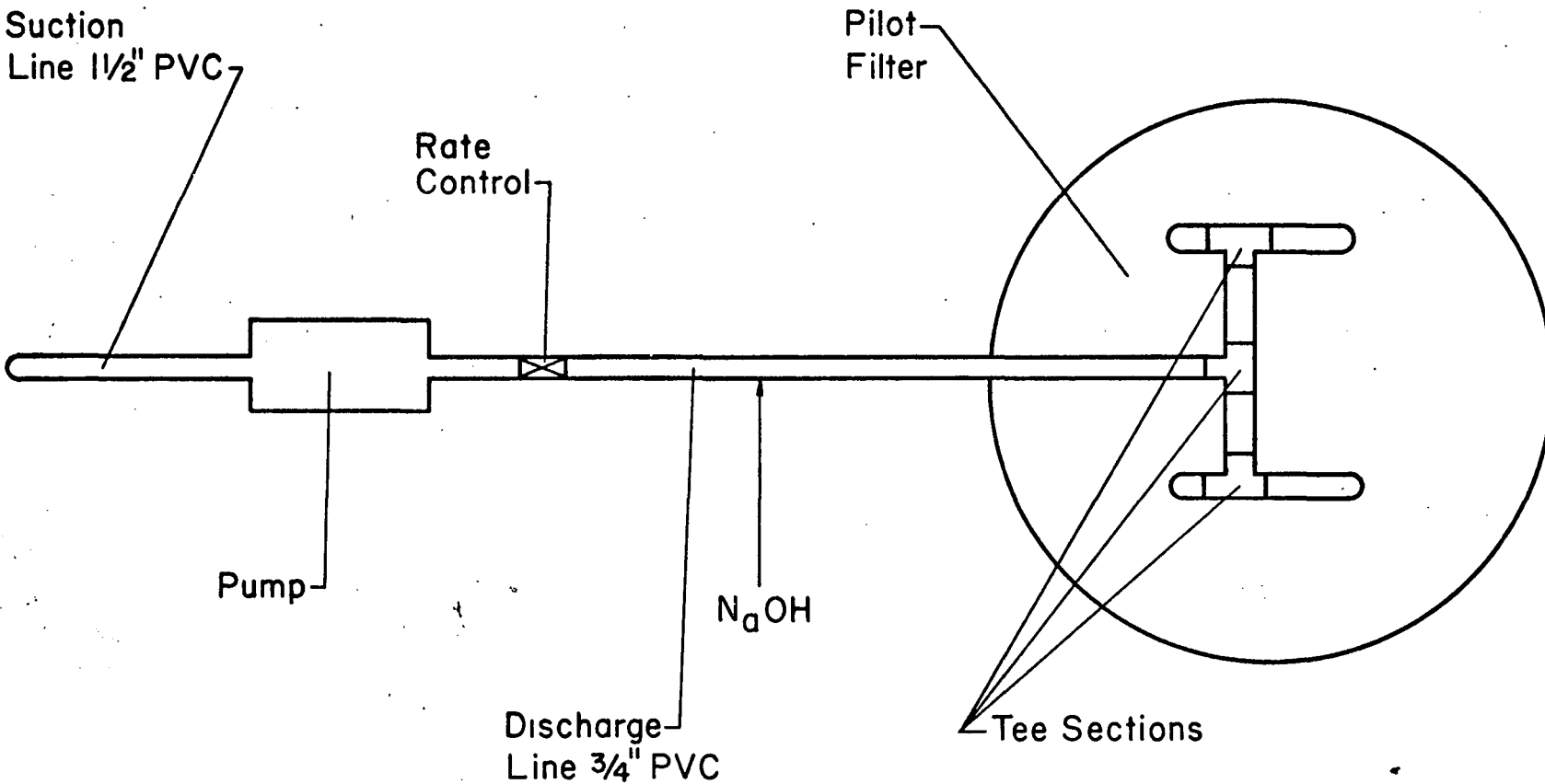


Fig. 2 Schematic Flow Diagram

with the proper flow rate from each source to the distribution system previously described.

Control valve capacities used were 1, 1.6 and 2 gpm. These flow rates onto the three ft diameter pilot filter were equivalent to loadings of 203, 326, and 407 gpd/sq ft respectively. The equivalent loading rates for the plant trickling filters were 8.85, 14.2 and 17.7 MGAD respectively. The average loading onto the plant trickling filters during the research was about 19 MGAD.

A sodium hydroxide solution was added after the rate control valve to raise the pH. A chemical feed pump¹ injected the solution from a twenty gallon chemical tank containing the sodium hydroxide stock solution into the pilot plant influent to raise the pH. Sodium hydroxide flakes were mixed with distilled water in quantities and concentrations as dictated by the flow rate and/or the flow pattern.

Distilled water had to be used in order to eliminate precipitation of iron and calcium carbonate from the tap water at the elevated pH in the stock NaOH solution. These precipitates from the tap water clogged the strainer in the chemical tank as well as the chemical feed pump prior to the use of distilled water. In a full scale plant operation, a blending basin would be used and the chemicals would be added at full strength so that the precipitates would not be a problem.

The pilot filter was designed to be as nearly equivalent to the plant filters as possible. Not only were they using the same sewage, but they were also experiencing similar environmental conditions such as temperature variations and precipitation.

¹Model 475C manufactured by Mec-O-Matic

SAMPLING AND ANALYSIS PROCEDURES

Analyses were conducted on both grab and composite samples. Grab samples were used to supplement the composite samples, mostly in the early experimental stages. Composite samples, Monday through Thursday, were prepared from samples taken during the 8:00 to 3:00 PM daytime work shift. The composite samples were prepared by plant personnel taking 90 ml of each hourly grab sample and adding this to the daily sample.

Samples were taken at three locations when using the first flow scheme of the plant filter influent as the pilot filter influent. One location was the plant and pilot filter influent which were identical, the second was the pilot filter effluent and the third location was the plant filter effluent. The plant filter influent sample was eliminated for the second flow scheme using the plant filter effluent as the pilot filter influent.

Grab samples were taken periodically to check the pH and the temperature. One series of grab samples was taken hourly for 20 consecutive hours to determine the diurnal variation in the pH. Composite samples were used for most of the nitrogen, BOD and COD analyses.

Composite samples were refrigerated at the Bethlehem Sewage Treatment Plant prior to performing the laboratory analyses. Samples were then brought to the sanitary engineering laboratory located in the Fritz Engineering Laboratory of Lehigh University.

Analyses were performed for nitrogen in the ammonia, nitrite, and nitrate forms. These analyses along with BOD and COD analyses were conducted according to Standard Methods (1). The nitrite test used was the diazotization method using 1-naphthalamine sulfanilic acid. The direct nesslerization method was used for ammonia analysis and the brucine method was used for nitrate analysis.

A spectrophotometer¹ was used to determine the per cent transmittance of the samples after the color development in the various analyses for the colorimetric tests. Standard solutions were prepared for each of the different nitrogen forms, and calibration curves (Figs. 3,4,5) were prepared for each by diluting the standard solutions and analyzing the diluted samples by the normal procedure.

¹Bausch & Lomb Spectronic 20

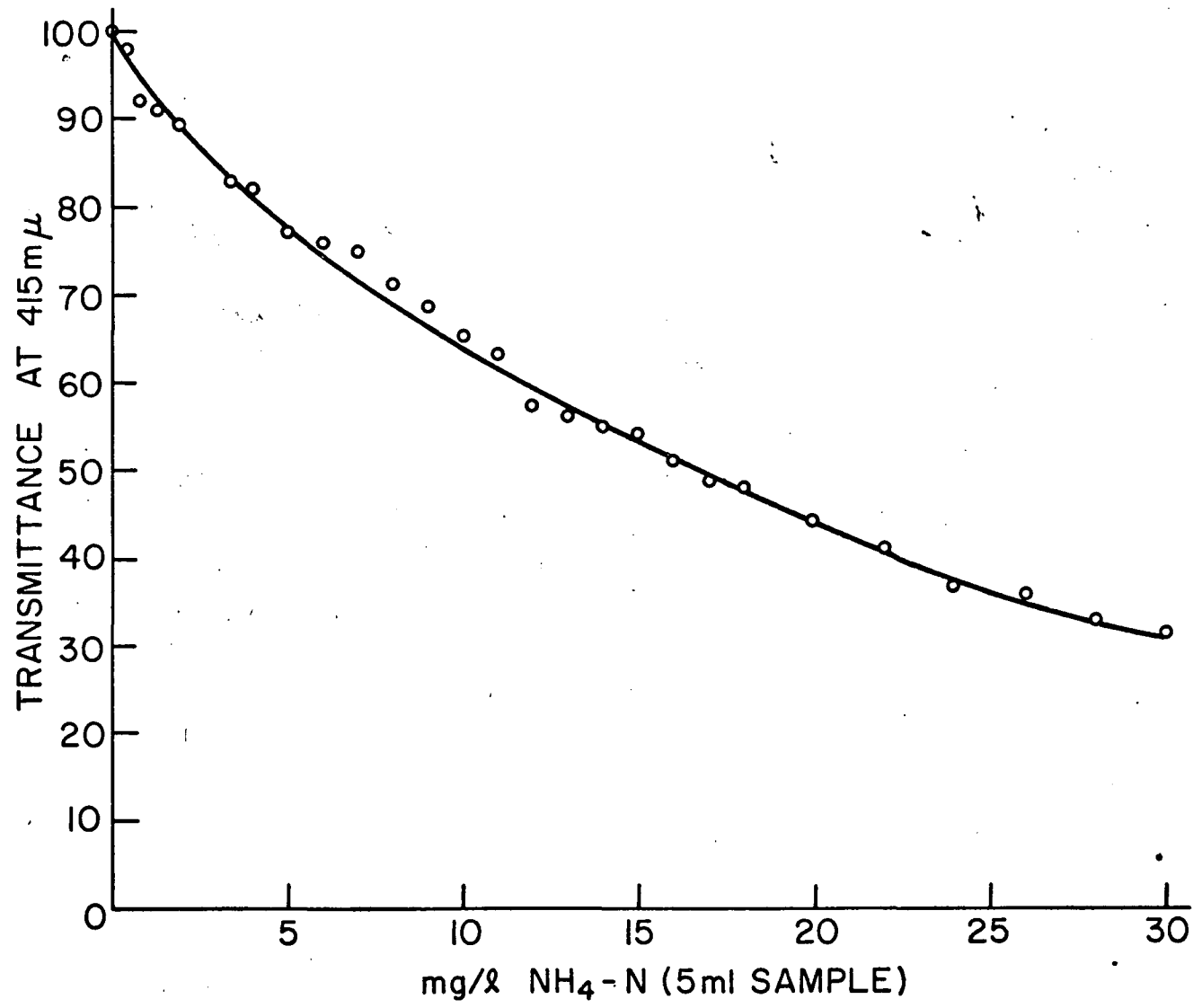


Fig. 3 Ammonia Calibration Curve

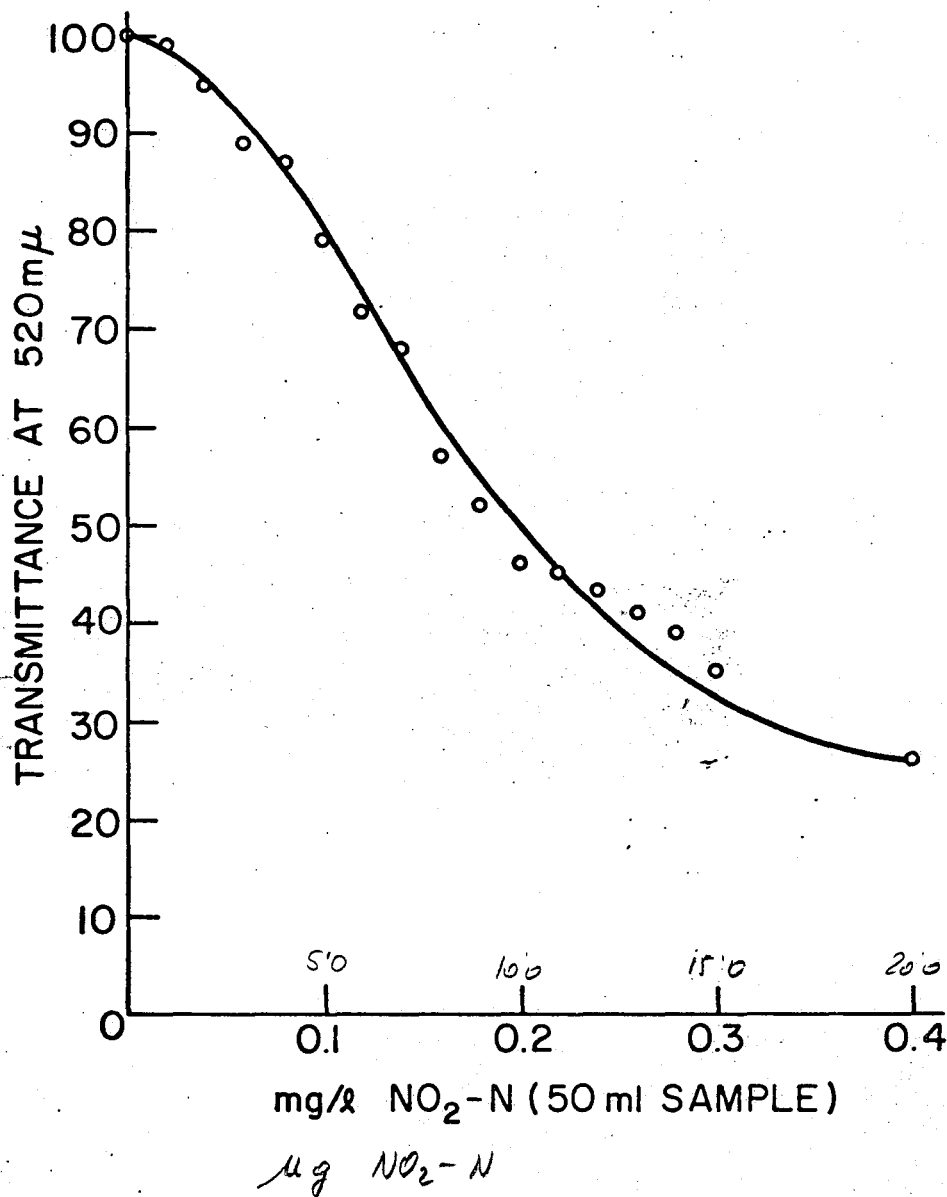


Fig. 4 Nitrite Calibration Curve

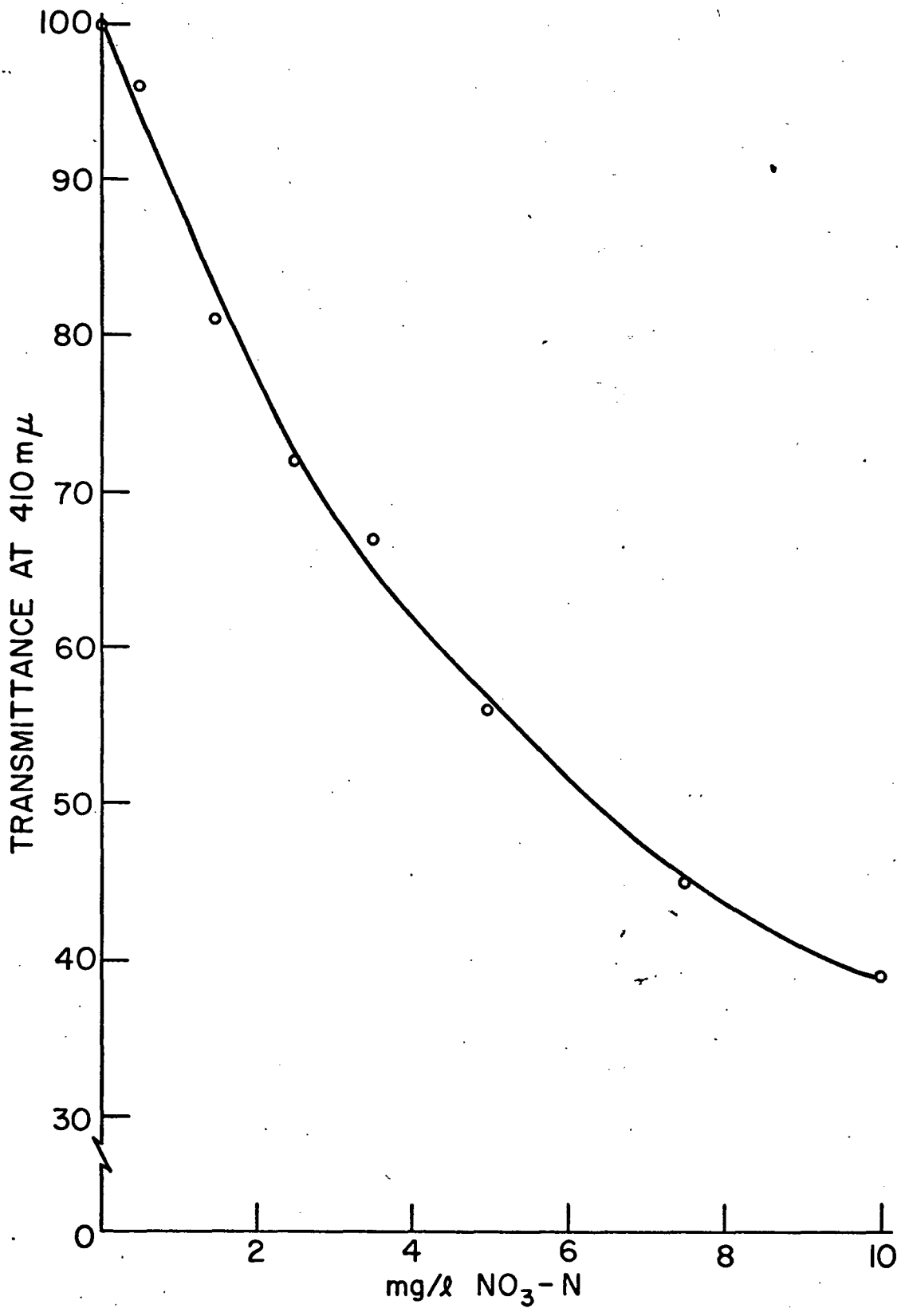


Fig. 5 Nitrate Calibration Curve

PILOT PLANT OPERATING RESULTS

As previously stated, the research was divided into five rather distinct phases of operation. Results of each phase will be presented followed by a discussion of the overall results.

The purpose of Phase I was to determine whether or not the pilot trickling filter results approximated those of the plant filters. Results listed in Table 1 indicate that the two were practically equivalent in operating results. Phase I lasted about two weeks with all laboratory analyses conducted on grab samples. The spectrophotometer was out of order for approximately a month beginning on July 27; as a result, no nitrogen analyses were conducted during that period.

TABLE I

Results of Phase I

Date	Effluent COD (mg/l)		Effluent NO ₃ ⁻ (mg/l)	
	Pilot	Plant	Pilot	Plant
7/15	168	136	1.4	1.9
7/21	73.5	29	1.1	1.2
7/23	77.3	73.4	0.5	0.5
7/27	61.3	69.5	-	-
7/28	65.5	69.5	-	-

The beginning of Phase II operation was marked by the addition of chemicals on July 29. A record of the daily amount of NaOH added to the chemical storage tank is listed in Appendix A. An analysis of the amount of chemicals needed in a full scale plant operation to raise

the pH of the sewage to 8.5 and a cost analysis of the same is given in Appendix B.

As can be seen in Appendix A, it took a month to consistently add the correct amount of NaOH to bring the pH above 8.0. Since August had the pH below 8.0, the spectrophotometer out of order, and no composite samples, no valid results were obtained for nitrogen forms. However, this portion of Phase II did show a consistently close performance of COD and BOD removal by the plant and pilot trickling filters. Table 2 indicates a portion of the results.

TABLE 2

Comparison of BOD and COD Removal
in the Pilot and Plant Filters

Date	Effluent COD (mg/l) Pilot	Effluent COD (mg/l) Plant	Effluent BOD (mg/l) Pilot	Effluent BOD (mg/l) Plant
7/30	49.1	57.3	31.2	34.8
8/4	28.0	36.0	30.0	30.0
8/6	80.0	76.0	36.0	34.8
8/13	59.0	59.0	25.8	13.2
8/17	72.0	64.0	-	-
8/20	61.0	61.0	-	-

The complete test results for the portion of Phase II which included nitrogen analyses are given in Appendix C. Composite sampling began August 30 and continued for the duration of the pilot plant operation. As seen in Table 3, the amount of nitrate in the pilot effluent was greater than that in the plant trickling filter effluent

most of the time. Table 3 also indicates the amount of COD reduction in both the pilot and the plant filters.

TABLE 3

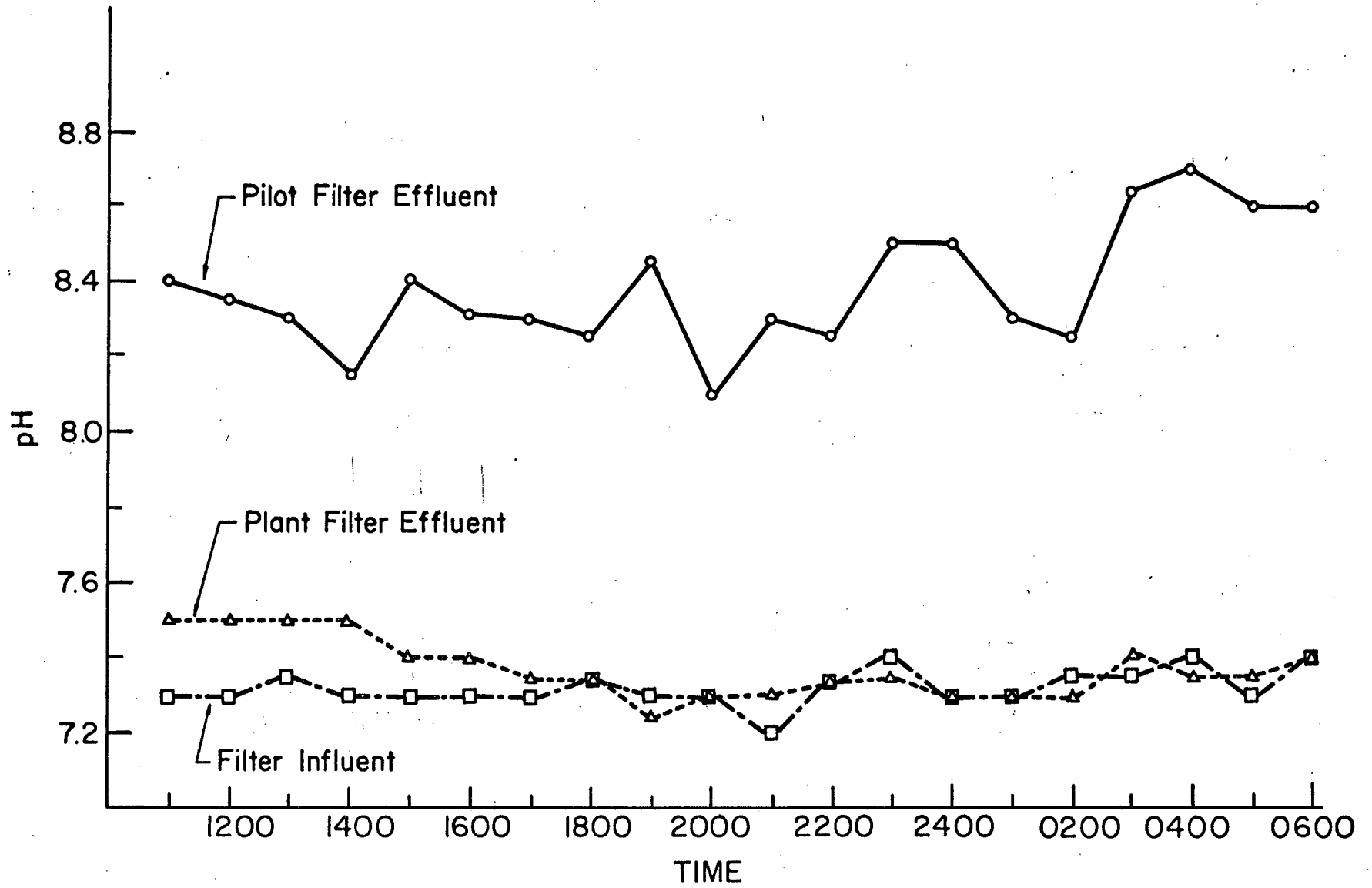
COD and NO_3^- Comparison in Phase II

Date	Influent		Effluent			
	COD mg/l	NO_3^-	Pilot COD mg/l	NO_3^-	Plant COD mg/l	NO_3^-
8/30	110	0.2	93	1.0	78	0.4
8/31	110	0.05	69.5	0.3	59	0.2
9/2	79.2	0.0	58.5	0.13	46	0.13
9/7	87.5	0.13	62.5	0.13	58.5	0.5
9/8	100	0.0	50	0.13	50	0.05
9/13	172	0.4	108	0.16	68	0.6
9/14	108	0.05	24	0.16	44	0.23

Phase III began September 21 when the flow rate was reduced to 203 gpd/sq ft. All of the data collected are presented in Appendix C. The reduced hydraulic loading, and as a result, the lower organic loading, caused the pilot effluent to have a greater concentration of both NO_2^- and NO_3^- in all 14 samples tested during the three week period. This indicates that by decreasing either the hydraulic rate or the organic loading onto the filter, the nitrification can be increased.

During this phase of the operation the diurnal variation of the pH was observed as shown in Fig. 6. There appears to be no appreciable diurnal variation although a slightly higher pH trend is discernible in the early morning hours from about 3:00 AM to 6:00 AM. This could be

Fig. 6 Diurnal Variation in pH



due to a slightly lower alkalinity in the sewage during this portion of the day.

On October 21, the flow scheme and flow rate were changed to start Phase IV operation. The hydraulic rate was increased while the organic loading was reduced by using the plant filter effluent as the pilot filter influent. The complete test results can be seen in Appendix C. On 8 of 9 days that tests were conducted, the nitrate level in the pilot effluent equaled or exceeded 1.0 mg/l. This is quite significant considering that during the 14 days that analyses were performed in Phase III only one analysis had a nitrate concentration greater than 0.75 mg/l in the pilot filter effluent. This indicates that the organic loading, not the hydraulic loading, is a more important variable for nitrification in trickling filters.

Phase V consisted of a three day set of tests to show that the nitrification in the pilot filter would drop with the cessation of chemical addition to raise the pH. Tests were discontinued after 3 days as a result of a pump failure and much colder weather. The pH of the pilot filter returned to the same value as the plant filters and the nitrate concentration dropped from Phase IV levels. The nitrate concentration did not decrease to the concentrations in the plant filters: this was anticipated since the plant filter effluent was the pilot filter influent and some additional nitrification is to be expected. Table 4 shows the actual test results.

TABLE 4

Results of Eliminating the Chemical Feed

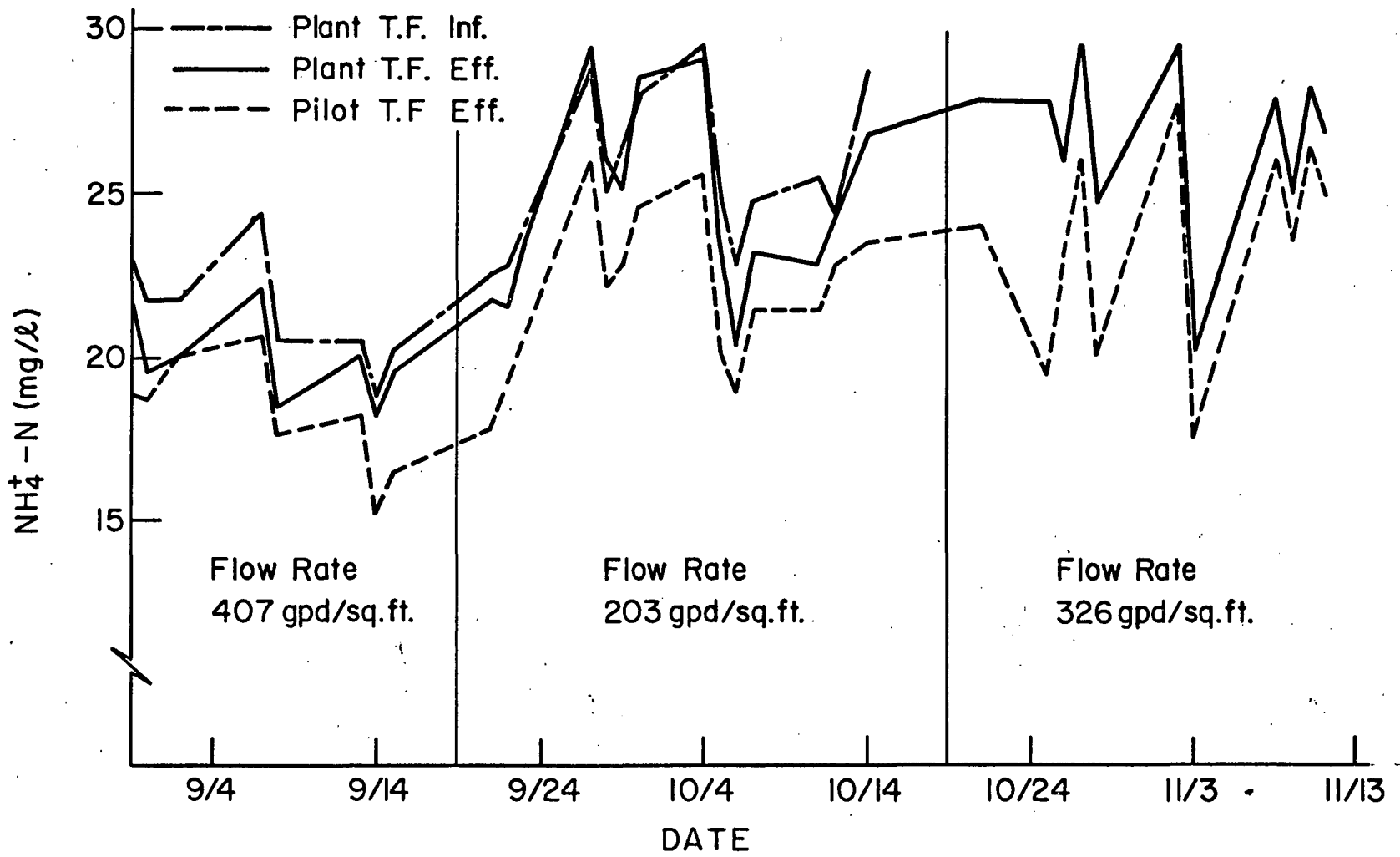
Date	Plant Filter			Effluent		
	pH	COD (mg/l)	NO ₃ ⁻	pH	COD (mg/l)	NO ₃ ⁻
11/9	7.4	81	0.13	7.8	81	0.6
11/10	7.5	112	0.4	7.6	117	0.9
11/11	7.5	-	0.68	7.5	-	1.09

The daily ammonia concentration in the influents and effluents is shown in Fig. 7. The last influent samples from the pilot filter and plant filter were taken October 14. On October 21, the plant filter effluent became the influent to the pilot filter. The effluent of the pilot filter consistently had lower ammonia concentrations than the effluent of the plant filter.

Daily nitrite levels are illustrated in Fig. 8 while Fig. 9 shows the variation in the nitrate nitrogen. The pilot filter effluent contained the highest nitrite level over 90 per cent of the time. This would indicate a greater Nitrosomonas activity in this unit due to the more optimum pH conditions.

Nitrate concentration in the pilot filter effluent was generally lower than in the plant filter effluent when the pilot filter operated at 407 gpd/sq ft. When the hydraulic loading was reduced to 203 gpd/sq ft, the average pilot filter effluent nitrate was 0.25 mg/l higher than the plant filter effluent. When the operation was changed to use the plant filter effluent as the pilot filter influent at a

Fig. 7 Daily Ammonia Concentrations



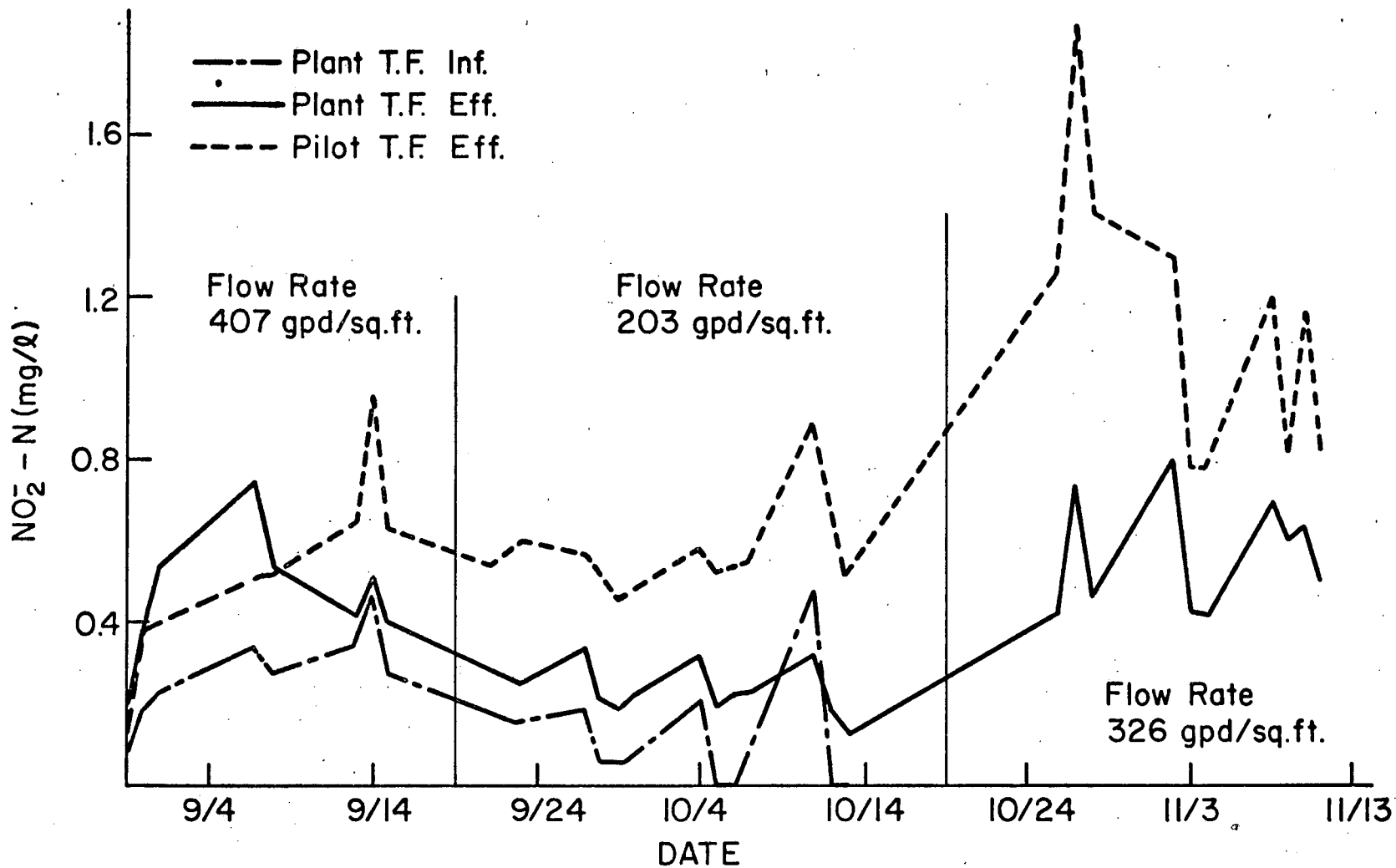
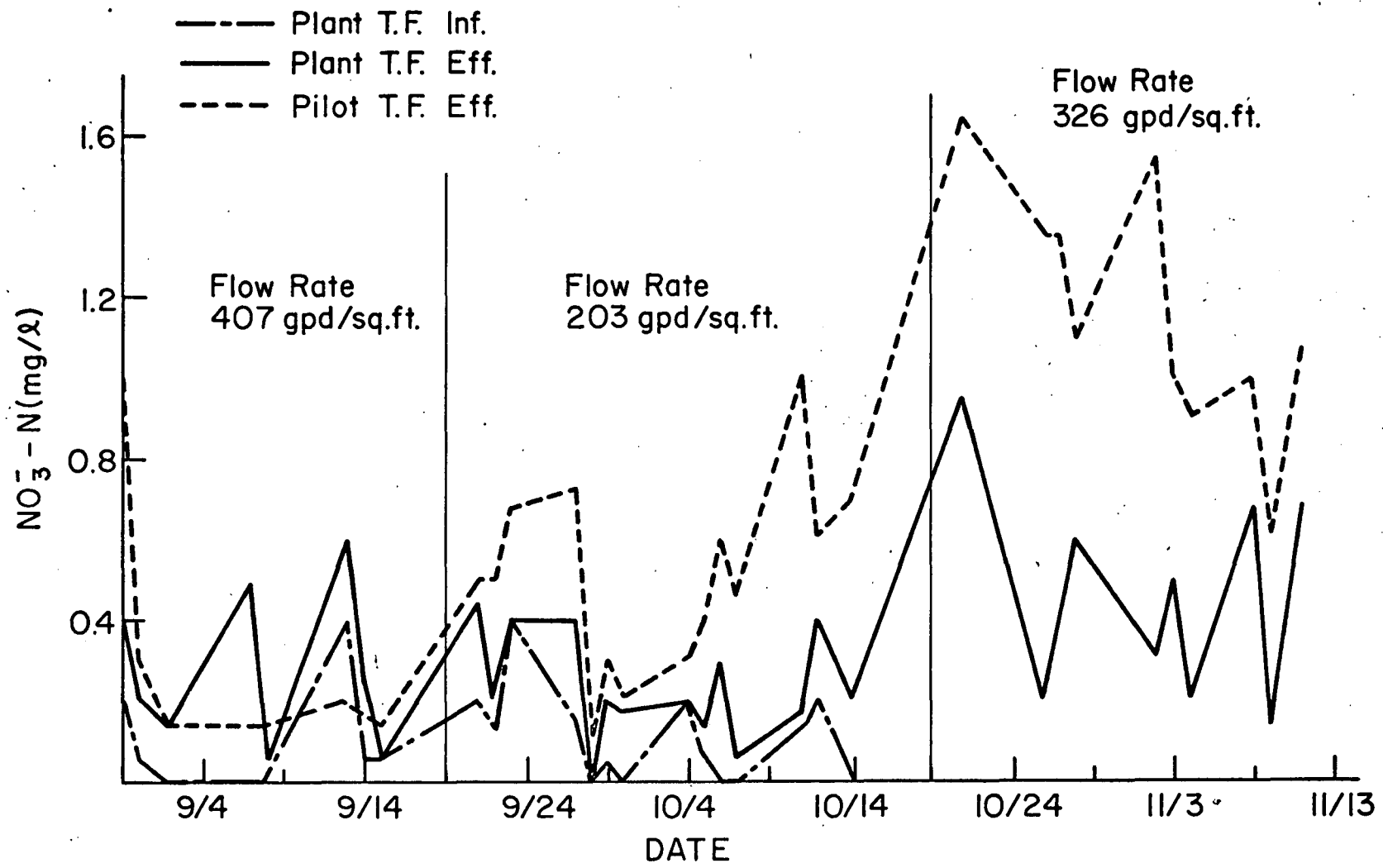


Fig. 8 Daily Nitrite Concentrations

Fig. 9 Daily Nitrate Concentrations



higher hydraulic loading rate of 326 gpd/sq ft, the nitrate concentration in the pilot filter effluent increased to about 0.75 mg/l greater than the plant effluent. When chemical addition was stopped on November 8, the nitrate concentration in the pilot filter effluent decreased. The results seem a clear indication that 1) the lower the organic loading the greater the nitrification and 2) the increased pH does improve the degree of nitrification.

Further support of the first statement is shown in Fig. 10. As the BOD loading decreased, the nitrate production in the pilot filter increased. This trend is also shown in Fig. 11 using the COD as a measure of the organic loading. It would appear from Fig. 12 that increased nitrification is at least partially dependent on the concentration of the organic loading onto the trickling filter.

During Phase IV operation the Pilot filter effluent nitrate concentration was about 1.25 mg/l NO_3^- -N. Over the entire research study nitrate in the plant trickling filter effluent was about 0.40 mg/l NO_3^- -N. Thus, Phase IV operation produced an increase of about 0.85 mg/l nitrate nitrogen. This concentration seems a very nominal increase, however, when considered in terms of pounds of oxygen per day for a 10 MGD plant, this nominal 0.85 mg/l increase in nitrate results in a decrease of 327 pounds per day of oxygen demand that would otherwise be exerted in the receiving stream.

In Fig. 13, the curve defined by the data of Fig. 11 has been extrapolated. This shows the probability of greatly increasing the nitrification in the trickling filters at Bethlehem by using a COD

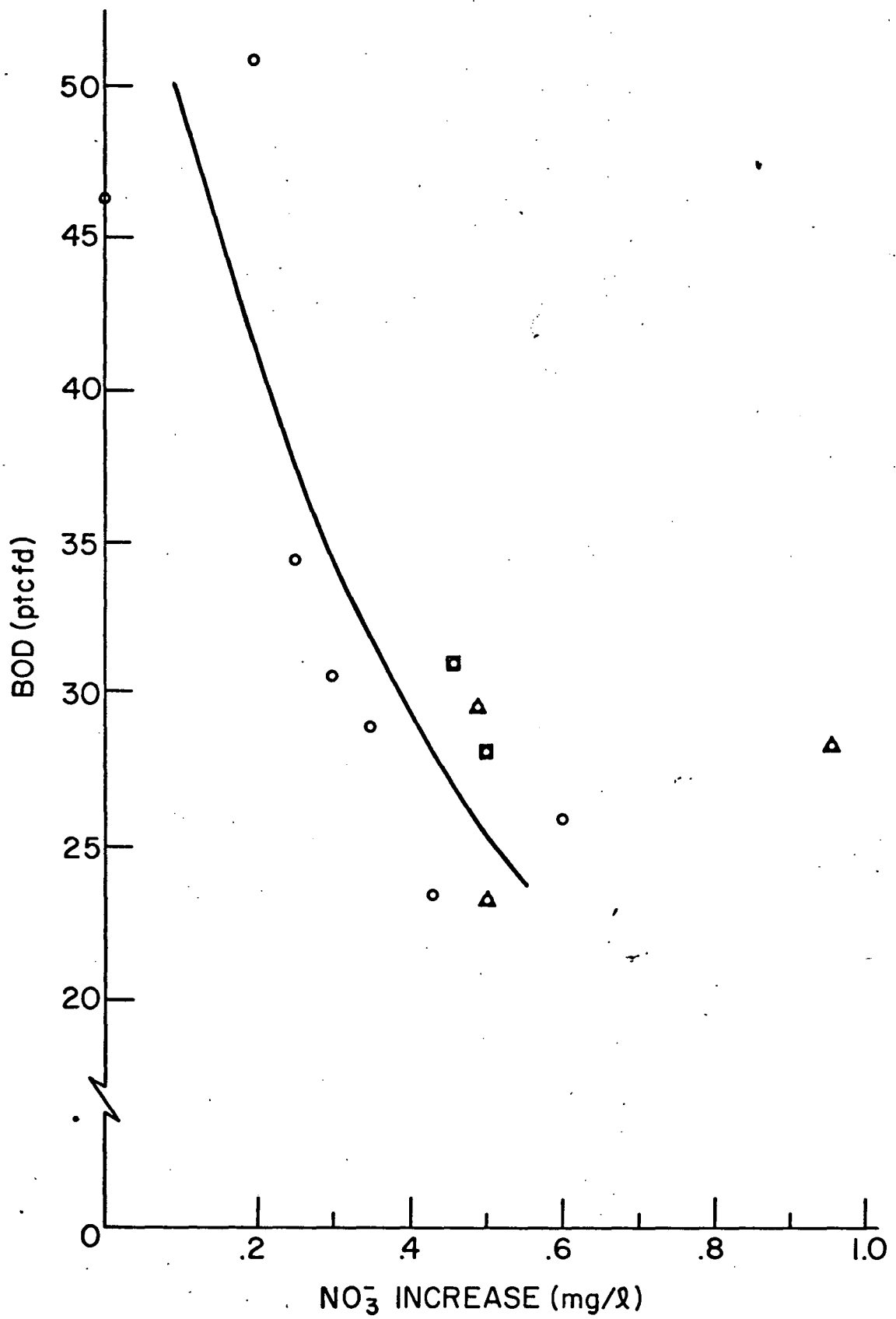


Fig. 10 BOD Loading vs. Nitrate Increase

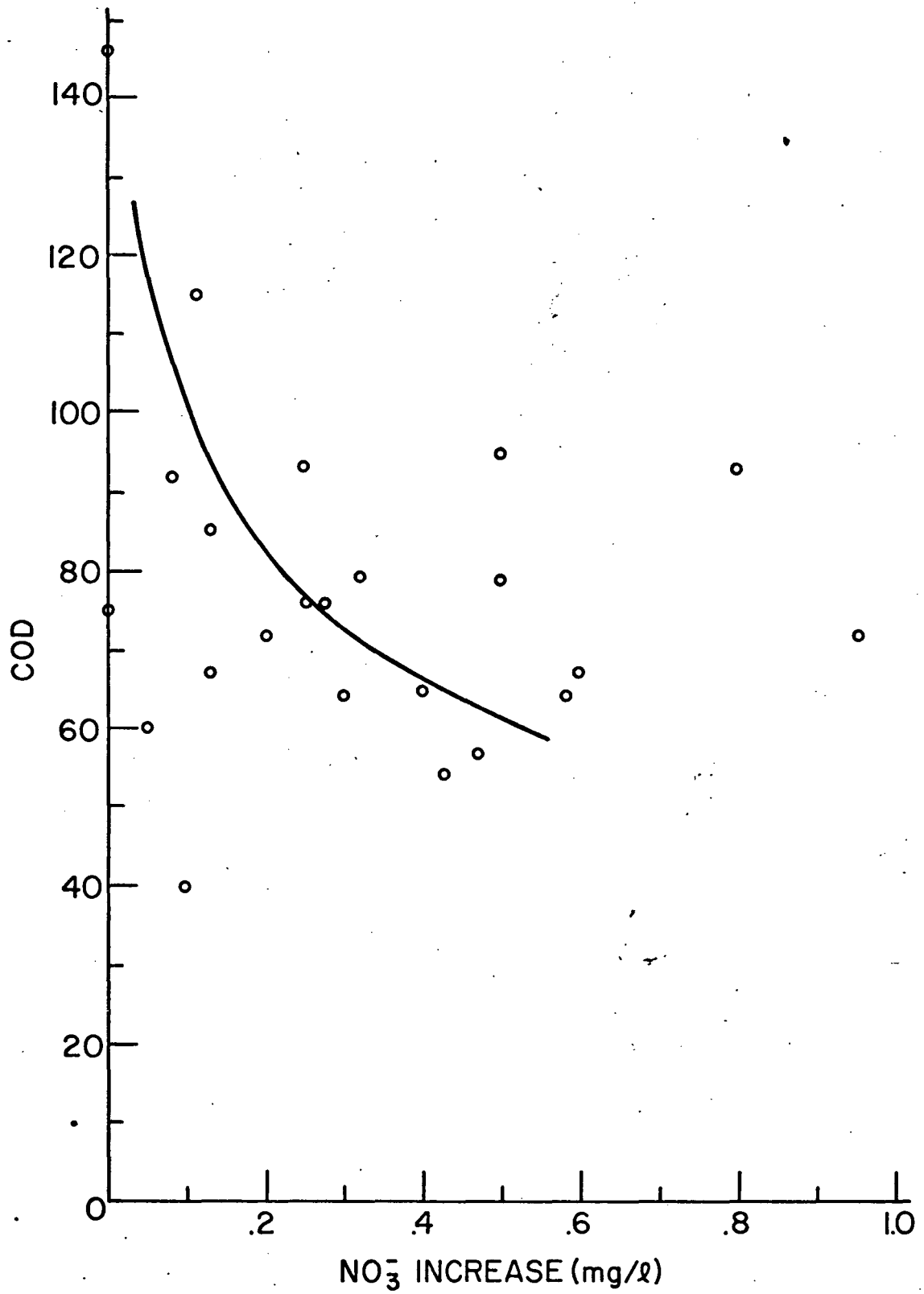


Fig. 11 COD Loading vs. Nitrate Increase

Fig. 12 COD Concentration vs. Nitrate Increase

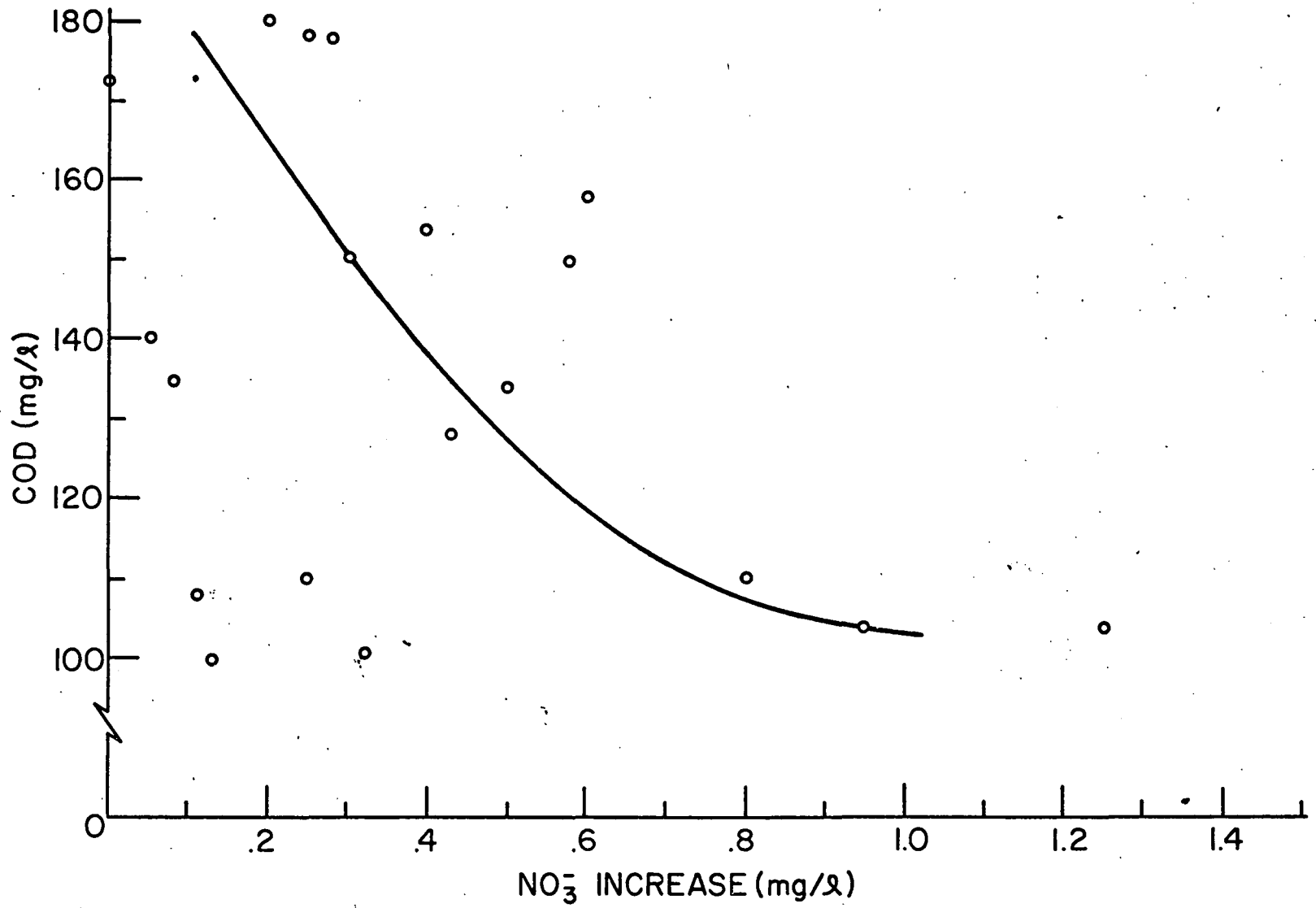
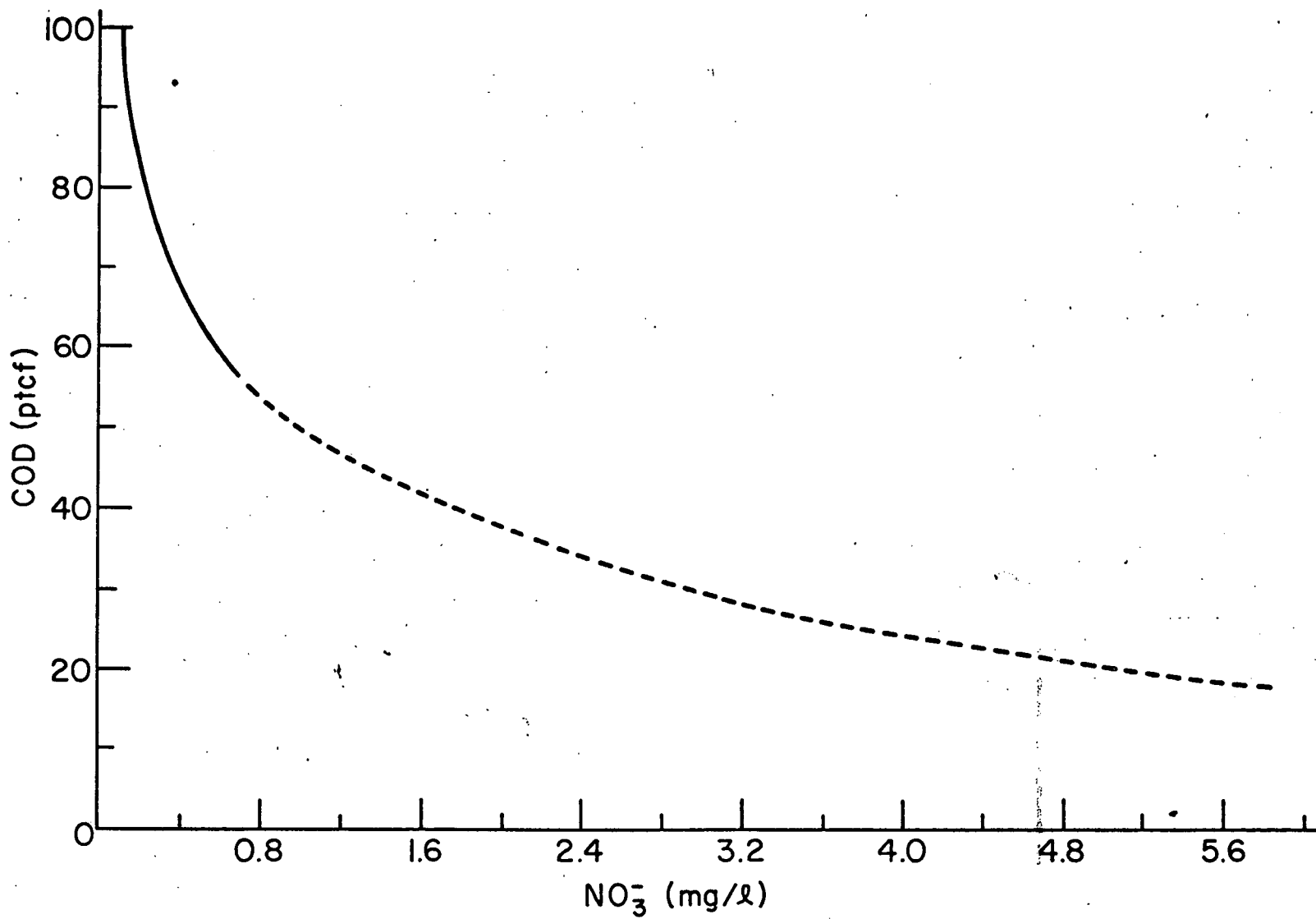


Fig. 13 Effect of COD Loading on Nitrification



loading of about 20 ptcfd. Time did not permit investigation of the effect this COD loading rate would have on nitrification and further studies need to be undertaken in this area.

Several difficulties were encountered in the pilot plant operation. Periodically, both the centrifugal supply pump and the chemical feed pump failed. Clogging of the flow control valve and of the intake in the chemical storage tank also caused interruptions. In addition the Bethlehem Sewage Treatment Plant was undergoing sand-blasting and painting of equipment and throughout the study both the primary and secondary clarifiers, as well as all four of the trickling filters were shut down for maintenance at various times. This resulted in variations in the sewage strength and quality.

The interference with perhaps the most deleterious effect on the test results was cyanide. On three different occasions cyanide concentrations exceeded 0.14 mg/l in the raw sewage. Cyanides are quite toxic to the nitrifying bacteria. The effects of the cyanide on the results of the study can not be thoroughly defined, but there probably was a deleterious effect on the nitrification in the pilot trickling filter.

SUMMARY AND CONCLUSIONS

From all the results of the study several conclusions can be drawn:

- a. Nitrification is increased in high rate trickling filters by raising the pH to the optimum level for bacterial growth.
- b. The organic loading onto the trickling filter has a definite effect on the nitrification, with increased nitrification as the organic loading decreases.
- c. The increase in nitrification due to pH adjustment is not sufficient to be of practical benefit at the organic loading rates experienced at the Bethlehem Sewage Treatment Plant.
- d. Periodic amounts of cyanide in substantial concentrations may have had a detrimental effect on the results of the study. The total effect is undefined but it is felt to be significant.

While it is acknowledged that this study has failed to show significant increase in nitrification by raising the pH, more work needs to be done, especially at reduced organic loadings on the pilot trickling filter. In addition, in view of the difficulty encountered, cyanide and other interfering substances should be monitored during the studies.

REFERENCES

1. American Public Health Association, STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 12th Ed., American Public Health Association, New York, 1965
2. Balakrishnan, S. and Eckenfelder, W. W., NITROGEN RELATIONSHIPS IN BIOLOGICAL TREATMENT PROCESSES - II. NITRIFICATION IN TRICKLING FILTERS, Water Research, Vol. 3, p. 167
3. Barth, E. F., Brenner, R. C. and Lewis, R. F., CHEMICAL-BIOLOGICAL CONTROL OF NITROGEN AND PHOSPHORUS IN WASTEWATER EFFLUENT, Journal WPCF, Vol. 40, No. 12, p. 2040 (1968)
4. Barth, E. F., Mulbarger, M., Ettinger, M. B. and Salotto, B. V., REMOVAL OF NITROGEN BY MUNICIPAL WASTEWATER TREATMENT PLANTS, Jour. WPCF, Vol. 38, No. 7, p. 1208
5. Department of the Environment, NITRIFICATION IN THE BOD TEST, Notes on Water Pollution, Water Pollution Research Laboratory, No. 52 (March 1971)
6. Doelle, H. W., BACTERIAL METABOLISM, Academic Press, New York, 1969
7. Eckenfelder, W. Wesley, Jr., WATER QUALITY ENGINEERING FOR PRACTICING ENGINEERS, Barnes and Noble, Inc., New York (1970)
8. Eliassen, Rolf and Tchobanoglous, George, REMOVAL OF NITROGEN AND PHOSPHORUS FROM WASTEWATER, Environmental Science and Technology, Vol. 3, p. 536 (1969)
9. Engle, M. S. and Alexander, M., GROWTH AND AUTOTROPHIC METABOLISM OF NITROSOMONAS EUOPAEA, Jour. Bact., Vol. 76, p. 217 (1958)
10. Gannon, John J. and Wezernak, Chester T., EVALUATION OF NITRIFICATION IN STREAMS, Jour. ASCE Sanitary Engineering Division, Vol. 94, No. SA5, p. 883 (October 1968)
11. Grundy, Richard D., STRATEGIES FOR CONTROL OF MAN-MADE EUTROPHICATION, Environmental Science and Technology, Vol. 5, No. 12, p. 1184 (December 1971)
12. Johnson, Walter K. and Schroepfer, George J., NITROGEN REMOVAL BY NITRIFICATION AND DENITRIFICATION, Jour. WPCF, Vol. 36, No. 8, pp. 1015-1036 (1964)
13. Lees, Howard, BIOCHEMISTRY OF AUTOTROPHIC BACTERIA, Butterworths Scientific Publications, London (1955)

14. Painter, H. A., A REVIEW OF LITERATURE ON INORGANIC NITROGEN METABOLISM IN MICROORGANISMS, Water Research, Vol. 4, p. 393
15. Sawyer, Clair N. and McCarty, Perry L., CHEMISTRY FOR SANITARY ENGINEERS, 2nd Ed., McGraw-Hill Book Company, New York (1967)
16. Schroeder, Edward D. and Moore, Stephen F., THE EFFECT OF NITROGEN FEED RATE ON DENITRIFICATION, Water Resources, Vol. 5, No. 7, p. 445 (July 1971)
17. Thimann, Kenneth V., THE LIFE OF BACTERIA, The Macmillan Company, New York (1965)
18. Wild, H. E., Sawyer, C. N. and McMahon, T. C., Jour. WPCF, Vol. 43, No. 9, pp. 1845-1854, FACTORS AFFECTING NITRIFICATION KINETICS

APPENDIX A

CHEMICAL FEED DATA

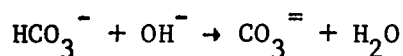
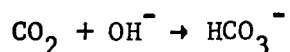
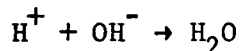
<u>Date</u>	<u>NaOH Added</u> (grams)	<u>Solution Level</u> (gallons)		<u>Resultant</u> <u>Effluent pH</u>
		<u>Before Water</u> <u>Added</u>	<u>After Water</u> <u>Added</u>	
PHASE II				
7/29	135	0	6	7.9
7/30	500	1.5	16	7.95
8/2	210	1.5	7	8.15
8/3	200	2	6	7.85
8/4	200	1	6.5	-
8/5	200	1.5	7	7.9
8/6	600	1.5	16	7.85
8/9	200	0.5	6	7.8
8/10	260	1	7	7.8
8/11	255	1.5	8	8.05
8/12	255	3	8	8.0
8/13	830	3	18	7.9
8/15	245	1	8	7.9
8/17	280	4	9	7.9
8/18	235	6	6	8.1
8/19	435	2.5	8	7.95
8/20	900	5	14	8.25
8/23	300	6	9	8.0
8/24	300	6	9	8.28
8/25	300	6	9	-
8/26	900	2	18	7.95
8/30	300	10	12	7.9
8/31	0	9	9	8.0
9/1	0	5	5	7.8
Chemical Pump Cleaned Out				
9/2	600	0	7	7.9
9/3	2000	2	13	8.6
9/4	600	8	12	8.25
9/6	700	1.5	6.5	8.5
9/7	700	2.5	7.5	8.3
9/8	700	3.5	9	8.2
9/9	800	5.5	10.5	8.3
9/10	1200	7	15.5	-
9/13	700	4.5	9.5	-
9/14	700	6.5	11.5	8.6
9/15	700	7.5	12.5	-
9/16	700	8.5	14	8.8
9/17	700	10	15	-

APPENDIX A (continued)

<u>Date</u>	<u>NaOH Added</u>	<u>Level Before</u>	<u>Level After</u>	<u>Resultant Effluent pH</u>
PHASE III				
9/20	250	4	9	8.2
9/21	400	5.5	10.5	8.4
9/22	400	7	12	8.7
9/23	400	9	14	8.85
9/24	200	10.5	15	8.1
9/27	350	5.5	10.5	8.55
9/28	300	7	10	8.4
9/29	350	7.5	12.5	-
9/30	400	9	14	8.45
10/1	350	10	14	8.6
10/4	450	5.5	12	8.25
10/5	350	9	13	8.4
10/7	500	7	11	8.15
10/8	400	9	13	8.4
10/11	350	7	11	-
Chemical Feed Pump Cleaned				
10/13	700	0	6.5	-
10/14	500	1.5	6.5	8.4
10/15	1200	2	13	8.7
PHASE IV				
10/22	300	7	11	8.5
10/25	300	2	6	-
10/26	200	6	9	-
10/27	300	5	9	8.4
10/28	450	5	11	-
11/1	450	1	7	-
11/2	450	3	9	-
End of Chemical Feed				

APPENDIX B

The amount of hydroxyl ion required to raise the pH of the sewage through the pilot filter was determined theoretically. This amount was compared to the observed NaOH usage. The theoretical equations used were as follows:



The first equation is for the increase in hydroxyl ions needed to neutralize the hydrogen ions when raising the pH. Taking the pH from 7.2 to 9.0 resulted in a net OH^- increase of about 0.10 meq/l. In the second equation the CO_2 is reduced by the hydroxyl ion to the bicarbonate ion. Using the nomographs in Standard Methods (1), and a total alkalinity of 100 mg/l as CaCO_3 , the CO_2 concentration was reduced 30 mg/l or 0.6 meq/l. Likewise, the HCO_3^- reduction was 11 mg/l or 0.22 meq/l.

The total amount of NaOH required came out to 0.92 meq/l which was 36.8 mg/l. For a flow of 1440 gpd the theoretical NaOH requirement was 200 grams/day. This compares quite favorably with the observed value of 247 grams/day, the difference was probably due to fluctuations in the pH and/or alkalinity.

Using lime, $\text{Ca}(\text{OH})_2$, at \$20/ton as a source of OH^- , the costs of raising the pH from 7.2 to 9.0 for a 10 MGD plant are:

THEORETICAL	\$28.25/DAY
OBSERVED	\$35.00/DAY

APPENDIX C

PILOT AND PLANT TRICKLING FILTER INFLUENT

<u>Date</u>	<u>Sample</u>	<u>pH</u>	<u>COD</u>	<u>BOD</u>	<u>NH₄⁺</u>	<u>NO₂⁻</u>	<u>NO₃⁻</u>
PHASE II							
8/11	G	7.2	99	-	16.5	0.07	0.1
8/13	G	7.25	91	63.0	17.0	0.09	0.1
8/16	G	7.2	83	-	20.0	0.07	0.2
8/17	G	7.2	96	-	16.0	0.09	0.0
Spectronic 20 Out of Order for Two Weeks							
8/30	G	7.0	60	-	16.5	0.07	0.0
8/30	C	7.0	110	-	23.0	0.08	0.2
8/31	C	7.1	110	-	21.7	0.19	0.05
9/2	C	7.05	79.2	-	21.7	0.23	0.0
9/7	C	7.15	87.5	-	24.3	0.34	0.13
9/8	C	7.25	100.0	-	20.3	0.27	0.0
9/13	C	-	172	-	20.3	0.35	0.4
9/14	C	7.3	108	-	18.7	0.48	0.05
PHASE III							
9/21	C	7.3	128	55	22.4	0.16	0.3
9/22	C	-	150	72	22.8	-	0.2
9/23	C	7.35	178	120	23.9	0.16	0.4
9/27	C	7.45	150	-	28.7	0.10	0.15
9/28	C	7.35	140	-	25.0	0.06	0.0
9/29	C	7.3	178	81	26.0	0.06	0.05
9/30	C	7.3	-	-	27.8	0.06	0.0
10/4	C	7.35	94	-	29.5	0.21	0.2
10/5	C	7.4	-	67.5	25.0	0.0	0.05
10/6	C	7.35	158	61.5	22.8	0.0	0.0
10/7	C	7.4	-	-	24.7	0.10	0.0
10/11	C	7.4	-	-	25.5	0.49	0.13
10/12	C	-	154	-	24.3	0.0	0.2
10/13	C	7.3	180	-	26.7	0.0	0.0

APPENDIX C (continued)

PLANT TRICKLING FILTER EFFLUENT

<u>Date</u>	<u>Sample</u>	<u>pH</u>	<u>COD</u>	<u>BOD</u>	<u>NH₄⁺</u>	<u>NO₂⁻</u>	<u>NO₃⁻</u>
PHASE II							
8/11	G	7.2	79.3	-	12.0	0.11	0.7
8/13	G	7.35	59	10.8	11.5	0.13	1.2
8/16	G	7.3	67	-	20.0	0.09	0.6
8/17	G	7.35	72	-	13.5	0.08	0.3
Spectronic 20 Out of Order for Two Weeks							
8/30	G	7.1	76	-	21.5	0.11	0.4
8/30	C	7.1	78	-	20.5	0.11	0.4
8/31	C	7.6	57	-	18.7	0.39	0.2
9/2	C	7.2	46	-	20.0	0.54	0.13
9/7	C	7.4	58.5	-	22.0	0.75	0.5
9/8	C	7.4	50	-	18.4	0.53	0.05
9/13	C	-	68	-	20.0	0.42	0.6
9/14	C	7.5	44	-	18.1	0.52	0.23
PHASE III							
9/21	C	7.5	88	33.0	21.7	0.34	0.65
9/22	C	-	103	48.0	21.4	-	0.13
9/23	C	7.5	83	52.8	23.5	0.25	0.4
9/27	C	7.5	95	-	29.5	0.27	0.4
9/28	C	7.4	96	-	26.0	0.21	0.0
9/29	C	7.4	111	49.2	25.0	0.19	0.2
9/30	C	7.5	-	-	28.7	0.23	0.17
10/4	C	7.5	53	-	29.1	0.32	0.2
10/5	C	7.45	-	45.7	23.5	0.19	0.13
10/6	C	7.5	134	46.3	20.3	0.23	0.3
10/7	C	7.5	-	-	23.2	0.23	0.05
10/11	C	7.6	-	-	22.8	0.32	0.17
10/12	C	-	114	-	24.3	0.19	0.4
10/13	C	7.4	120	-	26.7	0.13	0.0
PHASE IV							
10/21	C	7.45	-	-	27.8	0.32	0.4
10/25	C	-	85	-	27.8	0.51	0.55
10/26	C	7.5	80.7	-	26.0	0.42	0.2
10/27	C	-	104	39.4	29.5	0.74	0.4
10/28	C	-	-	41.4	24.7	0.46	0.6
11/2	C	-	104	-	29.5	0.80	0.3
11/3	C	-	134	32.5	20.0	0.42	0.5
11/4	C	-	-	-	25.0	0.42	0.2
11/8	C	7.6	111	-	27.8	0.7	0.68

APPENDIX C (continued)

PILOT TRICKLING FILTER EFFLUENT

<u>Date</u>	<u>Sample</u>	<u>pH</u>	<u>COD</u>	<u>BOD</u>	<u>NH₄⁺</u>	<u>NO₂⁻</u>	<u>NO₃⁻</u>
PHASE II							
8/11	G	7.9	55.5	-	11.5	0.09	0.5
8/13	G	8.0	59	25.8	16.5	0.14	1.0
8/16	G	7.9	55	-	18.0	0.13	0.6
8/17	G	7.9	64	-	10.0	0.13	0.4
Spectronic 20 Out of Order for Two Weeks							
8/30	G	7.95	28	-	11.5	0.33	1.5
8/30	C	7.8	93	-	18.7	0.2	1.0
8/31	C	7.9	69.5	-	19.4	0.37	0.3
9/2	C	7.7	58.5	-	20.0	0.41	0.13
9/7	C	8.6	62.5	-	20.6	0.51	0.13
9/8	C	8.2	50	-	17.5	0.51	0.13
9/13	C	-	108	-	15.2	0.95	0.16
9/14	C	8.8	24	-	15.2	0.95	0.16
PHASE III							
9/21	C	8.3	84	37.9	17.8	0.6	0.73
9/22	C	-	111	51.6	19.4	0.52	0.5
9/23	C	8.4	107	48	20.6	0.6	0.68
9/27	C	8.05	99	-	26.0	0.58	0.73
9/28	C	8.05	88	-	22.0	0.51	0.05
9/29	C	8.2	119	58.8	22.8	0.46	0.3
9/30	C	8.1	-	-	24.3	0.49	0.2
10/4	C	8.05	45	-	25.5	0.58	0.3
10/5	C	8.05	-	55.8	20.0	0.52	0.4
10/6	C	8.1	113	53.5	18.7	0.51	0.6
10/7	C	7.9	-	-	21.4	0.55	0.45
10/11	C	7.9	-	-	21.4	0.90	1.0
10/12	C	-	117	-	22.8	0.65	0.6
10/13	C	7.8	120	-	26.0	0.51	0.2
PHASE IV							
10/21	C	8.3	-	-	22.8	1.0	1.65
10/25	C	-	76.5	-	19.4	3.0	3.0
10/26	C	8.4	68	-	23.5	1.26	1.35
10/27	C	-	72.5	43	26.0	1.861	1.35
10/28	C	-	-	49.2	20.0	1.4	1.09
11/2	C	-	136	-	27.8	1.3	1.55
11/3	C	-	117	42	17.5	0.74	1.0
11/4	C	-	-	-	25.0	0.78	0.9
11/8	C	8.2	69.7	-	26.0	1.2	1.0

ABOUT THE AUTHOR

Dennis Eston Harman was born on May 28, 1948 in Norristown, Pennsylvania. He was the first of three children born to Quentin Eston Harman and Ruth E. Harman of Lansdale, Pennsylvania.

Mr. Harman grew up in the town of Lansdale, Pennsylvania, where he attended North Penn High School. He graduated from North Penn in 1966 in the top five per cent of his class. Mr. Harman spent his next four years at the Pennsylvania State University in State College, Pennsylvania, where he majored in Civil Engineering. On June 13, 1970, Mr. Harman received the degree of Bachelor of Science in Civil Engineering as well as a commission as a second lieutenant in the United States Army. He was named a Distinguished Military Graduate by the Army Reserve Officer Training Corps at Penn State. In September of 1970 he began graduate studies at Lehigh University in Bethlehem, Pennsylvania.

During his college years, he became a student member of the American Society of Civil Engineers. In addition he became a member of Chi Epsilon, the civil engineering national honorary fraternity.

Mr. Harman will enter active military duty on May 10, 1972 for six months of training. Upon completion of his training, he will become a member of the United States Army Reserves. He then plans to work in the field of sanitary engineering.