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# TRICKLING FILTER TREATMENT OF FRUIT PROCESSING WASTE WATERS


U.S. ENVIRONMENTAL PROTECTION AGENCY

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# TRICKLING FILTER TREATMENT OF FRUIT PROCESSING WASTE WATERS

by

National Canners Association
Research Foundation
1950 Sixth Street
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for the

OFFICE OF RESEARCH AND MONITORING

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# ABSTRACT

Two high rate trickling filters were evaluated for treating fruit canning liquid wastes; one was 7.5 feet deep and had provision for heating the treated waste and for forced aeration; the other was 21.5 feet deep and was operated at ambient temperatures and with natural aeration; both were packed with a high void ratio plastic medium.

Nitrogen added to the cannery waste improved the removal of BOD and COD. In the absence of added nitrogen a thick fungal slime developed with odors characteristic of anaerobic microbial action. The need for adding phosphorous was not demonstrated.

More often than not, percent removals declined with increasing organic loadings; the pounds of BOD or of COD removed per unit volume increased with higher loadings.

Elevated temperatures were not consistently shown to improve the performance of the experimental filter.

Forced aeration was not proven to be beneficial in the filter treatment, but increased aeration maintained higher levels of dissolved oxygen in the effluent.

The top third of the 21.5 foot trickling filter accomplished 80% of the filter's total BOD removal under a light hydraulic loading. The top third removed a much higher percentage of reducing sugars than of total BOD, 67% compared to 32%.

The natural aeration filter maintained a slightly higher dissolved oxygen concentration in the effluent at all three tested depths than did the experimental filter with 300 cubic feet per minute of forced aeration.

Under the conditions of this study, increasing the depth of the filter medium beyond 14 feet added very little to the filter's performance.

This report is submitted in fulfillment of Project 12060 EAE under the partial sponsorship of the Office of Research and Monitoring, Environmental Protection Agency.

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## SECTION I

## RECOMMENDATIONS

Additional performance data are needed on the operation of trickling filters for canning waste treatment (1) at elevated temperatures with carefully controlled heating and adequate nutrient addition; and (2) with forced aeration including rates above 3.6 cubic feet of air per cubic foot of filter medium per minute.

More operational and maintenance data are needed to relate costs to BOD removals under varying conditions of aeration and temperatures. Additional information on the performance of trickling filters at different depths of the plastic medium should be collected, using a range of hydraulic and organic loadings.

The micro-flora on the packing medium should be studied with relation to (1) BOD removal efficiencies at different temperatures, filter depths, and other operating conditions, and (2) nutrient requirements for optimum performance.

## SECTION II

## INTRODUCTION

### PURPOSE AND SCOPE OF THE PROJECT

The purpose of this project was to evaluate and compare the performance of two high rate trickling filter systems in reducing the pollutional capacity of liquid wastes from fruit canning operations.

The scope of the project included locating the units at a cannery and modifying them for operation on fruit processing waste water. Modifications included the updating of schematic drawings, installation of insulation material, procurement of a heating system, procurement of a nutrient feed system, and replacement of the packing medium in one of the filters.

### BACKGROUND

No actual filtering of particles from the waste stream is performed by trickling filters. The waste water, introduced at the top of the filter, percolates down through the packing medium. During the contact time between the film of water and the slime growth on the filter medium, organic compounds are subjected to enzymatic breakdown and utilization. The slime microfloras use the organic compounds as energy sources in maintaining cell growth. When the filter is operated as a roughing filter, providing only partial treatment to the waste water, the effluent will have a reduced potential capacity for causing water pollution if discharged to a stream or will require less treatment if discharged to a municipal treatment facility.

The treatment of combined domestic and industrial wastes by trickling filters is now and has been a standard practice for many years. When the design loads of a conventional rock filled trickling filter system are not appreciably exceeded, the results are usually satisfactory (2). Generally, the success of trickling filters depends on good operational control in feeding a balanced waste that is uniform in volume and composition.

The treatment of food canning wastes by the trickling filter method has had a long and varied history. Under certain optimum conditions, the system has been successful (1, 9). Many investigators have experienced little success with conventional rock filled filters (1, 2). Several reasons have been advanced for the failure of the rock filter in providing adequate treatment to food wastes.

Canning operations may necessitate a sudden change in the volume discharged or produce a sudden change in the character of the waste. The most frequent change in the nature of the effluent is a sudden increase in alkalinity or acidity. Related to these changes is the possible stop and go nature of plant operations caused by fluctuating arrival of the raw product. Preseason attempts to build up the necessary microbial growth are rarely successful as there is a need for a continuous application of waste over the filter medium. The need to maintain optimum slime growth throughout the season cannot usually be fulfilled by normal cannery operations.

Another undesirable characteristic of fruit canning wastes is the deficiency of the waste in certain microbial nutrients such as nitrogen and possibly phosphorous. In addition to the waste being deficient in certain nutrients, fruit waste contains a high concentration of sugars and acids. These simple compounds are readily degraded by the micro-organisms and as such exert a high immediate oxygen demand. Conventional rock filters are not able to satisfy this immediate oxygen demand, especially under heavy organic loadings.

In recent years significant changes have been made in the basic principles of trickling filter treatment of wastes. One of the most important has been the development of plastic media as a substitute for rock. Many investigators (6, 7, 10) have experienced great success with plastic filled trickling filters. Much of the early work done in England is described in detail by Chipperfield (8). Germain (4) and Stack (3) outlined work done in this country, tracing the development of synthetic media for use in trickling filters. The National Canners Association has evaluated the application of plastic filled trickling filters in treating food canning wastes. The results of these studies, using a small pilot scale trickling filter system, have been reported (5).

The urgency for the development of information regarding the treatment of industrial wastes is repeatedly emphasized by demands for improvements in the quality of our environment. The demand for pollution abatement means less discharge of pollutants into natural water courses and improvements in the efficiency of municipal treatment systems. To enable canners to meet these demands, comprehensive information must be developed for the various treatment methods applicable to food processing wastes. It appears that plastic filled trickling filters have a greater potential in satisfying the immediate oxygen demand of food waste than have rock filled trickling filters.

This report discusses results obtained from a two year study of a trickling filter using forced aeration and controlled temperature and a trickling filter using natural aeration.

## PROCEDURES

### Equipment

A pilot scale forced aeration-controlled temperature trickling filter system used in the study was developed by the Aerojet-General Corporation to treat up to 10,000 gallons of raw sewage per day. It consisted of a treatment column 14 feet deep and a reservoir tank 6 feet deep, both cylindrical and 3.75 feet in diameter, with meters, heaters, pumps, and piping.

The treatment column was packed with a honeycombed polyvinyl chloride medium, Surfpac, registered by Dow Chemical Company; see Figure 1. The medium is welded into modules about 19x21x39 inches in dimensions, some of them cut to fit the cylindrical shape of the column, has 27 square feet of surface per cubic foot, and has a volumetric void ratio of 0.94. The column packing was 7.5 feet deep, with a cross sectional area of 11.1 square feet, giving 83 cubic feet of treatment volume.

Waste to be treated was collected in one section of a wet well sump, and was pumped from the sump to a reservoir in the first series of tests. In the second series, two 55-gallon drums preceded the sump, and the reservoir received its flow from the second drum. The primary waste flow was pumped from the reservoir to the top of the column. The recycle flow was collected at the bottom of the column and pumped to the top. The primary and recycle flows were distributed over the surface of the medium by separate fixed nozzles. Nutrient could be added to the recycle flow.

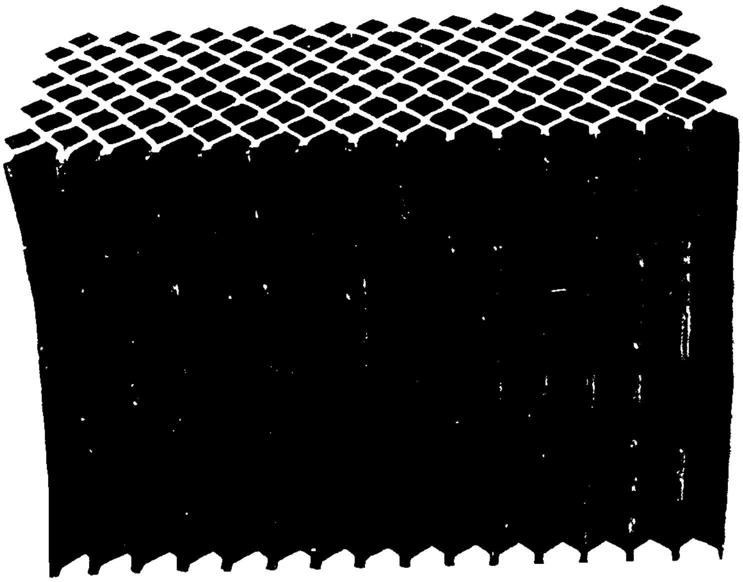

Fig. 1 Single Bundle of Plastic Packing Medium

In the elevated temperature runs, the waste was heated in the reservoir tank by a steam plate coil in the first series of experimental runs and by direct steam injection in the second. In the second series the injected air was also heated. The treatment column and the reservoir were insulated to reduce heat loss with black, 1/4 inch, closed cell neoprene; the pipes were insulated with fiber glass wrappings. Thermometers were placed in the column and in the reservoir.

A blower forced air into the bottom of the column. Air flow was measured at an orifice plate in a vent pipe at the top of the column in the first series and after the blower in the second.

Schematic drawings of the system as modified for the two series of tests are in Figures 2 and 3, and photographs of the unit in Figures 4 and 5.

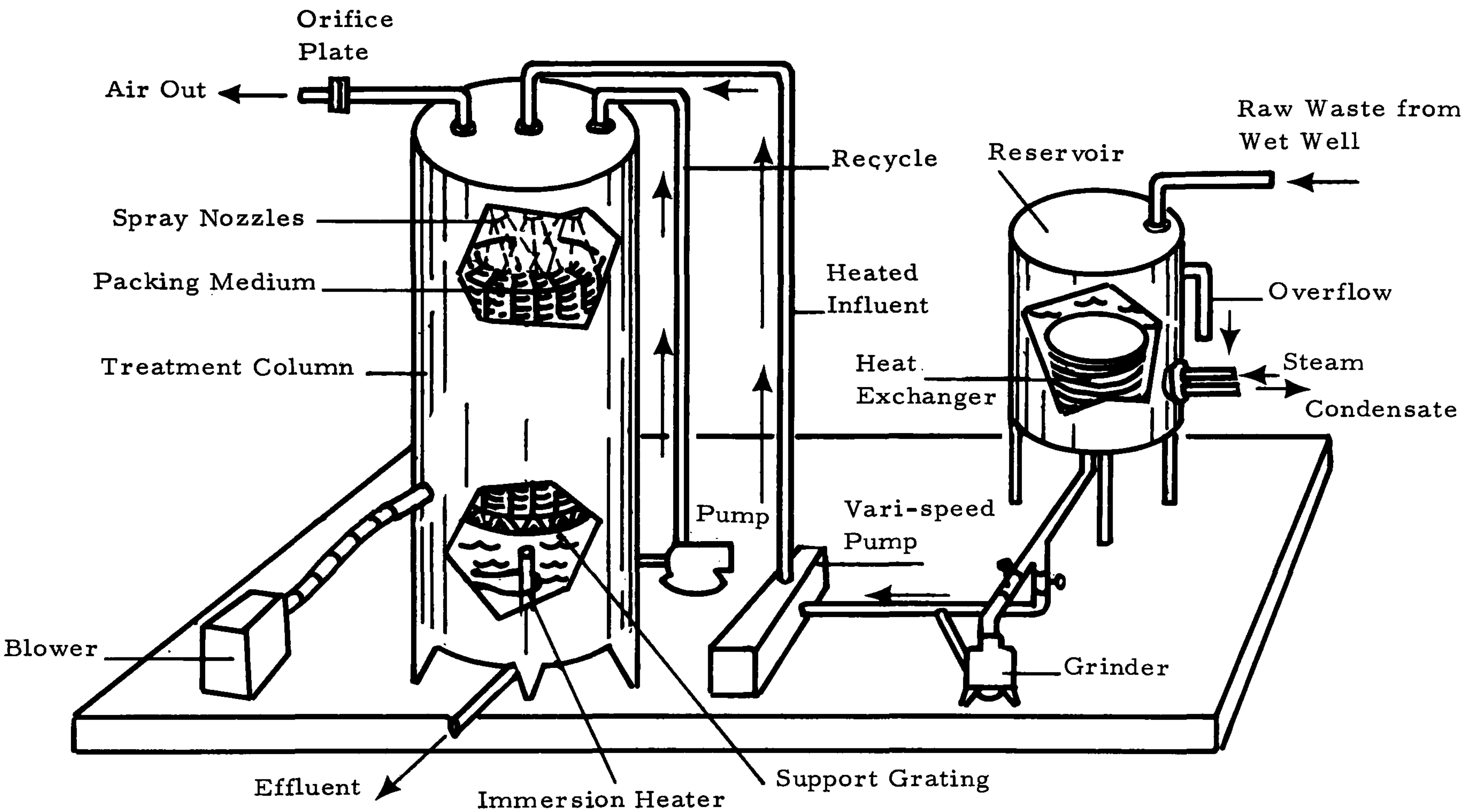


Figure 2 Schematic Drawing of Forced Aeration, Controlled Temperature Trickling Filter, First Series

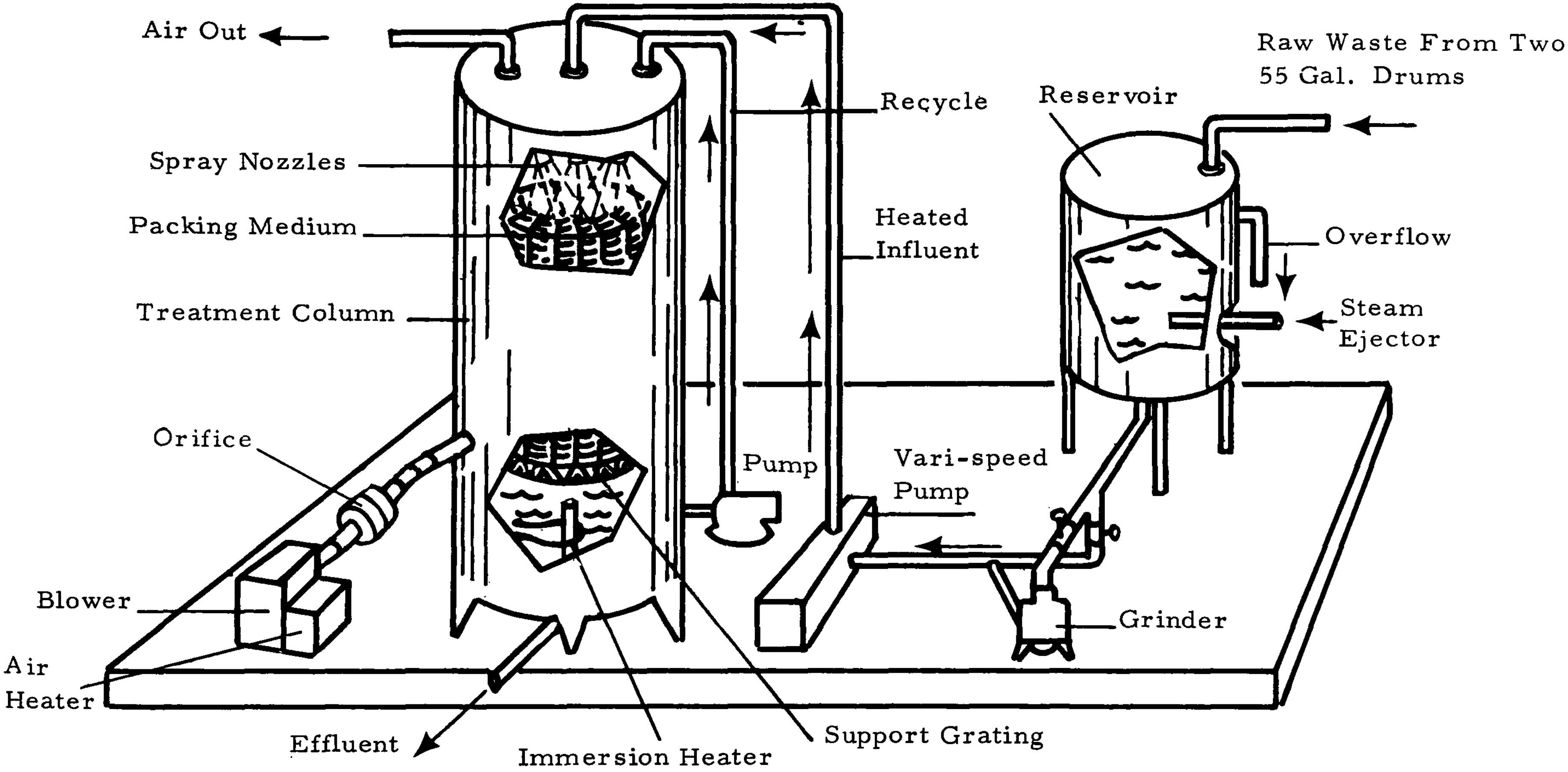


Figure 3 Schematic Drawing of Forced Aeration, Controlled Temperature Trickling Filter, Second Series

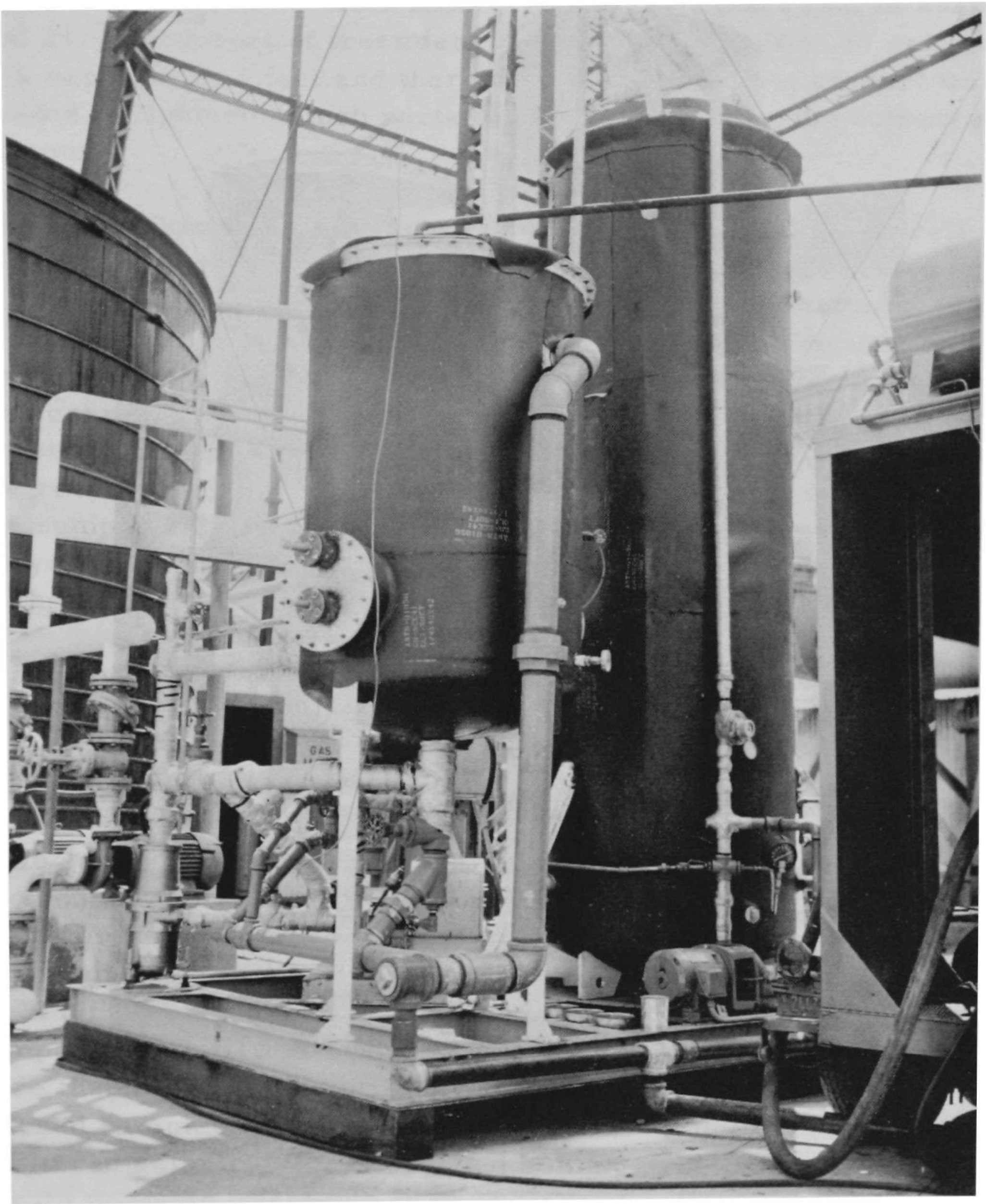


Figure 4 Front View - Pilot Trickling Filter

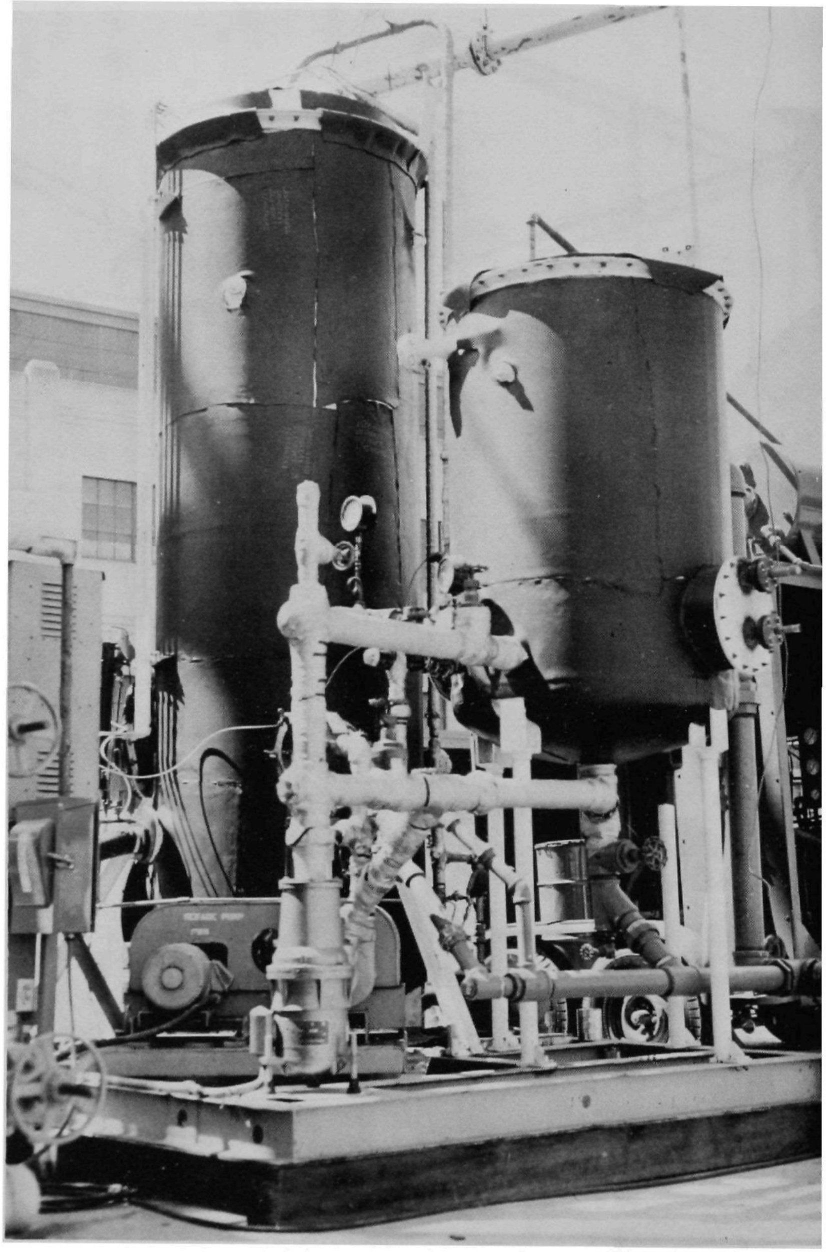

Figure 5 Side View - Pilot Trickling Filter

The natural aeration trickling filter was a larger unit designed and built with the help of the Engineering Section of the Del Monte Corporation. The treatment column was 29 feet deep and 12 feet in diameter; it was packed 21.5 feet deep with the same plastic medium as was used in the forced aeration filter, giving 113 square feet of surface and 2410 cubic feet of treatment volume. The medium is self-supporting to a depth of 21.5 feet and therefore no intermediate support was needed. Eighteen 4-inch ports allowed air to enter the bottom of the column.

The waste flow from the cannery entered one side of a wet well sump 5.7 feet in diameter and 10 feet deep. The sump was divided equally in two by a baffle that extended to 6 inches from the bottom. Waste from the inlet side was pumped to the top of the column and treated waste was returned to the other side of the sump, from which waste was carried away by overflow. A larger flow was pumped to the filter than entered the system from the cannery; the excess constituted the recycle volume. (For example, if 100 gpm of fresh waste entered the sump and 200 gpm was pumped to the filter, the ratio of fresh to recycled flow was 1:1.) The waste was evenly distributed at the top of the filter from four, notched, V-shaped troughs rotating at 2 RPM.

A schematic drawing and a photograph of this unit are in Figures 6 and 7, and additional details are in reference 11.

Sampling and Determinations

Grab samples of the influent and effluent flows were secured every two hours from the forced aeration filter and every four hours from the natural aeration filter. The samples were refrigerated and those from each day's run (of 16 or fewer hours) were composited. Except for the first series of runs from the forced aeration unit, half of each composite was filtered through cotton or glass wool. The composites were then held frozen until they were tested in the laboratory. The filtered samples were used for BOD and COD determinations; the unfiltered samples, for suspended solids. The filtering was to eliminate possible effects on BOD or COD of cells ruptured by freezing. For the second series of runs sampling points at the 7.2 and 14.4 foot depths of the plastic medium in the natural aeration unit were added; the 7.2 foot depth sample was for direct comparison to the effluent from the total depth of the forced aeration filter.

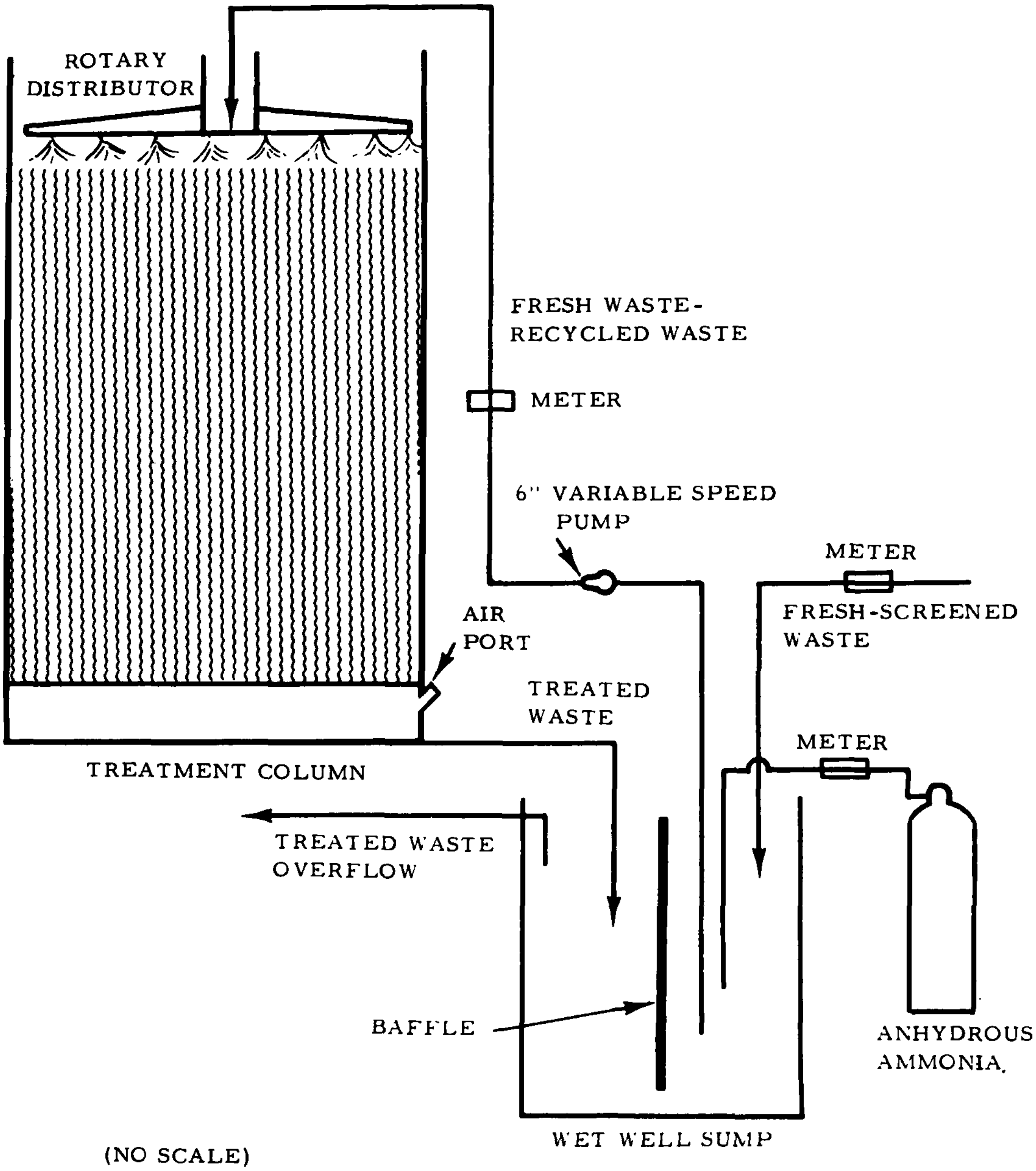


Figure 6 Schematic Diagram of High Rate Trickling Filter Treatment System

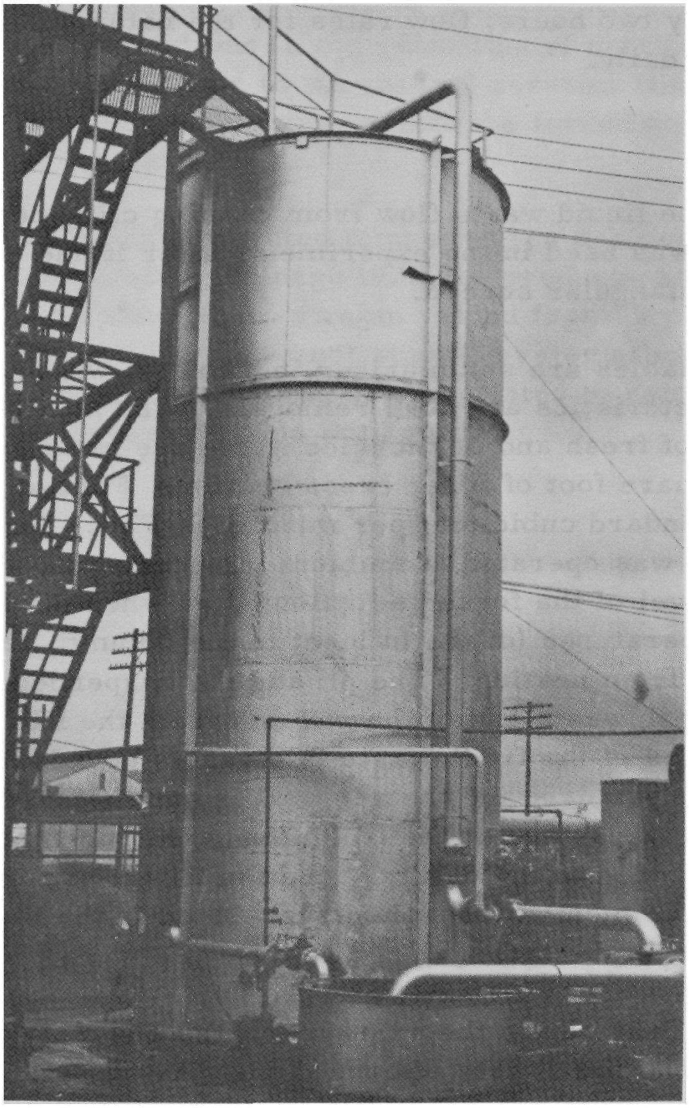

Figure 7 Overall View of the Trickling Filter System

Each sample was analyzed for BOD, COD, suspended solids, and pH. Influent and effluent dissolved oxygen were measured in the morning and in the afternoon starting part way through the second series of runs. The laboratory methods are referenced in the Appendix. Temperatures and air pressures for the forced aeration system were recorded every two hours; flow rates for the natural aeration unit were adjusted daily.

Operations

A portion of the liquid waste flow from canning cling peaches and fruit cocktail was used in the experiments after it had passed through a 20-mesh rectangular screen.

Operating variables are summarized in Table 1, which also lists influent characteristics and BOD removals. The nominal hydraulic loading rates of fresh and of recycled waste are given in gallons per minute per square foot of filter cross section. Forced air, where used, is in standard cubic feet per minute (SCFM). The natural aeration filter was operated at ambient temperatures, presumably at about the level of the forced aeration filter when the latter was not heated. Temperatures (of the influent to the column) above 100 degrees came from heating. The pH and the suspended solids (in ppm) of the fresh waste and of the effluent from the filters are listed. The organic load of the fresh waste is given as pounds of BOD per 1000 cubic feet per day; and the removal is summarized in the same units and as a percentage of the fresh load. Nitrogen as anhydrous ammonia was added to the natural aeration filter; nitrogen and phosphorous as di-ammonium phosphate were used in the forced aeration filter, as noted in the table.

The values in Table 1 are the averages of the several days' runs under each of the listed sets of conditions. Averaged daily observations are in Appendix B; also tabulated there are data on the concentrations of BOD and COD, pounds and percent removal of COD, influent and effluent dissolved oxygen, and the temperature of the effluent from the forced aeration filter.

At start-up the forced aeration filter was fed 0.45 and 0.75 gallons per minute per square foot of fresh and of recycled waste, respectively; and the natural aeration filter, 0.35 and 0.88 gpm/sq ft. Sufficient microbial slime developed in four or five days to consider the units operational.

Hydraulic loadings of the fresh and recycle streams were nominally as listed in the tables. Intermittant blocked flows and breakdowns caused some fluctuations. Nitrogen, when used, was added at a ratio calculated to approximate one part of nitrogen to 20 parts of BOD removed; phosphorous, in the forced aeration filter only, at one part of phosphorous to 100 parts of BOD removed. Mechanical difficulties caused variations in the quantities of nutrients added. In particular, nutrient addition to the natural aeration filter fell off at the end of the first series of runs, and to the forced aeration filter at the end of the second series.

Problems in maintaining elevated temperatures are described in the discussion of temperature on page 19. The products being canned and the strength of the plant waste stream varied from day to day. The floras in the filter slimes were not studied systematically so that generally their composition could not be related to removal efficiencies and its change over time is not known.

Table 1. Operating Variables and BOD Removals

| gpm/sq ft | | SCFM | | pH | | ppm SS | | BOD lbs * | | BOD% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| fresh | recyc. | air | temp. | fresh | effl. | fresh | effl. | fresh | remov. | remov. | Notes |
| Natural aeration filter, first series, 21.5 ft. depth | | | | | | | | | | | |
| 0.66 | 0.66 | - | amb. | 6.0 | 6.0 | 480 | 540 | 640 | 300 | 47 | |
| .88 | .88 | - | " | 7.1 | 5.3 | 670 | 940 | 940 | 160 | 17 | fungus, odor |
| .88 | .88 | - | " | 6.9 | 6.6 | 710 | 1030 | 1100 | 360 | 31 | $NH_3$ added |
| 1.55 | .88 | - | " | 6.3 | 5.5 | 680 | 600 | 1720 | 270 | 19 | $NH_3$ deficient |
| Forced aeration filter, first series | | | | | | | | | | | |
| 0.42 | 0.72 | 300 | 83 | 6.7 | 5.5 | 650 | 850 | 1240 | 270 | 20 | |
| .81 | .86 | 300 | 83 | 6.2 | 5.3 | - | - | 2200 | 500 | 20 | |
| .41 | 1.34 | 300 | 110 | 5.8 | 5.0 | 710 | 1140 | 1340 | 330 | 25 | N and P added |
| .73 | .99 | 300 | 111 | 6.6 | 5.2 | 620 | 1000 | 2120 | 100 | 5 | do. |
| .98 | 1.16 | 300 | 110 | 6.9 | 5.7 | 720 | 1390 | 3170 | 770 | 25 | do. |
| 1.20 | .97 | 300 | 112 | 7.8 | 6.6 | 870 | 910 | 3510 | 1140 | 32 | do. |
| Natural aeration, second series, 7.2 ft. depth | | | | | | | | | | | |
| 0.44 | 0.44 | - | amb | 8.4 | 8.2 | 450 | 420 | 1550 | 580 | 42 | $NH_3$ added |
| .44 | .44 | - | " | 7.6 | 7.8 | 550 | 730 | 1730 | 660 | 38 | do. |
| .44 | .44 | - | " | 7.8 | 7.7 | 720 | 1240 | 1860 | 710 | 38 | do. |
| .44 | .44 | - | " | 7.7 | 7.7 | 810 | 1450 | 1830 | 620 | 33 | do. |
| .44 | .44 | - | " | 7.2 | 6.3 | 770 | 2020 | 1860 | 500 | 27 | do. |
| .44 | .44 | - | " | 7.8 | 6.3 | 670 | 1540 | 1810 | 510 | 31 | do. |
| Forced aeration filter, second series | | | | | | | | | | | |
| 0.55 | 1.06 | 100 | 81 | 8.4 | 8.1 | 450 | 530 | 1860 | 240 | 13 | N and P added |
| .44 | 1.08 | 200 | 80 | 7.6 | 5.8 | 550 | 880 | 1660 | 240 | 15 | do. |
| .40 | 1.03 | 300 | 80 | 7.8 | 5.9 | 720 | 870 | 1570 | 330 | 21 | do. |
| .50 | .92 | 100 | 117 | 7.7 | 6.0 | 810 | 2070 | 2010 | 350 | 18 | do. |
| .52 | .90 | 200 | 117 | 7.2 | 6.1 | 770 | 790 | 2110 | 310 | 15 | nutrient deficient |
| .49 | .90 | 300 | 106 | 7.8 | 6.0 | 670 | 570 | 1920 | 240 | 13 | do. |

* Pounds/1000 cubic feet/day

## SECTION III

## DISCUSSION

The observations resulting from the study are summarized in Table 1 and detailed in Appendix B.

On many days in the first series of runs unexpected organic concentrations were observed in the effluent from the filters: (1) BOD was close to or higher than COD instead of much lower, as expected and as observed in the fresh waste and in the effluent samples of the second series; and (2) effluent BOD exceeded the fresh waste BOD in some runs. In two instances it appears that the influent BOD determination was incorrectly low (770 and 800 ppm when the COD was 2980 and 2900, respectively); these data have been omitted from further calculations. On the other days, the discrepant results seem to be excessively high BOD concentrations in the effluent, since the fresh waste BOD's were compatible both with the concurrent COD's and with the BOD's observed on other days. BOD loadings and removals in the forced aeration filter, recalculated by omitting the discrepant observations, are in Table 2; COD figures are listed for comparison.

Table 2. COD and Recalculated BOD Removals

| BOD lbs * | | BOD% | COD lbs. * | | COD% | |
|---|---|---|---|---|---|---|
| fresh | remov. | remov. | fresh | remov. | remov. | Notes |
| 1170 | 200 | 17 | 1820 | 710 | 38 | no nutrient, amb. temp. |
| 2160 | 310 | 15 | 3860 | 1520 | 40 | " " " " |
| 1160 | 270 | 23 | 1880 | 920 | 50 | N & P added, elev. temp. |
| 2170 | 500 | 23 | 3290 | 1670 | 52 | " " " " " |
| 2880 | 660 | 23 | 4870 | 1890 | 39 | " " " " " |
| 3510 | 1140 | 32 | 5720 | 2280 | 39 | " " " " " |

* Pounds/1000 cubic feet/day

Another possible explanation for the discrepant results is that the character of the filter effluents was different from that ordinarily found. Most of the discrepant runs were during the periods of increasing filter loadings without added nutrients and the periods immediately following these when nutrients were added. The type of slime in at least the natural aeration filter changed twice at about these times, but the microflora was not studied in much detail. The ratio of COD to BOD can be changed in the observed direction by partial treatment of food processing wastes. The COD method used during the first series of runs is especially subject to false low readings of partially oxidized wastes; the lower temperature at which the test is run does not result in complete oxidation of complex organic molecules. For the second series an improved COD method was used. This tends to explain the fact that COD removals were higher than BOD removals in the first but not in the second series. However, it does not explain the runs when the effluent BOD's exceeded the fresh waste BOD's. Since some removal of BOD was expected even during inefficient operation, the explanation via inaccurate effluent COD determinations is considered unlikely.

NUTRIENTS

The necessity of adding nutrients, at least nitrogen, to fruit wastes for efficient pollution removals was well demonstrated. In the first series, the natural aeration filter was run for three weeks without added nutrients. At first the performance of the filter was good, but with time a heavy fungal growth was established on the packing medium and objectionable odors developed; the performance of the filter decreased noticeably. The thick growth probably produced anaerobic conditions which caused the odor. Anhydrous ammonia was then fed into the filter at about one pound of nitrogen per 20 pounds of BOD removed. Within three or four days the heavy fungal slime was replaced by a thin, translucent film of motile bacteria. The effluent changed in appearance to that of an activated sludge effluent, and its floc particles settled readily. BOD removal increased from 17% before to 31% after the addition of nitrogen. During the last runs of the first series the supply of ammonia was decreased and then shut off, and BOD removals fell to 19%. Higher hydraulic and organic loadings were probably partly responsible, but fungi partly replaced bacteria in the slime during this period.

The forced aeration filter observations also showed the advantage of added nutrients. The first four sets of runs in the first series form two pairs with comparable organic loadings but with and without added nutrients. Both the COD data and, after dropping the suspect observations (Table 2), the BOD data showed increased removals when nutrients were added. The deficiency in nutrients could also have explained the poor performance of this filter in the elevated temperature runs of the second series.

The need for adding phosphorous to fruit canning wastes for efficient treatment was not shown by the experiments.

## LOADING

The fresh waste strength as measured by the concentration of BOD, COD, or SS varied from day to day. Even so, hydraulic and organic loadings were highly correlated and their effects on removals are not completely separable. Percent removals generally declined with increasing organic load.

The pounds of BOD and of COD removed increased considerably with higher loadings. For loadings and removals both expressed as pounds/1000 cubic feet/day, BOD removal exceeded 1100 lbs at a loading of about 3500; and COD removal was almost 2300 lbs at a loading of about 5700 in the forced aeration filter. The maximum removal in the natural aeration filter was about 700 lbs of BOD, at the maximum loading of 1860 lbs.

## TEMPERATURE

Elevated temperatures were not shown to improve the performance of the forced aeration filter under the conditions of these experiments. Heating system malfunctions prevented the maintenance of a constant elevated temperature, especially in the first series of runs. In addition, the temperature of the system dropped each weekend (generally for one day) when the cannery was not operating, no fresh waste was available, and the unit had to be switched to recycling only. Feed pump malfunctions cut off the added nutrients part way through the elevated temperature runs in the second series, and differences in hydraulic and organic loadings could account for some of the differences in removal efficiency in the temperature experiments. When nutrients were deficient, percent removals at ambient temperature (in the first series of runs) were better than those at elevated temperature (in the second series), considerably as measured by COD and slightly as measured by BOD. With added nutrients, the elevated temperature runs were superior to those at ambient temperature in the percentage removal of both BOD and COD, even though the highest loadings were in the elevated temperature runs. The population density of thermophilic bacteria in the filter may never have reached a high enough concentration to provide the expected higher removal rates. Possibly these bacteria require trace elements (such as boron) that may have been lacking. Since the bios was not studied, the responsible factors are not known.

## AERATION

The experiments did not show directly that forced aeration improved filter performance. The operational difficulties mentioned under temperature, above, may have obscured the beneficial effects of aeration. BOD removals increased with increased aeration at ambient temperatures, but a decreasing organic load in the same comparison may have been responsible. At elevated temperatures BOD removals decreased with increased aeration but nutrient deficiency was an interference. The dissolved oxygen (DO) concentration in the filter effluent was measured during the elevated temperature runs, and went up with increased aeration (dissolved oxygen data are in Appendix B). The DO was mostly zero and averaged 0.23 ppm with 100 standard cubic feet per minute (SCFM) aeration; it averaged 0.83 at 200 SCFM and 1.10 at 300 SCFM.

## EFFECT ON pH

The highest percentage removals of BOD were accompanied by the least reductions in pH through the natural aeration filter. Comparisons when other important conditions were approximately constant were few for the forced aeration filter, but overall the same effect seemed to be indicated. The pH of both the fresh waste and the filter effluents was generally lower in the first than in the second series of runs; see Table 1 and Appendix B.

## FILTER DEPTH

The second series of runs with the natural aeration filter provided information on removals and other waste characteristics at different filter depths. Data are in Table 3 and in the Appendix. The averages from the 14.4 foot depth in most of Table 3 are of fewer runs than the averages of the other two depths; but the overall averages in the bottom line of the table cover the same runs for all three depths.

Table 3. Trickling Filter Performance at Three Depths

| gpm/sq. ft. | | SS ppm | | | | BOD lbs/1000 cu. ft./day | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | depth, feet | | | 7.2 ft. depth | | | 14.4 ft. depth | | | 21.5 ft. depth | | |
| fresh | recyc. | fresh | 7.2 | 14.4* | 21.5 | load | remov. | %rem. | load | remov. | %rem. | load | remov. | %rem. |
| 0.44 | 0.44 | 450 | 420 | 240 | 360 | 1550 | 580 | 42 | 920 | 550 | 60 | 520 | 240 | 45 |
| .44 | .44 | 550 | 730 | - | 820 | 1730 | 660 | 38 | - | - | - | 580 | 270 | 45 |
| .44 | .44 | 720 | 1240 | 1430 | 1130 | 1860 | 710 | 38 | 890 | 330 | 37 | 620 | 270 | 43 |
| .44 | .44 | 810 | 1450 | 1280 | 1620 | 1830 | 620 | 33 | 900 | 360 | 41 | 610 | 250 | 40 |
| .44 | .44 | 770 | 2020 | 1310 | 1350 | 1860 | 500 | 27 | 950 | 290 | 31 | 620 | 200 | 32 |
| .44 | .44 | 670 | 1540 | 1380 | 1460 | 1810 | 510 | 31 | 890 | 270 | 30 | 610 | 220 | 35 |
| 0.44 | 0.44 | 710 | 1410 | 1300 | 1290 | 1800 | 530 | 32 | 900 | 320 | 35 | 600 | 230 | 37 |

* 14.4 ft. data are based on fewer samplings than the others; the overall averages in the bottom line are directly comparable.

The top third of the column removed 32% of the BOD; the top two-thirds, 35%; and the whole filter, 37%. Of the BOD removed, about 80% was taken out by the top section, 15% by the middle section, and 5% by the bottom section. COD removals were similar. The top third of the filter removed 67% of the reducing sugars, more than twice as high a percentage removal as that of the total BOD. (Eighty-four percent of the BOD in the fresh waste was composed of reducing sugars.)

The DO concentration was maintained in the natural aeration filter at almost the same level by all three filter depths, slightly higher than the concentration in the effluent from the smaller filter with 300 SCFM of forced aeration. At comparable depths the natural aeration filter performed much better than the forced aeration filter. The fresh waste to both filters was identical, but the former generally operated at lower organic and hydraulic loadings than the latter.

It is concluded that, under the condition of this study, increasing the depth of the filter medium beyond 14 feet is not advantageous.

# SECTION IV

## ACKNOWLEDGEMENTS

The National Canners Association Western Research Laboratory wishes to express its appreciation to the Environmental Protection Agency and to the Canners League of California for financial support given to the research described in this report. Without this support the research would not have been possible. The project team is indebted to the Water and Waste Problems Committee of the Canners League of California for valuable assistance and guidance to the research program.

Appreciation is expressed to many persons associated with Plant No. 3, Del Monte Corporation, where the two trickling filter systems were located. Without their cooperation during the installation and operation of the filters, the results reported herein could not have been obtained.

The Aerojet-General Corporation supplied the pilot forced aeration-controlled temperature trickling filter unit. Personnel of the company were instrumental in providing assistance in installation and operation of the unit:

Frank D. Ducey    G.E. Rose    K.E. Price

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Much of the credit for the success of this project must go to the team that carried out the tasks of operating the units, collecting the data and samples, and performing the analyses required to obtain the results. The project team included the following:

Carol Barnes
David Diosi
Larry Johnson
Charles Small
Brenda O'Flaherty
Bob Watkins
Tom Murphy

In addition to the project team, valuable contributions were made to the research effort by the following staff personnel of the National Canners Association.

| | |
|---|---|
| Allen Katsuyama | Jack Ralls |
| Ron Tsugita | Stuart Judd |
| Norman Olson | Nabil Yacoub |

Other contributions were made by many individuals concerned with the implementation of the project. We acknowledge the assistance given by these unnamed individuals and look forward to future cooperation in research projects which seek to find answers and solutions to halt the pollution of everyone's environment.

Walter A. Mercer
Project Coordinator

Walter W. Rose
Project Leader

## SECTION V

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# SECTION VI

## GLOSSARY

| | |
|---|---|
| BOD | Biochemical oxygen demand; usually $BOD_5$, meaning the demand measured in a five-day test; a common measure of pollutional strength. |
| COD | Chemical oxygen demand; a measure of pollutional strength determined more rapidly than BOD and usually roughly 50% greater than BOD. |
| DO | Dissolved oxygen |
| hydraulic loading | The quantity of liquid applied to a treatment system, usually measured in gallons per minute per unit of area. |
| organic loading | The quantity of BOD, COD, or other pollutional material applied to a treatment system; usually measured in pounds per unit of volume per day. |
| pH | The negative logarithm of the hydrogen ion concentration; a measure of the functional acidity or alkalinity of a liquid. |
| ppm | Parts per million |
| SCFM | Standard cubit feet per minute; a standardized measure of air flow. |
| SS | Suspended solids; insoluble material measured by filtering. |

## SECTION VII

## APPENDICES

### A. LABORATORY METHODS

Except as noted, laboratory determinations were carried out by the procedures described in:

> American Public Health Association, American Waterworks Association, and Water Pollution Control Federation. Standard Methods for the Examination of Water and Wastewater, 12th Edition, American Public Health Association (1965).

The methods used were:

BOD as a five-day biochemical oxygen demand;
COD, chemical oxygen demand, in the first series by the procedure in National Canners Association. Laboratory Manual for Food Canners and Processors, vol. 2, p. 352, Avi Publishing Company (1968); in the second series by the Jeris modification (Jeris, J.S. A Rapid COD Test, Water and Wastes Engineering 4 (5), 89-91 (1967);
SS, suspended solids, by glass fiber filtration;
pH by glass electrode; and
DO, dissolved oxygen, by the sodium azide-Winkler method.

### B. DETAILED DATA

Data on each of the daily composites for both filters and both series of studies are in the following tables. Table 7 repeats data from those runs listed in Table 6 when samples were drawn from all three depths of the natural aeration filter.

Table 4. Natural Aeration Trickling Filter, First Series

| Hydr. * | | Influent | | | | | | | Effluent | | | | | | | Org. * | | Removal * | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw | Rec. | COD | BOD | SS | | DO, ppm | | | COD | BOD | SS | | DO, ppm | | | COD | BOD | COD | COD | BOD | BOD | Air | |
| | | ppm | ppm | ppm | pH | AM | PM | Temp. | ppm | ppm | ppm | pH | AM | PM | Temp. | lbs | lbs | lbs | % | lbs | % | SCFM | Nutr. |
| 0.66 | 0.66 | 2130 | 1700 | - | 5.3 | | | | 1250 | 900 | - | 5.2 | | | | 790 | 630 | 320 | 41 | 300 | 47 | | |
| | | 2930 | 2370 | - | - | | | | 1670 | 1540 | - | - | | | | 1080 | 880 | 470 | 43 | 310 | 35 | | |
| | " | 2500 | 1890 | - | 6.3 | | | | 1410 | 980 | - | 6.4 | | | | 920 | 700 | 400 | 44 | 380 | 48 | | |
| " | | 2810 | 2240 | - | 6.2 | | | | 1350 | 980 | 1100 | 6.8 | | | | 1040 | 830 | 540 | 52 | 650 | 79 | | |
| " | " | 2350 | 1860 | 670 | 6.1 | | | | 920 | 820 | 900 | 5.7 | | | | 870 | 690 | 530 | 61 | 390 | 56 | | |
| | " | 1780 | 1100 | 280 | 7.9 | | | | 1630 | 1080 | 120 | 5.6 | | | | 660 | 410 | 60 | 9 | 10 | 2 | | |
| | " | 2900 | 800 | 490 | 6.4 | | | | 1250 | 160 | 60 | 6.2 | | | | 1080 | 300 | 610 | 57 | 240 | 80 | | |
| " | " | 2530 | 1240 | - | - | | | | 1130 | 850 | - | - | | | | 940 | 460 | 520 | 56 | 150 | 32 | | |
| Ave. 0.66 | 0.66 | 2480 | 1640 | 480 | 6.0 | | | | 1320 | 920 | 540 | 6.0 | | | | 920 | 640 | 430 | 47 | 300 | 47 | | |
| 0.88 | 0.88 | 3600 | 1790 | - | 7.5 | | | | 2120 | 1540 | - | 5.1 | | | | 1780 | 890 | 880 | 41 | 120 | 14 | | |
| " | | 2500 | 2060 | - | 5.0 | | | | 2050 | 1920 | 672 | 4.9 | | | | 1240 | 1020 | 220 | 18 | 70 | 7 | | |
| " | | 2840 | 1600 | 60 | 6.2 | | | | 1420 | 1440 | - | 5.3 | | | | 1400 | 800 | 700 | 50 | 80 | 10 | | |
| " | | 3400 | 1860 | 810 | 7.9 | | | | 1500 | 1530 | 600 | 5.5 | | | | 1680 | 920 | 940 | 56 | 160 | 17 | | |
| " | " | 3180 | 2150 | 1030 | 6.4 | | | | 1500 | 1650 | 680 | 5.2 | | | | 1580 | 1060 | 830 | 53 | 250 | 24 | | |
| ' | | 3260 | 2000 | 450 | 6.7 | | | | 1430 | 1610 | 1060 | 5.5 | | | | 1620 | 990 | 910 | 56 | 200 | 19 | | |
| " | | 2480 | 1800 | 620 | 8.1 | | | | 1400 | 1400 | 720 | 5.5 | | | | 1220 | 890 | 530 | 44 | 200 | 22 | | |
| " | " | 2900 | 1940 | 670 | 8.8 | | | | 1530 | 1500 | 1880 | 5.4 | | | | 1440 | 960 | 680 | 48 | 220 | 22 | | |
| Ave. 0.88 | 0.88 | 3070 | 1900 | 670 | 7.1 | | | | 1660 | 1580 | 940 | 5.3 | | | | 1510 | 940 | 710 | 47 | 160 | 17 | | |
| 0.88 | 0.88 | 2380 | 2250 | 670 | 7.5 | | | | 1300 | 1430 | 910 | 6.8 | | | | 1620 | 1120 | 980 | 60 | 400 | 36 | | N |
| " | ' | 3200 | 2330 | 550 | 8.6 | | | | 1140 | 1040 | 330 | 6.7 | | | | 1580 | 1150 | 1020 | 64 | 640 | 56 | | " |
| | ' | 2870 | 2010 | 620 | 8.5 | | | | 930 | 1270 | 740 | 6.6 | | | | 1420 | 1000 | 960 | 68 | 360 | 36 | | " |
| | " | 3080 | 1840 | 710 | 8.3 | | | | 1540 | 1700 | 1590 | 9.3 | | | | 1520 | 910 | 760 | 50 | 70 | 8 | | |
| | | 3010 | 1940 | 600 | 6.0 | | | | 1700 | 1820 | 910 | 6.1 | | | | 1490 | 980 | 650 | 44 | 70 | 7 | | " |
| | | 3420 | 2520 | 870 | 5.2 | | | | 1740 | 1840 | 510 | 5.9 | | | | 1690 | 1260 | 840 | 49 | 340 | 27 | | ' |
| ' | | 3260 | 2490 | 590 | 5.5 | | | | 1260 | 1750 | 400 | 5.8 | | | | 1600 | 1230 | 980 | 61 | 370 | 30 | | |
| " | | 3390 | - | 830 | 6.2 | | | | 1140 | - | 2530 | 6.5 | | | | 1680 | - | 1120 | 66 | - | - | | |
| " | " | 3630 | 2410 | 950 | 6.1 | | | | 1100 | 1190 | 1330 | 5.8 | | | | 1800 | 1190 | 1290 | 72 | 600 | 50 | | " |
| Ave. 0.88 | 0.88 | 3240 | 2220 | 710 | 6.9 | | | | 1320 | 1510 | 1030 | 6.6 | | | | 1600 | 1100 | 960 | 60 | 360 | 31 | | N |
| 1.54 | 1.54 | 3020 | 2180 | 600 | 6.8 | | | | 1820 | 1650 | 380 | 6.5 | | | | 2620 | 1880 | 1040 | 40 | 460 | 24 | | N** |
| " | " | 3310 | 2310 | 800 | 6.6 | | | | 2000 | 1720 | 840 | 6.4 | | | | 2870 | 2000 | 1140 | 40 | 510 | 26 | | |
| " | | 2980 | 800 | - | - | | | | 1600 | 980 | 580 | 6.5 | | | | 2580 | 690 | 1200 | 46 | (-170) | - | | " |
| " | ' | 3250 | 2020 | 1040 | 4.8 | | | | 1910 | 1560 | 820 | 4.6 | | | | 2820 | 1740 | 1170 | 42 | 390 | 22 | | " |
| " | | 2640 | 1710 | 1190 | 6.6 | | | | 1730 | 1250 | 930 | 5.0 | | | | 2280 | 1480 | 790 | 35 | 400 | 27 | | |
| ' | ' | 4980 | 1450 | 560 | 7.8 | | | | 1690 | 960 | 540 | 5.6 | | | | 4310 | 1250 | 2850 | 66 | 430 | 34 | | " |
| " | | 2290 | 1580 | 440 | 5.2 | | | | 1300 | 1520 | 400 | 4.7 | | | | 1990 | 1370 | 850 | 43 | (-50) | - | | ' |
| | " | 2040 | 1450 | 400 | 4.9 | | | | 1100 | 1270 | 470 | 4.7 | | | | 1760 | 1260 | 810 | 46 | 160 | 13 | | |
| " | " | 2680 | 1260 | 560 | 8.4 | | | | 1160 | 880 | 390 | 5.6 | | | | 2330 | 1090 | 1320 | 57 | 330 | 30 | | " |
| " | " | 2040 | 1620 | 530 | 5.5 | | | | 930 | 1300 | 600 | 4.9 | | | | 1780 | 1400 | 960 | 54 | 270 | 20 | | " |
| 1.54 | 1.54 | 2920 | 1640 | 680 | 6.3 | | | | 1520 | 1310 | 600 | 5.5 | | | | 2530 | 1420 | 1210 | 47 | 270 | 19 | | N** |

* Hydraulic load (raw and recycle) in gal./min/sq ft; organic load and pounds removal in lbs/1000 cu ft/day.
** Decreasing nutrient addition.

Table 5. Forced Aeration Trickling Filter, First Series

| Hydr.* Raw | Hydr.* Rec. | Influent COD ppm | Influent BOD ppm | Influent SS ppm | Influent pH | Influent DO, ppm AM | Influent DO, ppm PM | Influent Temp. | Effluent COD ppm | Effluent BOD ppm | Effluent SS ppm | Effluent pH | Effluent DO, ppm AM | Effluent DO, ppm PM | Effluent Temp. | Org.* COD lbs | Org.* BOD lbs | Removal* COD lbs | Removal* COD % | Removal* BOD lbs | Removal* BOD % | Air SCFM | Nutr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.39 | 0.64 | 2500 | 1890 | | 6.3 | | | 83 | 1750 | 1540 | - | 5.2 | | | 76 | 1510 | 1160 | 450 | 30 | 210 | 18 | 300 | |
| " | 1.26 | 3400 | 1860 | 810 | 7.9 | | | 85 | 2170 | 1770 | 1180 | 5.5 | | | 74 | 2110 | 1150 | 880 | 42 | 50 | 5 | " | |
| " | " | 3180 | 2150 | 1030 | 6.4 | | | 85 | 1810 | 2010 | 1490 | 5.5 | | | 79 | 1980 | 1330 | 860 | 43 | 90 | 7 | " | |
| .42 | .76 | 2810 | 2240 | | 6.2 | | | 78 | 1840 | 1510 | | 5.5 | | | 76 | 1900 | 1520 | 660 | 35 | 500 | 33 | " | |
| .45 | .36 | 2900 | 800 | 490 | 6.4 | | | 83 | 1590 | 1100 | 200 | 5.9 | | | 75 | 2100 | | 940 | 45 | | | " | |
| .47 | .35 | 1780 | 1100 | 280 | 7.9 | | | 85 | 1590 | 1080 | 520 | 5.3 | | | 80 | 1340 | 850 | 150 | 11 | 20 | 2 | " | |
| " | .38 | 2350 | 1860 | 670 | 6.1 | | | 81 | 990 | 830 | 840 | 5.7 | | | 80 | 1770 | 1400 | 1020 | 58 | 780 | 56 | " | |
| Ave. 0.42 | 0.72 | 2700 | 1700 | 650 | 6.7 | | | 83 | 1680 | 1410 | 850 | 5.5 | | | 77 | 1820 | 1240 | 710 | 38 | 270 | 20 | 300 | |
| 0.72 | 1.24 | 2840 | 1600 | | 6.2 | | | 83 | 1730 | 1540 | | 5.2 | | | 80 | 3280 | 1850 | 1280 | 39 | 80 | 4 | 300 | |
| .74 | .27 | 2530 | 1240 | | | | | 82 | 1690 | 1140 | | | | | 78 | 3000 | 1460 | 1000 | 33 | 120 | 8 | " | |
| .84 | .68 | 3210 | 2010 | | | | | 86 | 1540 | 1420 | | | | | 78 | 4320 | 2700 | 2250 | 52 | 790 | 29 | " | |
| .85 | .97 | 2500 | 2060 | | 5.0 | | | 83 | 1240 | 1310 | | 5.2 | | | 79 | 3380 | 2800 | 1700 | 50 | 1020 | 36 | " | |
| .92 | 1.08 | 3600 | 1790 | - | 7.5 | | | 82 | 2690 | 1620 | - | 5.6 | | | 77 | 5310 | 2640 | 1350 | 25 | 270 | 10 | " | |
| Ave. 0.81 | 0.86 | 2940 | 1740 | | 6.2 | | | 83 | 1780 | 1410 | - | 5.3 | | | 79 | 3860 | 2200 | 1520 | 40 | 500 | 20 | 300 | |
| 0.27 | 1.18 | 3260 | 2490 | 590 | 5.5 | | | 108 | 1318 | 1740 | 560 | 5.2 | | | 80 | 1410 | 1080 | 840 | 60 | 330 | 30 | 300 | N, P |
| .36 | 1.70 | 3250 | 2020 | 1040 | 4.8 | | | 104 | 1990 | 1550 | 1990 | 4.5 | | | 94 | 1880 | 1160 | 730 | 39 | 270 | 23 | " | " |
| .45 | 1.50 | 3280 | 2250 | 670 | 7.5 | | | 120 | 1860 | 1840 | 1080 | 5.5 | | | 101 | 2370 | 1630 | 1050 | 44 | 300 | 18 | " | " |
| .57 | .97 | 2040 | 1620 | 530 | 5.5 | | | 107 | 870 | 1170 | 910 | 4.8 | | | 107 | 1860 | 1470 | 1060 | 57 | 410 | 28 | " | " |
| Ave. 0.41 | 1.34 | 2960 | 2100 | 710 | 5.8 | | | 110 | 1510 | 1575 | 1140 | 5.0 | | | 96 | 1880 | 1340 | 920 | 50 | 330 | 25 | 300 | N, P |
| 0.65 | 1.04 | 3420 | 2520 | 870 | 5.2 | | | 109 | 1780 | 2170 | 820 | 5.1 | | | 95 | 3560 | 2520 | 1700 | 48 | 350 | 14 | 300 | N, P |
| .68 | " | 2980 | 770 | - | 6.5 | | | 103 | 1080 | 860 | | 5.9 | | | 92 | 3220 | | 2060 | 64 | | | " | " |
| .69 | 1.27 | 2900 | 1940 | 670 | 8.8 | | | 120 | 1810 | 1500 | 1550 | 5.5 | | | 105 | 3230 | 2170 | 1220 | 38 | 500 | 23 | " | " |
| " | 1.01 | 2680 | 1260 | 560 | 8.4 | | | 117 | 540 | 1360 | 830 | 5.0 | | | 102 | 2990 | 1400 | 2390 | 80 | (-100) | | " | " |
| .84 | .54 | 3010 | 1940 | 600 | 6.0 | | | 97 | 2200 | 2000 | 440 | 5.2 | | | 94 | 4040 | 2600 | 1090 | 27 | (-100) | | " | " |
| .38 | 1.05 | 2040 | 1450 | 400 | 4.9 | | | 117 | 850 | 1570 | 1340 | 4.8 | | | 103 | 2700 | 1920 | 1580 | 58 | (-140) | - | " | " |
| Ave. 0.73 | 0.99 | 2840 | 2230 | 620 | 6.6 | | | 111 | 1380 | 1830 | 1000 | 5.2 | | | 99 | 3290 | 2120 | 1670 | 52 | 100 | 5 | 300 | N, P |
| 0.90 | 1.18 | 3080 | 1840 | 710 | 8.3 | | | 100 | 1260 | 980 | 680 | 6.0 | | | 93 | 4450 | 2660 | 2640 | 59 | 1250 | 47 | 300 | N, P |
| .92 | " | 3880 | 2310 | 900 | 6.7 | | | 122 | 2930 | 2130 | 1210 | 6.2 | | | 115 | 5720 | 3400 | 1410 | 25 | 270 | 8 | " | " |
| .94 | .95 | 2290 | 1580 | 440 | 5.2 | | | 117 | 1710 | 1220 | 1530 | 5.0 | | | 103 | 3440 | 2380 | 870 | 25 | 550 | 23 | " | " |
| .95 | 1.20 | 3630 | 2410 | 950 | 6.1 | | | 105 | 2250 | 2080 | 980 | 5.3 | | | 99 | 5510 | 3660 | 2100 | 38 | 500 | 14 | " | " |
| 1.01 | 1.01 | 3020 | 2180 | 600 | 6.8 | | | 99 | 2040 | 1900 | 1270 | 5.5 | | | 95 | 4890 | 3530 | 1580 | 32 | 450 | 13 | " | " |
| " | " | 3310 | 2310 | 800 | 6.6 | | | 110 | 2170 | 2000 | 1930 | 5.6 | | | 101 | 5360 | 5330 | 1850 | 34 | 450 | 13 | " | " |
| .99 | 1.20 | 3390 | | 830 | 6.2 | | | 118 | 1723 | 1820 | 1470 | 5.4 | | | 110 | 5410 | - | 2660 | 49 | - | - | " | " |
| 1.04 | 1.54 | 2870 | 2010 | 620 | 8.4 | | | 100 | 810 | 720 | 2500 | 5.9 | | | 95 | 4770 | 3320 | 3470 | 73 | 2120 | 64 | " | " |
| 1.06 | 1.20 | 2480 | 1800 | 620 | 8.1 | | | 116 | 2200 | 1470 | 930 | 6.3 | | | 104 | 4240 | 3060 | 470 | 11 | 560 | 18 | " | " |
| Ave. 0.98 | 1.16 | 3110 | 2060 | 720 | 6.9 | | | 110 | 1900 | 1590 | 1390 | 5.7 | | | 102 | 4870 | 3170 | 1890 | 39 | 770 | 25 | 300 | N, P |
| 1.13 | 0.85 | | 1450 | | | | | 108 | | 1070 | - | | | | 104 | | 2620 | | | 690 | 26 | 300 | N, P |
| 1.17 | 1.50 | 3200 | 2330 | 550 | 8.6 | | | 111 | 1550 | 1670 | 960 | 6.5 | | | 93 | 6000 | 4390 | 3090 | 52 | 1250 | 28 | " | " |
| 1.29 | .57 | 2640 | 1710 | 1190 | 7.1 | | | 116 | 1930 | 990 | 860 | 6.6 | | | 110 | 5450 | 3530 | 1460 | 27 | 1480 | 42 | " | " |
| Ave. 1.20 | 0.97 | 2920 | 1830 | 870 | 7.8 | | | 112 | 1740 | 1240 | 910 | 6.6 | | | 106 | 5720 | 3510 | 2280 | 39 | 1140 | 32 | 300 | N, P |

* Hydraulic load (raw and recycle) in gal. /min/sq ft; organic load and pounds removal in lbs/1000 cu ft/day.

Table 6. Natural Aeration Trickling Filter, Second Series *

| Run | INFLUENT | | | | | | EFFLUENT 1/3 Filter depth | | | | | | EFFLUENT 3/3 Filter depth | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | COD ppm | BOD ppm | SS ppm | pH | DO ppm AM | DO ppm PM | COD ppm | BOD ppm | SS ppm | pH | DO ppm AM | DO ppm PM | COD ppm | BOD ppm | SS ppm | pH | DO ppm AM | DO ppm PM |
| a | 4800 | 2500 | 420 | 7.8 | | | 3600 | 1500 | 300 | 8.1 | | | 3100 | 1200 | 220 | 8.0 | | |
| b | 2700 | 1800 | 150 | 8.6 | | | 1600 | 1000 | 190 | 8.4 | | | 1500 | 900 | 160 | 8.2 | | |
| c | 3100 | 2100 | 250 | 8.4 | | | 2100 | 1500 | 200 | 7.8 | | | 1900 | 1300 | 200 | 8.0 | | |
| d | 3700 | 2000 | 600 | 8.5 | | | 2200 | 1500 | 600 | 7.6 | | | 2000 | 1300 | 500 | 7.6 | | |
| e | 3600 | 1900 | 700 | 8.7 | | | 1800 | 1000 | 700 | 8.9 | | | 1900 | 900 | 700 | 8.8 | | |
| f | 3500 | 2300 | 550 | 8.5 | | | 2100 | 1400 | 550 | 8.6 | | | 1900 | 1300 | 400 | 8.4 | | |
| AVE | 3570 | 2100 | 450 | 8.4 | | | 2230 | 1320 | 420 | 8.2 | | | 2050 | 1130 | 360 | 8.2 | | |
| g | 3100 | 2200 | 370 | 7.9 | | | 2100 | 1500 | 510 | 7.7 | | | 1900 | 1300 | 550 | 7.2 | | |
| h | 4000 | 2800 | 600 | 8.1 | | | 2300 | 1700 | 410 | 7.8 | | | 2100 | 1500 | 360 | 7.5 | | |
| i | 3400 | 2200 | 550 | 7.8 | | | 2000 | 1300 | 700 | 8.1 | | | 1800 | 1100 | 500 | 7.7 | | |
| j | 3000 | 2000 | 550 | 7.4 | | | 2000 | 1300 | 650 | 7.7 | | | 2000 | 1300 | 600 | 7.6 | | |
| k | 3500 | 2500 | 700 | 7.2 | | | 2000 | 1400 | 1400 | 7.5 | | | 1900 | 1200 | 2100 | 7.2 | | |
| AVE | 3400 | 2340 | 550 | 7.6 | | | 2080 | 1440 | 730 | 7.8 | | | 1940 | 1270 | 820 | 7.4 | | |
| l | 4000 | 2700 | 800 | 7.7 | | | 2300 | 1400 | 1000 | 8.0 | | | 2100 | 1300 | 800 | 8.0 | | |
| m | 4100 | 2700 | 690 | 7.5 | | | 2900 | 1900 | 1400 | 7.5 | | | 2300 | 1600 | 1000 | 7.4 | | |
| n | 4600 | 2800 | 840 | 7.8 | | | 2300 | 1200 | 1900 | 7.3 | | | 2200 | 1300 | 2300 | 7.1 | | |
| o | 4000 | 2300 | 750 | 7.8 | 4.4 | 2.9 | 2400 | 1400 | 980 | 7.8 | 2.2 | 1.9 | 2100 | 1400 | 850 | 7.7 | 2.0 | 1.2 |
| p | 4900 | 2400 | 700 | 7.9 | 3.1 | 3.9 | 2500 | 1600 | 1200 | 7.9 | 2.2 | 2.4 | 2300 | 1400 | 950 | 7.8 | 1.9 | 2.4 |
| q | 3500 | 2200 | 550 | 8.0 | 3.7 | - | 2900 | 1800 | 980 | 7.9 | 1.5 | - | 2300 | 1500 | 850 | 7.6 | 1.3 | - |
| AVE | 4180 | 2520 | 720 | 7.8 | 3.7 | 3.4 | 2550 | 1550 | 1240 | 7.7 | 1.9 | 2.2 | 2220 | 1420 | 1130 | 7.6 | 1.7 | 1.8 |

| Run | 1/3 Filter depth Loading** | | 1/3 Filter depth Removal** | | | | 3/3 Filter depth Loading** | | 3/3 Filter depth Removal** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | COD lbs | BOD lbs | COD lbs | COD % | BOD lbs | BOD % | COD lbs | BOD lbs | COD lbs | COD % | BOD lbs | BOD % |
| a | 3540 | 1840 | 880 | 25 | 730 | 40 | 1190 | 620 | 420 | 35 | 320 | 52 |
| b | 1990 | 1330 | 810 | 41 | 590 | 44 | 670 | 440 | 300 | 45 | 220 | 50 |
| c | 2290 | 1550 | 740 | 32 | 440 | 28 | 770 | 520 | 300 | 39 | 200 | 38 |
| d | 2730 | 1480 | 1110 | 41 | 370 | 25 | 910 | 490 | 420 | 46 | 170 | 35 |
| e | 2660 | 1400 | 1330 | 50 | 660 | 47 | 890 | 470 | 420 | 47 | 250 | 53 |
| f | 2580 | 1700 | 1030 | 40 | 670 | 39 | 860 | 570 | 390 | 45 | 250 | 44 |
| AVE | 2630 | 1550 | 980 | 38 | 580 | 42 | 880 | 520 | 380 | 43 | 240 | 45 |
| g | 2290 | 1620 | 740 | 32 | 510 | 32 | 770 | 540 | 300 | 39 | 220 | 41 |
| h | 2950 | 2070 | 1250 | 42 | 820 | 40 | 990 | 690 | 470 | 48 | 320 | 46 |
| i | 2510 | 1620 | 1030 | 41 | 660 | 41 | 840 | 540 | 400 | 48 | 270 | 50 |
| j | 2210 | 1480 | 730 | 33 | 520 | 35 | 740 | 490 | 250 | 34 | 170 | 35 |
| k | 2580 | 1840 | 1100 | 43 | 810 | 44 | 860 | 620 | 390 | 45 | 320 | 52 |
| AVE | 2510 | 1730 | 970 | 38 | 660 | 38 | 840 | 580 | 360 | 43 | 270 | 45 |
| l | 2950 | 1990 | 1250 | 42 | 960 | 48 | 990 | 670 | 470 | 48 | 350 | 52 |
| m | 3020 | 1990 | 880 | 29 | 490 | 30 | 1010 | 670 | 440 | 44 | 270 | 40 |
| n | 3390 | 2070 | 1690 | 50 | 1180 | 57 | 1140 | 690 | 600 | 53 | 370 | 54 |
| o | 2950 | 1700 | 1180 | 40 | 670 | 39 | 990 | 570 | 470 | 48 | 220 | 39 |
| p | 3610 | 1770 | 1770 | 49 | 590 | 33 | 1210 | 590 | 640 | 53 | 240 | 41 |
| q | 2580 | 1620 | 440 | 17 | 290 | 18 | 860 | 540 | 290 | 34 | 170 | 32 |
| AVE | 3080 | 1860 | 1200 | 38 | 710 | 38 | 1030 | 620 | 480 | 46 | 270 | 43 |

Table 6. Natural Aeration Trickling Filter, Second Series, continued *

| Run | INFLUENT COD ppm | INFLUENT BOD ppm | INFLUENT SS ppm | INFLUENT pH | INFLUENT DO AM | INFLUENT ppm PM | EFFLUENT 1/3 Filter depth COD ppm | EFFLUENT 1/3 Filter depth BOD ppm | EFFLUENT 1/3 Filter depth SS ppm | EFFLUENT 1/3 Filter depth pH | EFFLUENT 1/3 Filter depth DO AM | EFFLUENT 1/3 Filter depth ppm PM | EFFLUENT 3/3 Filter depth COD ppm | EFFLUENT 3/3 Filter depth BOD ppm | EFFLUENT 3/3 Filter depth SS ppm | EFFLUENT 3/3 Filter depth pH | EFFLUENT 3/3 Filter depth DO AM | EFFLUENT 3/3 Filter depth ppm PM | 1/3 Filter depth Loading** COD lbs | 1/3 Filter depth Loading** BOD lbs | 1/3 Filter depth Removal** COD lbs | 1/3 Filter depth Removal** COD % | 1/3 Filter depth Removal** BOD lbs | 1/3 Filter depth Removal** BOD % | 3/3 Filter depth Loading** COD lbs | 3/3 Filter depth Loading** BOD lbs | 3/3 Filter depth Removal** COD lbs | 3/3 Filter depth Removal** COD % | 3/3 Filter depth Removal** BOD lbs | 3/3 Filter depth Removal** BOD % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| r | 4400 | 2500 | 560 | 7.7 | - | 3.3 | 3200 | 2000 | 1800 | 7.8 | - | 1.8 | 2800 | 1800 | 1200 | 7.3 | - | 1.5 | 3250 | 1840 | 890 | 27 | 360 | 20 | 1090 | 620 | 400 | 37 | 180 | 29 |
| s | 4300 | 2600 | 980 | 7.7 | 2.0 | 2.1 | 3000 | 1800 | 2000 | 7.2 | 0.5 | 1.7 | 2800 | 1800 | 2500 | 7.5 | 0.3 | 0.3 | 3170 | 1920 | 950 | 30 | 590 | 31 | 1060 | 640 | 370 | 35 | 270 | 42 |
| t | 4000 | 2600 | 600 | 8.0 | 2.3 | 2.2 | 2600 | 1600 | 1600 | 7.6 | 1.1 | 1.0 | 2600 | 1600 | 2800 | 7.2 | 0.5 | 0.3 | 2950 | 1920 | 1030 | 35 | 740 | 38 | 910 | 640 | 270 | 30 | 240 | 38 |
| u | 4200 | -- | 750 | 7.4 | 1.9 | 2.2 | 2500 | -- | 1600 | 7.9 | 1.8 | 1.0 | 2300 | -- | 2700 | 7.3 | 0.7 | 0.9 | 3100 | -- | 1260 | 41 | -- | - | 1040 | -- | 470 | 45 | -- | - |
| v | 3600 | 1900 | 570 | 7.6 | 3.1 | 2.4 | 2100 | 1200 | 1000 | 8.2 | 2.0 | 1.6 | 1900 | 1000 | 1300 | 8.2 | 2.6 | 2.4 | 2660 | 1400 | 1110 | 42 | 510 | 36 | 890 | 470 | 420 | 47 | 220 | 47 |
| w | 4400 | 2200 | 730 | 7.5 | - | 3.2 | 2500 | 1400 | 1500 | 8.0 | - | 2.6 | 2400 | 1400 | 1200 | 7.8 | - | 2.5 | 3250 | 1620 | 1410 | 43 | 590 | 36 | 1090 | 540 | 500 | 46 | 190 | 35 |
| x | 4300 | 2800 | 760 | 7.6 | - | 2.6 | 3400 | 2000 | 880 | 8.2 | - | 1.5 | 3000 | 1600 | 500 | 7.7 | - | 1.9 | 3170 | 2070 | 660 | 21 | 490 | 28 | 1060 | 690 | 320 | 30 | 290 | 42 |
| y | 4300 | 2600 | 790 | 7.7 | 3.4 | 3.1 | 2600 | 1700 | 1300 | 7.8 | 2.4 | 2.1 | 2300 | 1600 | 1000 | 7.5 | 3.4 | 2.5 | 3170 | 1920 | 1250 | 39 | 670 | 35 | 1060 | 640 | 490 | 46 | 240 | 38 |
| z | 3900 | 2600 | 1400 | 7.7 | 2.7 | 2.6 | 2400 | 1400 | 1400 | 6.6 | 2.1 | 1.4 | 2200 | 1200 | 1400 | 6.6 | 1.5 | 1.4 | 2880 | 1920 | 1110 | 38 | 890 | 46 | 960 | 640 | 420 | 44 | 340 | 53 |
| AVE | 4160 | 2480 | 810 | 7.7 | 2.5 | 2.6 | 2700 | 1640 | 1450 | 7.7 | 1.7 | 1.6 | 2480 | 1490 | 1620 | 7.5 | 1.2 | 1.5 | 3070 | 1830 | 1070 | 35 | 620 | 33 | 1020 | 610 | 410 | 40 | 250 | 40 |
| aa | 3900 | 2500 | 760 | 7.3 | - | 2.9 | 2700 | 1700 | 1600 | 6.7 |  | 1.0 | 2500 | 1500 | 2100 | 6.3 | - | 1.5 | 2880 | 1840 | 890 | 31 | 590 | 32 | 960 | 620 | 340 | 35 | 250 | 40 |
| bb | 4300 | 2400 | 660 | 7.3 | 2.1 | 2.6 | 3000 | 1800 | 2200 | 6.5 | 1.5 | 0.2 | 2700 | 1800 | 1900 | 6.4 | 0.6 | 0.2 | 3170 | 1770 | 950 | 30 | 440 | 25 | 1060 | 590 | 390 | 37 | 150 | 25 |
| cc | 4100 | 2700 | 950 | 7.4 | - | 2.4 | 3000 | 1800 | 820 | 7.1 | - | 1.6 | 2700 | 1600 | 370 | 6.9 | - | 2.2 | 3020 | 1990 | 800 | 26 | 550 | 33 | 1010 | 670 | 340 | 34 | 270 | 40 |
| dd | 4300 | 2500 | 560 | 7.3 | 2.5 | 2.1 | 3000 | 1900 | 1900 | 5.9 | 1.3 | 0.6 | 2900 | 1800 | 1200 | 5.7 | 1.9 | 1.1 | 3170 | 1840 | 950 | 30 | 440 | 24 | 1060 | 620 | 340 | 32 | 180 | 29 |
| ee | 4500 | 2500 | 900 | 6.9 | 1.8 | 1.8 | 3400 | 2000 | 3600 | 5.5 | 0.5 | 0.6 | 3500 | 1900 | 1200 | 5.6 | 1.2 | 0.9 | 3320 | 1840 | 810 | 24 | 360 | 20 | 1110 | 620 | 250 | 22 | 150 | 24 |
| AVE | 4220 | 2520 | 770 | 7.2 | 2.1 | 2.3 | 3020 | 1840 | 2020 | 6.3 | 1.1 | 0.8 | 2860 | 1720 | 1350 | 6.2 | 1.2 | 1.2 | 3110 | 1860 | 880 | 28 | 500 | 27 | 1040 | 620 | 330 | 32 | 200 | 32 |
| ff | 4200 | 2800 | 790 | 7.5 | - | 2.9 | 2600 | 1800 | 2200 | 6.0 | - | 1.0 | 2100 | 1400 | 1000 | 5.8 | - | 0.9 | 3100 | 2070 | 1180 | 38 | 740 | 36 | 1040 | 690 | 420 | 50 | 340 | 49 |
| gg | 3900 | 3000 | 800 | 8.8 | - | - | 2600 | 1700 | 1400 | 6.1 | - | - | 2000 | 1400 | 830 | 6.5 | - | - | 2880 | 2210 | 960 | 33 | 960 | 43 | 960 | 740 | 470 | 49 | 390 | 53 |
| hh | 4400 | 2700 | 830 | 8.1 | - | 2.4 | 2500 | 1500 | 400 | 7.8 | - | - | 2100 | 1300 | 230 | 7.6 | - | 3.0 | 3250 | 1990 | 1410 | 43 | 880 | 44 | 1090 | 670 | 570 | 52 | 350 | 52 |
| ii | -- | -- | -- | - | 3.5 | 2.9 | 2300 | 1400 | -- | 7.2 | 2.4 | 1.6 | 2200 | 1600 | -- | 7.0 | 3.2 | 2.8 | -- | -- | -- | - | -- | - | -- | - | -- | - | -- | - |
| jj | 4200 | 2500 | 650 | 7.8 | 1.6 | 1.5 | 3000 | 1800 | 870 | 6.3 | 1.2 | 0.7 | 2300 | 1700 | 1100 | 5.9 | 2.0 | 1.1 | 3100 | 1840 | 880 | 28 | 510 | 28 | 1040 | 620 | 470 | 45 | 200 | 32 |
| kk | 3400 | 2100 | 650 | 7.6 | 2.1 | - | 2900 | 2000 | 1100 | 5.7 | 1.0 | - | 2700 | 1800 | 1400 | 5.6 | 1.0 | - | 2510 | 1550 | 370 | 15 | 70 | 45 | 840 | 520 | 170 | 20 | 80 | 15 |
| ll | 3600 | 2100 | 570 | 7.1 | - | 3.9 | 2600 | 1800 | 1600 | 5.5 | - | 0.0 | 2600 | 1600 | 1400 | 5.4 | - | 0.2 | 2660 | 1550 | 740 | 28 | 220 | 14 | 890 | 520 | 250 | 28 | 120 | 23 |
| mm | 3100 | 2100 | 570 | 8.5 | 2.1 | - | 2700 | 1600 | 2100 | 6.1 | 0.1 | - | 2300 | 1500 | 3000 | 5.5 | 0.0 | - | 2290 | 1550 | 300 | 13 | 370 | 24 | 770 | 520 | 200 | 26 | 150 | 29 |
| nn | 3700 | 2400 | 590 | 7.5 | - | 1.9 | 2800 | 1800 | 2400 | 5.9 | - | 0.0 | 2600 | 1700 | 2800 | 5.9 | - | 0.0 | 2730 | 1770 | 660 | 24 | 440 | 25 | 910 | 590 | 270 | 30 | 170 | 29 |
| oo | 3800 | 2400 | 600 | 7.6 | - | 2.3 | 2900 | 1900 | 1800 | 6.3 | - | 0.1 | 2500 | 1600 | 1400 | 6.0 | - | 0.9 | 2800 | 1770 | 660 | 24 | 370 | 21 | 940 | 590 | 320 | 34 | 190 | 32 |
| AVE | 3810 | 2460 | 670 | 7.8 | 2.3 | 2.5 | 2690 | 1730 | 1540 | 6.3 | 1.0 | 0.8 | 2340 | 1560 | 1460 | 6.1 | 1.6 | 1.3 | 2810 | 1810 | 800 | 27 | 510 | 31 | 940 | 610 | 360 | 37 | 220 | 35 |

* Fresh and recycle hydraulic loads both 0.44 gallons per minute per square foot; nitrogen added.

** Organic load and pounds removal in lbs/1000 cu ft/day.

Table 7. Natural Aeration Trickling Filter, Second Series, Depth Comparisons *

| Run | COD, ppm | | | | BOD, ppm | | | | Suspended Solids | | | | pH | | | | DO, ppm | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Filter depth | | | | Filter depth | | | | Filter depth | | | | Filter depth | | | | | Filter depth | | | | | |
| | Influent | 1/3 | 2/3 | 3/3 | Influent | 1/3 | 2/3 | 3/3 | Influent | 1/3 | 2/3 | 3/3 | Influent | 1/3 | 2/3 | 3/3 | Influent | | 1/3 | | 2/3 | | 3/3 | |
| | | | | | | | | | | | | | | | | | AM | PM | AM | PM | AM | PM | AM | PM |
| a | 4800 | 3600 | 2700 | 3100 | 2500 | 1500 | 1000 | 1200 | 420 | 300 | 244 | 244 | 7.8 | 8.1 | 8.2 | 8.0 | | | | | | | | |
| b | 4100 | 2900 | 2800 | 2300 | 2700 | 1900 | 1600 | 1600 | 690 | 1400 | 1100 | 1000 | 7.5 | 7.5 | 7.4 | 7.3 | | | | | | | | |
| c | 4000 | 2400 | 2200 | 2100 | 2300 | 1400 | 1300 | 1400 | 750 | 980 | 2200 | 850 | 7.8 | 7.8 | 7.5 | 7.7 | 4.4 | 2.9 | 2.2 | 1.9 | 2.2 | 1.4 | 2.0 | 1.2 |
| d | 3500 | 2900 | 2500 | 2300 | 2200 | 1800 | 1600 | 1500 | 550 | 980 | 1000 | 850 | 8.0 | 7.9 | 7.4 | 7.6 | 3.7 | | 1.5 | | 1.5 | | 1.3 | |
| e | 4400 | 3200 | 3000 | 2800 | 2500 | 2000 | 1800 | 1800 | 560 | 1800 | 1200 | 1200 | 7.7 | 7.8 | 7.4 | 7.3 | | 3.3 | | 1.8 | | 1.7 | | 1.5 |
| f | 4000 | 2600 | 2700 | 2600 | 2600 | 1600 | 1600 | 1600 | 600 | 1600 | 1600 | 2800 | 8.0 | 7.6 | 7.3 | 7.2 | 2.3 | 2.2 | 1.1 | 1.0 | 1.4 | 0.9 | 0.5 | 0.3 |
| g | 3600 | 2100 | 2000 | 1900 | 1900 | 1200 | 1100 | 1000 | 570 | 1000 | 1100 | 1300 | 7.6 | 8.2 | 8.1 | 8.2 | 3.1 | 2.4 | 2.0 | 1.6 | 2.2 | 2.3 | 2.6 | 2.4 |
| h | 4400 | 2500 | 2500 | 2400 | 2200 | 1400 | 1500 | 1400 | 730 | 1500 | 1800 | 1200 | 7.5 | 8.0 | 7.9 | 7.8 | | 3.2 | | 2.6 | | 2.6 | | 2.5 |
| i | 4300 | 3400 | 3000 | 3000 | 2800 | 2000 | 1500 | 1600 | 760 | 880 | 570 | 500 | 7.6 | 8.2 | 7.9 | 7.7 | | 2.6 | | 1.5 | | 1.4 | | 1.9 |
| j | 3900 | 2400 | 2300 | 2200 | 2600 | 1400 | 1200 | 1200 | 1400 | 1400 | 1400 | 1400 | 7.7 | 6.6 | 6.6 | 6.6 | 2.7 | 2.6 | 2.1 | 1.4 | 1.4 | 0.6 | 1.5 | 1.4 |
| k | 3900 | 2700 | 2600 | 2500 | 2500 | 1700 | 1600 | 1500 | 760 | 1600 | 1600 | 2100 | 7.3 | 6.7 | 6.6 | 6.3 | | 2.9 | | 1.0 | | 1.3 | | 1.5 |
| l | 4100 | 3000 | 2800 | 2700 | 2700 | 1800 | 1800 | 1600 | 950 | 820 | 720 | 370 | 7.4 | 7.1 | 6.9 | 6.9 | | 2.4 | | 1.6 | | 1.8 | | 2.2 |
| m | 4500 | 3400 | 3200 | 3500 | 2500 | 2000 | 1900 | 1900 | 900 | 3600 | 1600 | 1200 | 6.9 | 5.5 | 5.7 | 5.6 | 1.8 | 1.8 | 0.5 | 0.6 | 1.2 | 1.1 | 1.2 | 0.9 |
| n | 3900 | 2600 | 2100 | 2000 | 3000 | 1700 | 1600 | 1400 | 800 | 1400 | 1400 | 830 | 8.8 | 6.1 | 6.1 | 6.5 | | | | | | | | |
| o | 4400 | 2500 | 2300 | 2100 | 2700 | 1500 | 1600 | 1300 | 830 | 400 | 325 | 230 | 8.1 | 7.8 | 7.6 | 7.6 | | 2.4 | | 2.0 | | 2.3 | | 3.0 |
| p | 4200 | 3000 | 2400 | 2300 | 2500 | 1800 | 1600 | 1700 | 650 | 870 | 560 | 1100 | 7.8 | 6.3 | 6.0 | 5.9 | 1.6 | 1.5 | 1.2 | 0.7 | 1.0 | 0.6 | 2.0 | 1.1 |
| q | 3400 | 2900 | 2800 | 2700 | 2100 | 2000 | 1900 | 1800 | 650 | 1100 | 1200 | 1400 | 7.6 | 5.7 | 5.7 | 5.6 | 2.1 | | 1.0 | | 1.1 | | 1.0 | |
| r | 3600 | 2600 | 2400 | 2600 | 2100 | 1800 | 1500 | 1600 | 570 | 1600 | 1800 | 1400 | 7.1 | 5.5 | 6.0 | 5.4 | | 2.2 | | 0.8 | | 0.5 | | 0.8 |
| s | 3100 | 2700 | 2700 | 2300 | 2100 | 1600 | 1700 | 1500 | 570 | 2100 | 2000 | 3000 | 8.5 | 6.1 | 5.8 | 5.5 | 2.1 | | 0.1 | | 0.1 | | 0 | |
| t | 3700 | 2800 | 3000 | 2600 | 2400 | 1800 | 1900 | 1700 | 590 | 2400 | 2100 | 2800 | 7.5 | 5.9 | 6.0 | 5.9 | | 1.9 | | 0 | | 0 | | 0 |
| u | 3800 | 2900 | 2900 | 2500 | 2400 | 1900 | 1700 | 1600 | 600 | 1800 | 1700 | 1400 | 7.6 | 6.3 | 5.9 | 6.0 | | 2.3 | | 0.1 | | 0.4 | | 0.9 |
| AVE | 3980 | 2810 | 2610 | 2500 | 2440 | 1700 | 1570 | 1520 | 710 | 1410 | 1300 | 1290 | 7.7 | 7.0 | 6.9 | 6.8 | 2.6 | 2.4 | 1.3 | 1.2 | 1.3 | 1.3 | 1.3 | 1.4 |
| % Removal | | 29 | 34 | 37 | | 30 | 36 | 38 | | | | | | | | | | | | | | | | |
| % Increase | | | | | | | | | | 99 | 83 | 82 | | | | | | | | | | | | |

Table 7. Natural Aeration Trickling Filter, Second Series, Depth Comparisons, continued *

| Run | 1/3 Filter Depth | | | | | | 2/3 Filter Depth | | | | | | 3/3 Filter Depth | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Loading ** | | Removal ** | | | | Loading** | | Removal** | | | | Loading** | | Removal** | | | |
| | COD lbs | BOD lbs | COD lbs | COD % | BOD lbs | BOD % | COD lbs | BOD lbs | COD lbs | COD % | BOD lbs | BOD % | COD lbs | BOD lbs | COD lbs | COD % | BOD lbs | BOD % |
| a | 3540 | 1840 | 880 | 25 | 730 | 40 | 1770 | 920 | 770 | 44 | 550 | 60 | 1190 | 620 | 420 | 44 | 320 | 52 |
| b | 3020 | 1990 | 880 | 29 | 490 | 30 | 1510 | 1000 | 480 | 32 | 410 | 41 | 1010 | 670 | 440 | 44 | 270 | 40 |
| c | 2950 | 1700 | 1180 | 40 | 670 | 39 | 1480 | 850 | 660 | 45 | 370 | 44 | 990 | 570 | 470 | 48 | 220 | 39 |
| d | 2580 | 1620 | 440 | 17 | 290 | 18 | 1290 | 810 | 370 | 29 | 220 | 27 | 860 | 540 | 290 | 34 | 170 | 32 |
| e | 3250 | 1840 | 890 | 27 | 360 | 20 | 1620 | 920 | 520 | 32 | 260 | 28 | 1090 | 620 | 400 | 37 | 180 | 29 |
| f | 2950 | 1920 | 1030 | 35 | 740 | 38 | 1480 | 960 | 480 | 32 | 370 | 38 | 910 | 640 | 270 | 30 | 240 | 38 |
| g | 2660 | 1400 | 1110 | 42 | 510 | 36 | 1330 | 700 | 590 | 44 | 300 | 43 | 890 | 470 | 420 | 47 | 220 | 47 |
| h | 3250 | 1620 | 1410 | 43 | 590 | 36 | 1620 | 810 | 700 | 43 | 260 | 32 | 1090 | 540 | 500 | 46 | 190 | 35 |
| i | 3170 | 2070 | 660 | 21 | 590 | 28 | 1590 | 1030 | 480 | 30 | 480 | 47 | 1060 | 690 | 320 | 30 | 290 | 42 |
| j | 2880 | 1920 | 1110 | 38 | 890 | 46 | 1440 | 960 | 590 | 41 | 520 | 54 | 960 | 640 | 420 | 44 | 340 | 53 |
| k | 2880 | 1840 | 890 | 31 | 590 | 32 | 1440 | 920 | 480 | 33 | 330 | 36 | 960 | 620 | 340 | 35 | 250 | 40 |
| l | 3020 | 1990 | 800 | 26 | 660 | 33 | 1510 | 1000 | 480 | 32 | 330 | 33 | 1010 | 670 | 340 | 34 | 270 | 40 |
| m | 3320 | 1840 | 810 | 24 | 360 | 20 | 1660 | 920 | 480 | 29 | 220 | 24 | 1110 | 620 | 250 | 22 | 150 | 25 |
| n | 2880 | 2210 | 960 | 33 | 960 | 43 | 1440 | 1110 | 660 | 46 | 520 | 47 | 960 | 740 | 470 | 49 | 390 | 53 |
| o | 3250 | 1990 | 1410 | 43 | 880 | 44 | 1620 | 1000 | 770 | 48 | 410 | 41 | 1090 | 670 | 570 | 52 | 350 | 52 |
| p | 3100 | 1840 | 880 | 28 | 510 | 28 | 1550 | 920 | 660 | 43 | 330 | 36 | 1040 | 620 | 470 | 45 | 200 | 32 |
| q | 2510 | 1550 | 370 | 15 | 70 | 45 | 1250 | 770 | 220 | 18 | 70 | 9 | 840 | 520 | 170 | 20 | 80 | 15 |
| r | 2660 | 1550 | 740 | 28 | 220 | 14 | 1330 | 770 | 440 | 33 | 220 | 29 | 890 | 520 | 250 | 28 | 120 | 23 |
| s | 2290 | 1550 | 300 | 13 | 370 | 24 | 1140 | 770 | 150 | 13 | 150 | 20 | 770 | 520 | 200 | 26 | 150 | 29 |
| t | 2730 | 1770 | 660 | 24 | 440 | 25 | 1360 | 890 | 260 | 19 | 180 | 20 | 910 | 590 | 270 | 30 | 170 | 29 |
| u | 2800 | 1770 | 660 | 24 | 370 | 21 | 1400 | 890 | 330 | 24 | 260 | 29 | 940 | 590 | 320 | 34 | 190 | 32 |
| AVE | 2940 | 1800 | 860 | 29 | 530 | 32 | 1470 | 900 | 500 | 34 | 320 | 35 | 980 | 600 | 360 | 37 | 230 | 37 |

* Fresh and recycle hydraulic loads-both 0.44 gallons per minute per square foot; nitrogen added.
** Organic load and pounds removal in lbs/1000 cu ft/day.

Table 8. Forced Aeration Trickling Filter, Second Series

| Hydr. load | | Influent | | | | | | | Effluent | | | | | | | Load * | | Removal * | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw gpm/ft² | Recyc. gpm/ft² | COD ppm | BOD ppm | SS ppm | pH | DO AM | ppm PM | Temp °F | COD ppm | BOD ppm | SS ppm | pH | DO AM | ppm PM | Temp. °F | COD #s | BOD #s | COD #s | % | BOD #s | % | Air SCFM | Nutr. |
| 0.54 | 0.90 | 4800 | 2500 | 420 | 7.8 | | | 81 | 4100 | 1900 | 240 | 7.6 | | | 80 | 4170 | 2170 | 610 | 15 | 520 | 24 | 100 | N,P |
| 0.57 | 1.13 | 2700 | 1800 | 150 | 8.6 | | | 84 | 2400 | 1600 | 140 | 7.0 | | | 84 | 2460 | 1640 | 270 | 11 | 180 | 11 | 100 | " |
| 0.54 | 1.08 | 3100 | 2100 | 250 | 8.4 | | | 80 | 2600 | 1800 | 150 | 7.4 | | | 80 | 2690 | 1820 | 430 | 16 | 260 | 14 | 100 | " |
| 0.54 | 1.08 | 3700 | 2000 | 600 | 8.5 | | | 81 | 2800 | 1800 | 650 | 6.8 | | | 80 | 3210 | 1740 | 780 | 24 | 180 | 10 | 100 | ' |
| 0.54 | 1.08 | 3600 | 1900 | 700 | 8.7 | | | 81 | 3400 | 1900 | 1100 | 10.5 | | | 80 | 3130 | 1650 | 180 | 6 | 0 | 0 | 100 | |
| 0.59 | 1.08 | 3500 | 2300 | 550 | 8.5 | | | 81 | 2700 | 1900 | 900 | 9.2 | | | 80 | 3290 | 2160 | 750 | 23 | 370 | 17 | 100 | " |
| Ave. 0.55 | 1.06 | 3570 | 2100 | 450 | 8.4 | | | 81 | 3000 | 1820 | 530 | 8.1 | | | 80 | 3160 | 1860 | 500 | 16 | 238 | 13 | 100 | N,P |
| 0.54 | 1.08 | 3100 | 2200 | 370 | 7.9 | | | 80 | 2700 | 2100 | 700 | 6.1 | | | 80 | 2690 | 1910 | 350 | 13 | 90 | 5 | 200 | N,P |
| 0.54 | 1.08 | 4000 | 2800 | 600 | 8.1 | | | 80 | 3000 | 2300 | 800 | 6.3 | | | 80 | 3470 | 2430 | 870 | 25 | 430 | 18 | 200 | " |
| 0.54 | 1.08 | 3400 | 2200 | 550 | 7.8 | | | 81 | 2500 | 1800 | 600 | 6.2 | | | 81 | 2950 | 1910 | 780 | 26 | 350 | 18 | 200 | " |
| 0.36 | 1.08 | 3000 | 2000 | 550 | 7.4 | | | 80 | 2400 | 1900 | 700 | 5.5 | | | 80 | 1740 | 1160 | 350 | 20 | 60 | 5 | 200 | ' |
| 0.23 | 1.08 | 3500 | 2500 | 700 | 7.2 | | | 81 | 2500 | 1800 | 1600 | 5.2 | | | 81 | 1270 | 900 | 370 | 29 | 250 | 28 | 200 | " |
| Ave. 0.44 | 1.08 | 3400 | 2340 | 550 | 7.6 | | | 80 | 2620 | 1980 | 880 | 5.8 | | | 80 | 2420 | 1660 | 540 | 23 | 244 | 15 | 200 | N,P |
| 0.23 | 1.08 | 4000 | 2700 | 800 | 7.7 | | | 76 | 2400 | 1600 | 1100 | 6.4 | | | 75 | 1450 | 980 | 580 | 40 | 400 | 41 | 300 | N,P |
| -- | -- | 4100 | 2700 | 690 | 7.5 | | | - | -- | -- | -- | - | | | - | -- | -- | -- | - | -- | - | 300 | " |
| 0.45 | 1.08 | 4600 | 2800 | 840 | 7.8 | | | 81 | 4100 | 2700 | 720 | 6.6 | | | 80 | 3330 | 2030 | 360 | 11 | 80 | 4 | 300 | |
| 0.45 | 1.08 | 4000 | 2300 | 750 | 7.8 | 4.4 | 2.9 | 83 | 2900 | 1900 | 900 | 5.9 | 2.2 | 2.5 | 83 | 2890 | 1660 | 790 | 27 | 290 | 18 | 300 | |
| -- | -- | 4900 | 2400 | 700 | 7.9 | 3.1 | 3.9 | - | 2900 | 2000 | 860 | 5.6 | 2.2 | 2.6 | - | -- | -- | -- | - | -- | - | 300 | " |
| 0.45 | 0.90 | 3500 | 2200 | 550 | 8.0 | 3.7 | - | - | 2600 | 1700 | 780 | 5.1 | 0.9 | - | - | 2530 | 1590 | 650 | 26 | 360 | 23 | 300 | " |
| Ave. 0.40 | 1.03 | 4180 | 2520 | 720 | 7.8 | 3.7 | 3.4 | 80 | 2980 | 1980 | 870 | 5.9 | 1.8 | 2.6 | 79 | 2550 | 1570 | 660 | 26 | 333 | 21 | 300 | N,P |

Table 8. Forced Aeration Trickling Filter, Second Series, continued

| | Hydr. load | | Influent | | | | | | | Effluent | | | | | | | Load * | | Removal * | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw gpm/ft² | Recyc. gpm/ft² | COD ppm | BOD ppm | SS ppm | pH | DO AM | ppm PM | Temp °F | COD ppm | BOD ppm | SS ppm | pH | DO AM | ppm PM | Temp °F | COD #s | BOD #s | COD #s | % | BOD #s | % | Air SCFM | Nutr. |
| | 0.45 | 1.08 | 4400 | 2500 | 560 | 7.7 | - | 3.3 | 122 | -- | -- | -- | - | - | 0.0 | 121 | 3180 | 1810 | -- | - | -- | - | 100 | N, P |
| | 0.50 | 0.90 | 4300 | 2600 | 980 | 7.7 | 2.0 | 2.1 | 118 | 4200 | 2200 | 1000 | 6.0 | 0.0 | 0.0 | 114 | 3420 | 2070 | 80 | 2 | 320 | 16 | 100 | " |
| | 0.54 | 0.90 | 4000 | 2600 | 600 | 8.0 | 2.3 | 2.2 | 112 | 3300 | 2000 | 6500 | 5.6 | 0.0 | 0.0 | 112 | 3470 | 2260 | 600 | 17 | 520 | 23 | 100 | " |
| | 0.45 | 0.90 | 4200 | -- | 750 | 7.4 | 1.9 | 2.2 | 117 | 3500 | -- | 3100 | 5.1 | 0.0 | 0.0 | 115 | 3040 | -- | 510 | 17 | -- | - | 100 | " |
| | 0.54 | 0.90 | 3600 | 1900 | 570 | 7.6 | 3.1 | 2.4 | 122 | 3300 | 1800 | 2200 | 6.0 | 0.0 | 0.0 | 122 | 3130 | 1650 | 260 | 8 | 90 | 6 | 100 | ' |
| | 0.54 | 0.90 | 4400 | 2200 | 730 | 7.5 | - | 3.2 | 121 | 3200 | 1800 | 625 | 5.4 | - | 0.0 | 120 | 3820 | 1910 | 1040 | 27 | 350 | 18 | 100 | ' |
| | 0.50 | 0.90 | 4300 | 2800 | 760 | 7.6 | - | 2.6 | 114 | 3900 | 2200 | 1900 | 6.9 | - | 0.8 | 112 | 3420 | 2230 | 320 | 9 | 480 | 22 | 100 | |
| | 0.50 | 0.90 | 4300 | 2600 | 790 | 7.7 | 3.4 | 3.1 | 118 | 3500 | 2300 | 750 | 6.7 | 0.7 | 0.6 | 119 | 3420 | 2070 | 550 | 16 | 240 | 12 | 100 | " |
| | 0.50 | 0.90 | 3900 | 2600 | 1400 | 7.7 | 2.7 | 2.6 | 112 | 3400 | 1900 | 500 | 6.4 | 0.5 | 0.8 | 111 | 3100 | 2070 | 390 | 13 | 560 | 27 | 100 | " |
| Ave. | 0.50 | 0.92 | 4160 | 2480 | 810 | 7.7 | 2.5 | 2.6 | 117 | 3550 | 2020 | 2070 | 6.0 | 0.2 | 0.2 | 116 | 3330 | 2010 | 465 | 14 | 352 | 18 | 100 | N, P |
| | 0.54 | 0.90 | 3900 | 2500 | 760 | 7.3 | - | 2.9 | 116 | 3600 | 1900 | 750 | 6.5 | - | 0.8 | 114 | 3390 | 2170 | 260 | 8 | 520 | 24 | 200 | N, P** |
| | 0.54 | 0.90 | 4300 | 2400 | 660 | 7.3 | 2.1 | 2.6 | 115 | 3700 | 2200 | 670 | 6.0 | 0.2 | 0.9 | 115 | 3730 | 2080 | 520 | 14 | 170 | 8 | 200 | " |
| | 0.54 | 0.90 | 4100 | 2700 | 950 | 7.4 | - | 2.4 | 117 | 4000 | 2300 | 700 | 6.8 | - | 1.2 | 117 | 3560 | 2340 | 90 | 2 | 340 | 14 | 200 | " |
| | 0.50 | 0.90 | 4300 | 2500 | 560 | 7.3 | 2.5 | 2.1 | 120 | 3200 | 2100 | 810 | 5.7 | 0.2 | 1.1 | 121 | 3420 | 1990 | 870 | 25 | 320 | 16 | 200 | " |
| | 0.50 | 0.90 | 4500 | 2500 | 900 | 6.9 | 1.8 | 1.8 | 120 | 4100 | 2200 | 1000 | 5.7 | 1.0 | 1.0 | 118 | 3580 | 1990 | 320 | 9 | 240 | 12 | 200 | " |
| Ave. | 0.52 | 0.90 | 4220 | 2520 | 770 | 7.2 | 2.1 | 2.3 | 117 | 3720 | 2140 | 790 | 6.1 | 0.4 | 1.0 | 117 | 3540 | 2110 | 420 | 12 | 310 | 15 | 200 | N, P** |
| | 0.45 | 0.90 | 4200 | 2800 | 790 | 7.5 | - | 2.9 | 110 | 3600 | 2300 | 650 | 5.8 | - | 1.6 | 106 | 3040 | 2030 | 440 | 14 | 370 | 18 | 300 | N, P** |
| | 0.45 | 0.90 | 3900 | 3000 | 800 | 8.8 | - | - | 85 | -- | -- | -- | - | - | - | 83 | 2820 | 2170 | -- | - | -- | - | 300 | " |
| | 0.45 | 0.90 | 4400 | 2700 | 830 | 8.1 | - | 2.4 | 105 | 3700 | 2300 | 480 | 7.1 | - | 1.1 | 108 | 3180 | 1950 | 500 | 16 | 290 | 15 | 300 | |
| | 0.45 | 0.90 | -- | -- | -- | - | 3.5 | 2.9 | 104 | -- | -- | -- | - | 1.5 | 1.1 | 112 | -- | -- | -- | - | -- | - | 300 | " |
| | 0.50 | 0.90 | 4200 | 2500 | 650 | 7.8 | 1.6 | 1.5 | 105 | 3500 | 2200 | 630 | 5.8 | 0.5 | 0.8 | 109 | 3340 | 1990 | 550 | 16 | 240 | 12 | 300 | " |
| | 0.45 | 0.90 | 3400 | 2100 | 650 | 7.6 | 2.1 | - | 109 | 3100 | 2000 | 600 | 6.1 | 1.0 | - | 109 | 2460 | 1520 | 220 | 9 | 70 | 5 | 300 | " |
| | 0.54 | 0.90 | 3600 | 2100 | 570 | 7.1 | - | 3.9 | 108 | 3600 | 2200 | 510 | 5.8 | - | 1.8 | 110 | 3130 | 1820 | -- | - | -- | - | 300 | ' |
| | 0.54 | 0.90 | 3100 | 2100 | 570 | 8.5 | 2.1 | - | 110 | 2900 | 1900 | 580 | 5.8 | 1.0 | - | 108 | 2690 | 1820 | 170 | 6 | 170 | 9 | 300 | " |
| | 0.50 | 0.90 | 3700 | 2400 | 590 | 7.5 | - | 1.9 | 114 | 3200 | 2000 | 540 | 5.6 | - | 1.2 | 108 | 2940 | 1910 | 160 | 5 | 320 | 17 | 300 | " |
| | 0.54 | 0.90 | 3800 | 2400 | 600 | 7.6 | - | 2.3 | 106 | 3400 | 2100 | 530 | 5.7 | - | 1.4 | 104 | 3300 | 2080 | 350 | 11 | 260 | 12 | 300 | " |
| Ave. | 0.49 | 0.90 | 3810 | 2460 | 670 | 7.8 | 2.3 | 2.5 | 106 | 3380 | 2130 | 570 | 6.0 | 1.0 | 1.3 | 106 | 2990 | 1920 | 331 | 11 | 242 | 13 | 300 | N, P** |

* Organic load and pounds removal in lbs/1000 cu ft/day.

** Decreasing nutrient addition.

| 1 Accession Number | 2 Subject Field & Group | |
|---|---|---|
| | 05D | **SELECTED WATER RESOURCES ABSTRACTS** INPUT TRANSACTION FORM |

5 *Organization*

National Canners Association, Berkeley, California

6 *Title*

TRICKLING FILTER TREATMENT OF FRUIT PROCESSING WASTE WATERS

10 *Author(s)*

Mercer, Walter A.
Rose, Walter W.

16 *Project Designation*

12 060 EAE

21 *Note*

22 *Citation*

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37 pages, 7 figures, 8 tables, and 11 references.

23 *Descriptors (Starred First)*

*Canneries, *Industrial wastes, *Biological treatment, Aerobic treatment, Organic wastes, Waste treatment

25 *Identifiers (Starred First)*

Forced aeration - controlled temperature trickling filter

27 *Abstract*

Two high rate trickling filters were evaluated for treating fruit canning liquid wastes; one was 7.5 feet deep and had provision for heating the treated waste and for forced aeration; the other was 21.5 feet deep and was operated at ambient temperatures and with natural aeration; both were packed with a high void ratio plastic medium.

Nitrogen added to the cannery waste improved the removal of BOD and COD. In the absence of added nitrogen a thick fungal slime developed with odors characteristic of anaerobic microbial action. More often than not, percent removals declined with increasing organic loadings; the pounds of BOD removed per unit volume increased with high loadings. Elevated temperatures were not consistently shown to improve the performance of the experimental filter. Forced aeration was not proven beneficial but maintained higher levels of dissolved oxygen.

The top third of the 21.5 foot trickling filter accomplished 80% of the filter's total BOD removal under a light hydraulic loading. The natural aeration filter maintained a slightly higher dissolved oxygen concentration in the effluent than did the experimental filter with forced aeration.

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