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THE EFFICIENCY OF TRICKLING FILTERS IN SEWAGE TREATMENT OPERATIONS

A THESIS

Presented to

the Faculty of the Graduate Division

Georgia Institute of Technology

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Sanitary Engineering

By

James Hunt Stovall

September 1956

THE EFFICIENCY OF TRICKLING FILTERS

IN SEWAGE TREATMENT OPERATIONS

APPROVED:

Date Approved by Chairman: 7 September 1956

ACKNOWLEDGMENTS

The writer wishes to express his grateful appreciation to Dr. R. S. Ingols, thesis advisor, for the unselfish gift of his time and advice.

Further gratitude is expressed to Professor Richard King and Professor Hugh A. Wyckoff for their assistance in serving as a reading committee; to Dr. R. H. Fetner and Mrs. Linnelle T. Hilley for their suggestions; to Mr. R. S. Leonard for providing transportation during the field sampling period; to Miss Gloria Perkins for her encouragement during this study; and to Mrs. Martha M. McCalla who typed this thesis.

The writer wishes to also express his appreciation to the many sewage treatment plant operators and personnel of the cities of Atlanta and Marietta, Georgia, for their willing cooperation during the period of field sampling.

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SUMMARY

A study of the trickling filters at five sewage treatment plants in the vicinity of Atlanta, Georgia, was undertaken. The technical literature contains much information on studies of trickling filters at sewage treatment plants operating in northern climates, and has in recent years reported results in temperate climates in the United States. There is a lack of information, however, for areas experiencing a climate such as Atlanta. It was felt that a study of several filters under different operating conditions would give an insight into low-rate trickling filter performance in this area.

Samples of the filter influent were collected in the dosing chamber, and filter effluent samples were taken from the effluent channel. The D.O. content and sewage temperature were recorded in the field immediately after taking each sample. Additional portions of each sample were stabilized and taken to the laboratory for further tests. The physical features of each filter were also recorded.

The 5-day 20°C B.O.D. of each sample was determined, and the decrease in B.O.D. of the sewage passing through the filters was computed to determine the removal efficiency. The loading rate of each filter, expressed in pounds of B.O.D. per acre-foot per day, was determined.

Each sample was further analyzed for nitrate content, and nitrate production increase through the filter was noted. The total organic nitrogen content was measured in both influent and effluent samples, and

the per cent nitrogen removed by the filter was recorded. However, this determination was dropped early in this study since its importance seemed slight.

The following conclusions were drawn:

1. This study has shown that each trickling filter had its own operating characteristics. When plotted on a graph, the performance results of a filter generally fell within a narrow band during daily operation. Results obtained from one filter should not be used without qualification to anticipate performance of a second filter.

2. Nitrification tended to increase as effluent D.O. increased; a high content of each was found in those filters where ventilation was adequate. For nitrification to occur in a filter, adequate ventilation must be provided.

3. Nitrification was low or completely blocked in filters where ventilation was restricted by continuous ponding, regardless of the momentary loading. Nitrification did not show an increase even at extremely low B.O.D. loadings.

4. Nitrification decreased as B.O.D. loading increased in filters where ventilation was adequate, when all filters were considered together. However, when individual filters were analyzed this tendency was not so pronounced.

5. Within the time limit of this study temperature variations were not significant.

6. From the analyzed data and comparison of filter stone size and effectiveness, it appears that stone not less than 2.5 inches in diameter should be specified in trickling filter design.

CHAPTER I

INTRODUCTION

General.--One of the most important concepts that a design engineer ever learns is the relationship of efficiency to cost. Economy on the installation cost of an engineered device may be the governing factor in many instances, but when the efficiency of a device can be increased, then a higher initial cost may be justified. A thorough understanding of the mechanisms involved in any item to be designed or improved is therefore an important asset to the engineer. This study is being made in order to gain a better understanding of trickling filter performance so that this knowledge may be applied to trickling filter design.

The Trickling Filter, or Biological Filter as it is sometimes called, is used in many domestic sewage and industrial waste treatment plants throughout the world as an efficient means of secondary or complete treatment of these wastes. Its importance has been recognized for many years by those concerned with waste treatment. Although there has been much research on trickling filters, some controversary still remains among the various engineers, biologists and chemists as to how the processes that occur within the filter effect its performance efficiency.

Description.--The modern trickling filter as we generally see it is a large circular concrete structure varying from 100 to 175 feet in diameter and having an average depth of seven feet, with a range of from 2.5 to 10 feet. The interior of the filter is filled with crushed stone or blast furnace slag ranging from 1.5 to 4.0 inches in size. The filter stone come within one foot of the top of the concrete walls and are supported on the bottom by a porous tile floor which rests on a sloping concrete floor.

Settled sewage is applied to the filter stone by a revolving distributor. The distributor consists of two or more perforated pipes with each arm extending half the diameter of the bed and revolving approximately six to nine inches above the stone. Generally the distributor is driven by jet action of the sewage as it is emitted through orifices 3/8 to 1/2 inch in diameter. Where sufficient hydraulic head is not available the distributor may be mechanically operated.

As the applied sewage trickles over the stone, microscopic and macroscopic flora and fauna consume the dissolved, colloidal and suspended "food" material of the sewage or waste and accomplish their purpose in reducing the food concentration of the liquor going to the river. The transformations occurring within the filter are numerous and consist of complicated inter-related actions and reactions of a physical, chemical and biological nature. The various organisms constituting a filter produce a mass of slime attached to the stone surface; this gelatinous mass being called "zoogleal slime." The condition or appearance of this aerobic slime growth on the stone of a trickling filter is one of the first visible indices of the operating efficiency of that filter.

Once the sewage has passed through the interstices of the filter bed, it passes through the porous filter tile and into a collection channel. This channel serves the dual purpose of removing the effluent liquid from the filter while at the same time permitting the free flow of air into and out of the filter bottom.

Franks (1)* defines a trickling filter thusly:

> A trickling filter, which is not a filter in the usual sense may be defined as a bed of filtering media of various kinds, sizes, and shapes; and of varying depths and areas; over which settled sewage is distributed by diverse means and at different rates; and where the sewage, upon trickling through, is so altered in character by complex biotic, chemical, and physical means as to render it sufficiently stable to be innocuous to health and prevent nuisance downstream. As will be noted, this definition is very broad, but any attempt to make it more specific places upon it limitations which are subject to numerous differences of opinion.

<u>History</u>.--The history of sewage treatment has been adequately reported by Emmerson (2), Imhoff (3) and others. Development of the trickling filter has been described by Emmerson (2), Jones (4) and Imhoff (3).

Jones (4) states that the trickling filter was originally developed to reduce the area required by intermittent sand filters. Col. George E. Waring, Jr., and the Massachusetts State Department of Health did early important development work in 1891 and 1892.

Bloodgood (5) states that the first experimental gravel filters in the United States were built at the Lawrence Experiment Station of the Massachusetts State Board of Health in 1889. He further states that a small experimental filter was built at Madison, Wisconsin, in 1901, and that the first municipal installation was made in Atlanta, Georgia, in 1903. Jones (4) indicates that the first municipal trickling filter plant in this country to go into operation was at Reading, Pennsylvania, in 1908.

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*The reference numbers enclosed in parentheses refer to the literature cited in the Bibliography.

<u>The Trickling Filter in Sewage Treatment</u>.--As has been previously stated, the trickling filter does its work largely by biological straining of the liquid sewage. Therefore the oxidation of this food material lessens its oxygen demand when the treated sewage is discharged into a receiving body of water. The oxygen demand is normally spoken of as the Biochemical Oxygen Demand (B.O.D.). A good indication of filter performance is found by determining the decrease in B.O.D. of sewage passing through the filter. Samples are taken of the influent sewage being applied to the filter and of the effluent sewage leaving the filter. Analyses of these samples indicate the B.O.D. removed by the filter.

The rate at which sewage is applied to a filter determines its type. Filters to which sewage is applied at a rate of from one to four million gallons per day (M.G.D.) per acre (M.G.A.D.), and from 200 to 600 pounds of B.O.D. per acre-foot per day are called "standard or low-rate" trickling filters. Similarly, a loading rate of 16 to 20 M.G.A.D. and a B.O.D. loading in excess of 1,000 pounds per acre-foot per day classifies a "high-rate" trickling filter. Normally recirculation of part or all of the effluent from the high-rate filter is specified.

The trickling filter receives the sewage after primary treatment, which usually consists of removing large coarse material, allowing sand and grit to settle, and removing suspended sewage solids. The liquid sewage supernatant then flows into a dosing chamber and is periodically applied to the filter. Dosing cycles vary from continuous dosing during high flow to 15 or 20 minute intervals during low flows at night. A secondary clarifier may or may not follow a trickling filter, although it generally does.

Where secondary treatment of sewage is provided, trickling filters are found in over one half of the domestic sewage treatment plants in the United States. Of approximately 300 sewage treatment plants built at various army camps in this country during World War II, over 50 per cent of the secondary treatment units were trickling filters (6).

Factors Effecting Filter Performance.--Early studies at the Lawrence Experiment Station in Massachusetts were instrumental in revealing the operating characteristics of trickling filters. Since then much research has been devoted toward a better understanding of all phases of work accomplished within filters.

Factors effecting trickling filter performance are: (a) presence of adequate types and quantities of bacterial growth upon filter stone, (b) quantity of waste applied to filter, (c) strength of waste, (d) waste temperature, (e) size and depth of stone, (f) ventilation in filter bed, (g) underdrainage design, (h) method of applying waste to filter, (i) time elapsed between dosing cycles, (j) primary treatment of waste, (k) pH, (l) age of sewage, and (m) operation and care given filters. These factors are inter-related and can not therefore be completely isolated individually to discover the function of each. This must be borne in mind in the present study of trickling filters.

When a trickling filter is first put into operation and sewage is applied to the filter, a thin slimy grey layer is soon noticed. Holtje (7) reports that microscopic examination of the film reveals that this film is made up of countless bacteria embedded in a clear gelantinous matrix. He further states that the zoogleal bacteria are aided by various other bacteria, each type having a specific function and occurring at different levels in the bed where specific environmental conditions suit them.

As sewage continues to come into contact with the bacterial growth on the filter stone, more organic material is deposited and the layer increases in thickness. As the layer becomes too thick, bacteria closest to the stone surface begin to die and a period of "sloughing" or "filter unloading" occurs. Unloading is heaviest as spring approaches, and may again become heavy in the fall. The zoogeal slime layer is thickest in winter and thinnest during the summer. However, more B.O.D. is removed in the summer when the slime layer is thinnest and temperature is highest. Studies by Heukelekian (8) have borne this out.

Heukelekian (8) further states that "the quantity of film in a filter bed is determined by the net effect of two opposing factors, (a) accumulation and (b) unloading and oxidation."

As might be expected, the build-up of the zoogleal slime in a new filter takes time. In the summer an active growth is established in a short period of time, whereas filters put into operation during cold winter months require more time to develop efficient operation. No sharp break occurs in the increased B.O.D. removal as a filter matures, but as loading continues, a larger per cent of the applied B.O.D. is removed. Breaking-in periods of from three months to one week were required in New Jersey and Florida as reported by Rudolfs (9) and Grantham (10), respectively. Grantham (10) further reported that the breaking-in period required the same amount of time whether a new filter was placed in operation or an old filter was reactivated after a period of idleness.

The vertical distribution of film quantity is more even in the summer, while during the winter the growth is heaviest near the top of the filter, according to Heukelekian (8). A thinner layer of zoogleal slime is found as respiration rates are increased. This allows a more intimate contact of food and slime and helps to explain why trickling filters operate better in the summer.

The effect of temperature upon B.O.D. removal has been studied by many. In general one might expect an increase in B.O.D. removal during the summer due to the accelerated rate of biochemical activity. Rudolfs (9) agrees that temperature increase has an important effect on effluent B.O.D. decrease. Sorrels (11) was unable to notice any temperature effect in his studies on experimental filters.

Nitrogen present in raw sewage is generally contributed by humans in the form of urea and complex nitrogen compounds according to Eckenfelder (12). Hydrolysis of the urea and organic nitrogen compounds yields ammonia as sewage flows to the treatment plant.

The removal of all types of nitrogenous compounds from sewage for the purpose of reducing the fertilizing capacity of the effluent is a more difficult matter than the removal of B.O.D. A committee of the American Society of Civil Engineers (13) reports that no matter how completely sewage may be treated and the nitrogenous compounds oxidized, there is no known feasible method of reducing the nitrogen by more than 50 to 55 per cent.

Nitrification occurs in a trickling filter when ammonia is oxidized into nitrites by a form of nitrifying bacteria. Nitrites are further oxidized by other bacteria into nitrates. Holtje (7) has published information to present a clear understanding of nitrifying organisms.

Nitrification occurring as sewage passes over trickling filter media gave the early sanitary engineers and chemists a means with which to measure filter effectiveness. The B.O.D. determination is used more widely today, but nitrification still gives a valuable insight into trickling filter performance. Nitrate production in a filter is important in that nitrates are an additional oxygen asset to a receiving stream.

It is presumed that since nitrification is at least a two-step process, occurrence must be in vertical steps within the filter. Formerly it was believed that nitrification took place only after oxidation of carbonaceous material in the top of filter beds had been accomplished. However, it now appears that nitrification tends to occur in greater quantities in the upper two feet of a filter. For this to occur sufficient oxygen must be present and if an adequate oxygen supply is available, carbonaceous oxidation and nitrification can then occur simultaneously. Heukelekian (14) demonstrated this in his laboratory studies.

Limiting the oxygen supply to a filter either by ponding or by greatly overloading the filter and depositing an excessive amount of organic matter, will restrict or prevent nitrification. Therefore carbonaceous oxidation limits nitrification in the top one to two feet by using much of the available oxygen. Studies by Heukelekian (15), Ingols (16), and Imhoff (17) have shown the relationship between oxygen supply, nitrification and carbonaceous oxidation.

As filter loading increases, nitrification decreases and the point of nitrate production moves downward in the filter. When the loading rate approaches 1,000 pounds B.O.D. per acre-foot per day, nitrification becomes less and may eventually be blocked. Studies by Rudolfs (9), Grantham (18), and Heukelekian (15) have shown this to be true.

The effect of dosing time on filters was studied by Levine (19). His studies show that as the frequency of dosing is increased, nitrification is increased. When dosing rates were increased from 20 to 5 minutes, no change was noticed; but as they were increased to 2.5 minutes, an increase in nitrification was apparent.

In summarizing nitrification, Heukelekian (14) states that "the presence of nitrates in an effluent constitutes proof that: (a) the nitrifying organisms are established, (b) the system is aerobic, (c) contact time is adequate, and (d) ammonia nitrogen is present in adequate quantities."

Filter loading rates, both hydraulic and organic, have long been recognized as important considerations in the design of efficiently operating trickling filters. This one phase of study has perhaps received more attention in trying to understand trickling filter operations than any other criteria.

The efficiency of a trickling filter may be defined as the removal of B.O.D. per unit of area or volume of the filter. One unfamiliar with trickling filters would normally expect a decrease in efficiency as the loading is increased. On the contrary at low B.O.D. loading rates efficiency is low but increases as the loading increases. The effluent B.O.D. may be higher as B.O.D. loading increases, but per cent removal will increase. However, as the loading greatly exceeds a given design condition, filter effectiveness will tend to decrease to some extent.

Studies of pilot plant filters by Rudolfs (9) and Sorrels (11), studies of normal operation at the Fort Worth sewage treatment plant by Mahlie (20), and studies by Grantham (21) on the University of Florida filters all substantiate the fact that filters operate more effectively at increased loading rates.

In 1937 loading rates of 250 pounds B.O.D. per acre-foot per day were recommended by Hall (22), whereas present day practice allows loading rates of from 400 to 600 pounds B.O.D. for low-rate filters.

Grantham (21) indicates from his Florida studies that loadings up to 3700 pounds B.O.D. per acre-foot per day give no decrease in per cent B.O.D. removal, although nitrification does not occur at this loading rate. The high Florida temperatures obviously aid filter performance.

The optimum depth for a trickling filter has long been a controversial subject, while all concerned agree that B.O.D. removal is a function of depth. Trickling filters in the northern part of the United States are usually six to eight feet deep while a four foot depth might be adequate in Florida according to Grantham (18).

It has been previously mentioned that the levels of oxidation and reduction move upward in the summer and downward in the winter. It is then possible for a filter adequate for summer operation to be too shallow for winter operation. Rudolfs (23) also points out that filter depth adequate for one locale might be totally inadequate for another.

Velz (24) has presented a mathematical approach for filter depth design. He states: "The rate of extraction of organic matter per interval of depth of a biological filter bed is proportional to the remaining concentration of organic matter, measured in terms of its removability."

It must be realized that not all B.O.D. is removable, regardless of the number of times the waste passes through a filter. Studies by Sorrels (11) and Velz (24) have indicated that the removal of soluble and insoluble B.O.D. is a function of loading and filter depth. Such studies led to the findings of Velz (24) as quoted in the preceeding paragraph.

The proper selection of stone size for a trickling filter might well determine the future possibilities of filter ponding. Small stone give a large surface area available for zoogleal growth while voids volume is small. With an increase in stone size the volume of the voids increases and surface area, or film area, decreases. It has been shown in full-scale plant operation that filters with stone size less than two inches in diameter have a greater tendency to clog than filters with stone size of 2.5 to 3.5 inches. This tendency will be studied for filters in the Atlanta area.

Ventilation and air supply have been discussed previously in connection with nitrification and B.O.D. loading rates. Since the trickling filter is an aerobic treatment device and the zoogleal organisms require large quantities of oxygen, this item can not be overlooked in its importance to filter efficiency. This factor in tricking filter design will be studied in this thesis.

Laboratory studies by Levine (19) showed that ponding soon occurred when the air supply to the bottom filter vents was stopped, nitrification decreased and effluent B.O.D. was higher.

Piret's (25) laboratory studies on filters showed that air flows downward through the filters in winter and upward during summer.

Underdrainage systems must be designed to carry away the imposed hydraulic loads and to permit air to circulate through the filter bottom. The designer establishes these characteristics and once the filter is constructed the plant operator has no means of controlling the underdrainage system.

The frequency of dosing cycles has been previously discussed. The importance of the method of applying sewage to the filters can not be overlooked. It has been found that the application of sewage in spray form, rather than in liquid jets, will give increased operating efficiency. Studies by Levine (19), Mahlie (20) and Lumb (26) substantiate this fact.

Filter "sloughing" or unloading, as has been mentioned earlier, tends to occur when film mass becomes too heavy upon the stone. This unloading has also been attributed to the burrowing action of psychoda fly larvae when they become numerous. Wide temperature variations and high hydraulic loading rates tend to produce sloughing, and shock loads of toxic wastes remove zoogleal slime growth in similar fashion.

Wastes with pH varying from six to eight will not seriously effect filter performance, nor in general cause sloughing, according to Heukelekian (27).

Rudolfs (28) has indicated that nitrification is best shortly after sloughing and decreases slightly as film thickness increases. This is due in part to decrease in the volume of voids and the corresponding decrease in available oxygen, and possibly by the reduction of the nitrate to nitrogen gas because of diffusion of the thick anaerobic film.

In addition to the design characteristics of the plant and the many uncontrollable variables, the feature of plant operation is important in describing sewage treatment plant effectiveness. Sylvester (29) made a survey in Washington State in 1953 to determine the factors that contributed to either good or poor operation of sewage treatment plants in that state. He found that good operation was usually found where plant operation personnel had been hired because of their past experience. In nearly every case where the treatment plant was not operating satisfactorily he found that the operators had been arbitrarily assigned the job of plant operation, regardless of their previous experience.

It is readily seen from this discussion of trickling filter operation, that due to the large number of variables existing, one must cautiously qualify his interpretations when reporting trickling filter performance. Although many trickling filters have similar design characteristics, no two filters are exactly alike, and any attempted comparison of results must be made with this thought in mind.

CHAPTER II

SCOPE OF STUDY AND DESCRIPTION OF PLANTS

Purpose.--Practically all of the early studies of trickling filters occurred in the northern part of the United States, in England or in Germany. About 1930, work was begun in Texas, and in the late 1930's the University of Florida instituted a research program in sewage treatment. Since temperature is an important feature in sewage treatment, studies from the latter two agencies have given us a better idea of what we can expect in Georgia.

After considering the above it was decided to make a study of trickling filters in the vicinity of Atlanta, Georgia. The city of Atlanta had not had a sewage chemist for the past two and one-half years so no recent records were available. However, a study of two Atlanta plants was made in 1950 by Bakkum and Nippler (30).

Approach.--Within the vicinity of Atlanta are between 15 and 20 sewage treatment plants employing trickling filters as the secondary treatment device. All of the trickling filters are of the standard rate type, although due to overloaded conditions some plants are loaded at rates approaching those of high-rate filters.

While this study was in its preliminary discussion stage, it was felt that a complete study of filters at two plants would give the desired insight into trickling filter operation in this area. The filters were to be studied under all loading conditions of day and night as well as on different days of the week.

Accordingly, study was begun on one plant operating at maximum hydraulic design capacity and yet producing a high quality effluent. A search was then made to locate a second plant where filters produced a high quality effluent. Since most plants in this area are operating under overloaded conditions, difficulty in finding a second plant with performance similar to the first was soon obvious. It was at this time that the concept of this thesis was changed.

If within an area only 30 miles square there existed such a varied range of trickling filter performance, then perhaps the most informative study would be one which would include analyses of several plants. The number of plants to be studied was therefore increased from two to five. It was realized, however, that the number of samples taken per plant would necessarily have to be decreased. The sampling commenced on May 10, 1956, and ended on July 26, 1956.

Description of Plants.--Table 1 is a description of the five plants studied. All plants have bar racks, equipment for grease removal, continuous sludge removal equipment for both primary and secondary clarifiers, digesters and open sludge drying beds. With the exception of the Egan Park Plant all plants have grit chambers. In addition to bar racks, comminutors are also used at South River.

Table 2 is a detailed description of the low-rate trickling filters.

Types of Wastes Treated.--At each plant the predominate type of waste is from domestic sources. However, each plant treats waste of an industrial origin as follows:

EGAN PARK: Waste from an automobile assembly plant
Waste from the Atlanta Municipal Airport

SOUTH RIVER: Waste from a hosiery mill (including dye)
Waste from a chicken packing plant
Other industrial wastes

Table 1. Description of Plants

Plant	Date Built	Design Capacity in m.g.d.	Daily Flow in m.g.d. min.	Daily Flow in m.g.d. max.	Clarifiers Primary	Clarifiers Secondary	Filters
Atlanta							
Egan Park	1945	2.0	0.5	2.2	2	2	2
South River	1936	12.0	4.5	16.0	2	2	4
Marietta							
East Side	1949	1.0	0.1	1.8	2	2	2
South Side	1945	1.0	0.2	1.3	2	2	2
West Side	1956	1.0	0.1	0.6	2	2	2

Table 2. Trickling Filter Data

Plant	Dosing Chambers	Dosing Cycle in minutes	Depth in feet	Diameter in feet	Stone Size in inches	Volume per Filter acre-feet
Egan Park	2	5-10	6.25	136	2.5-3.5	2.08
South River	4	Continuous	6.25	173	1.5-2.5	3.38
East Side	2	5-10	6.0	115	2.0-3.0	1.428
South Side	2	10-14	6.0	115	2.5-3.5	1.428
West Side	2	10-20	7.0	115	2.5-3.5	1.665

EAST SIDE: Waste from a hosiery mill (including dye)
(This plant has a long outfall sewer line)

SOUTH SIDE: Waste from a knitting mill (some dye at times)

WEST SIDE: Waste from a chicken packing plant
Waste from a hosiery mill (no dye)

Studies to be Made.--The Biochemical Oxygen Deamand (B.O.D.) determination in sewage treatment is well known. B.O.D. removal through the filter gives the best single indication of trickling filter performance.

Nitrite and nitrate production in trickling filters was one of the earliest yardsticks used in determining trickling filter efficiency. More laboratory work is required in its determination than in the B.O.D. test, but its importance can not be overlooked in a study of filter performance.

Reduction of nitrogen quantities passing through a filter gives additional information concerning the nature of trickling filters. The total nitrogen test was run on early samples but was later dropped since its value in this study seemed slight.

CHAPTER III

SAMPLING PROCEDURE AND LABORATORY ANALYSES

Sampling Procedure

Methods of Sampling.--Many chances for error occur even under controlled sampling conditions. Providing continuous sampling equipment or stationing a man at one point to take continuous samples can eliminate such variables as the change in volume of flow and character of the waste. This was not possible in the study under discussion, so the samples taken were "grab samples."

Since this study was limited to the trickling filter, sampling was confined to this area of the sewage treatment plant. Samples were taken in the dosing chamber preceeding the filter and again as effluent left the filter. As each pair of samples was taken, the following information was noted: sample number, date, time, flow, temperature of sewage, Dissolved Oxygen (D.O.) in the sewage, weather, recent weather conditions, number of filters in operation, last time the filters were flooded, general appearance of sewage and appearance of zoogleal growth on the filter stone.

Sampling Apparatus.--It was desirable to collect the sewage samples without entrance of additional atmospheric oxygen. A standard sampling can as described in Standard Methods (31) was used. With this can two D.O. samples can be collected at once. The can is so designed that as it is submerged in sewage, the bottles fill and overflow with a volume equivalent to three times the volume of the D.O. bottle. In this manner a representative sample of sewage is collected with entrance of a minimum amount of oxygen.

The sampling can was used whenever possible, but on some occasions when dosing chambers were continually discharging, bottles had to be filled individually by dipping them into the sewage.

Disposition of Samples.--It was desired to know the condition of the sample at the time it was taken. The D.O. determination was immediately made on collected samples, but laboratory facilities were not available at the plants for other tests to be made. Samples to be used in other tests were therefore stabilized at the time taken in order to secure accurate results.

The addition of 20 ml/l concentrated hydroxide to the nitrification samples, and 20 ml/l concentrated acid to the samples for total nitrogen determination stopped bacterial action immediately. Samples for B.O.D. determination were tightly stoppered and brought to the laboratory for further analysis.

Laboratory Analyses

Dissolved Oxygen Test.--The Alsterberg (Azide) Modification of the Winkler Method as described in Standard Methods (31) was used to determine D.O. in the samples. This method is used for samples containing more than 0.1 mg/l nitrite nitrogen, which one would expect to find present in trickling filter effluents.

Biochemical Oxygen Demand.--Trickling filter influent samples of three, six and nine ml/l were filtered through coarse filter paper to remove suspended material and placed in D.O. dilution bottles. These 265 ml bottles were then filled with B.O.D. dilution water and incubated for five days at 20°C. Filter effluent samples of 5, 10 and 15 ml were similarly prepared and incubated.

The incubation room was a photographic dark room where temperature was kept at 20°C ± 1°, but on occasions temperature varied as much as -2° and +6°C for short periods of time due to inefficient operation of the air cooler.

B.O.D. dilution water was prepared in accordance with Standard Methods (31). The dilution water was aerated for four days after addition of the required nutrients, and was stored for one to two days in the dark room before being used. On one occasion when dilution water was stored on a window sill in the presence of sunlight, a growth of algae was noticed. On another occasion nitrification occurred in the dilution water after it had been stored in the dark room for over a month. In both instances the dilution water could not be used.

After the incubation period had elapsed the D.O. content of the samples was determined and the 5-day 20°C B.O.D. was computed. (See Appendix for sample calculations.)

Nitrification.—It was not deemed necessary to distinguish between nitrites and nitrates present. The Reduction Method (Tentative) as described in Standard Methods (31) was used.

As has been previously mentioned, concentrated hydroxide was added to the nitrification samples as they were collected. Immediately after they had been brought to the laboratory, they were allowed to settle for 30 to 45 minutes; then 100 ml were pipetted and concentrated to about 20 ml by boiling in a casserole. These samples were then rinsed into a test tube and filled to the 60 ml mark with ammonia-free water. A strip of aluminum was added, the tube was covered with a Bunsen valve, and the solution was allowed to sit overnight.

The following day these samples were distilled and the distillate analyzed as specified with results being reported as nitrite plus nitrate-nitrogen. Two aliquots of each sample were analyzed simultaneously and averaged in order that a continuous check could be made on laboratory procedure. (See Appendix for sample calculations.)

Total Nitrogen.--The total nitrogen determination includes ammonia and organic nitrogen, but does not include nitrite and nitrate nitrogen.

Samples for nitrogen determination were collected as previously described. Analysis of these samples was by the Kjeldahl technique as specified in Standard Methods (31). The total nitrogen determination was discontinued in the early part of the sampling period as its contribution to this study was of no practical significance.

CHAPTER IV

DISCUSSION OF RESULTS

Egan Park.--Figure 1 shows the results of analyses of six samples taken from May 10 to July 26, 1956, while the sewage content varied from 20 to 26°C. B.O.D. removal varied from 56 to 87% with filter loadings ranging from 123 to 860 pounds of B.O.D. per acre-foot per day. The highest B.O.D. removals occurred at maximum loading rates and lowest efficiency occurred at the lowest B.O.D. loading. At peak flows this plant operates at approximately 10% above its maximum hydraulic design capacity.

The filters exhibit a good zoogleal growth and adequate ventilation is apparent. No ponding occurred at any time during this study, and the effluent D.O. ranged from 3.0 to 5.4 p.p.m. These D.O. values are typical of good ventilation. Nitrification showed a slight tendency to decrease as B.O.D. loading increased.

South River.--The low-rate filters at this plant are overloaded to the extent that they operate at loads comparable to those of high-rate filters as shown by the data in Figure 2. The B.O.D. loadings ranged from 168 to 1580 pounds per acre-foot per day, and B.O.D. removals ranged from 46 to 78%, with the majority of the samples falling in the 50% range. Temperature varied only 4°C during the sampling period between May 15 to July 26, 1956. During peak flows this plant exceeded its design capacity by approximately 35%.

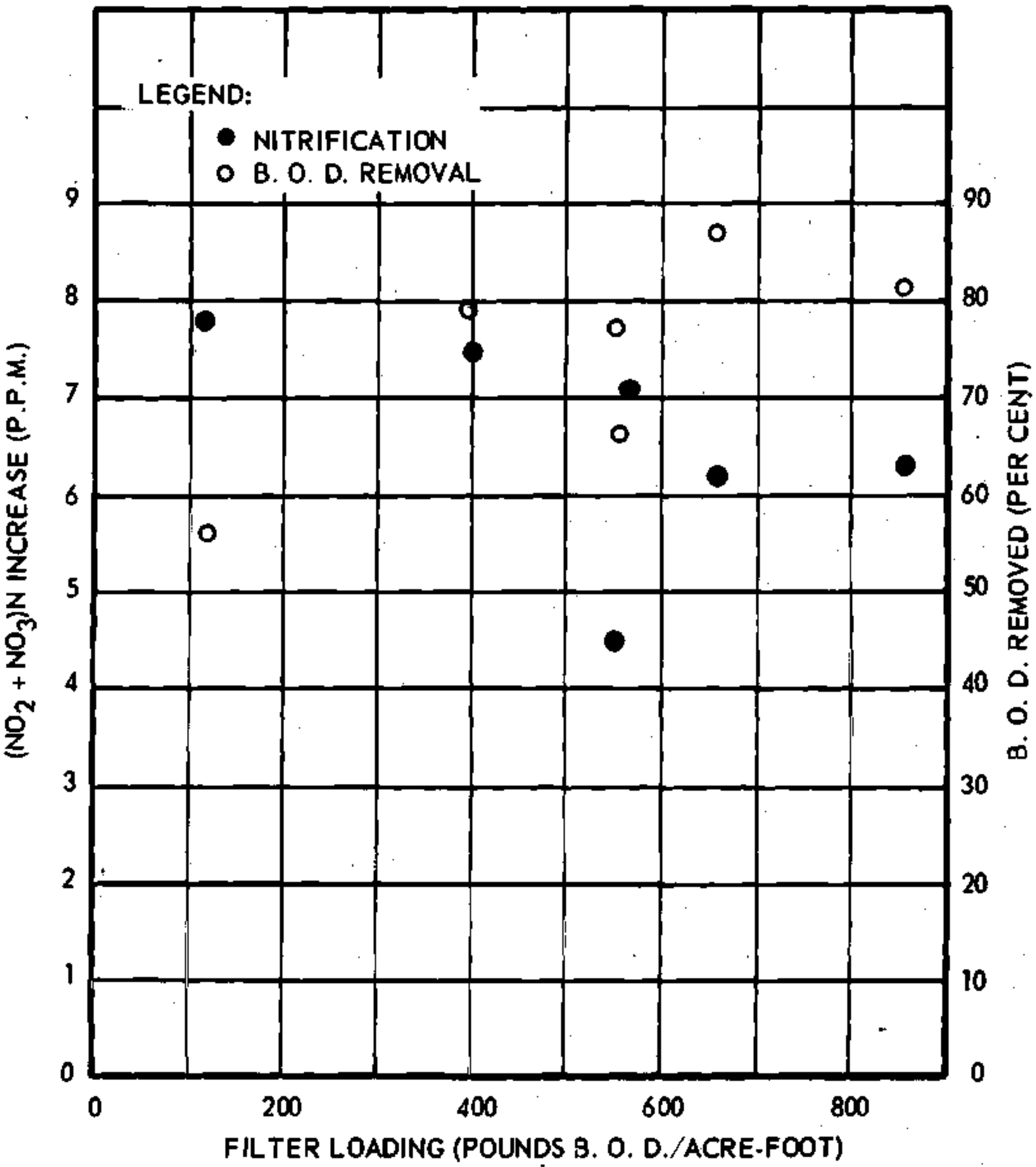

Figure 1. Effect of Filter Loading on Nitrification and B. O. D. Removal--Egan Park.

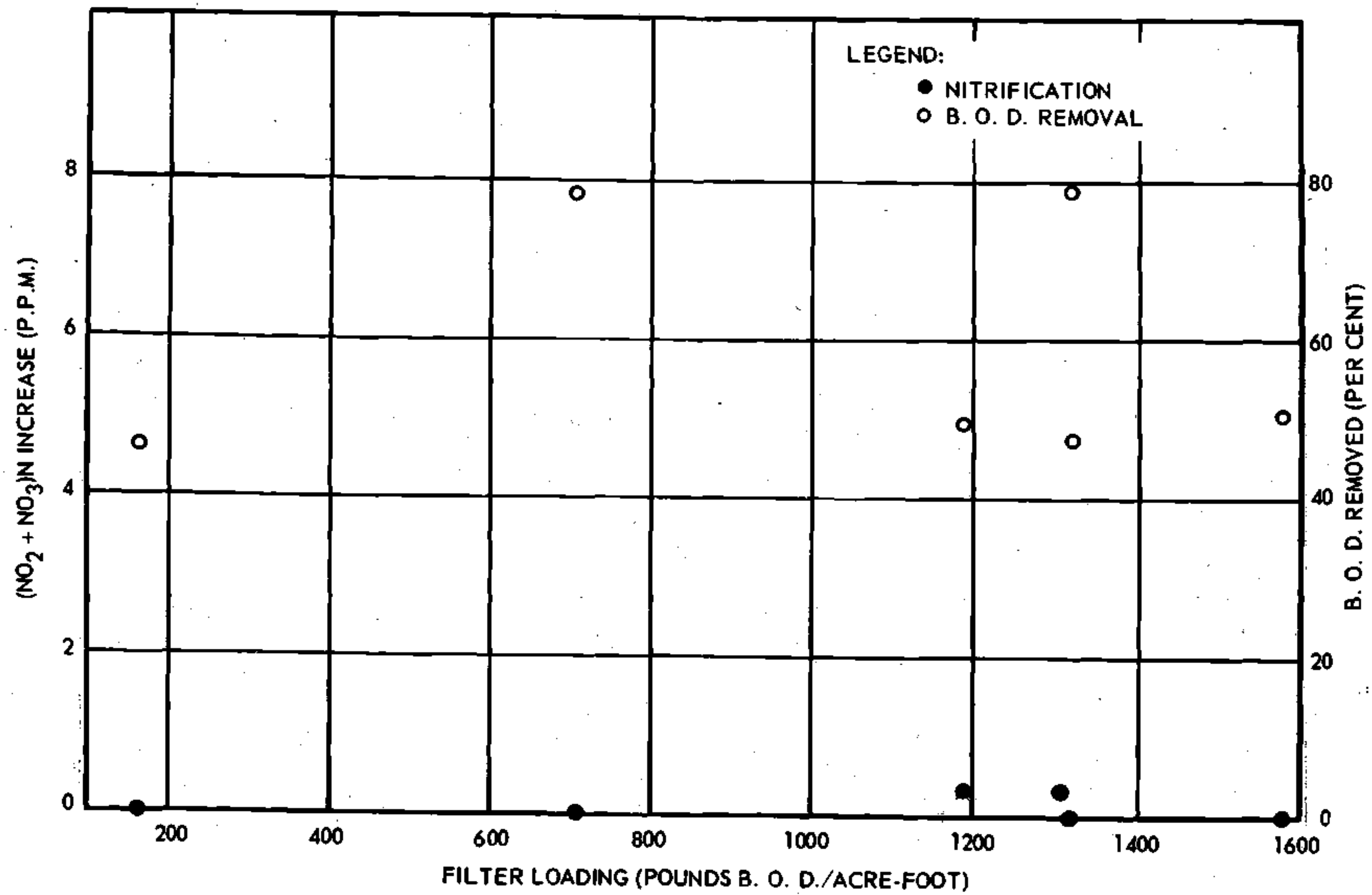

Figure 2. Effect of Filter Loading on Nitrification and B.O.D. Removal--South River.

All filters ponded continuously during this study, and bacterial growth was practically nil on the stone at the surface of the filters. Ventilation of the filters was further blocked by continuous submergence of the filter effluent channels. Dissolved oxygen was present in only three filter effluent samples, two of these occurring during a rainy spell lasting several days. This is clearly indicative of inadequate filter ventilation.

Nitrification occurred in two of the six samples taken, with only 0.3 p.p.m. nitrates being present in these samples. Even at low loads nitrification did not occur. The fact that small amounts of nitrates were present on two occasions shows that nitrifying organisms were established in the filter, but due to the high organic load and lack of adequate ventilation nitrification was effectively blocked.

High B.O.D. loading rates on the filters were partially caused by inadequate detention time in the primary clarifiers. Although dosing chambers were in use, the filters were dosed continually during most of the day.

It is interesting to note that this plant contains the smallest filter stone of any of the five plants studied.

East Side.--Figure 3 shows the results of analyses of seven samples taken from June 7 through June 22, 1956, when the temperature was relatively constant. The East Side Plant is operating at 80% above its design capacity during maximum flow periods.

During this study the filters ponded continuously, although the underdrain channels were not submerged like those at the South River

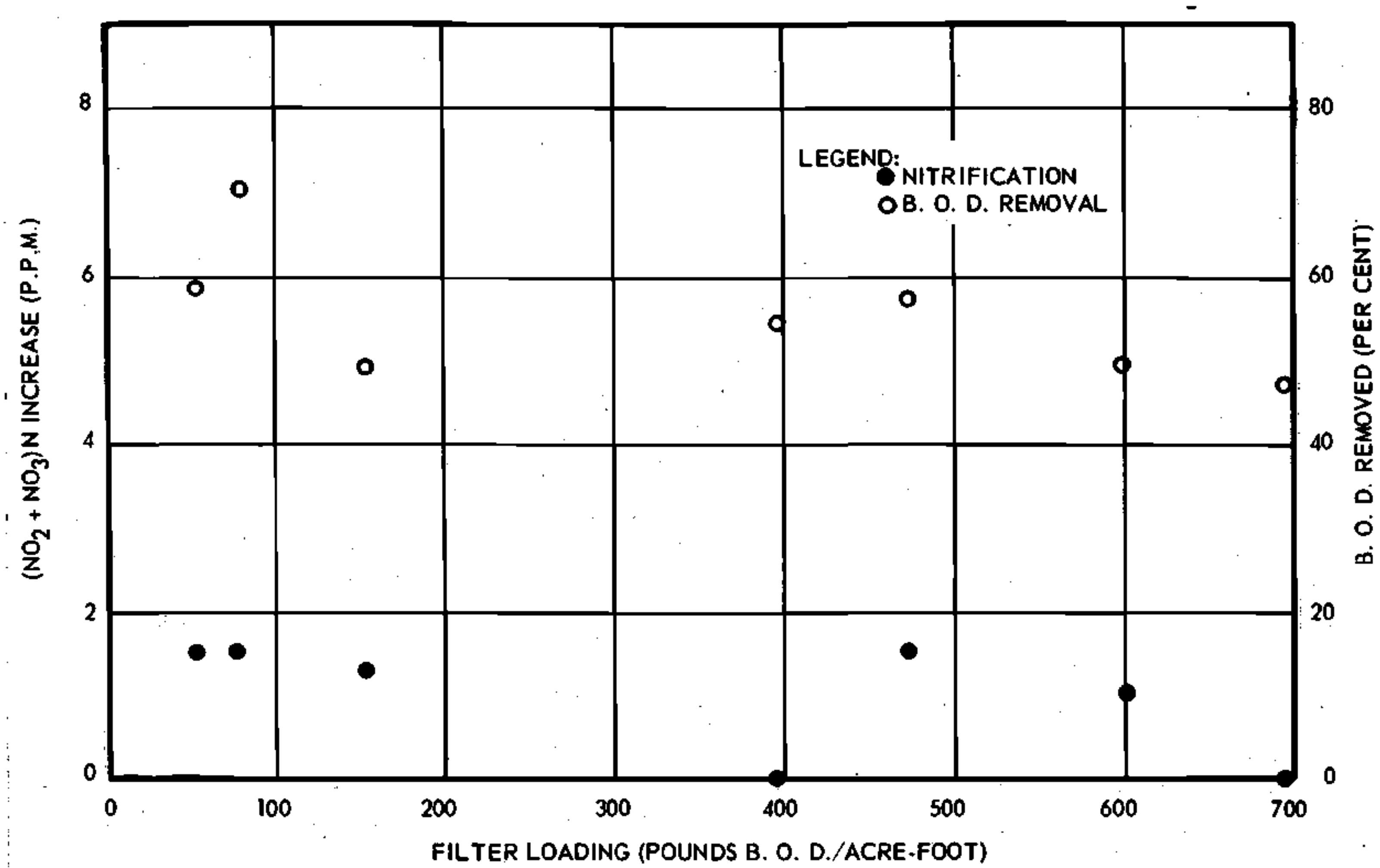

Figure 3. Effect of Filter Loading on Nitrification and B. O. D. Removal--East Side.

Plant. Dissolved oxygen content of the effluent was low, ranging from 1.0 to 2.7 p.p.m. The filter stone had a good bacterial growth.

Removal of B.O.D. ranged from 47 to 70% at loadings varying from 77 to 698 pounds of B.O.D. per acre-foot per day. The per cent B.O.D. removed decreased slightly as B.O.D. loading increased. Nitrification was limited by an inadequate air supply as a result of the filters ponding. Increase in nitrate content ranged from 0 to 1.5 p.p.m.

South Side.--Only four samples were taken at this plant from June 27 to July 29, 1956. Temperatures remained relatively constant and the plant experienced an overload of 20% above its design capacity during maximum periods of flow.

The data of Figure 4 shows that B.O.D. removal ranged from 72 to 82% as loading varied from 151 to 445 pounds of B.O.D. per acre-foot per day. The highest B.O.D. removal rates occurred at higher loadings. Good bacterial growth on the filter stone was observed during this study and no tendency toward ponding was noticed.

Nitrate content increased from 6.8 to 9.9 p.p.m. Aeration was adequate and filter effluent contained from 3.6 to 4.7 p.p.m. D.O.

West Side.--This plant has been in operation only seven months and is operating at about 50% of its design capacity during peak flows. Results of six samples analyzed between June 29 and July 16, 1956, are shown in Figure 5. Temperature remained constant during this period.

The B.O.D. loading ranged from 46 to 171 pounds per acre-foot per day, and B.O.D. removal ranged from 61 to 82% of the applied load.

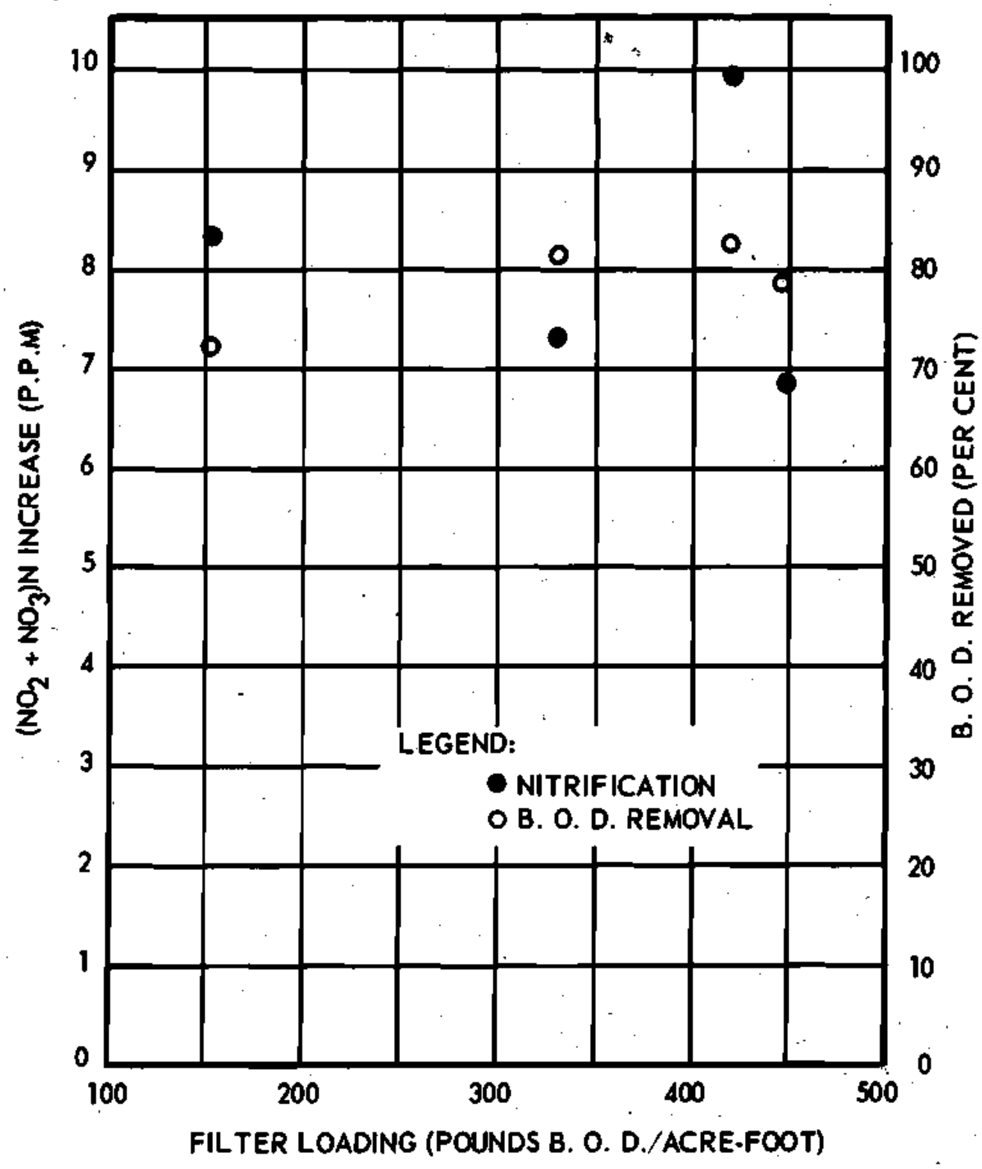

Figure 4. Effect of Filter Loading on Nitrification and B. O. D. Removal--South Side.

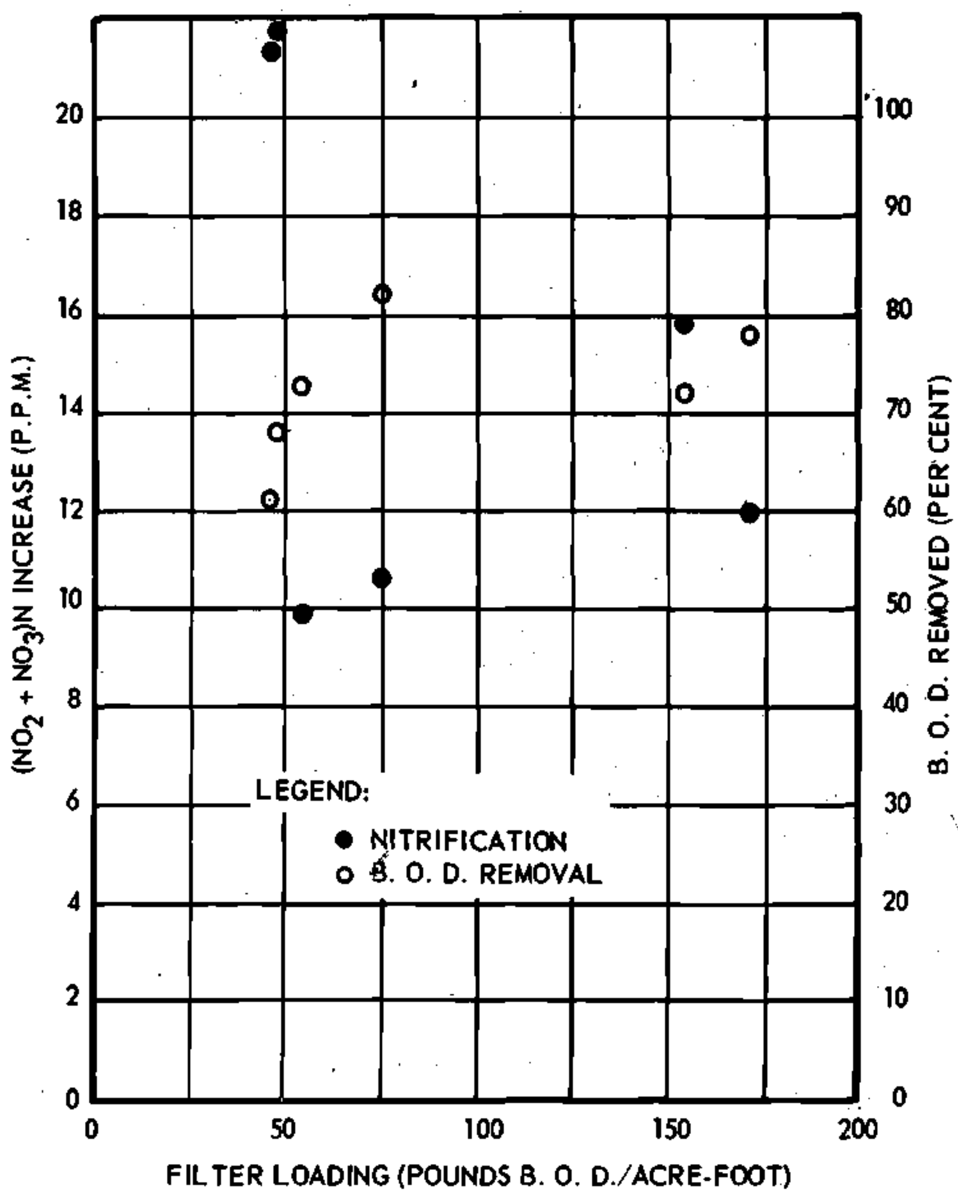

Figure 5. Effect of Filter Loading on Nitrification and B. O. D. Removal--West Side.

Filter growth was good, but not as heavy as that in other plants, excluding the South River Plant. This can be partly explained when one considers the length of time this plant has been in operation and the present loads imposed upon it. Dosing cycle intervals of as much as 20 minutes were noted during daytime.

Adequate ventilation of the filter produced an effluent with a D.O. content ranging from 4.6 to 6.0 p.p.m. Nitrate content ranged from 9.9 to 21.7 p.p.m. and was the highest degree of nitrification recorded in this study. The two samples containing the smallest nitrate content also contained partially treated effluent from one filter which was being flooded.

Comparison of Results.—Table 3 gives results obtained from the five plants studied. The overall average shows that for a loading of 470 pounds of B.O.D. per acre-foot per day the removal was 67%. Nitrate content increased 6.2 p.p.m. and filter effluent contained 3.5 p.p.m. D.O.

The data of Figure 6 clearly shows that those filters which contained considerable D.O. in their effluent were also highly nitrifying filters. The two filters which ponded continuously distinctly show the effect of insufficient ventilation upon nitrate production. The data of Figure 6 indicates that as effluent D.O. increased nitrate production also increased in plants where ventilation was adequate.

The data of Figure 7 again shows the distinction between filters having adequate ventilation and those where air supply is restricted. In the two filters in which the air supply was greatly restricted

Table 3. Average Results

Plant	B.O.D. Loading in pounds per acre-foot per day min.	max.	avg.	B.O.D. Removal (in per cent) min.	max.	avg.	Nitrate Production $(NO_2 + NO_3)N$ (in p.p.m.) min.	max.	avg.	Effluent D.O. (in p.p.m.) min.	max.	avg.
Egan Park	123	860	538	56	87	74	4.5	7.8	6.6	3.0	5.4	4.7
South River	168	1,580	1,046	46	78	58	0.0	0.3	0.1	0.0	3.0	1.0
East Side	77	698	350	47	70	55	0.0	1.5	1.0	1.0	2.7	1.9
South Side	151	445	335	72	82	78	6.8	9.9	8.1	3.6	4.7	4.2
West Side	46	171	93	61	82	72	9.9	21.7	15.2	4.6	6.0	5.5
Summary Data	46	1,580	470	46	87	67	0.0	21.7	6.2	0.0	6.0	3.5

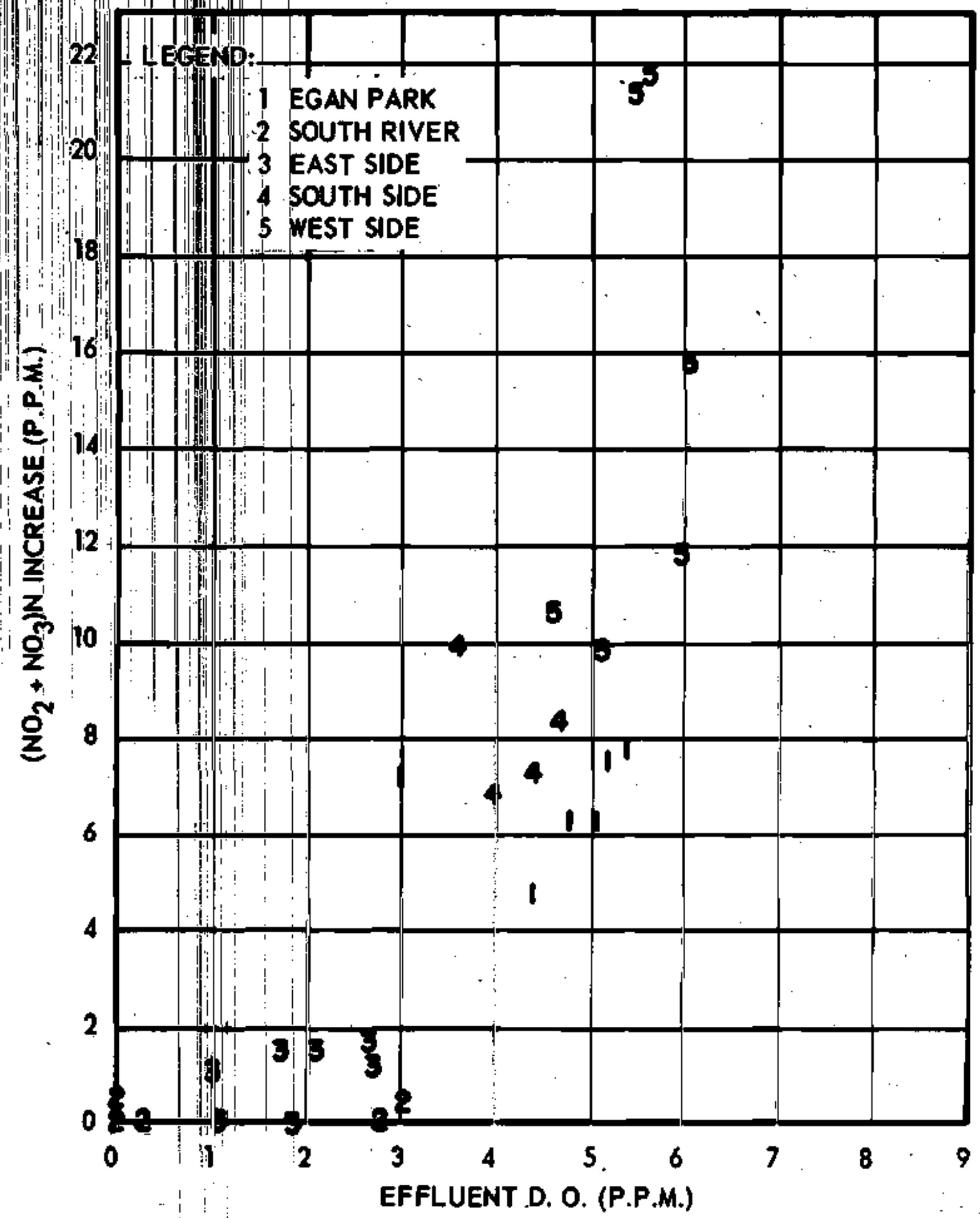

Figure 6. Relationship of Dissolved Oxygen and Nitrification--All Plants.

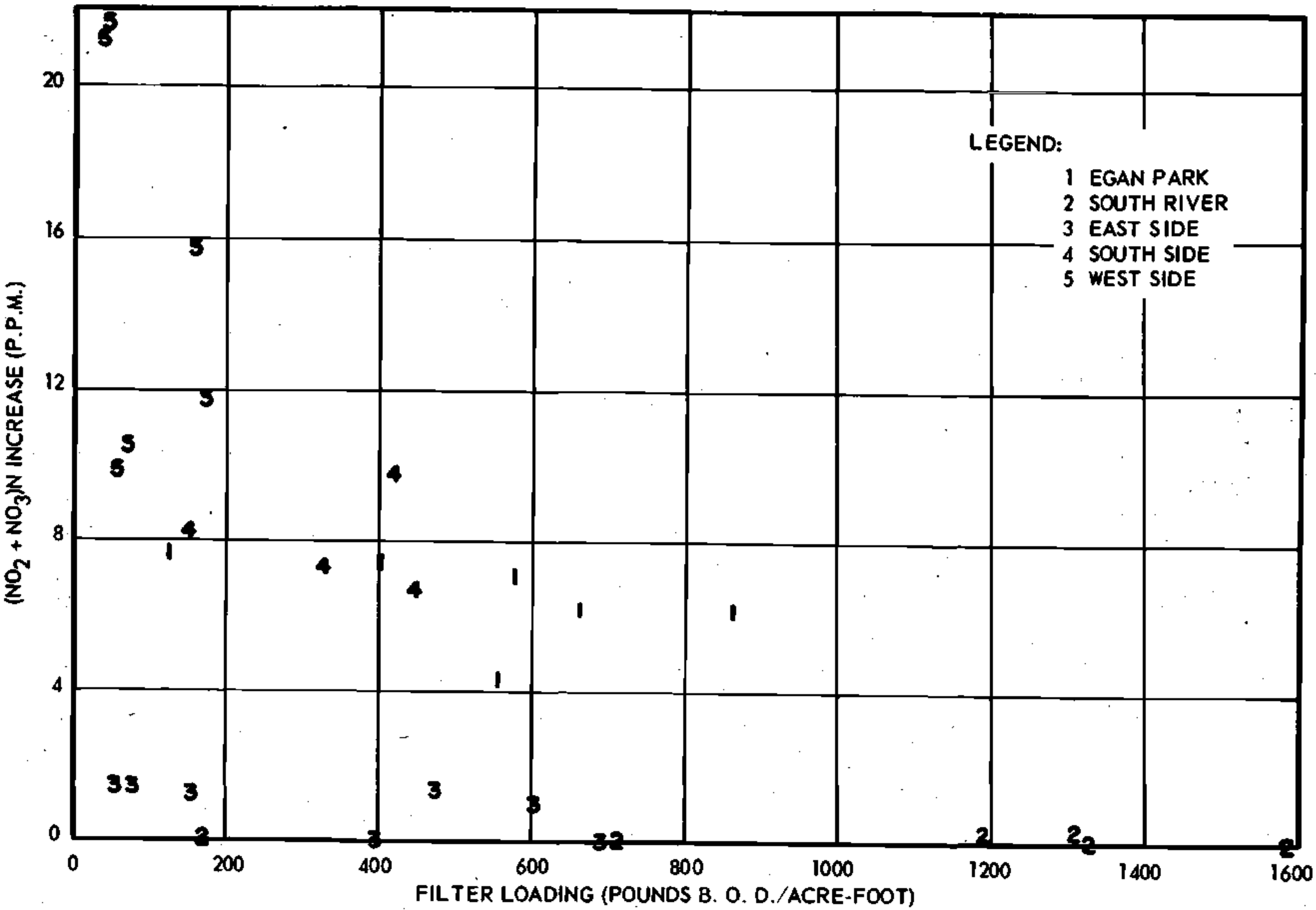

Figure 7. Effect of Filter Loading on Nitrification--All Plants.

nitrification was retarded or blocked completely. This clearly bears out the findings of Heukelekian (15), Ingols (16), Imhoff (17) and Levine (19) which show the effect of restricting air supply upon nitrification. This has been discussed earlier in the text.

In the filters where ventilation is adequate nitrification decreases as B.O.D. loading increases. This bears out the findings of Rudolfs (9), Grantham (18) and Heukelekian (15).

When considering all of the filters, the data of Figure 8 indicates that as effluent D.O. increases, per cent B.O.D. removal increases. However, examination of the data of the filters where ventilation was restricted did not reveal such a tendency. The same conclusion is obvious when data of the filters where ventilation is adequate is examined, although the results of each group of filters appear to fall within a small area on the graph. The filters with a higher effluent D.O. content do in general exhibit a greater per cent B.O.D. removal.

It is important that filter stone size be constant throughout the filter so that void spaces will not be filled and prevent ventilation within the filter. The removal of B.O.D. is apparently not a function of stone size, but the production of a high quality effluent requires that proper size stone be used in order to assure an adequate oxygen supply.

From the analyzed data and comparison of filter stone size and effectiveness, it appears that stone not less than 2.5 inches in diameter should be specified in trickling filter design.

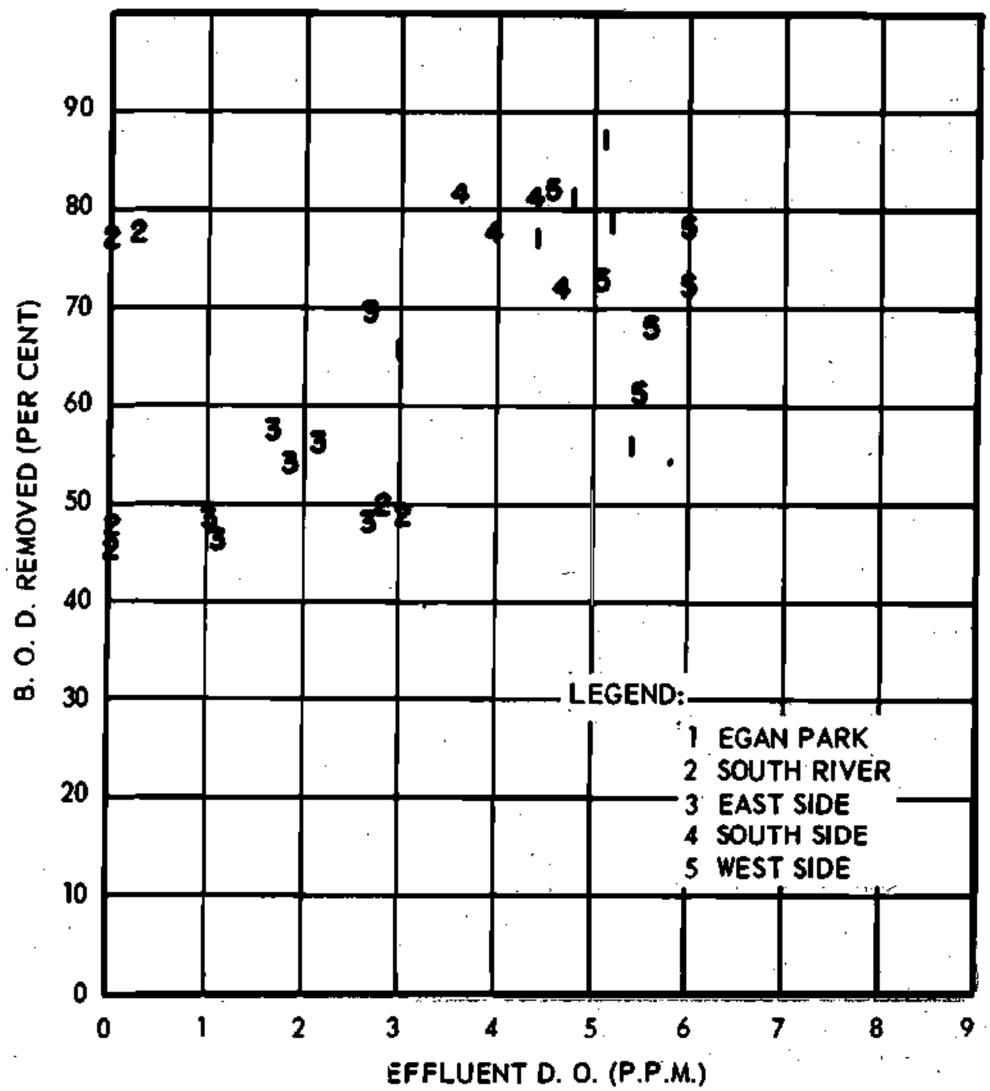

Figure 8. Relationship of Dissolved Oxygen and B.O.D. Removal--All Plants.

CHAPTER V

CONCLUSIONS

A study of trickling filters at five sewage treatment plants in the vicinity of Atlanta has revealed that each filter has its own operating characteristics.

Due to the many variables involved in sewage treatment, each plant must be studied on an individual basis. All variables must be taken into consideration over an extended period of time before specific statements can be made. When this has been accomplished, all analyzed data then describes the operating characteristics of the filter studied, but can not be construed to be representative of all filters. With these thoughts in mind, however, one can form a general opinion of trickling filter operation.

From data presented in this thesis the following general observations of the low-rate trickling filters studied can be stated:

1. Nitrification tended to increase as effluent D.O. increased in those filters where ventilation was adequate. For nitrification to occur in a filter, adequate ventilation must be provided.

2. Nitrification was low or completely blocked in those filters where ventilation was restricted by continuous ponding, regardless of the momentary loading. Nitrification did not show an increase even at extremely low B.O.D. loadings.

3. Nitrification decreased as B.O.D. loading increased in filters where ventilation was adequate, when all filters were considered together. However, when individual filters were analyzed, this tendency was not so pronounced.

4. Per cent B.O.D. removal did not appear to effect effluent D.O. However, filters with inadequate ventilation showed correspondingly lower per cent B.O.D. removal and effluent D.O. content than filters where ventilation was adequate.

5. Within the time limit of this study temperature variations were not significant.

6. Each filter appeared to have its own operating characteristics. When plotted on a graph, the results of B.O.D. removal and nitrate production fell within a narrow band. These limits were relatively constant when normal day by day operation was considered.

7. From the analyzed data and comparison of filter stone size and effectiveness, it appears that stone not less than 2.5 inches in diameter should be specified in trickling filter design.

CHAPTER VI

RECOMMENDATIONS

The total chemically combined nitrogen in filters decreases. Some study to justify this might be made to show the relationship of nitrites, nitrates, ammonia and total nitrogen.

APPENDIX

SAMPLE CALCULATIONS

Filter Calculations:

(a) Area $= \frac{D^2}{4}$

D = Inside diameter of filter in feet

$$= \frac{(3.14)(136 \text{ ft.})^2}{4} \times \frac{1}{43,560} \text{ ft.}^2\text{/acre}$$

$= 0.334$ acre

(b) Volume = Ad

A = Area in acres

d = depth in feet

$= (0.334 \text{ acre})(6.25 \text{ ft.})$

$= 2.08$ acre-feet

Biochemical Oxygen Demand (B.O.D.) Calculations:

(a) 5-day 20°C B.O.D.

$$= \frac{D.O._b - D.O._s}{S} \times V$$

$$= \frac{(8.0 \text{ p.p.m.} - 4.4 \text{ p.p.m.})}{6 \text{ ml}} \times 265 \text{ ml}$$

$= 159$ p.p.m. B.O.D.

$D.O._b$ = Dissolved Oxygen content of blank in p.p.m.

$D.O._s$ = Dissolved Oxygen content of sample in p.p.m.

S = Sample size in ml

V = Volume of dilution bottle in ml

(b) Pounds of 5-day 20°C B.O.D.

$= 8.34F$(B.O.D.)

$= (8.34$ lb./m.g.d.$)(0.8$ m.g.d.$)$

$\times$ (159 p.p.m. B.O.D.)

$= 1,060$ lbs. B.O.D.

F = Flow per filter in m.g.d.

8.34 = 1 p.p.m. = 8.34 lb./m.g.

Filter Loading:

$$\text{Loading} = \frac{P}{A.F.}$$

P = pounds 5-day 20°C B.O.D. per filter per day

$$= \frac{1,060 \text{ lbs. B.O.D.}}{2.08 \text{ acre-feet}}$$

A.F. = Volume of filter in acre-feet

$$= 510 \text{ lbs. B.O.D./acre-foot}$$

Filter Efficiency:

$$\text{Efficiency} = \frac{B.O.D._i - B.O.D._e}{B.O.D._i} \times 100$$

$B.O.D._i$ = Applied B.O.D. in p.p.m.

$$= \frac{159 \text{ p.p.m.} - 21 \text{ p.p.m.}}{159 \text{ p.p.m.}} \times 100$$

$B.O.D._e$ = Effluent B.O.D. in p.p.m.

$$= 87\%$$

Nitrate Content Increase:

$$\text{Increase} = (NO_2 + NO_3)N \text{ Effluent} - (NO_2 + NO_3)N \text{ Influent}$$

$$= 7.8 \text{ p.p.m.} - 0.5 \text{ p.p.m.}$$

$$= 7.3 \text{ p.p.m. } (NO_2 + NO_3)N$$

Total Organic Nitrogen Decrease:

$$\text{Per cent Nitrogen decrease} = \frac{I_n - E_n}{I_n} \times 100$$

I_n = Influent nitrogen in p.p.m.

E_n = Effluent nitrogen in p.p.m.

$$= \frac{29.6 \text{ p.p.m.} - 11.8 \text{ p.p.m.}}{29.6 \text{ p.p.m.}} \times 100$$

$$= 60\%$$

Table 4. Egan Park Sampling Data

No.	Flow in m.g.d.	B.O.D. Loading in pounds per acre-foot	Temp. °C	Influent D.O. (in p.p.m.)	Influent B.O.D. (in p.p.m.)	Influent NO_2 NO_3 (in p.p.m.)	Influent Total N (in p.p.m.)	Effluent D.O. (in p.p.m.)	Effluent B.O.D. (in p.p.m.)	Effluent NO_2 NO_3 (in p.p.m.)	Effluent Total N (in p.p.m.)	Removal B.O.D. (in per cent)	Removal Tot. N (in per cent)	Increase in NO_2, NO_3 (in p.p.m.)
1	2.0	662	20	1.7	165	0.8	31.6	5.1	21	7.0	16.1	87	49	6.2
4	2.0	554	24	0.9	138	0.0	35.9	4.4	32	4.5	22.6	77	37	4.5
7	1.8	123	22	1.7	34	0.5	22.3	5.4	15	8.3	8.3	56	63	7.8
8	2.1	400	22	1.2	95	0.0	37.8	5.2	20	7.5	12.8	79	67	7.5
27	1.9	572	26	0.4	150	0.6	—	3.0	51	7.7	—	66	—	7.1
29	1.8	860	27	0.1	143	0.3	—	4.8	27	6.6	—	81	—	6.3

Table 5. South River Sampling Data

No.	Flow in m.g.d.	B.O.D. Loading in pounds per acre-foot	Temp. °C	Influent D.O. (in p.p.m.)	Influent B.O.D. (in p.p.m.)	Influent NO_2 NO_3 (in p.p.m.)	Influent Total N (in p.p.m.)	Effluent D.O. (in p.p.m.)	Effluent B.O.D. (in p.p.m.)	Effluent NO_2 NO_3 (in p.p.m.)	Effluent Total N (in p.p.m.)	Removal B.O.D. (in per cent)	Removal Tot. N (in per cent)	Increase in NO_2, NO_3 (in p.p.m.)
3	10.3	710	25	2.1	111	0.0	—	0.3	24	0.0	—	78	—	0.0
5	6.2	168	26	1.9	44	0.0	—	0.0	24	0.0	—	46	—	0.0
23	11.8	1,190	26	1.9	164	1.4	—	3.0	81	1.7	—	49	—	0.3
24	9.8	1,580	26	1.7	197	1.1	—	2.8	98	1.1	—	50	—	0.0
28	14.5	1,320	28	0.1	129	0.6	—	0.0	68	0.4	—	47	—	0.0
30	13.6	1,310	29	0.0	156	0.0	—	0.0	35	0.3	—	78	—	0.3

Table 6. East Side Sampling Data

No.	Flow in m.g.d.	B.O.D. Loading in pounds per acre-foot	Temp. °C	Influent D.O. (in p.p.m.)	Influent B.O.D. (in p.p.m.)	Influent NO_2 NO_3 (in p.p.m.)	Influent Total N (in p.p.m.)	Effluent D.O. (in p.p.m.)	Effluent B.O.D. (in p.p.m.)	Effluent NO_2 NO_3 (in p.p.m.)	Effluent Total N (in p.p.m.)	Removal B.O.D. (in per cent)	Removal Tot. N (in per cent)	Increase in NO_2, NO_3 (in p.p.m.)
6	1.3	395	26	0.8	104	2.0	22.6	1.9	48	2.0	18.1	54	20	0.0
9	1.6	472	26	0.0	101	0.0	44.8	2.1	43	1.5	32.1	57	28	1.5
10	1.8	698	26	0.0	133	0.0	37.3	1.1	71	0.0	27.6	47	26	0.0
11	0.5	77	—	0.5	53	0.0	24.6	2.7	16	1.5	13.8	70	44	1.5
12	1.5	600	27	0.0	137	0.0	38.1	1.0	70	1.0	24.6	49	35	1.0
13	0.5	53	26	1.4	36	0.0	23.3	1.7	15	1.5	14.1	58	40	1.5
14	1.5	153	25	1.5	35	0.0	48.4	2.7	18	1.3	29.1	49	40	1.3

Table 7. South Side Sampling Data

No.	Flow in m.g.d.	B.O.D. Loading in pounds per acre-foot	Temp. °C	Influent D.O.	Influent B.O.D.	Influent NO_2 NO_3	Influent Total N	Effluent D.O.	Effluent B.O.D.	Effluent NO_2 NO_3	Effluent Total N	Removal B.O.D.	Removal Tot. N	Increase in NO_2, NO_3 (in p.p.m.)
				(in p.p.m.)				(in p.p.m.)				(in per cent)		
15	1.0	327	27	1.0	112	1.0	34.1	4.4	21	8.3	12.8	81	62	7.3
16	1.2	445	26	0.9	127	1.0	29.6	4.0	28	7.8	11.8	78	60	6.8
17	1.2	151	25	1.2	43	0.0	—	4.7	12	8.3	—	72	—	8.3
19	1.2	417	26	1.1	119	0.0	—	3.6	21	9.9	—	82	—	9.9

Table 8. West Side Sampling Data

No.	Flow in m.g.d.	B.O.D. Loading in pounds per acre-foot	Temp. °C	Influent D.O. (in p.p.m.)	Influent B.O.D. (in p.p.m.)	Influent NO_2, NO_3 (in p.p.m.)	Effluent D.O. (in p.p.m.)	Effluent B.O.D. (in p.p.m.)	Effluent NO_2, NO_3 (in p.p.m.)	B.O.D. Removal (in per cent)	Increase in NO_2, NO_3 (in p.p.m.)
18	0.37	57	25	0.9	63	0.7	5.1	17	10.6	73	9.9
20	0.34	76	25	0.4	89	0.3	4.6	16	10.9	82	10.6
21	0.28	48	26	0.4	68	0.0	5.6	22	21.7	68	21.7
22	0.25	46	25	1.0	71	0.0	5.5	28	21.4	61	21.4
25	0.52	171	26	3.3	131	1.7	6.0	29	13.5	78	11.8
26	0.48	158	25	2.7	131	1.1	6.0	37	16.9	72	15.8

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