THE UNIVERSITY OF WATERLOO RESEARCH INSTITUTE

THE USE OF PLASTIC-MEDIA TRICKLING FILTERS FOR WASTEWATER TREATMENT

by

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ABSTRACT

The applicability of plastic-media trickling filters as a "roughing" treatment for the meat-packing industry has been investigated. A pilot-plant study designed to obtain comprehensive operational data over a wide range of organic and hydraulic loadings was carried out and the data obtained were evaluated with respect to the design and operation of the process to reduce BOD and SS loadings to a level acceptable for discharge to municipal sewers.

The pilot-plant trickling filter, consisting of a 4 ft. x 4 ft. x 18 ft. "Flocor" packed tower, a final clarifier, and extensive pumping and monitoring facilities, was operated on-site at a large meat-packing plant under both winter and summer conditions for 2 years. The waste stream being treated received primary treatment in the form of screening and air flotation.

One of the major waste treatment operational problems encountered resulted from a five-day production week at the packing plant. During weekends when no flow was available, the filter was either placed on recycle or shut-down for a period of approximately 60 hours. Results obtained after start-up have shown that treatment efficiency can be recovered in a period of less than half a day.

Daily performance data have been obtained at hydraulic loadings from 0.5 to 2.0 gpm/ft^2 and organic loadings of 500 to 1500 lb COD/1000 ft^3/day. In addition the process has been subjected to diurnal fluctuations in the waste strength from 300 to 2400 mg/l COD.

The results of the study have been used to develop rational design procedures for trickling filters treating high strength organic wastes.

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1.0 INTRODUCTION

The trickling filter has been used for the treatment of wastewaters since 1893 when the first unit was put into operation in England. The conventional process, with rock media, has been used extensively in Great Britain and the United States for the treatment of domestic waters and, to a limited degree, for industrial waste. It has not been used to any great extent in Canada due mainly to the problems of operating the process in cold weather.

Two recent developments in the area of wastewater treatment have lead to a renewed interest in the trickling filter process. The first is the development of light-weight plastic media which has overcome many of the disadvantages of conventional rock media. The plastic media has a much higher surface area to volume ratio and, therefore a higher percentage of void space than conventional stone media. This allows significant increases in both hydraulic and organic loadings which can be applied to the media. Also, the lower specific weight of the plastic media in comparison to conventional rock media, has meant that filters are no longer limited to depths of 6-8 ft. and, therefore do not require such large areas of land for the same overall volume of media. Moreover, plastic media filters, which can be constructed to heights of 40 ft., have under certain conditions had their final clarification system installed directly underneath the filter tower further reducing land requirements.

The second development has been the increasing trend for municipalities to force local industries, through the enactment of industrial waste control legislation, to pay directly for the use of municipal sewage treatement systems in addition to general tax levies. Generally, this payment is a surcharge based on the industrial waste flow and pollutant concentrations which exceed those of normal domestic sewage. The various industries are then faced with a decision of whether to pay the surcharge or provide their own waste treatment system which will produce a suitable effluent for discharge to the municipal sewer system. The trickling filter process has the advantage that it can conveniently provide a wide range of treatment efficiencies and thereby be very attractive to industries requiring only partial treatment of their wastewaters.

One industry which frequently finds itself in the position of facing industrial waste surcharges while having only limited land available for the development of waste treatment facilities is the meat-packing industry. Many packing houses which were originally located on the outskirts of cities, are now virtually surrounded by other industrial developments or even residential neighbourhoods. Yet, as the cities are expanding, they are also requiring industry to assume more of the cost of operation of municipal sewage treatment plants.

Many meat-packers all across Canada are faced with this problem and there is a great lack of design and performance data for a trickling filter operating as a roughing process. Therefore, the Waterloo Research Institute under contract to Environment Canada, carried out this study in an attempt to provide this information.

1.1 Objectives

The basic objectives of the study were:

(a) to evaluate the trickling filter as a method of treatment for meat packing wastewaters, and

(b) to develop, design and operation parameters for its application.

1.2 Scope

The basic data required to fulfill these objectives was obtained through the operation of a pilot-plant plastic media filter to treat the wastewaters from the slaughter house and meat packing plant of J. M. Schneider Company Limited, Kitchener, Ontario. The range of hydraulic and organic loadings at which the pilot-plant was operated provided what is generally termed "roughing" treatment.

The pilot-plant data were used to develop performance and operational information on the applicability of the trickling filter to the treatment of meat packing wastes. In addition the data were utilized to evaluate existing design procedures for trickling filters operating under high organic and hydraulic loadings.

1.3 Acknowledgements

This study was funded through a contract with Environment Canada. The administrative assistance of Mr. R. E. Mills, Water Pollution Research Sub-Division, Environment Canada, Project Officer, is greatly appreciated.

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Chief Engineer and Mr. G. M. Kestle, Plant Engineer, provided technical and administrative inputs to the effective functioning of the project. Mr. John Lund as well as other operating personnel at J. M. Schneider Ltd. provided essential services as required and without their cooperation and assistance this project would have been seriously inhibited.

The day to day operation of the pilot-plant and analysis of the samples collected was most ably carried out by Mr. W. R. McGill, Mr. H. W. Campbell and Mr. G. N. Plant. The assistance of Mr. H. W. Chambers and Mr. I. Tkaczuk, Water Resources and Sanitary Engineering Laboratories, the University of Waterloo was invaluable in the successful completion of the large amounts of analytical and experimental work associated with this project.

2.0 LITERATURE REVIEW

Trickling filtration is a biological treatment process wherein wastewater is distributed over the surface of an inert support medium on which a microbial slime layer is developed. As the water flows over the slime-covered packing surface in a thin liquid film organic material and oxygen are absorbed and utilized by the slime layer accounting for the reduction in the organic components in the effluent waste.

Throughout their long period of use, extensive studies have been conducted to evaluate trickling filter performance, yet it would appear that adequate design formulations required for the development of design criteria are not available. Clear evidence of this fact is present in a recent paper by Baker and Graves (1) indicating the need for the development of a rational design procedure for trickling filters.

The problem has been further complicated by the recent introduction of plastic-media trickling filters which are being used extensively as roughing filters. Pilot-scale and full-scale studies (2, 3) have proven that these units can be operated effectively at high organic and hydraulic loading rates. Design formulations (4, 5) have been limited to those relationships considered to be valid for high-rate trickling filters using conventional media. Since this approach is unsatisfactory for the design of conventional high-rate filters, it is unlikely that it can provide adequate design criteria for the roughing filter using plastic media.

The purpose of this section of the report is:

(1) to review the present knowledge of trickling filter design and performance relationships,

(2) to discuss the various biological treatment schemes which have been used in the treatment of meat-packing wastes.

2.1 Performance Relationships for Trickling Filters

In recent years, many mathematical models have been developed to describe trickling filter performance. While these relationships may fit the data which has been generated, they have not considered all of the many factors required in the development of a complete theory of organic removal in trickling filters which can then be applied in a suitable mathematical equiation for design. One of the most recent literature reviews is that of Gromiec and Malina (6) which provides a summary of the theory and states the corresponding mathematical model for a considerable number of investigations conducted to evaluate trickling filter performance.

A literature review by Monadjemi (7) describes three approaches which have been formulated to predict trickling filter performance equiations: these approaches are identified as statistical, empirical, and mechanistic. The single statistical approach is that of Galler and Gotaas (8) who used multiple linear regression to develop a mathematical model. Empirical relationships include the theories, equiations and experimental studies of Velz (9), Fair and Geyer (10), Schulze (11), Howland (12), Bloodgood (13), Sinkoff (14), Stack (15), and Eckenfelder (16) as well as the infamous NRC equation (17). The empirical relationships have generally developed from the first-order reaction equation which will be further discussed as it is in its present form. Mechanistic approaches, which are based on biological principles, have been included in the studies of Ames (18), Atkinson (19), Swilley (20) and Maier (21, 22). This approach will also be discussed in detail later as it perhaps is the most likely to lead to realistic design procedures.

In his review of the literature, Maier (21) concludes that the effects of process variables such as hydraulic loading, organic loading, filter depth, temperature and recirculation are not well enough defined for present design procedures. He further concludes that the most promising approach is through a study aimed at the mechanism of purification.

The study by Baker and Graves (1) suggests the need for a rational design procedure. Three existing mathematical models, those of Eckenfelder (16), Galler and Gotaas (8) and the NRC equation (17), were used to determine the volume of media required to obtain a specific percentage removal under certain given conditions. The predicted volumes of media varied to such a degree that they would be unacceptable for design formulations. In these calculations, filter depth was held constant and the specific surface area of the media was not considered.

The two most recent developments in trickling filter performance equations, one based on first-order BOD removal and the second on a mechanistic approach are described in further detail below.

2.1.1 Modified First-Order BOD Removal Model

The most recent trickling filter model, based on the Velz approach of first-order BOD removal, is presented below as Equation 2-1.

$$s_e / s_o = \exp (-K_{20} \, \theta^{(T-20)} \, Ap \, D / Q^n) \qquad (2\text{-}1)$$

where s_o = influent substrate concentration, (mg/l)
s_e = effluent substrate concentration at depth D, (mg/l)
K_{20} = BOD removal rate coefficient at 20°C
θ = temperature coefficient
T = wastewater temperature, (°C)
Ap = specific surface area of medium, (ft^2/ft^3)
D = depth of filter, (ft)
Q = hydraulic loading rate, (gpm/ft^2)
n = hydraulic loading rate exponent

The above relationship, a modification of the equation developed by Eckenfelder (16), was reported by Gromiec and Malina (6) as adequately representing the performance of a plastic medium trickling filter treating domestic sewage.

In a study at the University of Waterloo (23), Equation 2-1 was used to determine the effect of temperature on the performance of a "Flocor" packed trickling filter treating domestic waste. It was realized that the constants determined for the relationship were valid only for the specific waste being treated and for the range of variables encountered in the pilot-scale study. Any attempt to utilize the relationship outside the range of operating conditions produced results which were considered unrealistic in terms of design calculations. It was evident that this formulation which adequately described the performance of the trickling filter for a specific set of operating conditions, was not satisfactory as a design equation or model to predict performance under different operating conditions.

2.1.2 Mechanistic Model

A more recent mathematical model, based on a consideration of the basic mechanisms controlling substrate removal has been proposed by Kornegay and Andrews (24, 25). A summary of the basis for this model and the resulting performance equation are described below.

The assumption was made that the aerobic zone, defined by the depth of penetration of oxygen in the slime layer, represents the major site of the biological reaction. The mass flux of oxygen across the slime-liquid interface is a function of the oxygen requirements of the slime layer and the concentration of dissolved oxygen at the air-liquid interface. At high substrate concentrations in the liquid film, the oxygen requirements of the slime layer are constant resulting in a constant depth of penetration of oxygen in the slime layer. At lower substrate concentrations there is a decreased oxygen requirement in the slime layer accompanied by an increased oxygen concentration at the slime-liquid interface for this condition there should be an increase in the depth of penetration of oxygen in the slime layer. For an increased flow rate and specific applied organic loading, the mass flux of oxygen across the air-liquid interface and slime-liquid interface increases, increasing the depth of the active slime layer.

For a specific substrate concentration and flow rate, a concentration gradient is established in the liquid film and slime layer. Variations in flow rate and influent substrate concentration result in proportional shifts in the substrate concentration gradient.

The Monod theory (26) was used to develop a relationship to determine the microbial growth rate and, thus, rate of substrate utilization at specific depths in an elemental volume of active slime layer. Since determination of the rate of substrate utilization for the elemental volume of active slime is dependent on establishing values for the substrate concentration gradient in the slime layer, use of the relationship is not practical; it is essential that the relationship be formulated in order to understand the mechanism of the biological reactions occurring within the slime layer.

An alternate procedure for determining the rate of substrate removal is available, as under steady-state conditions, the rate of substrate utilization equals the mass flux of substrate across the slime-liquid interface. Since the substrate concentration in the liquid film is directly proportional to the substrate concentration gradient in the slime layer, and the latter determines the rate of substrate removal, then the substrate concentration in the liquid film can be related to the rate of substrate utilization in the slime layer. The relationship existing between the substrate concentration in the liquid film and the rate of substrate utilization is presented in graphical form in Figure 2.1.1.

The mathematical relationship developed by Kornegay and Andrews (24, 25), relating ~~BOD-removal and~~ basic parameters is:

$$(so - se) + Kc \ln\left(\frac{so}{se}\right) = \frac{\mu_{max}\ (h)\ (X)}{Y}\ \frac{(A_p)\ (H)\ (D)}{Q} \qquad (2\text{-}2)$$

where s_o = influent substrate concentration, (mg/l)

s_e = substrate concentration at a filter depth D, (mg/l)

K_c = substrate concentration in the liquid film at one half the maximum mass flux, (mg/l)

$\mu_{max}\ (h)\ (X)/Y$ = maximum mass flux of substrate at the slime-liquid interface, ($mg/ft^2/hr$)

Ap = specific surface area of the filter medium, (ft^2/ft^3)

H = cross-sectional surface area of the filter, (ft^2)

D = filter depth, (ft)

Q = flow rate, (l/hr)

For a specific flow rate and influent substrate concentration Equation 2-2 can be used to establish effluent substrate concentrations at specific filter depths.

This model has been supported by laboratory work at the University of Waterloo using a single carbon source (27). Jank has developed procedures for evaluating the parameters which are found in the performance equiation. Lindsay (28), following the procedures proposed by Jank, used meat-packing wastewater on the same laboratory-scale trickling filter to evaluate constants for the model. He found similar trends in the results for a complex industrial waste as were predicted using the single carbon source, glucose, and concluded that the results from the laboratory filter could be used to predict the removal of soluble organic material in a full-scale plant.

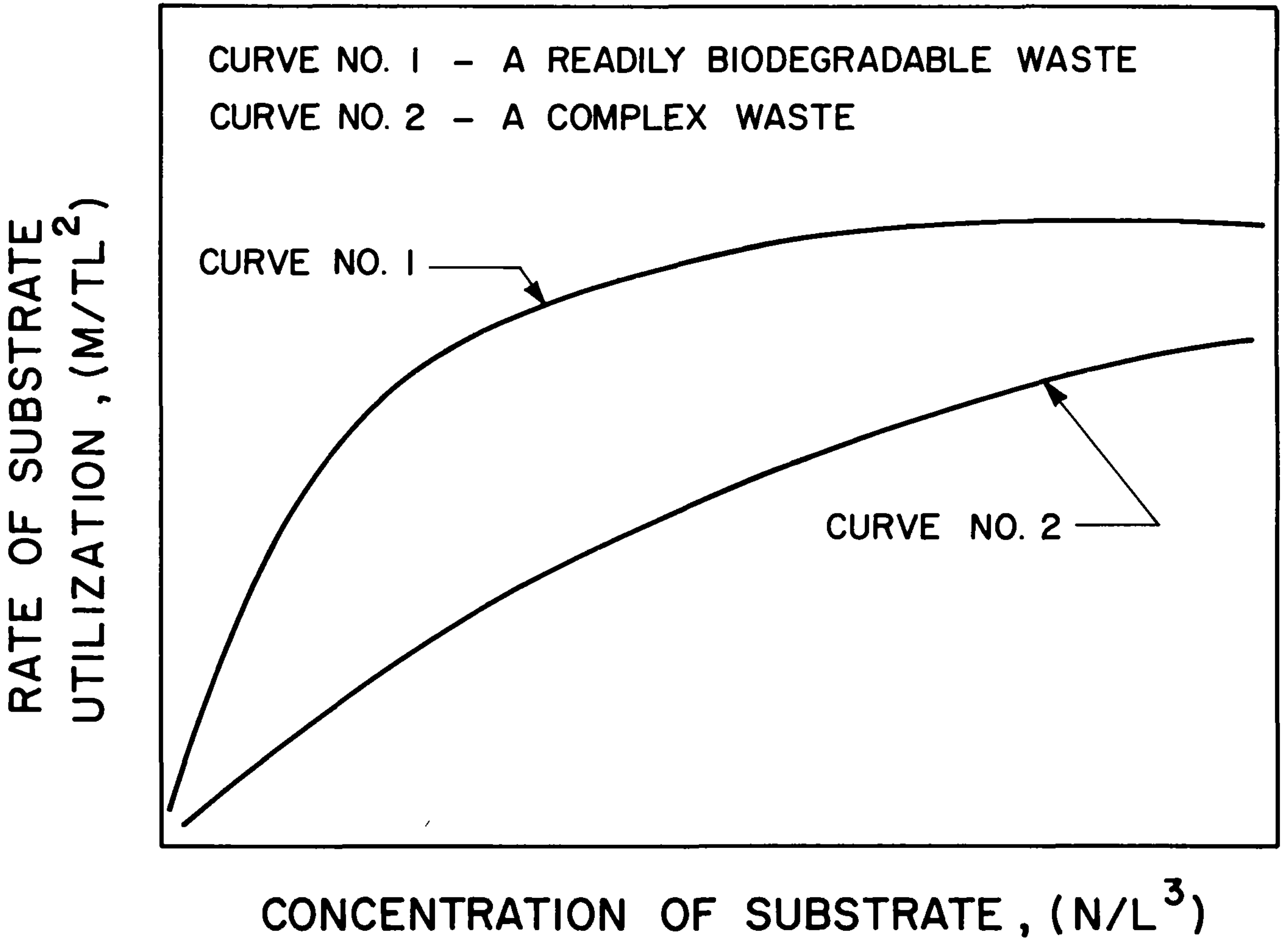


FIGURE 2.1.1 RELATIONSHIP BETWEEN SUBSTRATE CONCENTRATION IN THE LIQUID FILM AND THE SUBSTRATE UTILIZATION RATE

Since the model has the advantages of incorporating the effects of all significant parameters, it is expected, that if sufficient trickling filter data are obtained on a pilot-plant basis to evaluate these parameters, a most useful relationship will develop for trickling filter design.

2.1.1 Conclusions

The performance of trickling filters in the removal of organic materials from wastewater is affected by many factors such as hydraulic and organic loadings, characteristics of the applied wastewater, depth of filter, and physical characteristics of the medium. Although many models have been presented which relate many of the above factors to the efficiency of a trickling filter, no wholly satisfactory relationship has been developed to date.

Most of the relationships describing trickling filter performance are based on modifications of the first-order substrate removal rate theory initially proposed by Velz (9). The most widely accepted such relationship as reported above is that proposed by Eckenfelder (16). This equation basically relates the ratio of effluent concentration to the influent concentration with an average BOD removal rate constant, the filter depth and specific surface area, and hydraulic loading rate. Although several investigators have successfully used this relationship as well as empirical design formulae such as the NRC formula (17), or that developed by Galler and Gotaas (8) it must be emphasized that they are valid only for the range of conditions, i.e., waste characteristics, temperature, filter media, operation, etc., prevailing in the plants from which the performance data was collected and correlated to the quations. Any attempt to use such design relationships in other circumstances cannot be jusitified.

The most promising application for the newer plastic media trickling filters appears to be as a "roughing" process for more concentrated industrial wastes. However, no acceptable design relationships are currently available for this application. Most of the empirical and theoretical design equations have been developed or verified using data from filters treating domestic sewage. Using such design relationships for industrial applications will not lead to realistic designs.

In order to effectively design a trickling filter the engineer requires quantitative data on the following (29):

1. The BOD removal efficiency obtainable as a function of organic or hydraulic loading, and the effect of temperature on this efficiency.
2. Optimum depth in relation to construction and pumping costs as well as performance.
3. The relative benefits of recirculation.
4. Settling properties of solids produced as well as their quantity and dewatering properties.

While there is a considerable amount of information available relative to the above aspects of trickling filter design and performance it is generally inadequate to provide firm designs, especially for high rate and roughing applications. Much of the information available has been obtained from empirical studies and, while these are valuable especially for design under the same conditions as the study, there is a need for more fundamental understanding of trickling filter performance.

Theoretical models such as those developed by Atkinson (19), and Kornegay and Andrews (24) for example, need to be further developed and evaluated if more precise interpretation and prediction of trickling filter performance is to be available.

2.2 Treatment of Meat-Packing Wastes

The meat-packing industry is the largest food processing industry in Canada. According to the 1969 Dominion Bureau of Statistics records, the percentage increase in total meat slaughtered as carcass weight in 1966 was 3.5% over the average for the period 1961-1965. The total weight of dressed production beef, veal, pork, mutton and lamb has increased from 2,545 million pounds in 1963 to 3,024 million pounds in 1967. The slaughter and processing of this meach which is carried out in over 300 plants located in every province, generally in urban centers, results in the production of large volumes of highly concentrated organic wastewaters.

2.2.1 General Wastewater Characteristics

While the wastewater characteristics of a particular meat-packing plant vary according to its size, the type of animal processed, and the in-plant recovery methods of inedible products, a general range of characteristics indicates the magnitude of the problems involved.

TABLE 2.2.1

TYPICAL WASTEWATER CHARACTERISTICS

(lb. per 1,000 lb. Live Weight Kill)

Parameter	Average	Range
BOD	11.80	5.26 - 17.82
SS	9.00	4.18 - 21.55
Grease	8.16	4.88 - 32.60
Organic Nitrogen	.69	.27 - 1.22
Ammonia Nitrogen	.13	.03 - .71
Total Phosphorous	.11	.06 - .21
Soluble Phosphorous	.06	.02 - .13

The general range of waste load for the U.S. industry has been well documented in the 1968 report by the U.S. Department of the Interior, "The Cost of Clean Water" (30) and more recently in a study conducted by Crandall et al (31) using data from eight plants during the period between 1962 and 1969. The results of the latter study are typical and are shown in Table 2.2.1. The units of all parameters are expressed in terms of pounds per 1000 lb. of animal live weight slaughtered.

The limited Canadian data available indicate that these values are representative of this country's meat-packing industry as well.

2.2.2 Present Treatment Practices

Most of the meat-packing concerns are located in or adjacent to large municipal centers and discharge their waste into municipal sewers. Typical municipal industrial waste by-laws specify that any waste containing 300 mg/l BOD, 350 mg/l suspended solids and 100 mg/l grease shall be subject to a surcharge. Accordingly the meat-packing companies are compelled to compare this surcharge with the cost of providing their own basic waste treatment facility.

Considering the usual amounts of water used in meat-packing plants, about 1,350 gallons per 1,000 lb. Live Weight Kill, the raw wastewater from a plant could be expected to have a BOD ranging from 400 to 1,500 mg/l, SS from 300 to 1,600 mg/l and a grease content from 350 to 2,300 mg/l.

A treatment system capable of 50 to 70 percent reduction of the pollutant load would be a valuable tool for overall pollution control.

Indeed, it is only logical that such concentrated wastes be reduced in a high rate process and the final treatment be carried out in a process designed to produce a high quality effluent from moderately strong influent wastes.

While very little information has been published on the treatment schemes used for meat-packing plants in Canada, studies in the United States indicate that at least 99% of all plants will have some treatment facility by 1977.

Since the wastewater from this industry is generally considered to be relatively biogegradable, it is understandable that the treatment schemes used to date are similar to those used in municipal waste treatment. All the current biological waste treatment processes have been used with varying degrees of success (32). The most widely used processes include trickling filters, activated sludge, extended aeration, irrigation, stabilization pond systems and the anaerobic contact process, all of which are usually preceded by some treatment to reduce suspended solids and grease.

(i) Pre-treatment

In general, meat-packing plants which have their own biological treatment process also have pre-treatment facilities. Pre-treatment commonly involves the use of either a catch basin or an air flotation system. Although both types are used primarily for grease removal, they also reduce the concentration of suspended solids. Very little data is available with respect to the removal efficiency of this type of pre-treatment. The gross solids in the paunch material are normally disposed of before the waste enters the biological treatment system.

(ii) Trickling Filters

Trickling filters have not been widely used in the treatment of meat-packing wastes. This appears to be the result of high initial costs, high operating costs and the susceptibility of conventional trickling filters to becoming plugged. Steffen (33) reports that 95% BOD removal has been obtained with three-stage filters following extensive primary treatment, and that 85% removal has been obtained with a conventional two-stage high rate trickling filter. Although not stated in the literature, it is assumed that these filters were composed of rock media.

With respect to plastic media filters, Sak (3) reports the results obtained on two installations. In the first study 71% BOD removal was obtained with an organic loading of 616 lb. BOD/1000 ft.^{3}/day a hydraulic loading of 2.8 gpm/ft^2 and an influent BOD of approximately 2,000 mg/l. In the second study only 43% BOD removal was achieved with a comparable influent, but at a BOD loading in excess of 3,000 lb/1,000 ft^3/day. In the second case no information was given as to the hydraulic loading rate.

(iii) Activated Sludge

Steffen (33) reports that conventional activated sludge treatment has been used to a limited extent with varied success. No data was available for the efficiency of these systems. The limited use of conventional activated sludge is a result of the high capital cost involved and the need for well-trained personnel to supervise its operation.

(iv) Extended Aeration

Extended aeration is another method which has only been used to a limited extent in the treatment of meat-packing wastes. However, the process was used for a plant in Florida (34) due to a State regulation prohibiting the use of lagoon waste treatment because of possible ground water contamination. The treatment facilities built consist of sedimentation and grease-skimming, extended aeration, aerobic digestion, final settling, aerobic pond treatment and cholorination. The extended aeration tanks were designed on the basis of 20 lb. BOD/1,000 ft.^{3}/day with a detention time of 30 hours. The aerobic stabilization pond was designed on the basis of 50 lb. BOD/acre/day. Although only limited data had been collected at the time of publication, the results showed that 95% BOD removal, 89% suspended solids removal and 98% grease removal were being achieved. No specific problems were reported with the operation of the treatment plant.

(v) Disposal by Spray Irrigation

Disposal by irrigation is being successfully used for various trade wastewaters, however, very few instances are reported of its use by the meat industry. Steffen (33) reports two systems presently in use in the United States. At one site, the effluent from a trickling filter is being applied to agricultrual land. The waste has a BOD of approximately 200 mg/l and application rates have been as high as 39,000 gal/acre/day with no reported leaching of nutrients to a creek 30 ft. away. Improved crop yields have been realized on all the soils used in this system. The other irrigation system reported is disposing of 200,000 Imp. gal/day of raw waste after grease removal onto a 32 acre field. The field is irrigated in sections with each section receiving an application of 2 in/day for a period of one day, followed by a six day rest period. No data is available on the strength of the waste being applied.

Although no problems have been reported with either of the installations cited above, it is unlikely that disposal by irrigation will enjoy widespread use until considerably more research has been completed, particularly with respect to the possibility of ground water contamination.

(vi) Stabilization Ponds

Waste stabilization basins comprise the bulk of the industry-owned waste treatement systems reported in the literature. In areas where land costs are relatively low, stabilization ponds are favoured because of their low capital cost, low operating costs and simplicity of operation.

Lagoon systems may consist of an anaerobic pond, an aerobic pond or a combination of both. If complete treatment is desired, a combination or aerobic and anaerobic ponds is usually installed. Anaerobic ponds are sometimes used by themselves if their effluent is to be discharged to a municipality for further treatment. The degree of treatment achieved in anaerobic ponds is not generally of a sufficiently high quality to allow direct discharge of the effluent to a receiving water. Aerobic ponds give an acceptable effluent quality, however, unless the influent being treated is relatively weak, the large area requirements tend to make this system impractical.

Saucier (35) compares two installations in Tennessee where only one type of waste stabilization pond is used. One meat-packing plant used an anaerobic lagoon to treat a waste flow of 0.5 MGD and 1,560 mg/l BOD_5 before discharge to the municipal waste treatment plant. The daily organic loading on the lagoon is 15 lb. BOD/1,000 ft^3. The lagoon treatment results in an average removal of 86% of the BOD, 71% of the suspended solids and 88% of the grease applied.

The other plant utilizes an aerobic system, in this case an aerated lagoon, for complete treatment. The volume and strength of the waste are considerably lower being 0.1 MGD and 565 mg/l BOD_5 respectively. No loading values are given for the pond but 99% of the BOD_5 and the suspended solids are removed with a detention time of approximately 75 days.

The most efficient method of utilizing waste stabilization ponds appears to be through the use of an anaerobic lagoon as a roughing pond followed by one or more aerobic or aerated lagoons for final polishing.

Wymore and White (36) report results obtained from a plant in north-central Iowa consisting of pre-treatment, followed by two anaerobic lagoons in parallel, followed by two aerated lagoons in series. The anaerobic lagoons were loaded at 11.5 lb. BOD/1,000 ft^3.

This loading produced a BOD removal of approximately 60%. The aerated lagoons employed a diffused air system and were loaded at 200 lb. BOD/acre/day. The overall removal through the lagoon system was 98.3% BOD, 96.8% grease and 96.9% suspended solids.

In Minnesota, the MID Packing Co. has a system of anaerobic and aerobic ponds in series (37). The first anaerobic pond is loaded at 20 lb. BOD/1,000 ft^3/day while the first aerobic pond is loaded at 25 lb. BOD/acre/day. Because anaerobic digestion is very temperature dependent, a study was carried out during the winter to determine if the addition of external heat would be necessary. The design criteria was that a minimum temperature of 75°F must be maintained at all time. The first anaerobic pond experienced a rapid build-up of a layer of grease and scum while the second experienced very little. With an ambient temperature of 25.4°F, a drop of 5.1°F was found through Pond No. 1 and a drop of 9.5°F through Pond No. 2. The influent temperature to Pond No. 1 was 82°F. The difference in heat loss was attributed to the insulation qualities of the scum layer on the first pond. The average reduction in BOD through the anaerobic lagoons was 58.2%. No effluent was discharged from the aerobic ponds during the winter months but values of BOD under the ice were in excess of 200 mg/l.

Meat-packing treatment plants using all three types of stabilization ponds in combination are also in use. One plant at Cherokee, Iowa has a system composed of two anaerobic lagoons in parallel, an aerated lagoon and two aerobic lagoons in series (38). This plant has an overall BOD removal efficiency of 99.1% with a total detention time within the system of approximately 115 days.

In the literature surveyed there is only one reported case of serious odour problems arising from the use of anaerobic lagoons. This occurred in Edmonton, Alberta, where high production of hydrogen sulphide caused serious odour and corrosion problems (39). This was apparently brought under control by the addition of hydrated lime near the meat-packing plant discharge, to raise the pH to approximately 7.0. Steffen (33), however, reports that of a survey of ten plants treating meat-packing wastes by anaerobic lagoons, nine out of the ten reported nuisance odours.

(vii) Anaerobic Contact Process

When digested anaerobically, meat-packing wastes produce a quantity of methane gas. The heat produced by burning this gas, in combination with the high temperature of the incoming waste (85°F), is generally sufficient to maintain the required temperature of 90° to 93°F for anaerobic digestion. This characteristic of the waste resulted in the development of the anaerobic contact process for the treatment of meat-packing wastes and the subsequent installation of a full-scale plant at Albert Lea, Minnesota (33). The design of the plant was based on pilot scale studies carried out by Schroepfer et al (40) at Austin, Minnesota.

The anaerobic contact process in operation at Albert Lea (33) has produced a 90% reduction in applied BOD and an 80% reduction in suspended solids at loadings of 156 and 112 lb/1000 ft^3/day of BOD and SS respectively. Other anaerobic contact plants are also in operation which discharge the effluent from the anaerobic system to municipal treatment plants for further treatment.

2.2.3 Conclusions

It appears from the literature surveyed that waste from the meat industry is very amenable to biological waste treatment. Effluents of high quality are being obtained from many of the systems now in operation. However, with the exception of the anaerobic contact process, all systems which are well documented as to a high removal efficiency, require large areas of land. If the meat-packing plant is now in operation or is to be built in a rural or semi-rural area, this presents little problem since the price of land in these areas is usually relatively low. If the plant is located within a city it may be impossible to obtain the land required for installation of a system such as lagoons. The meat-packing plant is then faced with the problem of installing a treatment system with minimum area requirements, which is capable of reducing the waste load to a level acceptable to the city for discharge to the municipal treatment plant. The research reported herein presents one solution to the problem of the treatment of meat-packing wastes under the above constraints.

3.0 DESCRIPTION OF TEST FACILITY

In order to evaluate the use of plastic-media trickling filters for wastewater treatment, a comprehensive pilot-plant test program was undertaken. This program involved an intensive eighteen month study of a trickling filter pilot-plant treating meat-packing wastes.

The pilot-plant trickling filter unit was originally made available to the University of Waterloo by Canadian Industries Limited for a project used to study the effect of the Canadian cold weather climate on trickling filter operation and performance. The unit was constructed in January 1967 and subsequently placed in operation at the Waterloo Municipal Sewage Treatment Plant.

In June 1970, the pilot-plant was moved to a site adjacent to the waste treatment facilities of a Kitchener meat-packer. Preliminary operation of the pilot-plant was started in September, 1970, and continued until April, 1971. Although a definite program was not established for data collection, the operation of the plant throughout this initial period indicated where modifications to the pilot-plant system would be required in order to complete the comprehensive study which was carried out from June 1971 through November, 1972.

A general description of the wastewater characteristics, the trickling filter pilot-plant facility and its operation are presented in the following sections.

3.1 Wastewater Characteristics

The process wastewaters of the J.M. Schneider Co, Ltd, Kitchener, are typical of those from a medium to large size meat packing operation which includes slaughtering, processing and by-product recovery. Originally, these wastewaters were discharged directly to the municipal sewer system with minimal pretreatment.

In order to reduce the contribution of this waste load on the municipal treatment plant, the Company undertook the construction of a primary treatment facility on their own premises in the fall of 1968.

Briefly, this treatment facility receives two waste streams; a "paunch manure" stream and a "fat-bearing" waste stream. The "paunch manure" stream, containing high quantities of partially digested straw, grass, feed, etc., is passed over two vibrating screens where most of the particulate matter is removed. This stream is then discharged to the municipal sewer system. The "fat-bearing" waste stream, containing quantities of grease, blood and particulate matter is subjected to an air flotation system, consisting of two chambers, 25 ft. in diameter and 13 ft. deep, operating in parallel. A scum layer is continually scraped from the top of these two tanks for further disposal or by-product recovery. The underflow from this system is partially recirculated through the condensing system before being discharged to the municipal sewer.

Prior to construction of this treatment facility, the wastewater was discharged into the municipal sewer with only catch basin treatment.

The wastewater concentrations averaged about 1400 mg/l BOD_5, 800 mg/l TSS and 400 mg/l grease.

When the primary treatment works were installed, it was intended that the overall waste strength would be reduced by at least 50%. Through in-plant caretaking, the waste strength has been lowered even further.

The wastewater characteristics being discharged as effluent to the municipal sewer and used as the influent wastewater for this study, are presented in Table 3.1.1.

The values indicated in Table 3.1.1 for maximum and minimum are based on one hour composite samples or in the case of temperature and flow, continuous monitoring. The data for the average 24 hour composite are based on the daily operation studies of the plant which will be discussed in Section 5.1.

A previous study by Crandall (31) into the quantities of nitrogen and phosphorous in meat-packing wastewaters showed that there were sufficient quantities to produce biological growths in receiving streams. Measurements of these nutrients were performed on an intermittent basis throughout this study with the results appearing in Table 3.1.2

TABLE 3.1.1

PRESENT WASTEWATER CHARACTERISTICS

Parameter	Minimum	Maximum	Average 24 hr. Composite
BOD_5, mg/l	200	1,800	550
COD, mg/l	450	2,500	975
TSS, mg/l	150	580	300
Grease, mg/l	50	600	150
pH	6.6	9.8	7.5
Temperature, °F	70	98	- -
Flow, gph	10,000	100,000	42,000

TABLE 3.1.2

NUTRIENT CHARACTERISTICS

Parameter	Total	Soluble
NH_3 as N, mg/l	11.8 - 14	11.2 - 14
Organic N as N, mg/l	33 - 45	15.7 - 25.2
PO_4 as P, mg/l	- -	12 - 18

The meat-packing plant where this study has been conducted can be considered to have typical operations for most plants. The characteristics of the wastewater discharged from the plant corresponded generally with those found for a variety of meat-packing plants throughout the United States. However, the waste strength still exceeds the limits established by municipal industrial waste by-laws.

3.2 Description of the Pilot-Plant

The pilot-plant trickling filter consisted of three major components; a structural steel tower which contained "Flocor" packing, a settling chamber used as a clarifier and an instrument building housing the pumping unit, sampling equipment and monitoring instruments. The pilot-plant trickling filter as located on site is shown in Figure 3.2.1. At this time, all piping had been enclosed for protection from snow and ice.

The 24 ft. high structural steel tower supported the plastic-media packing "Flocor" which was supplied by Canadian Industries Limited for this study. The packing, shown in Figure 3.2.2 consisted of 18 modules, each 2 ft. x 4 ft. x 2 ft. deep, placed in layers of 2 modules, each layer being placed at right angles to the next. This provided a total media volume of 288 cu. ft. with a cross-sectional surface area of 16 sq.ft. An intermediate support was required in the tower providing an upper depth of 8 ft. of media and a lower depth of 10 ft. The packing media was enclosed on four sides by plastic sheeting to contain the wastewater within the media. Plywood sheeting was then bolted on the

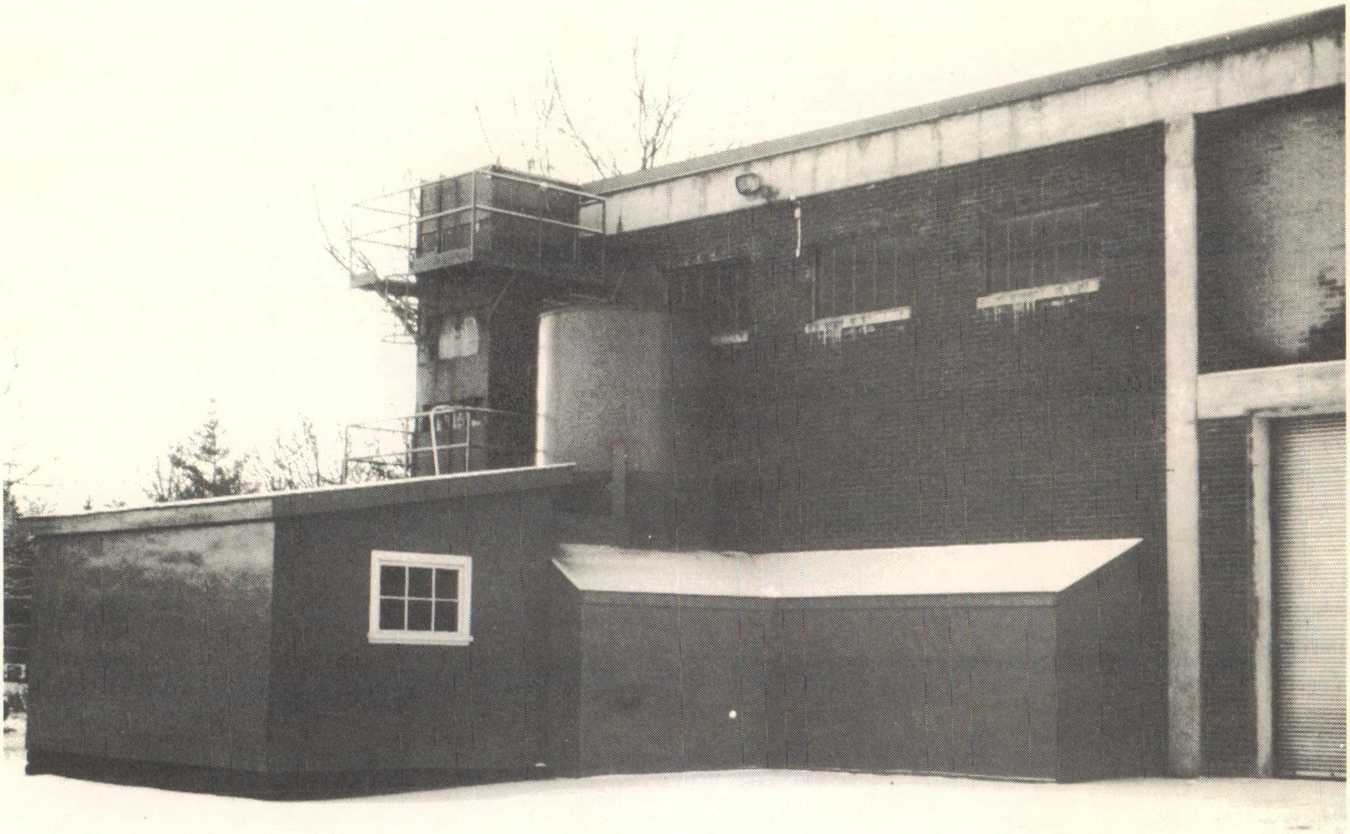


FIGURE 3.2.1

PILOT-PLANT TRICKLING FILTER INSTALLATION

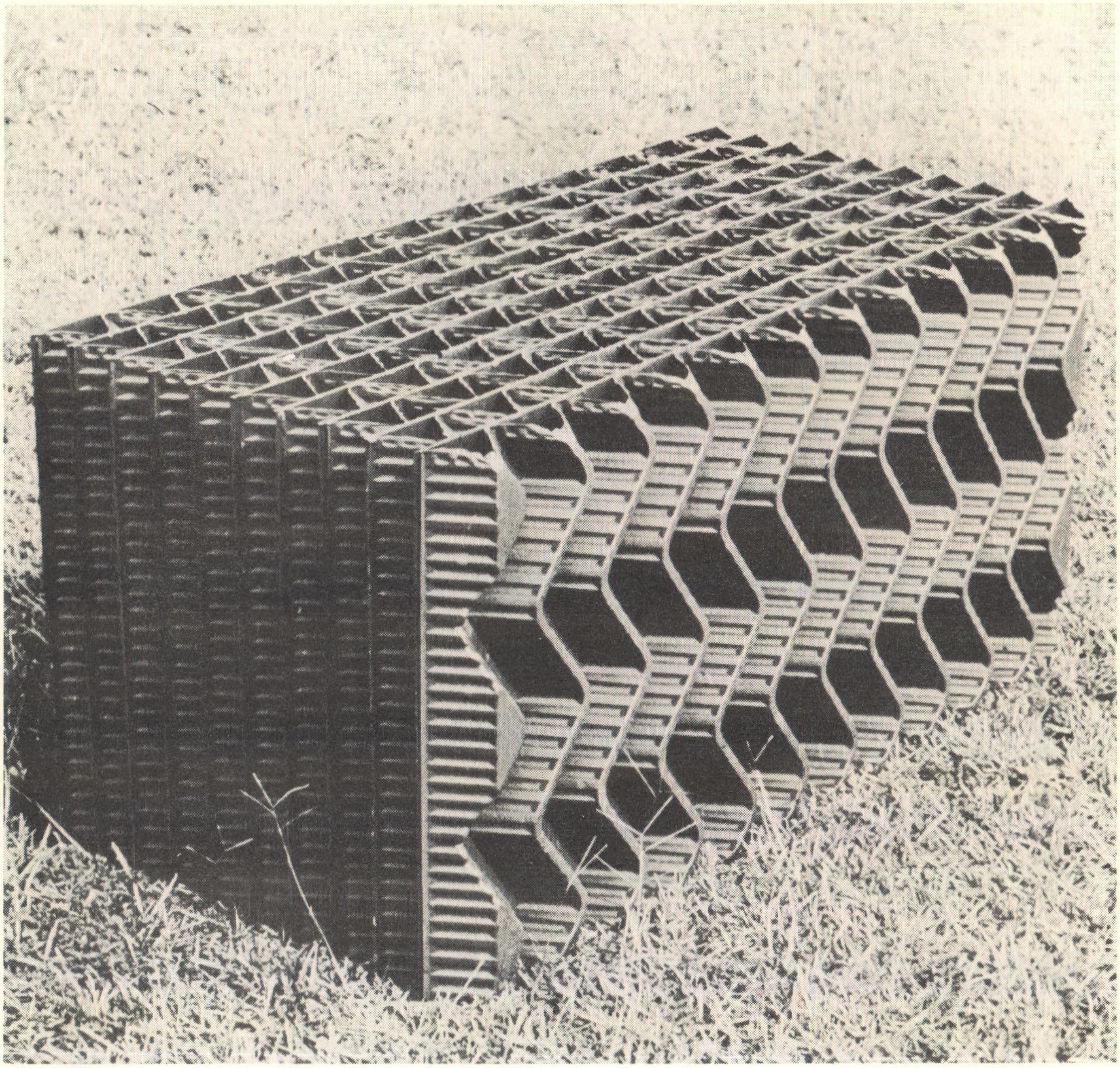


FIGURE 3.2.2

"FLOCOR" PLASTIC MEDIA MODULE

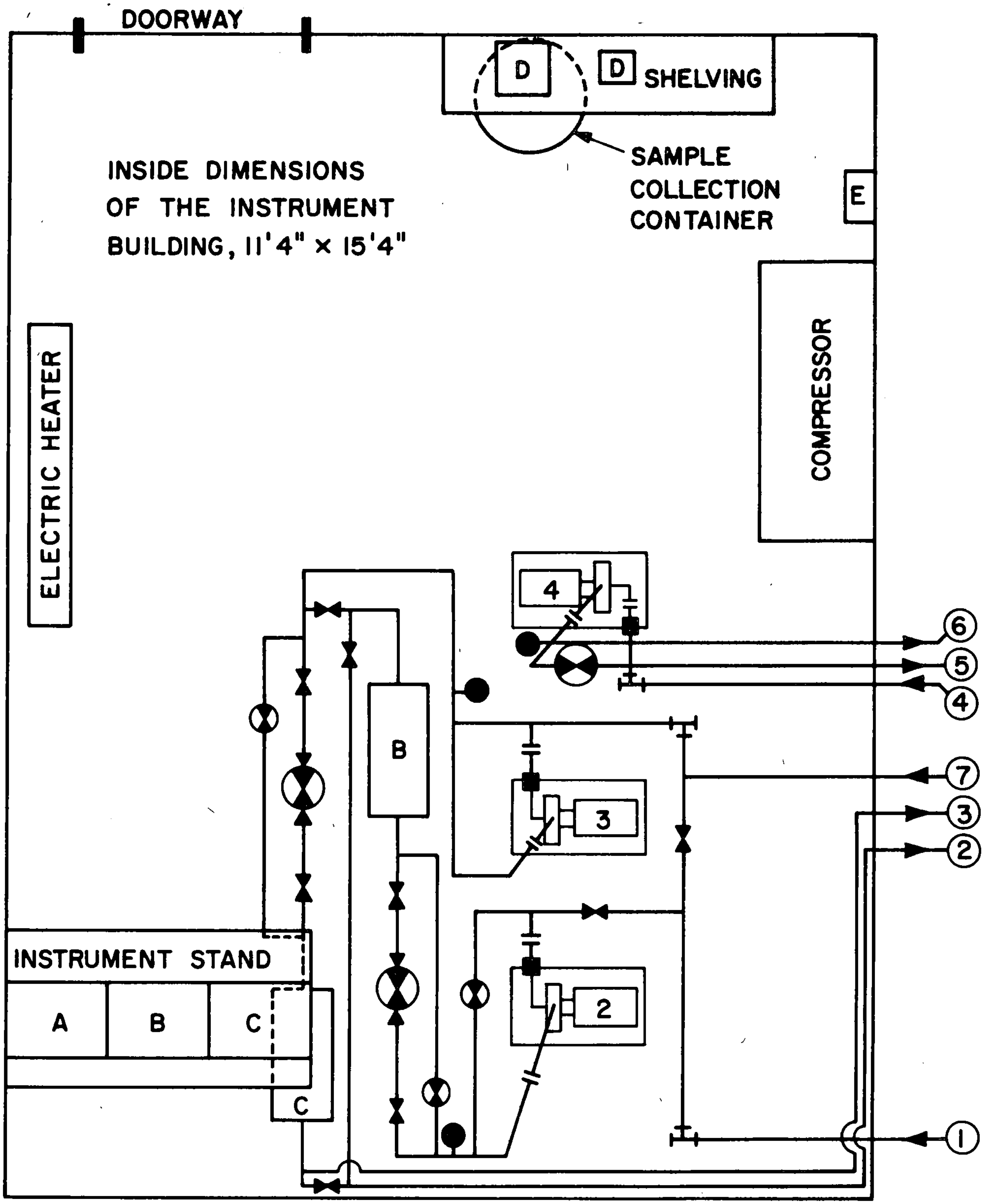
outside of the tower for protection. A stationary distribution system was used to distribute the waste evenly over the surface of the packing. The distribution system consisted of a 4 ft. x 4 ft. aluminum tray, 12" in depth containing 525-1/4" diameter holes drilled as an array of rows and columns spaced at 2" centres. The tray also had 4-1" diameter copper tubes 8" in height as a precaution for overflow in case the holes became partially or fully blocked.

The settling tank which was incorporated into the system to produce an effluent low in suspended solids was designed for a maximum flow rate of 19.2 gpm. At this flow rate the 2,000 gallon tank which was 7 ft. in diameter had an overflow rate of 720 gpd/sq.ft. of surface area, a detention time of 1.75 hours and a weir loading of 1,450 gpd/linear ft. of weir.

The instrumentation building shown diagramatically in Figure 3.2.3 was equipped with sampling and monitoring units. Two flow metering units (magnetic flow transmitters with recording controllers) were placed on the discharge side of the influent and recirculation pumps. Each unit was capable of measuring and controlling flow-rate from 4.0 to 30 gpm.

A 12-channel temperature recorder was used to measure and record the liquid temperature on the suction side of Pumps No. 2, 3 and 4, the ambient temperature and inside building temperature. A pH meter and recorder-controller was also placed in operation initially in the program to provide a continuous record of the pH of the influent waste.

The function of the various components of the pilot-plant trickling filter can best be described by referring to Figure 3.2.4, a flow diagram



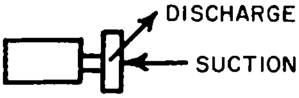
(SEE TABLE 3.2.1 FOR IDENTIFICATION OF SYMBOLS)

FIGURE 3.2.3

LAYOUT OF EQUIPMENT IN THE INSTRUMENT BUILDING

TABLE 3.2.1

IDENTIFICATION OF SYMBOLS USED IN FIGURE 3.2.3



- Hydr-O-Matic centrifugal pump

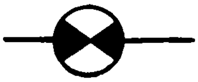
 - vacuum switch

 - 1 ½" PVC tee containing a stainless steel thermowell for liquid temperature measurement

 - Solenoid valve used for sampling

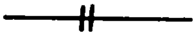
 - 1 ½" gate valve (bronze body)

 - 1" PVC diaphragm valve

 - Saunders pressure control valve; the valves in the flow metering section are 1" while the valve on the discharge side of pump No. 4 is 1 ½"

 - Foxboro magnetic flow transmitter

 - 1 ½" x 1" PVC reducing bushing

 - 1 ½" PVC union

INSTRUMENTATION

A - 12-point Foxboro -YEW electronic temperature strip chart recorder

B, C - Dynalog electronic recording controllers operated with the Foxboro magnetic flow transmitters

D - Radiometer pH meter and a YSI model 80 strip chart recorder

E - Foxboro pneumatic level controller

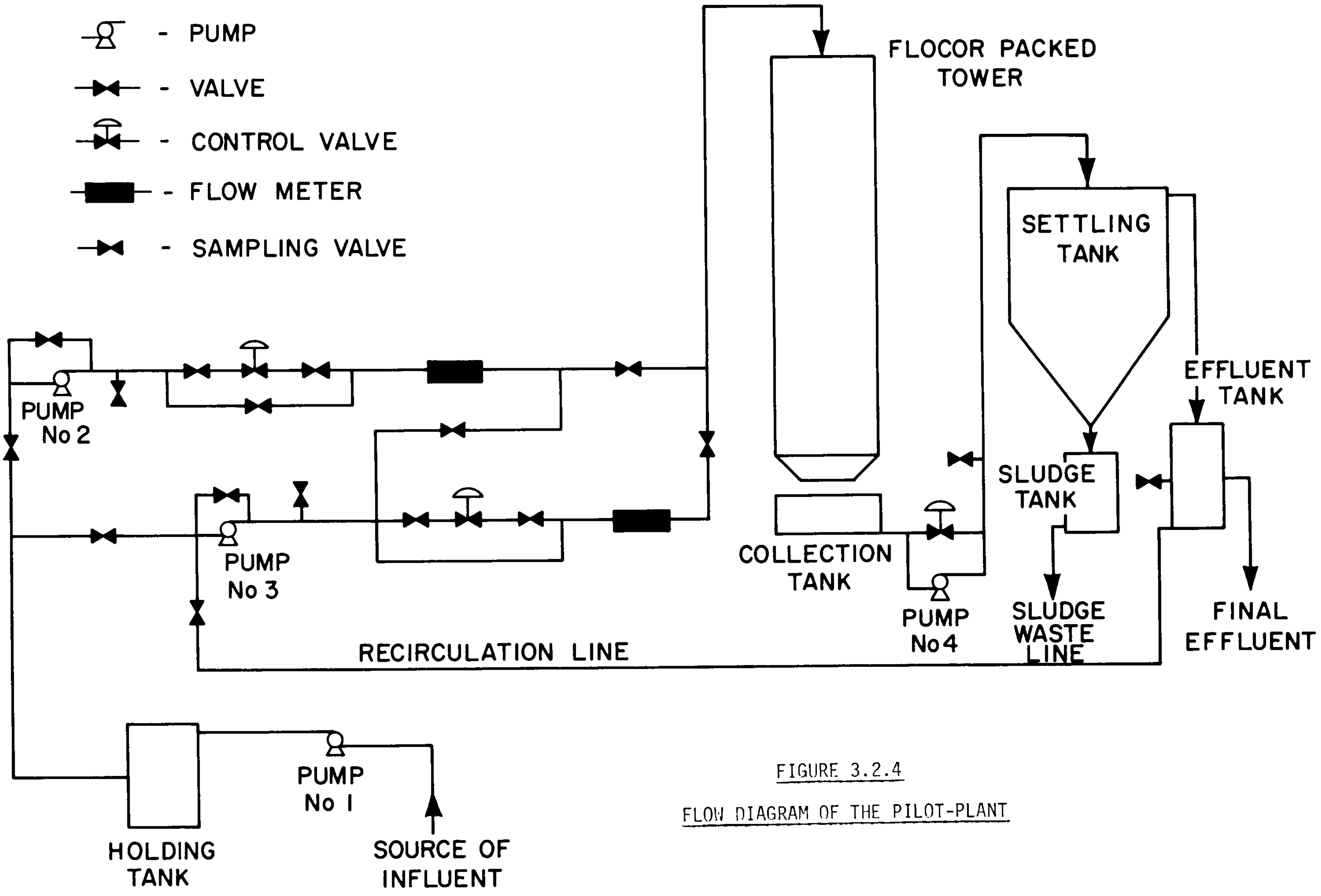


FIGURE 3.2.4

FLOW DIAGRAM OF THE PILOT-PLANT

of the pilot-plant. A submersible sump pump (Pump No.1) was used to lift the influent waste from a manhole located in the sewer outlet outside of the primary treatment plant to a 450 gallon holding tank located adjacent the instrument building. Centrifugal pumps with open-end impellers (Pumps No. 2 and/or No.3) were used to pump the waste to the top of the tower at a specific flow-rate measured and controlled by the flow metering units. The waste was distributed over the upper surface of the packing and allowed to trickle down over the packing surface coming into contact with a slime-layer of micro-organisms on the packing media. The effluent from the tower was collected in a square tank at the base of the tower and pumped either to the settling chamber (Pump No.4) or recirculated to the top of the filter (Pump No.3). The effluent from the weir of the settling tank was collected in a tank which discharged back to the manhole. The sludge which accumulated in the bottom of the settling tank was drained into a small tank for measurement prior to being wasted to the sewer.

3.3 Operation of Pilot-Plant

This section describes the operation of the pilot-plant in two parts. The first section relates the initial operation of the trickling filter prior to the comprehensive study to obtain the data on performance described in this report. Throughout this period, difficulties such as securing continuous flow and operation during cold weather periods were solved so that the pilot-plant could be operated throughout the actual study with a minimum of difficulty. The second part discusses briefly the operation of the pilot-plant throughout the study period. The overall operating conditions are discussed in Section 7 with reference to any difficulties which may be encountered for a full scale plant.

3.3.1 Initial Operation

Wastewater was first pumped over the filter media in September, 1970 from a manhole located in the outfall sewer adjacent to the existing primary wastewater treatment plant of J.M. Schneider Co. Ltd. A problem in maintaining continuous flow arose almost immediately with the low flow which occurred in the early hours of the morning. A weir was constructed in the manhole to back up a sufficient waste supply for the sump pump.

A thin layer of slime gradually developed on the media during the first week of operation. However, in attempting to operate over the weekend period, it was found that there was virtually no flow which could be pumped from the plant and the pumps were shut down. A similar situation occurred on subsequent weekends, and the pilot-plant was placed on recirculation for a period of about 60 hours from Friday night to Monday morning startup. By the end of the second week of continual operation a satisfactory bios had developed on the media surface.

Following installation of the monitoring equipment, samples were collected on a 24-hour composite basis to determine the relative efficiency of the operation. This operation was continued until January, 1971 when it was found that recirculating water throughout the weekend had no real benefit in maintaining Monday efficiency. This fact plus the problem of freezing pipes indicated that the plant might just as well not be operated on the weekends.

As the purpose of this initial operation of the pilot-plant was to determine problems in operation which might be faced in an in depth study of the filter, sufficient data to design a full-scale plant was not obtained. However, in attempting to analyse the limited data which was collected, it was found that the operating efficiency of the plant based on influent and effluent samples using the COD test showed a pattern of removal for the soluble portion but very little difference when the total COD of the samples was considered. Further evaluation of the data, indicated that suspended solids in the effluent were similar in magnitude to those in the influent indicating that the clarifier was highly over-loaded.

In order to provide for continual operation of the plant throughout the winter, it was determined that in future operation, all exterior piping would have to be protected. Delays in plant start-up occurred almost every week throughout the December-January period due to freeze-up of the pipes.

From the initial operation of the pilot-plant, a mode of operation was developed which would enable the comprehensive study presented in this report to proceed with the least amount of difficulty as well as provide an indication of areas of concern for a full-scale installation.

3.3.2 Operational Problems

Following the initial period of operation of the pilot-plant, which ended in early May, 1971, the system was shut-down until late June. The plastic media was washed by hosing from the top of the filter until it was felt little or none of the slime coating would be left in the filter media. Additional sampling ports, which will be described in detail later, were installed in the filter media.

The pilot-plant was placed into continual operation on June 28, 1971, with sampling starting immediately. A slime layer rapidly developed on the media within the first week of operation. Recirculation was employed during the first two weekends of operation to insure that the bios remained active. However, this practice was discontinued in August as again there appeared to be no difference in Monday's operating efficiency, whether recycle was employed on the weekends or not.

Limited operational problems occurred with the pilot-plant throughout the study period. These problems mainly centered on sump-pump blockages, blocking of the distribution tray and some maintenance difficulties with monitoring equipment. On two occasions, the sump pump was jammed by stubs of cow-horn which had by-passed the treatment facilities. The distribution tray was blocked by leaves, paunch manure, pieces of carrots and peas, plastic wrappers, etc., from time to time. Maintenance difficulties included breakdown of the temperature recorder, pH recorder, centrifugal pump and cracking of the holding tank. All problems were of a minor nature and were solved with little difficulty.

4.0 DATA COLLECTION PROGRAM

In order to evaluate the performance of a plastic-media trickling filter treating meat-packing waste, an extensive data collection program was carried out for approximately 18 months duration. This chapter outlines the testing, sampling and analytical programs followed for the collection of data while the pilot-plant was operated on a once-through basis.

4.1 Testing Program

To fulfill all of the objectives of the study, a data collection program was established which covered three types of programs as follows:

1. Daily Operation
2. Diurnal Variation
3. Depth Studies

The first two areas would be used to fulfill the primary objective of obtaining performance data on the operation of a pilot-plant trickling filter using a meat-packing waste. The effective operating ranges of hydraulic and organic loadings would be monitored to determine the effects of these variables on the performance of the process as a roughing and/or secondary treatment system.

The third area of the testing program would be used in the development of a rational process design procedure for treating high-strength organic wastes by the trickling filter process.

Since the treatment process was considered as a "roughing" type of process (i.e. partial treatment), the range of hydraulic flow rates which were originally considered for the study consisted of 1.0, 1.5 and 2.0 gpm/ft^2 for the three test programs. However, it was decided to expand the program to include a hydraulic flow rate of 0.5 gpm/ft^2 for at least the Daily Operation Studies. It has been stated by several authors and manufacturers of media that this hydraulic loading rate is the minimum at which complete wetting of the surface of the media can occur.

4.2 Sampling Procedures

The sampling techniques varied for all three of the testing programs.

For the Daily Operation program, samples of influent and effluent were collected on a 24 hour composite basis. A 200 ml sample of waste was collected every 5 minutes throughout the day on a timer solenoid sampling system. The samples were collected in 80 litre drums and a representative sample collected each morning to be taken to the laboratory for analysis. The samples for Friday were collected over a period of 8 to 10 hours or until the pilot-plant was shut down for the weekend. Samples were collected for at least a period of 20 operating days at each flow rate with the exception of the 0.5 gpm/ft^2 flow rate, which lasted only 9 operating days.

For the Diurnal Variation Studies, a similar type of procedure was used. Samples of influent and effluent were composited over a 1 hour time period for the 24 hours throughout the day. One run was made at each of the flow rates 1.0, 1.5 and 2.0 gpm/ft^2.

A different type of sampling procedure had to be used for the Depth Study program. The program consisted of collecting samples of depths in the filter media of 0, 4, 8, 13 and 18 ft. from the top of the media. At the intermediate depths, holes 2" in diameter were drilled a depth of 22" into the plastic media. Tubes of 1-1/2" diameter PVC, cut in half so as to form a trough were then inserted into the holes. When sampling was being performed, the tubes could be inverted to allow the waste to catch and flow out of the media to a sampling container. When not in use the tubes were turned bottom up and the waste flowed over them, continuing down through the media. It was desirable to maintain a constant concentration of waste strength for each sampling period, so the sump pump was shut down and only the waste from the holding tank used for each run. Samples were collected at all five locations as quickly as possible taking at most 10 to 12 minutes for the 1.0 gpm/ft^2 flow rate. The influent and effluent samples for the depth studies were collected at the top of the filter and below the downcover at the bottom of the filter. This procedure was carried out at hydraulic loading rates 1.0, 1.5, and 2.0 gpm/ft^2. Later in the program, grab samples of influent and effluent were taken at the 0.5 gpm/ft^2 flow rate to compare with the data for the other three flow rates. There was an insufficient quantity of flow from the intermediate depths over a short period of time to permit meaningful results to be obtained at these ports.

4.3 Analytical Tests

The analytical techniques used throughout the program for COD, BOD_5, suspended solids and pH were those presented in "Standard Methods" (41). The BOD_5 test was modified to suppress the nitrification effect which occurred in the BOD bottle. This was done by adding 1 ml of a 0.5 mg/l 1-Alyl1-2 thiourea solution for each litre of dilution water.

The analytical tests varied for each testing program. The tests employed are indicated in Table 4.3.1. As has been mentioned previously, the settling chamber was found to be inadequate at the higher flow rates. Consequently, based on preliminary settling studies, it was decided that samples which required settling (all effluent samples as well as some influent samples) would be allowed to settle in 500 ml graduated cylinders for a 1-hour period. A sample of 150 to 175 mls would then be siphoned from the cylinder as representative of the settled effluent. The results of this type of settling test will be discussed in Section 5.3.

In preliminary work, tests were performed for nitrogen and phosphorous levels. Samples were checked intermittently throughout the program to insure that sufficient nutrients for biological treatment were available.

4.4 Data Storage and Evaluation

The large quantity of data which was obtained in the three studies required that an efficient method of computer analysis be used. For this, the APL computer language and system available from the Computing Centre of the University of Waterloo was found to be most suitable.

TABLE 4.3.1

SCHEDULE OF ANALYTICAL TESTS

Sampling Program	Sample	Analyses
Daily Operation	Influent	Unsettled, settled, soluble COD, BOD_5 Unsettled, settled TSS, VSS pH
	Effluent	same
Diurnal Variation	Influent	Unsettled, settled, soluble COD
	Effluent	Unsettled, settled, TSS, VSS pH
Depth Studies	Influents	Unsettled, settled, soluble COD BOD_5 Unsettled, settled TSS, VSS pH
	Intermediate Depths	Settled soluble COD BOD_5 Settled TSS, VSS
	Final Effluent	Settled, soluble COD BOD Settled TSS, VSS pH

The system allows ready access from a typewriter terminal with instantaneous output. The language is most simple, in that instructions can be done briefly and neatly. Also, a multitude of library programs are available for statistical evaluation of data and regression to various functions.

The data was stored in the system in the form of coded vectors. This allowed for easy manipulation in the evaluation of dual vectors for performance calculations and in printing output.

5.0 PERFORMANCE DATA AND EVALUATION

Performance data on the operation of a pilot-plant trickling filter treating meat-packing waste was collected in two ways;

(a) on a 24-hour composite basis and

(b) on a 1-hour composite basis throughout a one day period.

The Daily Operation study would be used to evaluate the performance of the pilot-plant over a period of time, whereas the Diurnal Variation program would indicate the effects of fluctuation in waste strength throughout the day on the operating performance.

The hydraulic loading rates used in this study were typical of high-rate and "roughing" trickling filtration, ranging from 0.5 to 2.0 gpm/ft^2 or in terms of flow 8 to 32 gpm. These high flow rates produced organic loading rates which were generally higher than had been reported in previous studies.

This section provides statistical summaries of all data obtained in the two performance study programs and using these summaries, relates the overall performance of the pilot-plant to applied loading and other parameters.

5.1 Statistical Summary of Daily Operation Data

The data collection procedure and schedule of analyses has been outlined in Section 4.0 of this report. The results of the Daily Operation studies are presented in tabular form in Appendix A.

The data was analysed on the APL computer system using a library program for statistical calculation of mean, standard deviation, maximum and minimum. A summary of the results of this evaluation appears in Table 5.1.1. These results show all analytical tests which were performed in the laboratory on each day's influent and effluent samples with the exception of pH. The overall mean values are presented for the influent samples using all data points.

Prior to discussing the actual performance of the pilot-plant, some comments concerning the general nature of the waste water constituents are in order. Considering the relationship between the soluble fraction of the waste to the total organic concentration, it was found that the soluble portion accounts for 40 to 55% of the total COD. Similarly, the soluble BOD_5 averaged about 46% of the total BOD_5.

The ratio of soluble BOD_5 to soluble COD was about 0.5 and the ratio of total BOD_5 to total COD was slightly higher at 0.53. These two ratios were found to have an extremely wide range of variability, as values for the ratio of total BOD_5 to total COD ranged from 0.34 to 0.67.

The influent samples were settled in a graduated cylinder for a period of 60 minutes to determine the quantity of suspended solids which could be removed prior to filtration. Approximately 30% of the TSS would settle out, accounting for both 15% of the total BOD_5 and total COD. The ratios for total BOD_5 and total COD to TSS in the unsettled influent was 1.75 and 3.30 respectively.

TABLE 5.1.1

STATISTICAL SUMMARY OF DAILY OPERATIONAL DATA

Flow Rate gpm/ft^2	Statistical Parameter	COD, mg/l						BOD$_5$, mg/l						Suspended Solids, mg/l							
		Influent			Effluent			Influent			Effluent			Influent				Effluent			
		Un	S	Sol	Un	S	Sol	Un	S	Sol	Un	S	Sol	Unsettled		Settled		Unsettled		Settled	
														T	V	T	V	T	V	T	V
0.5	Sample Size	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	Mean	1077	895	484	861	556	343	517	445	230	357	225	141	327	278	229	197	325	276	121	109
	Std. Dev.	63	78	80	137	55	58	77	80	34	56	38	16	36	26	16	17	94	74	12	7
	Maximum	1156	1028	656	1056	627	421	643	604	296	540	288	168	392	326	248	216	466	386	144	120
	Minimum	964	784	413	680	475	231	383	348	189	263	167	108	272	246	200	164	190	168	102	94
1.0	Sample Size	21	21	21	21	21	21	12	12	12	12	12	12	21	21	21	21	21	21	21	21
	Mean	972	819	475	807	566	361	533	462	257	408	269	180	290	265	196	182	287	258	126	118
	Std. Dev.	118	74	52	113	82	71	76	53	28	47	34	33	49	46	27	25	62	52	23	21
	Maximum	1270	947	566	1012	725	544	627	548	299	473	318	228	412	382	276	258	416	350	180	176
	Minimum	817	720	386	587	440	262	372	357	210	330	209	126	202	192	164	156	194	186	86	84
1.5	Sample Size	25	25	25	25	25	25	12	12	12	12	12	12	25	25	25	25	25	25	25	25
	Mean	967	813	471	843	619	399	519	414	229	403	301	192	300	265	217	193	279	250	150	134
	Std. Dev.	150	125	74	165	104	81	70	50	30	52	46	34	72	60	56	48	59	49	30	25
	Maximum	1428	1207	737	1230	956	659	611	467	267	469	382	243	572	456	458	400	428	396	208	184
	Minimum	738	651	389	551	484	299	378	293	183	300	222	129	214	188	166	146	178	160	106	86
2.0	Sample Size	23	23	23	23	23	23	12	12	12	12	12	12	23	23	23	23	23	23	23	23
	Mean	934	807	458	837	634	394	492	427	221	410	308	192	280	254	200	184	271	247	143	132
	Std. Dev.	106	81	50	141	85	56	79	63	41	81	54	44	45	41	23	19	55	45	24	22
	Maximum	1143	929	574	1087	772	510	646	582	300	585	395	267	358	344	244	224	396	340	194	182
	Minimum	738	664	366	614	492	287	377	338	153	290	217	125	186	178	152	148	180	176	100	70
Overall	Size	78	78	78				45	45	45				78	78	78	78				
	Mean	971	822	470				515	436	234				295	263	208	188				
	Std. Dev.	127	97	--				75	62	-				56	48	-	-				

Un = Unsettled
S = Settled
Sol= Soluble

T = Total
V = Volatile

The ratio of volatile suspended solids to total suspended solids was determined as 0.89.

The waste can generally be characterized as a strong organic waste with about 50% of the organic material in a suspended or colloidal form following primary treatment by air flotation and screening.

5.2 Summary of Operating Performance

The overall performance of a trickling filter, including its final clarifier, in removing organic material from wastewater, is generally described in terms of percentage reduction or mass of material removed per unit volume of filter media relative to the applied organic loading. The expressions for mass loadings are determined from the product of concentration and flow rates resulting in units such as pounds of BOD per 1,000 cubic feet of filter media per day.

5.2.1 Percent Removal Efficiency

The mean removal efficiencies for the four hydraulic loading rates studied are presented in Table 5.2.1 for both total and soluble BOD and BOD_5 as well as total suspended solids.

These results are illustrated graphically in Figure 5.2.1 for percent removal of total and soluble BOD_5 versus applied organic loading. For the range of hydraulic loadings evaluated in this study it would appear that a linear relationship exists for both total and soluble BOD_5 removal. The soluble removal drops off drastically in terms of percent removal from about 40% at a loading of 100 lb BOD_5/1000 ft^3/day to around 10% at 350 lb/1000 ft^3/day. The total overall

BOD_5 removal also decreases with increased organic loading although not nearly to the same degree as soluble removal. At an applied loading of about 200 lb BOD_5/1000 ft^3/day the percent reduction is in excess of 55%, declining to slightly less than 40% at an applied loading of 800 lb BOD_5/1000 ft^3/day.

The declining removal of suspended solids as applied loading increases as shown in Table 5.2.1 should also be noted. This phenomena will be discussed in further detail in section 5.3.

5.2.2 Quantity of Material Removed

The treatment efficiency of the filter system has also been evaluated in terms of mass of organic material removed per unit volume of media as shown in Table 5.2.1 for total and soluble COD and BOD_5. The relationships for total and soluble BOD_5 appear in Figure 5.2.2.

The quantity of soluble BOD_5 remains rather constant at about 50 lb/1000 ft^3/day as the applied loading is increased. However, the removal of total BOD_5 increases from about 125 lb at a loading of 200 lb/1000 ft^3/day to almost 300 lb at a loading of 800 lb/1000 ft^3/day. At the lower loading, the soluble BOD_5 removal accounts for about 50% of the overall removal whereas at the higher loading rates, soluble removal is less than 20% of the total BOD_5 removal.

5.3 Effect of Filter on Suspended Solids Removal

In reviewing the data presented in Table 5.2.1 for total suspended solids, it was indicated that percentage removal of suspended solids

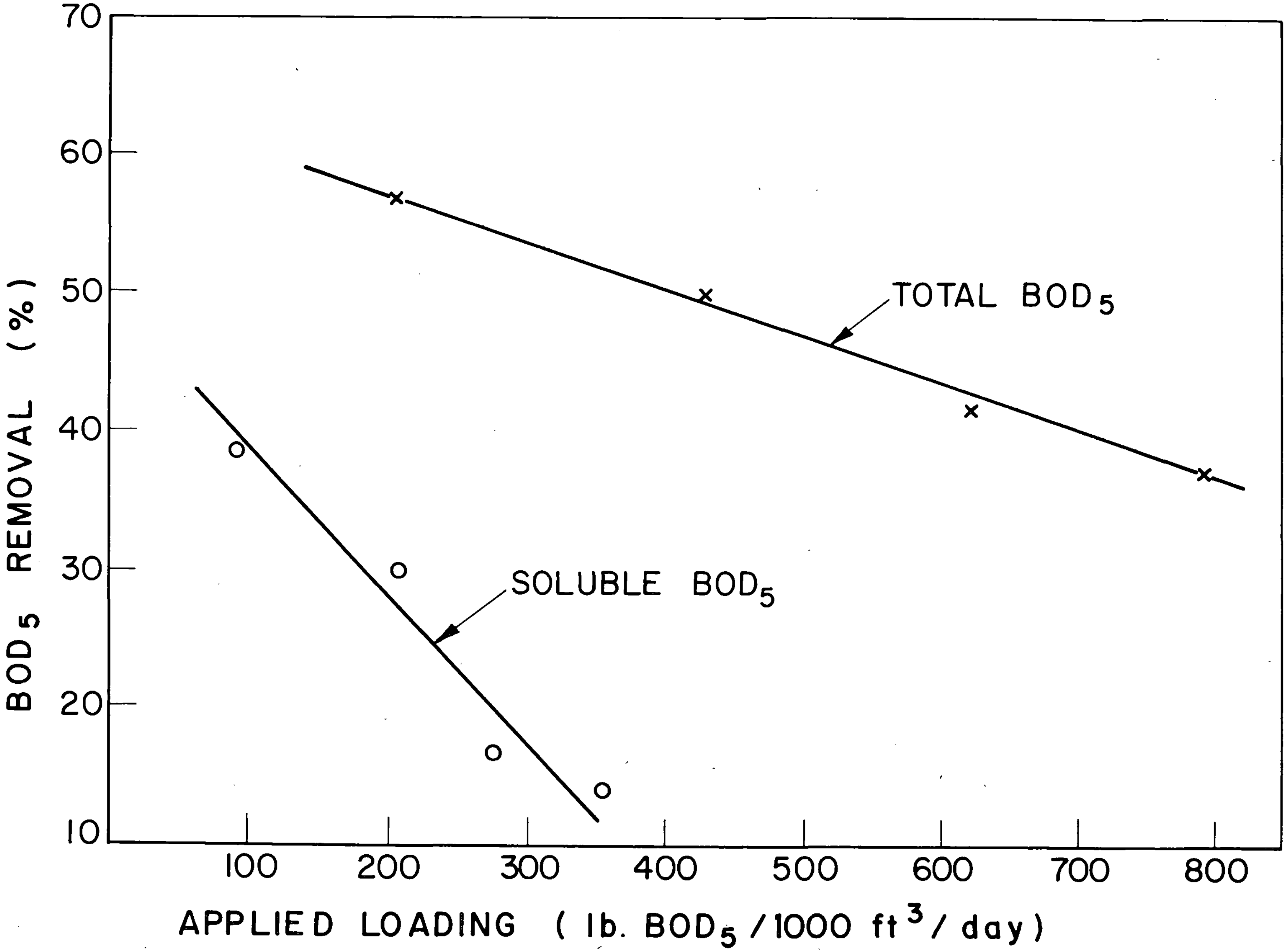


FIGURE 5.2.1

RELATIONSHIP OF PERCENT BOD_5 REMOVAL TO APPLIED ORGANIC LOADING

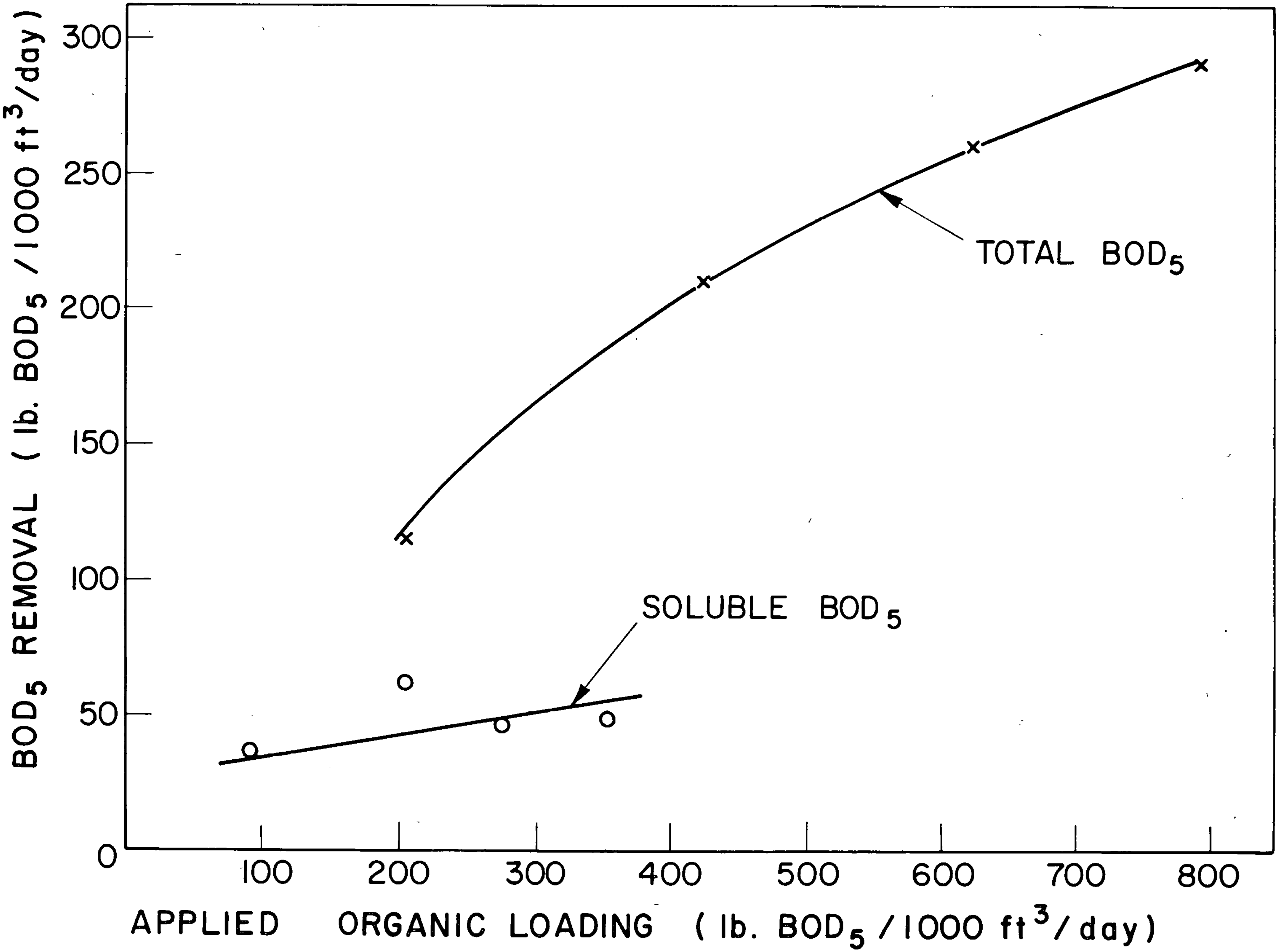


FIGURE 5.2.2

RELATIONSHIP OF QUANTITY OF BOD_5 REMOVAL TO APPLIED ORGANIC LOADING

TABLE 5.2.1

SUMMARY OF REMOVAL CALCULATIONS AT VARIOUS FLOW RATES

Flow Rate (gpm/ft^2)	Percentage Removal (%)					Mass Removed per Unit Volume (lb/1000ft^3/day)			
	COD		BOD$_5$		TSS	COD		BOD$_5$	
	Total	Sol.	Total	Sol.		Total	Sol.	Total	Sol.
0.5	48	29	57	38	63	209	57	117	36
1.0	42	24	50	30	57	325	91	211	62
1.5	36	15	42	16	50	417	86	262	45
2.0	32	14	37	14	49	480	103	294	47

decreases as the hydraulic loading rate increases. This is to be expected as one would imagine that the highest suspended solids removal would coincide with the highest percent BOD_5 removal.

This effect is even more clearly indicated in the results of settling tests which were conducted at hydraulic loading rates of 1.0, 1.5 and 2.0 gpm-ft^2 for influent and effluent grab samples collected for approximately similar concentrations of suspended solids. The samples were placed in 500 ml graduate cylinders and allowed to settle quiescently for various periods of time up to five hours. The results of this study appear in Figure 5.3.1.

The three influent samples all produced similar results, however there was a definite improvement in the settling characteristics of the suspended solids in the effluent samples. The settling characteristics clearly improve as the flow rate decreases.

The effect of improved settling characteristics of the suspended solids passing through the trickling filter is a rather complex phenomena. Since the settling techniques were similar for all three flow rates, then the changes in characteristics must be a function of the residence time within the filter itself. During this time, the solids are partially hydrolyzed and assimilated. At lower flow rates, the solids are absorbed into the slime matrix at a faster rate and are subsequently discharged as portions of the slime are sloughed from the surface of the filter. However, since the solids are then generally subjected to pumping to a clarifier (in this case, to sampling containers), where the slime particles are certain to be broken or sheared, there must be a further mechanism involved.

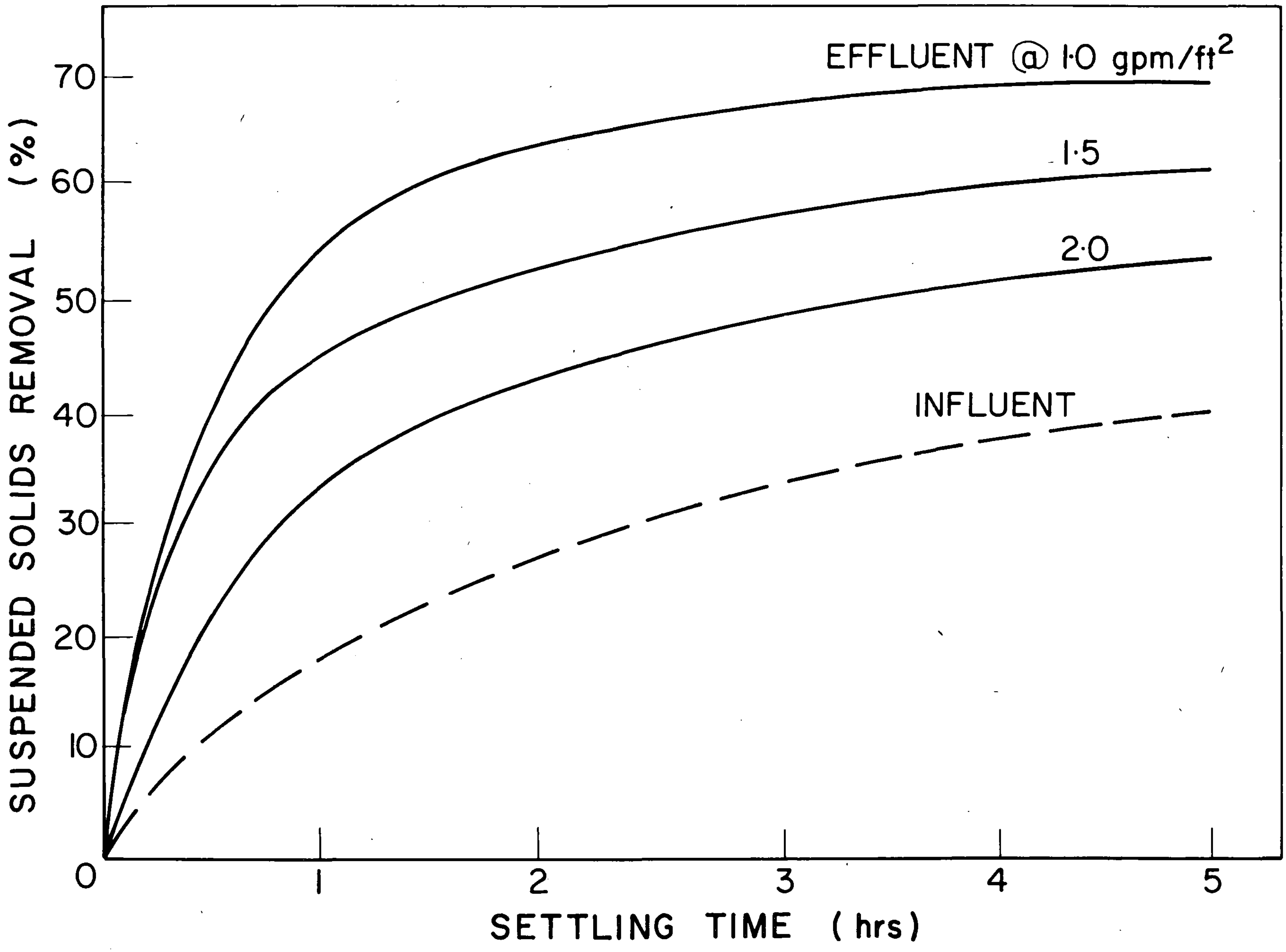


FIGURE 5.3.1

RELATIONSHIP OF PERCENT SUSPENDED SOLIDS REMOVAL TO SETTLING TIME

Recent work by Pavoni et al (42) into the mechanism of bioflocculation suggests that there is a high correlation between the presence of exocellular polymers and improved settling characteristics of biological solids. They state that "bioflocculation can be viewed as a result of the interaction of naturally produced, high molecular weight, long chain polyelectrolytes with bacterial cells, in such a fashion that these polyelectrolytes bridge the suspension under quiescent conditions."

It is possible then that the increased setteability of the suspended solids as the flow rate decreases is a function of both adsorption into the slime matrix and bioflocculation.

In section 4.3, the need to settle effluent samples in a graduated cylinder rather than use final effluent from the clarifier was mentioned. The validity of choosing a one-hour settling time is evident from the results of Figure 5.3.1, showing that approximately 85% of the settling occurs in the first hour.

5.4 Diurnal Variation

In most industrial situations where production schedules are not uniform and/or continuous throughout the day, there is some fluctuation in wastewater characteristics such as flow, organic concentration, pH, etc. It can be expected that these changes in the waste will also effect changes in the performance of a biological treatment system.

5.4.1 Variation in Wastewater Characteristics

While the pilot-plant was being operated at each of three flow rates, 1.0, 1.5 and 2.0 gpm/ft^2, a round-the-clock sampling study was performed. Each study consisted of collecting one hour composite samples of influent and effluent for a 24 hour period.

Tabular presentation of the data collected for the three sampling days appears in Appendix B. Graphical presentation showing the variation in Unsettled Influent COD and Settled Effluent COD throughout the day is given in Figures 5.4.1, 5.4.2, and 5.4.3 for flow rates 1.0, 1.5 and 2.0 gpm/ft^2. The variation in soluble COD and suspended solids follows a similar trend to the Total COD. The variation in pH throughout the day is shown in Figure 5.4.4 for all three.

The pattern of the fluctuation of some of the waste parameters at each flow rate is similar. There is a decrease in both COD and suspended solids in the early morning hours (2 to 6 A.M), occurring when washup during the night has been completed. When the production shift starts at approximately 6:30 to 7:00 A.M., the COD and suspended solids starts to increase. Between 9 and 10 A.M., there is a tremendous peak (2400 to 2700 mg/l COD) in the waste strength. This is due to the discharging of the cooking and rendering tanks. After this surge has passed (over a 2 to 3 hour period) the waste strength decreases to a rather constant level, between 1000 and 1500 mg/l COD, for the rest of the production day. The magnitude of these changes varies from day to day, however the general trend remains the same.

The variation in pH follows a trend from day to day also. Throughout the early morning period (1 A.M. to 5 A.M.), the pH is rather high being in the range 8.0 to 9.0. However, once production begins the pH drops to a range of 7.0 to 7.5 for the remainder of the day.

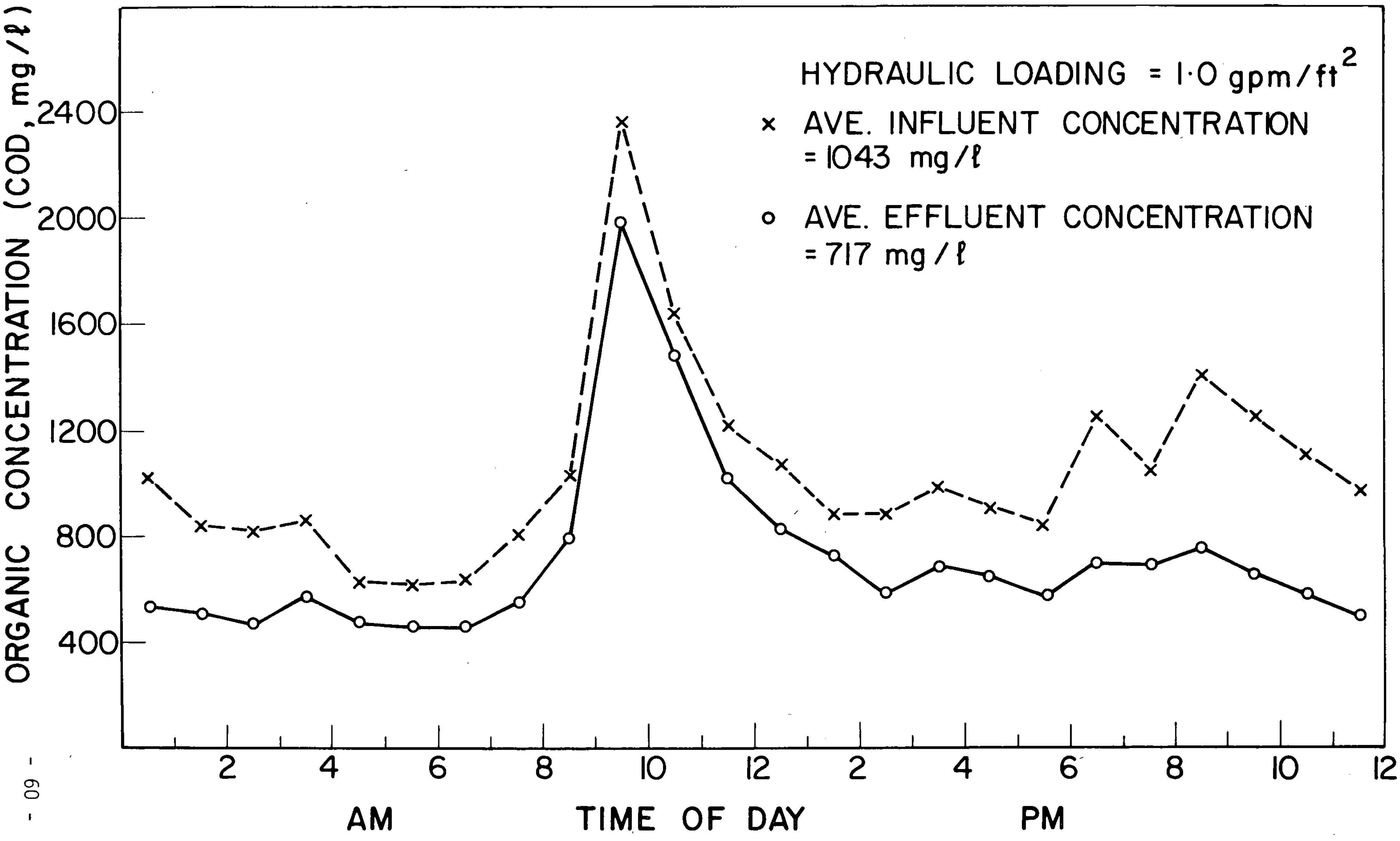


FIGURE 5.4.1

VARIATION IN ORGANIC CONCENTRATION THROUGHOUT DAY AT HYDRAULIC LOADING 1.0 gpm/ft^2

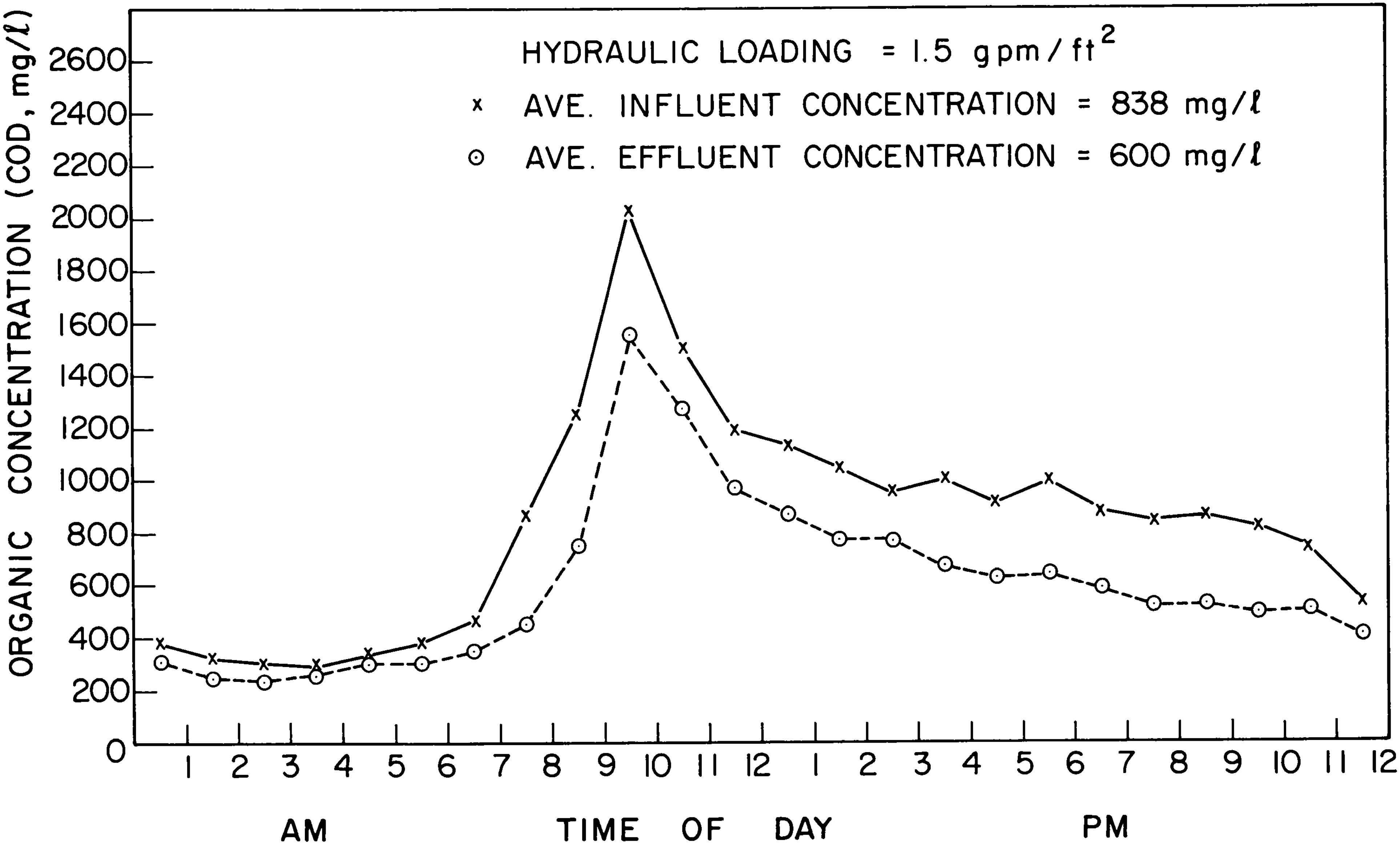


FIGURE 5.4.2

VARIATION IN ORGANIC CONCENTRATION THROUGHOUT DAY AT HYDRAULIC LOADING 1.5 gpm/ft^2

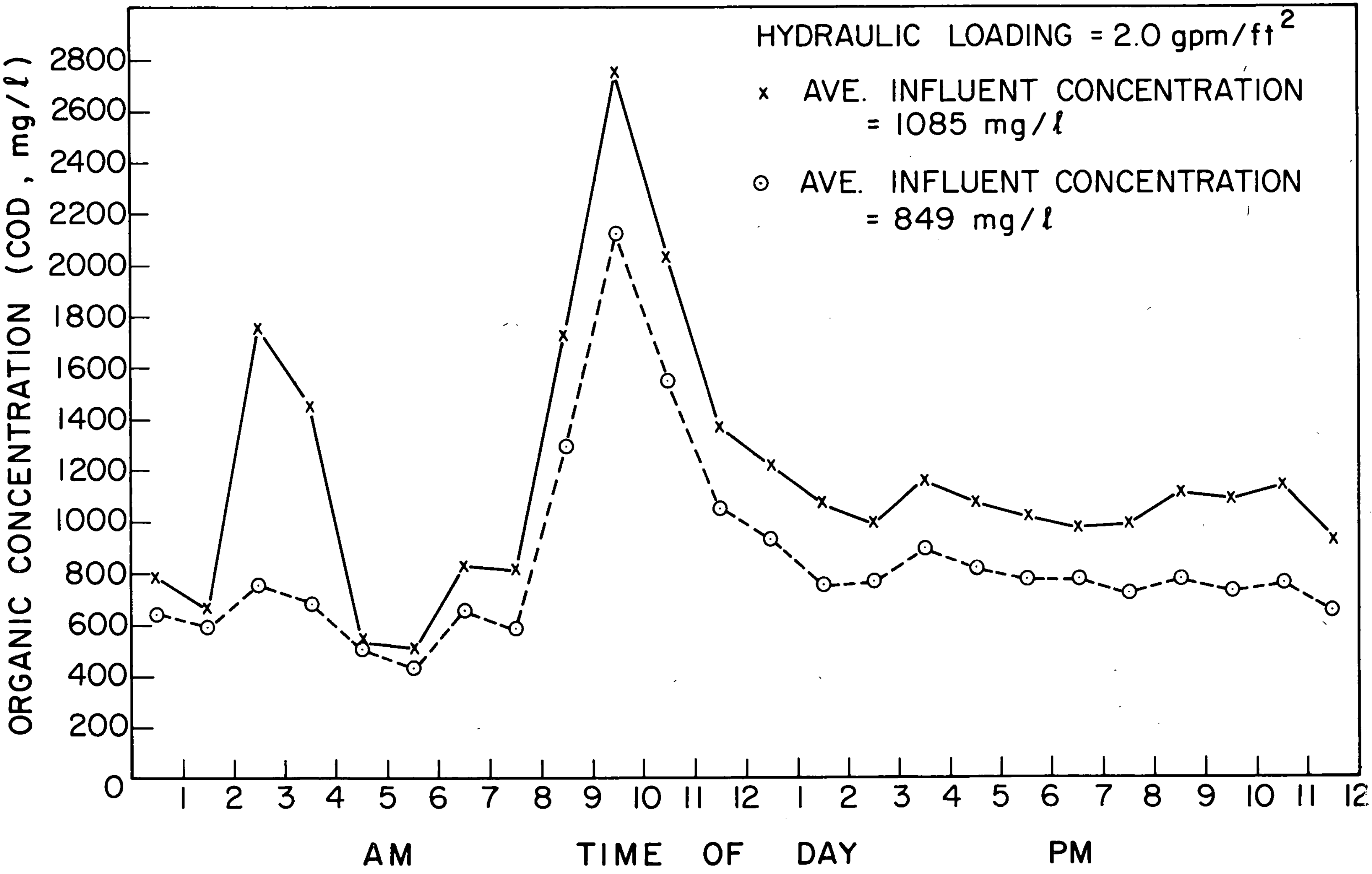


FIGURE 5.4.3

VARIATION IN ORGANIC CONCENTRATION THROUGHOUT DAY AT HYDRAULIC LOADING 2.0 gpm/ft^2

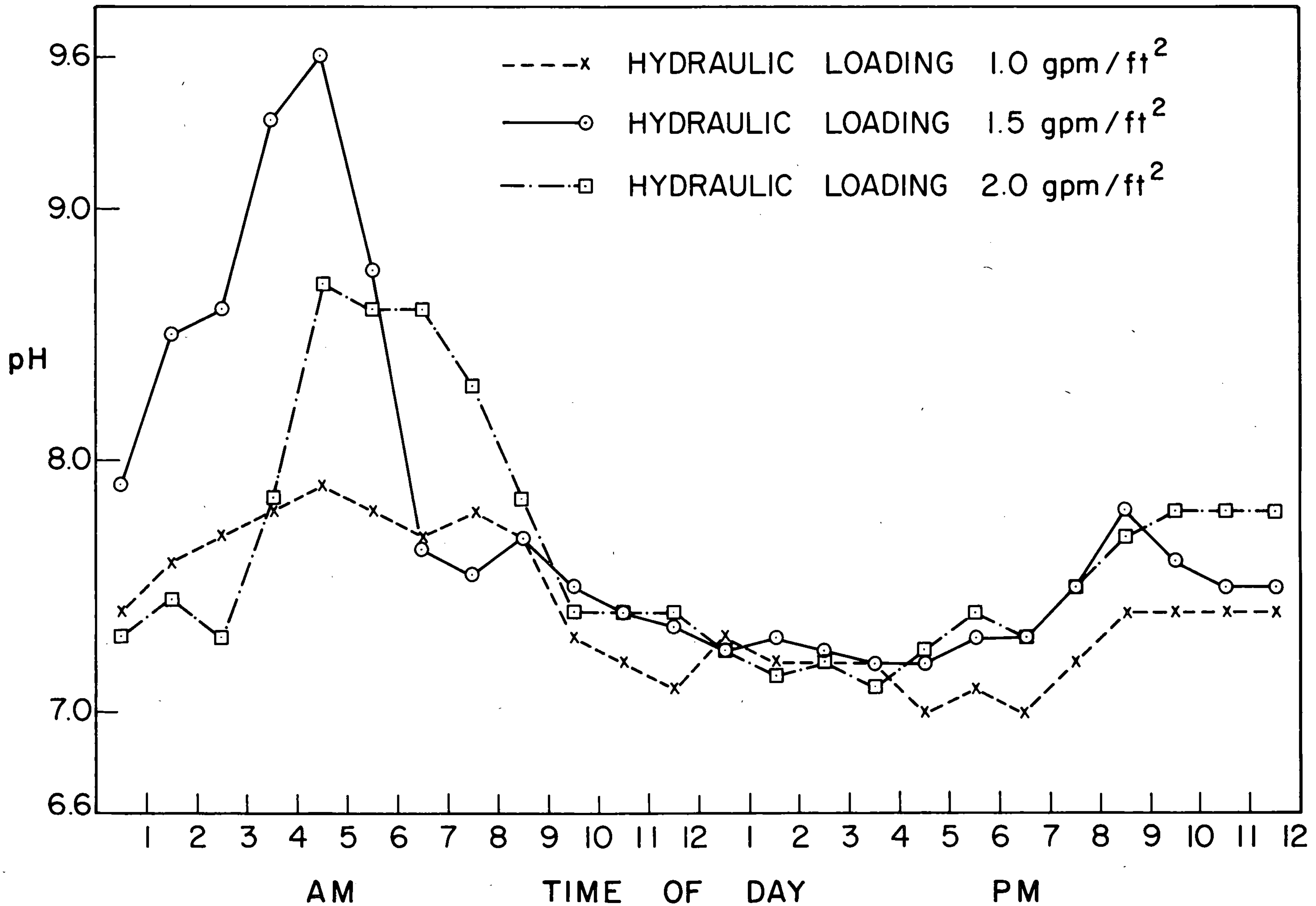


FIGURE 5.4.4

VARIATION IN pH THROUGHOUT DAY

5.4.2 Variation in Performance Throughout the Day

The effect of the fluctuations in organic concentration on removal by the filter is shown in Figure 5.4.5 for the removal of total COD. The results, in terms of percent removal, are presented in tabular form in Table 5.4.1 for both total and soluble COD.

When the concentration of COD in the waste is highly variable (between the hours of 1 A.M. and 12 noon), the performance of the filter is quite unstable. This is clearly shown at the 1.0 and 1.5 gpm/ft^2 hydraulic loadings, although it does not occur to such an extent at the 2.0 gpm/ft^2 loading. However, as the concentration becomes rather constant (after 2 P.M.), the performance of the pilot-plant stabilizes and there appears to be an increase in total removal efficiency. This pattern continues until early morning when the cycle is repeated.

The removal of soluble substrate shows an even more irregular pattern throughout the entire day at all three flow rates. It may be that with the soluble fraction of the waste, the plant never does become stable at any time throughout the day.

If mean concentrations of the influent over the 24 hour period are determined for the parameters total COD, soluble COD and TSS, it is found that they correspond closely with the average Daily Operation results for the same parameters. However if the removal results are compared between the three Diurnal Variation studies and the average Daily Operation results, it is found that for all three flow rates, the percent removal is considerably lower for the Diurnal Variation studies.

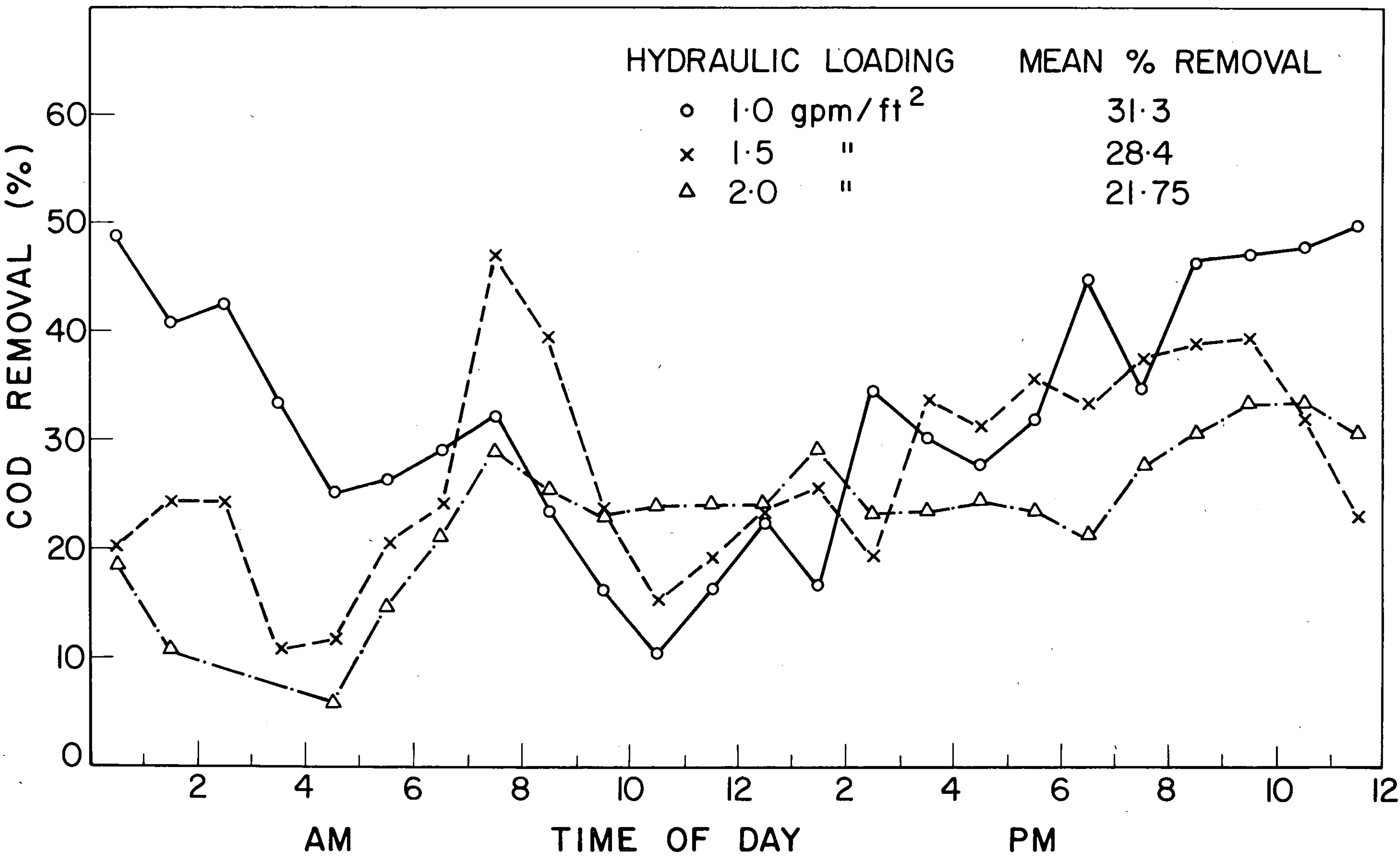


FIGURE 5.4.5

VARIATION IN FILTER PERFORMANCE THROUGHOUT DAY

The percentage removal results for the two programs are presented in Table 5.4.2. This comparison indicates the variation in treatability of the waste which can occur for a wastewater which has similar characteristics in terms of concentration of soluble and suspended or colloidal organic material.

5.5 Summary

A trickling filter operating as a "roughing" treatment for meat-packing wastes can generally be expected to remove in excess of 50% of the BOD applied to it in the range of 200 to 400 lb BOD/1000 ft^3 on a daily basis. As the loading is increased to 800 to 1000 lb BOD/1000 ft^3/day, the removal efficiency decreases to about 35%. Successful operation at loadings which are generally much higher than the normal range of 100 to 150 lb BOD/1000 ft^3/day for high-rate filtration systems has been demonstrated.

Wide fluctuations in the organic waste strength during the day cause some reduction in the performance of the filter, however, when the waste strength returns to normal the operating efficiency quickly stabilizes.

TABLE 5.4.1

DIURNAL VARIATION IN PERCENTAGE COD REMOVAL

Time	TOTAL			SOLUBLE		
	Flow Rate - gpm/ft^2			Flow Rate - gpm/ft^2		
	1.0	1.5	2.0	1.0	1.5	2.0
1	48.8	20.3	18.58	36.4	40.2	2.3
2	40.9	24.5	10.78	8.9	42.0	13.4
3	42.6	24.4	--	30.3	22.1	0.0
4	33.5	10.9	--	26.6	26.4	3.9
5	25.1	11.7	6.0	20.2	30.4	6.8
6	26.4	20.7	14.8	10.3	36.7	13.6
7	29.0	24.0	21.2	16.1	30.5	2.5
8	32.5	47.1	29.2	28.0	31.1	16.6
9	23.6	39.7	25.3	31.3	33.0	22.3
10	16.2	23.9	23.1	11.3	11.8	4.7
11	10.5	15.3	24.0	6.9	10.7	4.0
12	16.7	19.3	24.2	11.0	12.0	9.3
13	22.9	23.7	24.2	12.9	19.3	13.2
14	16.6	26.0	29.4	20.2	16.5	13.9
15	34.6	19.1	23.2	28.1	20.4	11.6
16	30.5	33.9	23.8	25.3	25.1	8.7
17	27.5	31.3	24.7	29.9	24.9	9.6
18	31.9	35.9	23.4	29.9	23.9	15.0
19	44.9	33.3	21.1	27.4	24.9	11.8
20	34.7	37.8	27.7	7.3	26-8	9.1
21	46.6	39.0	30.9	19.9	25.4	7.5
22	47.2	39.6	33.6	26.9	31.0	8.4
23	47.8	32.3	33.6	23.5	30.9	6.7
24	49.8	22.8	30.8	27.4	37.0	2.0

TABLE 5.4.2

COMPARISON OF DIURNAL VARIATION AND DAILY OPERATION PARAMETERS

Percentage Removal

Flow Rate gpm/ft^2	Diurnal Variation			Daily Operation		
	COD (mg/l)		TSS (mg/l)	COD (mg/l)		TSS (mg/l)
	Total	Soluble		Total	Soluble	
1.0	31.3	20.2	34.5	41.8	24.0	56.5
1.5	28.4	23.2	25.3	36.0	15.3	50.0
2.0*	21.75*	9.6	38.5*	32.1	14.0	48.9

* neglects the surge at 3 and 4 A.M.

6.0 DEVELOPMENT OF DESIGN PARAMETERS

The preceeding chapter has discussed the performance of the pilot-plant trickling filter in treating meat-packing waste. However, the results obtained from the two types of sampling programs cannot be used in the development of values for constants in either of the design formulations (i.e., the first-order equation or the Kornegay and Andrews equation). Both formulations require development of relationships of remaining concentrations of organic matter with depth of filter media for various flow rates.

This section describes the techniques used to obtain values for the constants for the two major design relationships for both total and soluble BOD_5.

6.1 First-Order Reaction Equation

The first-order reaction equation was first expressed by Velz in 1948. It has evolved through the work of many researchers to the form expressed in Equation 2-1 and rewritten as:

$$\frac{s}{s_o} = e^{-KD}/Q^n \qquad (6\text{-}1)$$

The factors Ap and θ have been included in K, the reaction rate constant. The specific surface area of the media is 29 ft^2/ft^3. The temperature factor was not evaluated as the waste temperature ranged between 70 and 98°F and this variation was not considered to be a significant influence on the results. The value of n is dependent on the configuration of the media. For the plastic media, "Flocor", this value was found to be 0.52 in a previous study (23) at the University of Waterloo.

The procedure used to evaluate the constant, K, has been outlined by Eckenfelder (43). Samples are collected at several depths in the media for at least three flow rates. The percentage of organic material remaining at each depth is plotted on semi-log paper against the corresponding value of $D_{/Q}n$. The slope of the line of best fit of the data yields the value of the reaction rate constant, K, to the base 10. The value of K to the base e can then be calculated by multiplying by 2.303.

6.1.1 Soluble BOD_5 Results

The data for soluble BOD_5 removal was collected and analyzed according to the procedure outlined above, established by Eckenfelder. This data is presented in tabular form in Appendix C. For each value of $D_{/Q}0.5$, a set of values for the percentage of soluble BOD_5 remaining was generated. To simplify the evaluation of the reaction rate constant, the mean percentage remaining and standard deviation of each set of numbers was calculated. These results are presented in Table 6.1.1. The mean value of percentage remaining was then plotted on semi-log paper against the corresponding value of $D_{/Q}0.5$, as shown in Figure 6.1.1.

The line of best fit for these results was determined by simple regression. The following relationship was used for this evaluation.

TABLE 6.1.1

SOLUBLE BOD_5 REMAINING AT VARIOUS DEPTHS AND HYDRAULIC LOADING RATES

Flow Rate (gpm/ft^2)	Sample * Point (ft)	Percent Soluble BOD_5 Remaining	
		Mean	Std. Dev.
1.0	4	94.67	6.16
	8	89.67	8.24
	13	83.05	8.40
	18	69.25	15.47
1.5	4	95.47	4.85
	8	93.13	4.94
	13	91.11	5.15
	18	81.20	7.31
2.0	4	91.74	7.55
	8	89.56	6.99
	13	85.90	6.27
	18	79.26	8.69

* Depth from top of filter

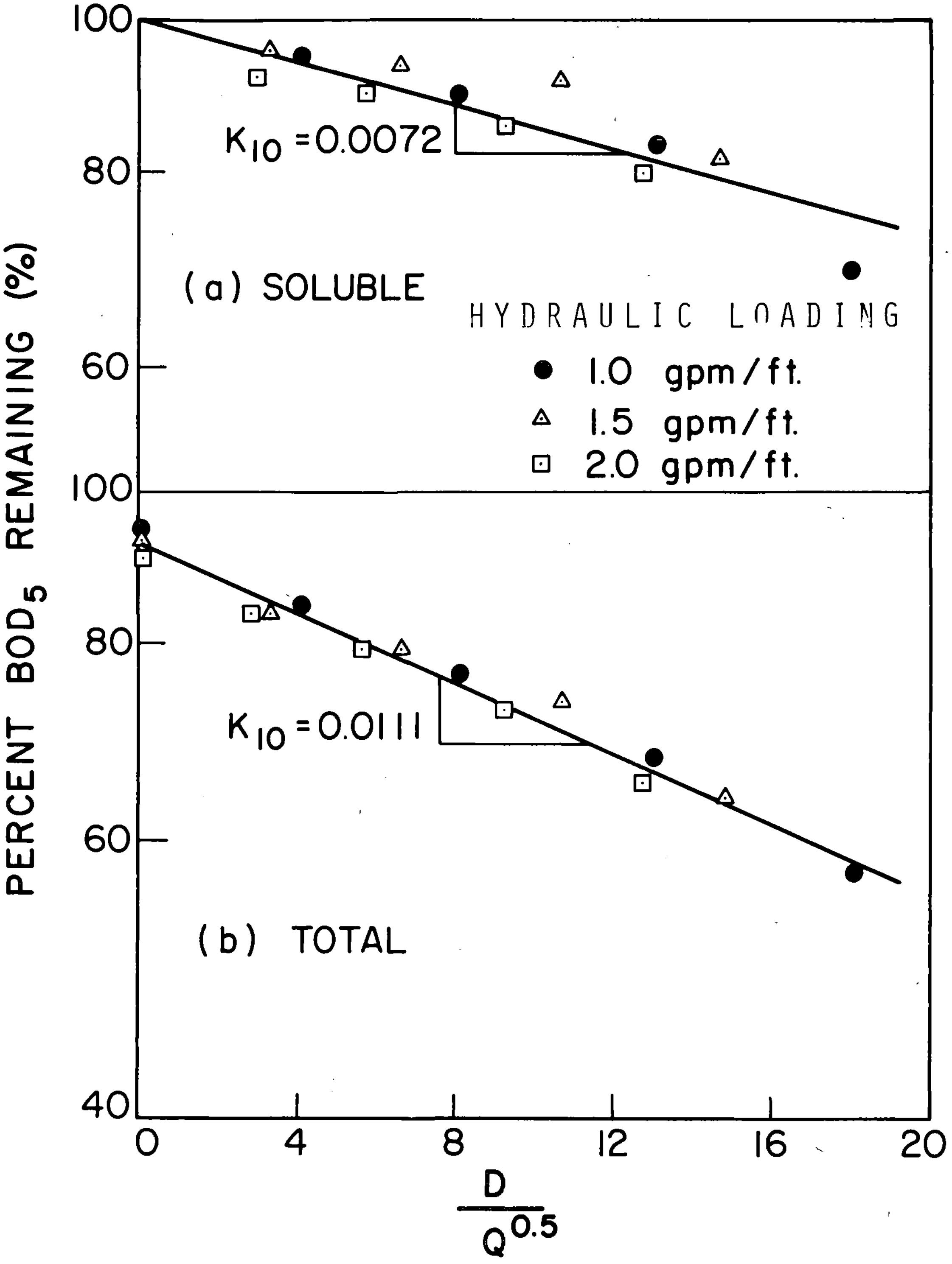


FIGURE 6.1.1

FIRST-ORDER BOD_5 REMOVAL

$Y = a + b X$

where Y = log (percentage remaining)

a = intercept

b = slope (K, reaction rate constant)

$X = D/Q^{0.5}$

The value of "b", which is numerically equal to the reaction rate constant, K_{10}, was found to be 0.0072. Taking K_{10} to the base e, yields a reaction rate constant 0.0166. The value of the intercept "a" was found to be 2.0025 which is approximately 100%, as it should be at zero depth. The correlation coefficient for the line of best fit was 0.936.

6.1.2 Total BOD_5 Results

The data for total BOD_5 was collected at the same time as the soluble BOD_5, however, the analysis of the samples gave results for unsettled influent as well as settled influent. The results at the zero depth also gave a value for percentage remaining even though the wastewater had not yet been applied to the filter.

Again, the mean value of percentage remaining and standard deviation for the values of $D/Q^{0.5}$, including zero depth, were calculated. These results appear in Table 6.1.2. A plot of these results is shown in Figure 6.1.1.

The line of best fit for the data was calculated as for soluble BOD_5 removal. In this case, instead of resulting in an intercept corresponding to 100% remaining, the value of "a" was found to be 1.967

TABLE 6.1.2

SETTLED BOD_5 REMAINING AT VARIOUS DEPTHS AND HYDRAULIC LOADING RATES

Flow Rate (gpm/ft^2)	Sample * Point (ft)	Percent Total BOD_5 Remaining	
		Mean	Std. Dev.
1.0	0 0	94.60	4.64
	4	84.85	7.55
	8	76.59	8.88
	13	67.97	9.97
	18	57.24	14.68
1.5	0 0	93.45	3.35
	4	83.87	5.43
	8	79.12	7.77
	13	73.03	10.40
	18	63.96	9.60
2.0	0 0	91.04	7.25
	4	83.59	6.32
	8	79.48	8.29
	13	72.42	8.62
	18	65.08	10.73

* Depth from top of filter media

or 92.66% total BOD_5 remaining. The value of "b", or the reaction rate constant, K_{10} was determined as 0.0111, which to the base e is 0.0256. This simple regression yielded a correlation coefficient of 0.991 indicating an extremely high correlation of the data to the first-order relationship.

The results of this analysis for the total BOD_5 depth study data are rather unique. In the past, the intercept of the plot of percent remaining versus D/Q^n has been shown to pass through 100% since no removal would occur before the waste was applied to the filter. However, with a waste containing a substantial quantity of suspended solids, it is evident that a certain percentage of the solids would settle out without any treatment by the filter. This factor has been taken into account with this type of analysis.

The resulting first-order equation for the removal of total BOD_5 by a pilot-plant trickling filter treating meat-packing wastes would have the following form:

$$\frac{s}{s_o} = 0.927e^{-0.0256D/Q^{0.5}} \qquad (6\text{-}3)$$

6.2 Kornegay and Andrews Equation

A more fundamental approach to trickling filter performance evaluation has been developed from a consideration of the specific mechanisms which controls substrate removal in a trickling filter. Factors which have been taken into consideration are the flow characteristics of the water passing over the filter medium, the mass transfer of substrate and oxygen from the liquid to the slime layer and the utilization of substrate by microorganisms.

The work of Kornegay and Andrews using a fixed-film biological reactor has led to the development at the following relationship expressed previously as Equation 2-2:

$$(so - se) + Kc \ln \left(\frac{so}{se}\right) = \frac{\mu_{max}\,(h)\,(X)}{Y}\;\frac{(A_p)\,(H)\,(D)}{Q} \qquad (6\text{-}4)$$

Jank (27), using a vertical-plane laboratory scale trickling filter with glucose as a single substrate, has developed a procedure for the evaluation of the two constants, K_c (the concentration in the liquid phase at one half the maximum mass flux) and $\frac{\mu_{max}\,(h)(X)}{Y}$ (the maximum mass flux of substrate at the slime liquid interface) for the Kornegay and Andrews equation. The procedure basically involves two steps.

The first step requires that a relationship be developed between substrate concentration in the liquid phase and depth of filter media. This is obtained by sampling at various depths from the bottom to the top of the filter. One of the basic assumptions of this theory is that this relationship will be linear as was shown for glucose. Then for each set of values, the substrate removal can be calculated in terms of concentration (mg/l) removed per depth (foot) of filter media. The second step requires that a relationship be developed for the removal of substrate over the range of substrate concentrations expected to be encountered by the filter. This procedure is then repeated for various hydraulic loading rates.

The curve resulting from a plot of substrate removal per foot of filter depth and influent concentration is of the form of a parabola, as illustrated in Figure 2.1.1 and can be expressed as the function

$$y = \frac{x}{a + bx} \qquad (6\text{-}5)$$

or rewritten

$$y = \frac{x}{{}^{1}/_{b}\ ({}^{a}/_{b} + x)} \qquad (6\text{-}6)$$

where

y = removal of substrate, mg/l/ft

x = substrate concentration, mg/l

$1/b$ = constant, maximum concentration of substrate which can be removed per foot of filter depth, mg/l/ft

a/b = constant, substrate concentration at one half the maximum substrate removal, mg/l.

The constants a and b for the parabola are obtained by linearizing equation (6-5) to the form

$$\frac{x}{y} = a + b\,x \qquad (6\text{-}7)$$

and performing a simple regression analysis on the data.

Jank has shown that the constant K_c is numerically equal to the value of ${}^{a}/_{b}$ expressed as grams per litre. The constant $\frac{\mu_{max}\,(h)(X)}{Y}$ to the product of ${}^{1}/_{b}$ and the hydraulic loading rate per unit of wetted perimeter and is expressed as grams per day per square foot of surface area.

6.2.1 Soluble BOD_5 Results

The procedure by Jank outlined above was used for the analysis of the soluble BOD_5 results with one exception. A sufficient quantity of sample could not be collected at the intermediate ports for the 0.5 gpm/ft^2 flow rate. Consequently, only influent and effluent grab samples were taken. Based on the theory that the removal for a particular substrate concentration should be constant for the entire depth of filter media, substrate removal was calculated as the difference between influent and final effluent divided by the filter depth (18 feet).

McGill (44) has reanalyzed the data obtained by Jank with a view to determining the necessity of using the intermediate depth data points in lieu of only the influent and effluent results for the calculation of removal of substrate per foot of filter depth. He also suggested using the influent substrate concentration instead of the concentration in the liquid phase as Jank had used. He found that there was no significant difference in the values of K_c and $\frac{\mu_{max}(h)(X)}{Y}$ in comparing the two methods of evaluation. Obviously, there is a tremendous saving in costs and time required for sampling, analysis and data reduction when only the influent and effluent data points are used. This modification of Jank's basic procedure also permits the data from other trickling filter systems to be evaluated using the mechanistic model of Kornegay and Andrews.

The soluble BOD_5 data used in this analysis was that presented in tabular form in Appendix C and used in the previous section for evaluation of the first-order reaction equation. Two data sets are shown for high and low influent substrate concentrations in Figure 6.2.1. The relationship of concentration with depth is linear, however, the slopes of the lines, or removal, is greater for the higher concentrations.

The values for the constants $^1/b$, $^a/b$, $\frac{\mu_{max}(h)(X)}{Y}$ and K_c for the removal of soluble BOD_5 by the pilot-plant trickling filter appear in Table 6.2.1. Correlation coefficients for the regression of the linearized form of the parabola are also presented.

The data and lines of regression for the four hydraulic loading rates are presented in Figures 6.2.2, 6.2.3, 6.2.4 and 6.2.5.

The generally low correlation coefficients, especially at the flow rate 1.5 gpm/ft^2, can be attributed to variations in the treatability of wastewaters which have essentially the same initial BOD_5 concentration. The variation in treatability is clearly shown from this data. As an example, in Figure 6.2.3 for the 1.0 gpm/ft^2 flow rate, there are three influent concentrations of approximately 500 mg/l yet the removal varies by a factor of almost 2.

In attempting to account for these variations in results for removal at similar influent concentrations, the assumption has always been made that there must be changes occurring in the constituents of the waste which alter the waste's treatability but not its overall concentration. This explanation has evolved from the elimination of factors which might have contributed to a variation in results. Factors such as temperature, pH and even experimental procedure have been discounted in that wastewater

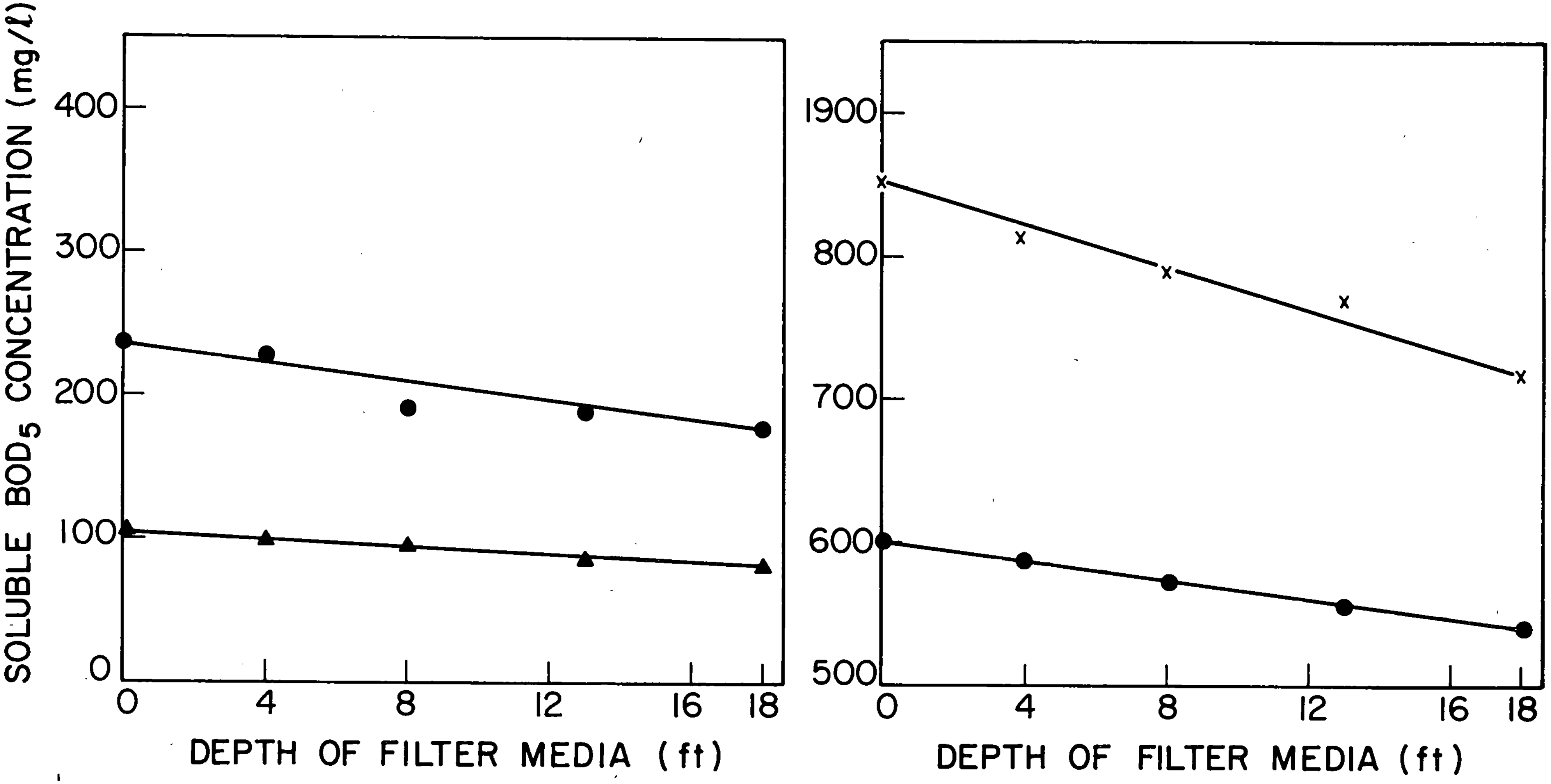


FIGURE 6.2.1

RELATIONSHIP OF SOLUBLE BOD_5 CONCENTRATION TO DEPTH OF FILTER MEDIA

TABLE 6.2.1.

VALUES OF CONSTANTS FOR EQUATION 2-2 BASED ON SOLUBLE BOD_5 REMOVAL USING MEAT-PACKING WASTE

Flow Rate gpm/ft^2	$1/b$ (mg/l/ft)	$\frac{\mu_{max}\,(h)(X)}{Y}$ $(g/day/ft^2)$	a/b (mg/l)	Kc (g/l)	Correl. Coeff.
0.5	9.94	1.20	275	0.275	0.83
1.0	8.99	2.18	203	0.203	0.85
1.5	10.53	3.82	698	0.698	0.58
2.0	8.78	4.25	496	0.496	0.75

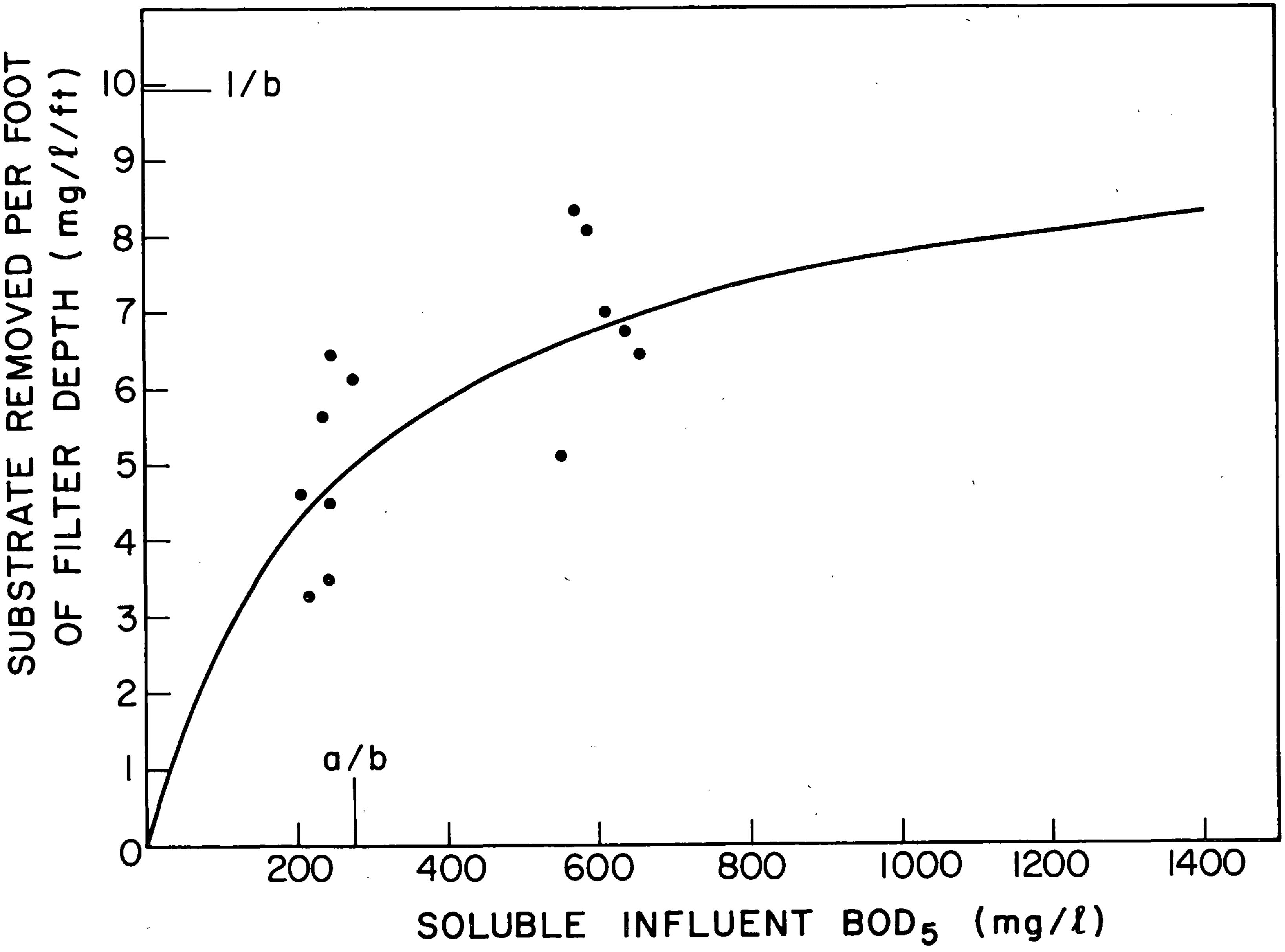


FIGURE 6.2.2

RELATIONSHIP OF SUBSTRATE REMOVED PER FOOT OF FILTER DEPTH TO INFLUENT SOLUBLE BOD_5 AT HYDRAULIC LOADING RATE 0.5 gpm/ft^2

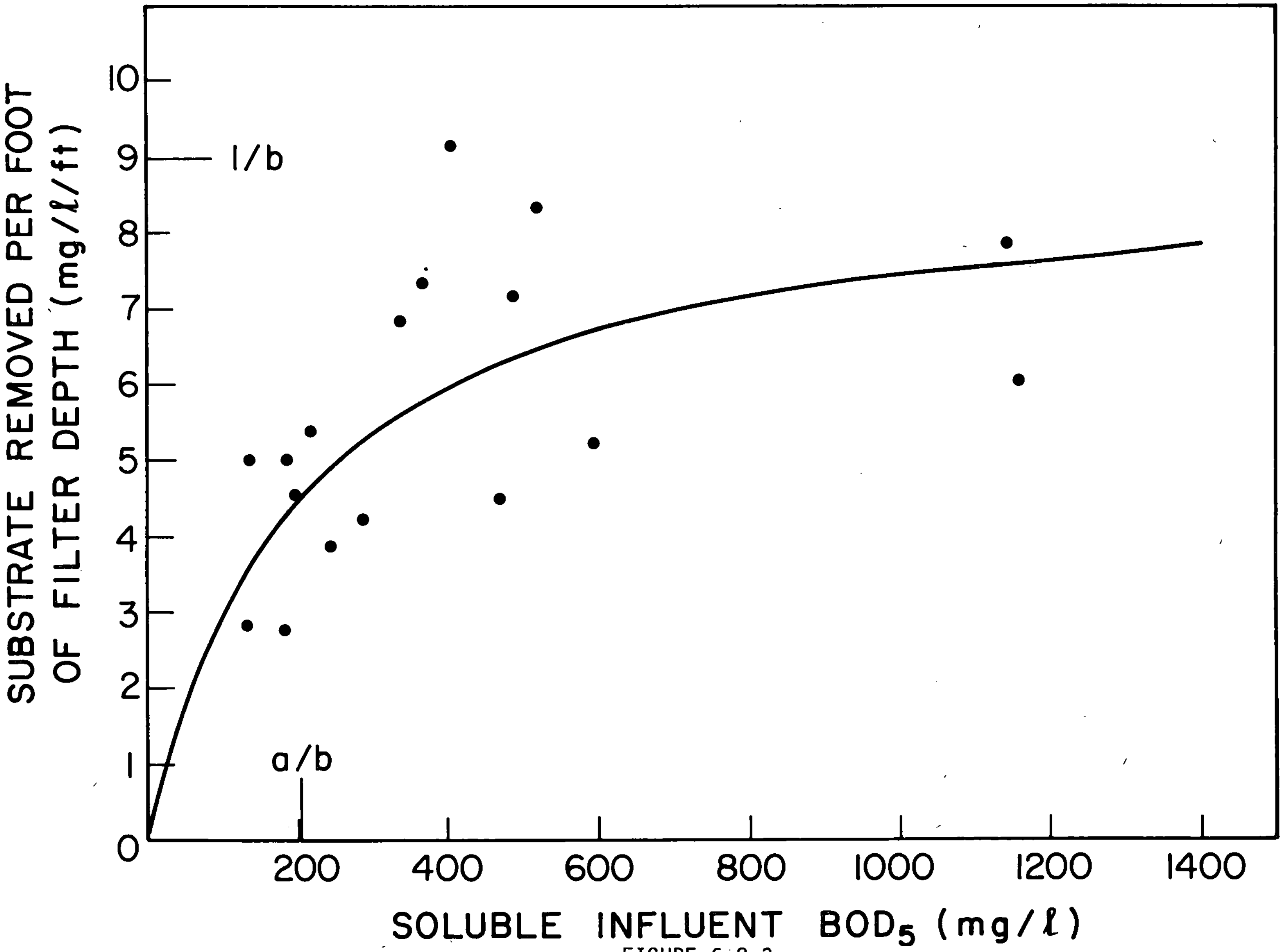


FIGURE 6.2.3

RELATIONSHIP OF SUBSTRATE REMOVED PER FOOT OF FILTER

DEPTH TO INFLUENT SOLUBLE BOD_5 AT HYDRAULIC LOADING RATE 1.0 gpm/ft^2

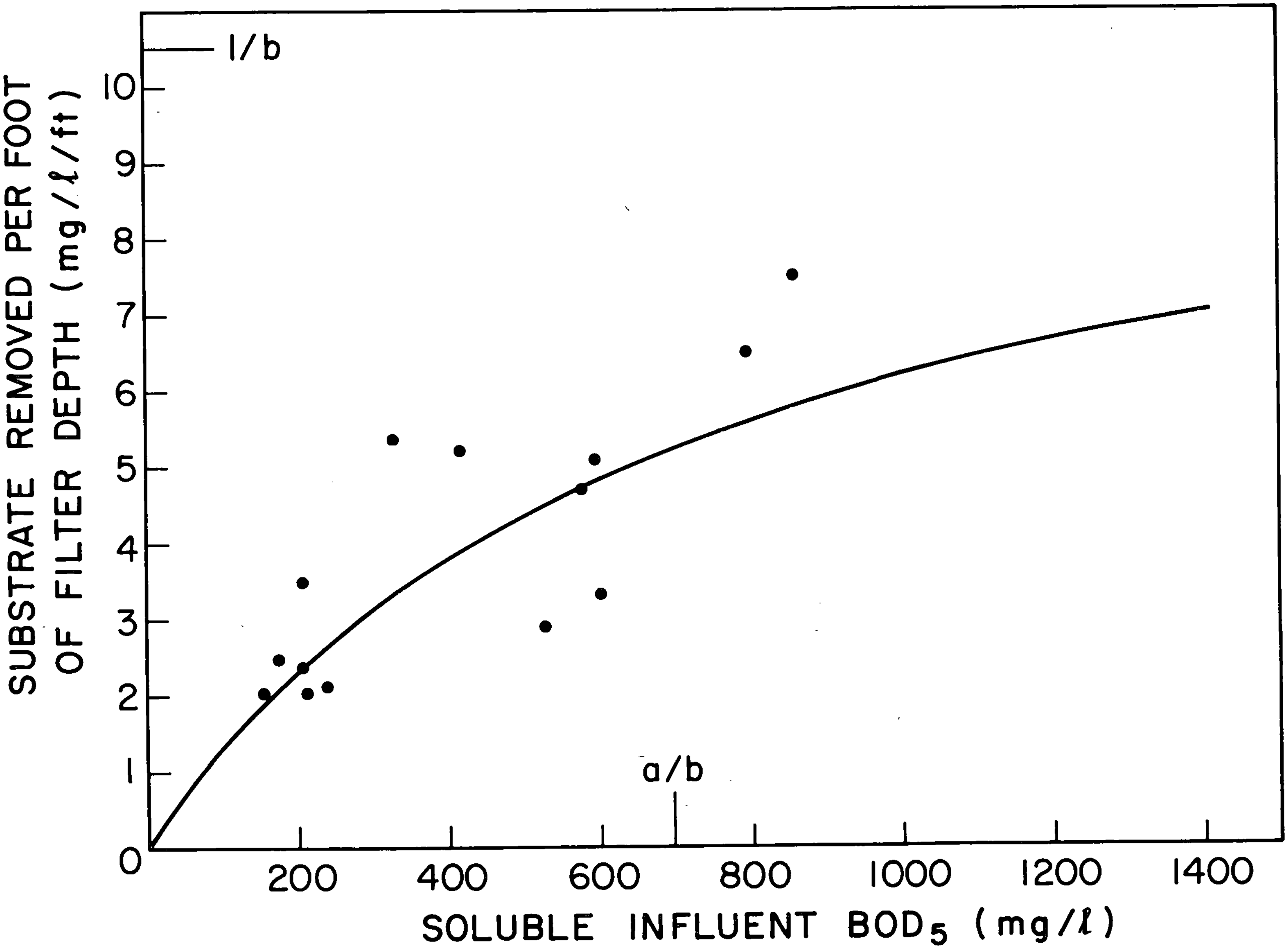


FIGURE 6.2.4

RELATIONSHIP OF SUBSTRATE REMOVED PER FOOT OF FILTER DEPTH TO INFLUENT SOLUBLE BOD_5 AT HYDRAULIC LOADING RATE 1.5 gpm/ft^2

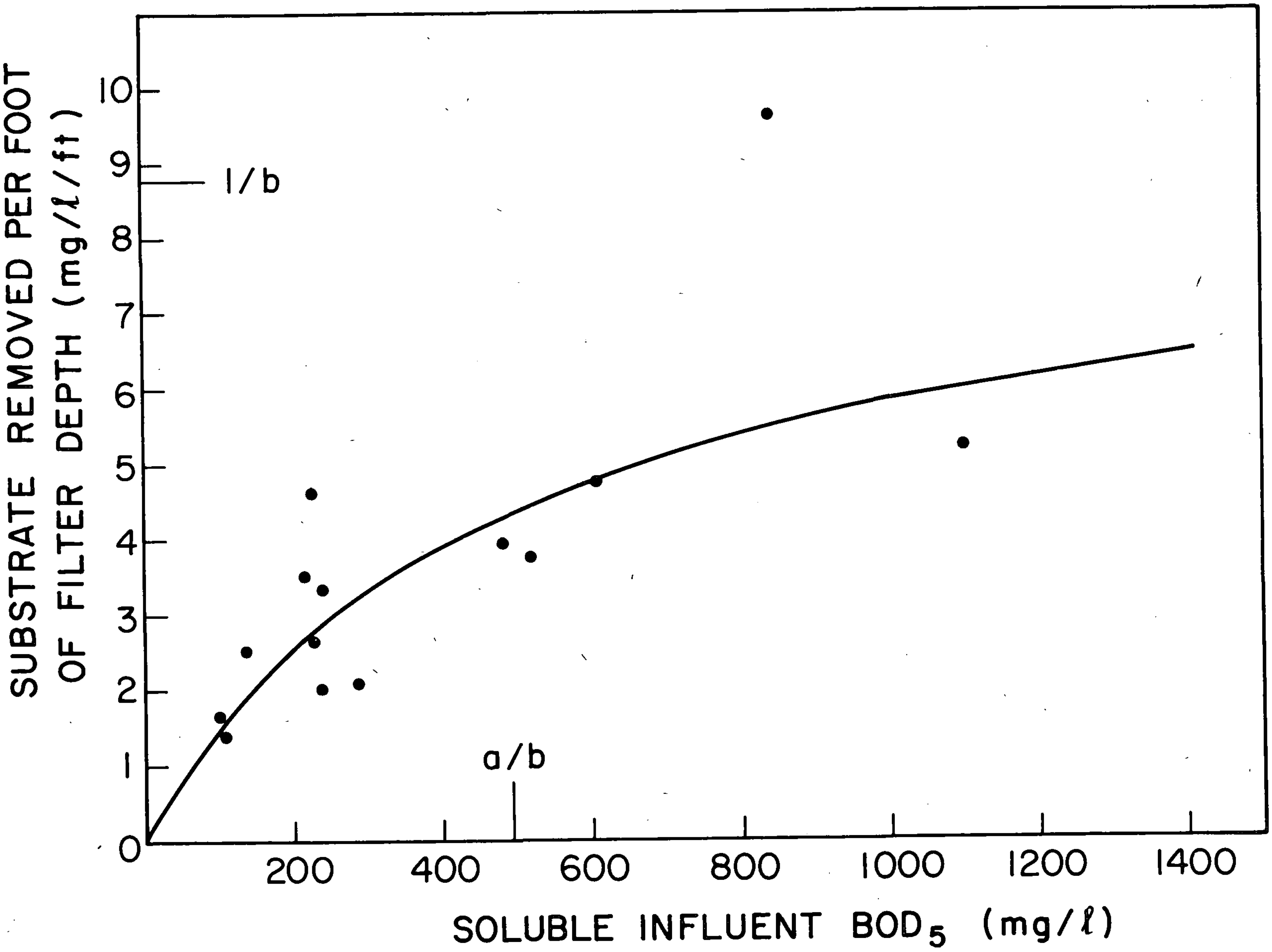


FIGURE 6.2.5

RELATIONSHIP OF SUBSTRATE REMOVED PER FOOT OF FILTER DEPTH TO INFLUENT SOLUBLE BOD_5 AT HYDRAULIC LOADING RATE 2.0 gpm/ft^2

temperatures and pH were found to be similar in magnitude when removal rates for particular influent concentrations were examined. The sampling and analytical techniques were performed continually according to a standard routine procedure.

These results, then can be considered representative of what can be expected for a complex industrial waste such as meat-packing wastewater. Possibly, more experimental data would alter the lines of regression somewhat, but it must be assumed that any changes would be insignificant.

6.2.2 Total BOD_5 Results

The Kornegay-Andrews formulation has to date only been used with soluble wastes. It has been shown to be applicable both to a single carbon source, such as glucose, and to a complex industrial waste such as meat-packing wastewater. However, since many industrial waste contain significant quantities of suspended solids, an attempt should be made to determine whether this mechanistic model can be adapted to predict the removal of total BOD_5 in a trickling filter system.

The approach used to determine values of the constants K_c and $\frac{\mu_{max}(h)(X)}{Y}$ is somewhat similar to that used in the analysis of the soluble BOD_5 data. In Figure 6.2.1, relationships of soluble BOD_5 concentration with depth of filter media were presented for a range of substrate concentrations. Linear relationships were developed, so that the removal could be determined either as the slope of the best fit line through the date according to Jank (27) or the difference between influent and effluent divided by the depth of filter media according to McGill (44).

In Figure 6.2.6, two representative sets are presented for the total BOD_5 depth study data. There appears to be a linear relationship developed between settled influent at zero depth and the settled effluents at the remaining sampling ports. However, it is quite evident that any linear relationship developed between the unsettled influent and settled effluent at any other port is not representative of the removal of total BOD_5 throughout the entire filter. Consequently, any relationships which are derived for removal of total BOD_5 with depth must be based on settled samples at each port. The design equation would then have to be modified to include a factor for the initial quantity of BOD_5 which could be removed by settling prior to passing the waste over the filter.

The derivation of the removal quantities at various influent concentrations has been discussed. The data sets are those used in the analysis of total BOD_5 for the first-order equation and are presented in Appendix C. In addition, several grab samples were also used to supplement the results for the 1.5 gpm/ft^2 flow rate.

The values of the constants $^1/_b$, $^a/_b$ $\frac{\mu_{max}(h)(X)}{Y}$ and K_c for the removal of total BOD_5 by the pilot plant trickling filter appear in Table 6.2.2. The correlation coefficients for the regression of the linear form of the parabola are also presented.

Graphical presentation of the data and the lines of best fit for the hydraulic loadings 1.0, 1.5 and 2.0 gpm/ft^2 are presented in Figures 6.2.7, 6.2.8 and 6.2.9. No results are presented for the 0.5 gpm/ft^2 flow rate,

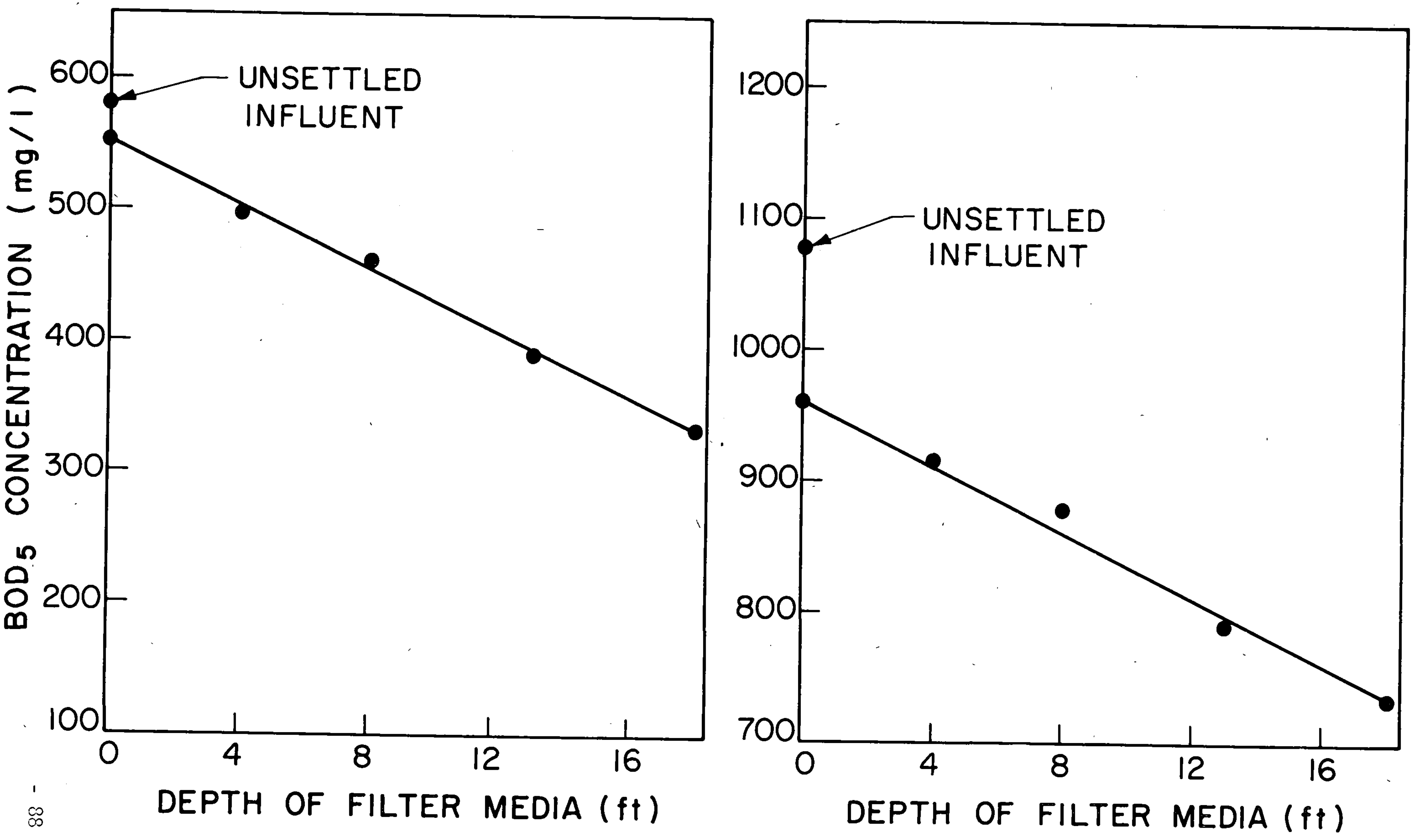


FIGURE 6.2.6

RELATIONSHIP OF TOTAL BOD$_5$ CONCENTRATION TO DEPTH OF FILTER MEDIA

TABLE 6.2.2

VALUES OF CONSTANTS FOR EQUATION 2-2 BASED ON TOTAL BOD_5 REMOVAL USING MEAT PACKING WASTE

Flow Rate (gpm/ft^2)	1/b mg/1/ft	$\frac{\mu_{max}(h)(X)}{Y}$ $(g/day/ft^2)$	a/b (mg/1)	Kc (g/1)	Correl. Coeff.
1.0	29.50	7.14	747	.747	.65
1.5	23.80	8.64	932	.932	.44
2.0	38.91	18.82	1,806	1.806	.48

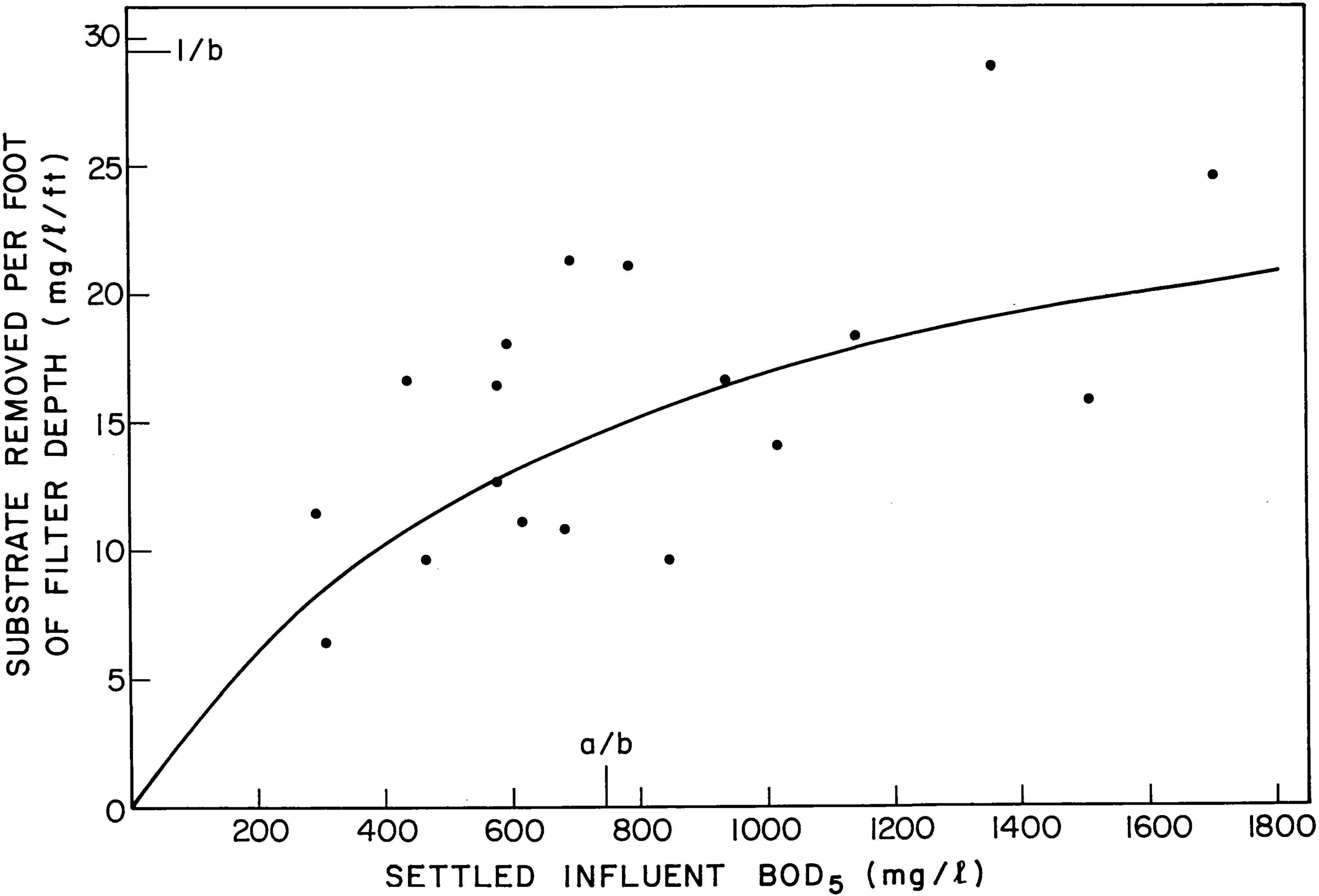


FIGURE 6.2.7

RELATIONSHIP OF TOTAL BOD_5 REMOVED PER FOOT OF FILTER DEPTH TO SETTLED INFLUENT BOD_5 AT HYDRAULIC LOADING 1.0 gpm/ft^2

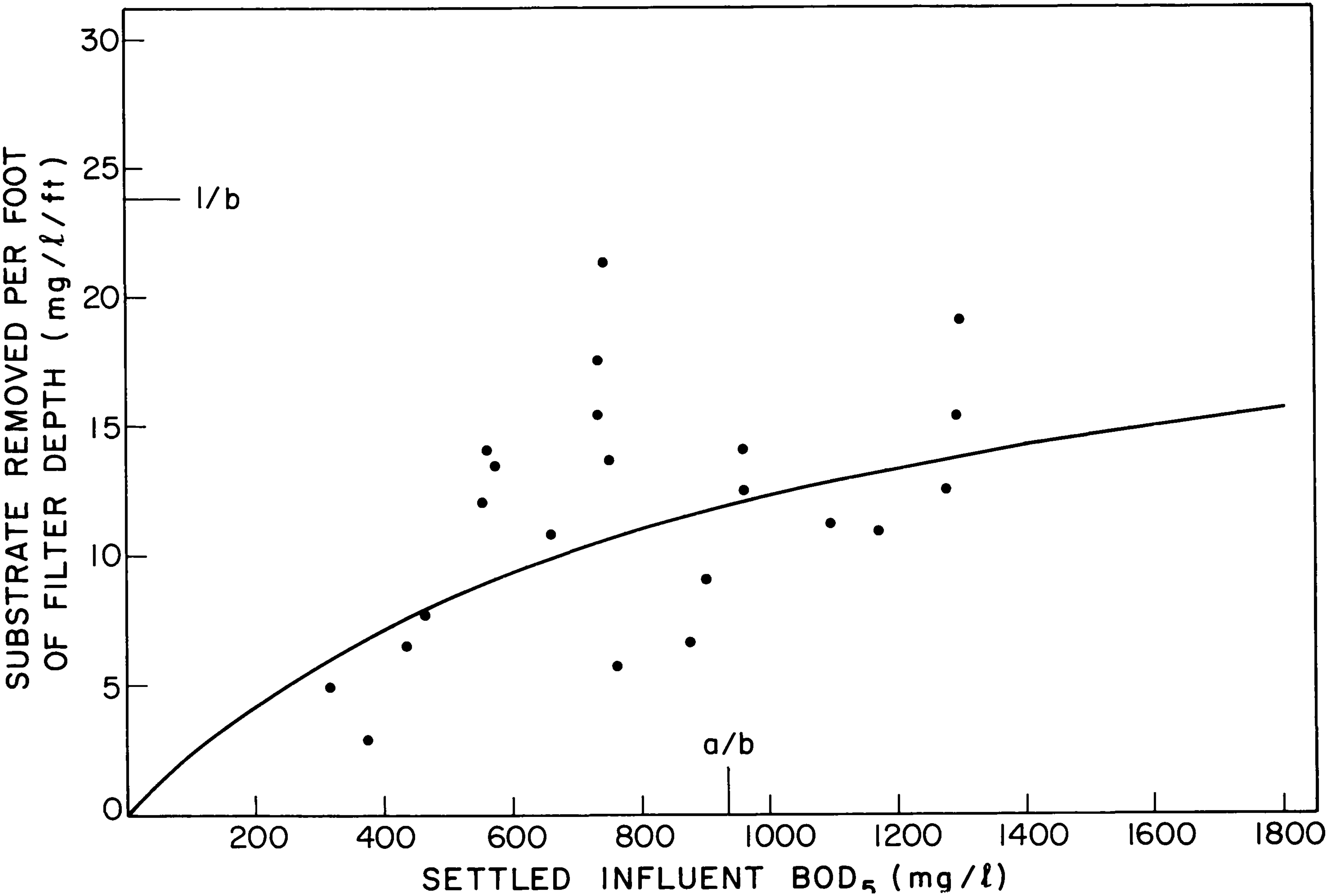


FIGURE 6.2.8

RELATIONSHIP OF TOTAL BOD_5 REMOVED PER FOOT OF FILTER DEPTH TO SETTLED INFLUENT BOD_5 AT HYDRAULIC LOADING RATE 1.5 gpm/ft^2

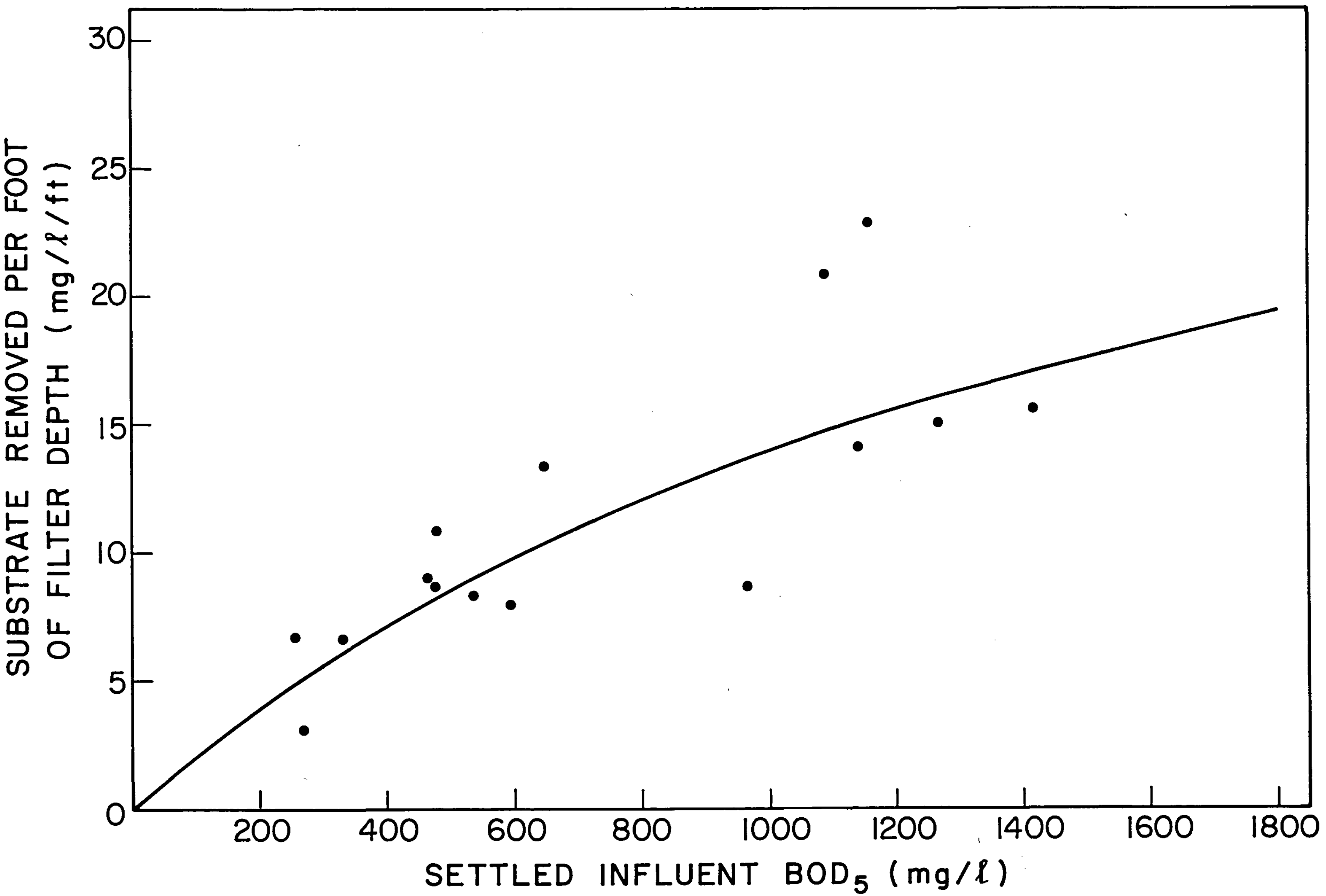


FIGURE 6.2.9

RELATIONSHIP OF TOTAL BOD_5 REMOVED PER FOOT OF FILTER DEPTH TO SETTLED INFLUENT BOD_5 AT HYDRAULIC LOADING RATE 2.0 gpm/ft^2

as the analyses did not include settled influent.

As for the soluble BOD_5 data results, the correlation coefficients of the linearized form of the parabola are quite low. Indeed the question might be raised as to whether the parabola is the most correct relationship for these results. Since the purpose of this discussion was not to determine the question of which relationship to use (i.e. linear, parabolic) but rather to determine whether or not the Kornegay and Andrews equation can be used with total BOD_5 results, no attempt was made to fit the data to other relationships. It would appear that the data does not fit the parabolic form to a statistically significant degree. Nevertheless, the trends as shown by the data indicate that indeed a parabolic fit through the data is realistic.

There is some theoretical justification in extending the mechanistic approach of Kornegay and Andrews to include the removal of suspended organic material of the relationship. In an earlier section, discussing the improved settleability of the solids as the wastewater came into contact with the slime surface of the filter, two phenomena were mentioned as possibly accounting for this improved settleability:

(i) the existence of long-chain polyelectrolytes, discussed in the work of Pavoni concerning bioflocculation in the settling chamber, and

(ii) physical adsorption of colloidal and suspended material into the slime matrix.

The phenomena of physical adsorption should be considered in further detail. A physical adsorbent, such as granular carbon; has a fixed capacity in relation to its surface area. Thus, only a limited quantity of particulate can be adsorbed before this capacity is exhausted. However, in the trickling filter system, there is the capability for self-regeneration, within the slime matrix. If the potential rate of adsorption is greater than or equal to the rate of generation of new sites for adsorption, then the filter slime surface would be continuously saturated. The growth of factor for the removal of soluble organic material according to the mechanistic model of Kornegay and Andrews, then there is justification in extending the model to include the removal of suspended and colloidal material.

Assuming, then, that Kornegay and Andrews approach is acceptable for use when suspended and colloidal material is included, the equation must be modified to allow for the initial removal of settleable BOD_5 material before the wastewater is applied to the filter.

Using the same factor as found for the first-order analysis (i.e. 92.66% of the initial BOD_5 will be applied to the filter), the Kornegay and Andrews equation can be expressed as:

$$(0.927\ s_o - s_e) + K_c \ln\left(\frac{0.927\ s_o}{s_c}\right) = \frac{\mu_{max}\,(h)(X)}{Y}\ \frac{(A_p)(H)(D)}{Q} \qquad (6\text{-}8)$$

The values of the constants K_c and $\frac{\mu_{max}\,(h)(X)}{Y}$ for this relationship are expressed in Table 6.2.2.

6.3 Comparison of Design Formulations

A brief discussion of the theory behind the two trickling filter equations was presented in the literature review. The procedures necessary to evaluate constants for both equations have been described in the preceding section.

It is necessary to compare the two formulations with respect to either the predictions of effluent BOD under given operating conditions, or the volume of media required to obtain a given effluent BOD_5 concentration for the same conditions in order to perhaps determine which is the more suitable equation for at least this work.

The Daily Operation data, presented in Section 5, has provided a sufficient indication of the performance of pilot-plant trickling filter under daily conditions, over a period of time. As a starting point then, the two design equations should predict effluent results which compare favourably with the Daily Operation results. Consider the following operating conditions to be constant:

Influent BOD_5 = 535 mg/l

Hydraulic Loading Rate = 1.0 gpm/ft^2

Depth = 18 ft.

Cross-sectional area = 16 ft.

Specific Surface Area of Media = 29 ft^2/ft^3

Total Daily Flow = 23,040 Imp. Gallons
(at 1gpm/ft^2) = 104,740 litres

Use of the values of the constants for the 1.0 gpm/ft^2 flow rate for the Kornegay and Andrews formulation expressed as equation (6-8), results in a settled effluent BOD$_5$ of 300 mg/l. Similarly, the first-order equation expressed as (6-3), yields a prediction of 314 mg/l. The mean settled BOD$_5$ effluent concentration for the Daily Operation program was 269 mg/l with a standard deviation of 34 mg/l. Clearly, then, the prediction of effluent by the Kornegay and Andrews equation gives the closest result to the Daily Operation average.

Recall that the correlation coefficients were rather low for the best fit lines of the linearized form of parabola for the Kornegay and Andrews evaluation. Still, the results predicted by this method appear to be slightly more accurate than those provided by the first-order reaction equation, even though the correlation coefficient for the first-order reaction best fit line was extremely high.

The results of both effluent predictions are higher in comparison to mean effluent concentration for the Daily Operation. However, in Section 5.1, the ratio of settled influent BOD$_5$ to unsettled influent BOD$_5$ was found to be 0.85. If this value is used rather than the 0.93 value found as the ratio of settled to unsettled BOD$_5$ results for the Depth Study data, then the effluent BOD$_5$ predictions come significantly closer to the value found for the Daily Operation study. The Kornegay and Andrews prediction is approximately 270 mg/l whereas the first-order result is 287 mg/l. These values are both well within the range of one standard deviation from the mean value.

Since both formulations appear to give realistic predictions of the effluent provided that the initial contribution of settleable BOD_5 can be accurately determined, further discussion of the sensitivity of the two equations to variations in the several parameters should be given. Campbell (45) has investigated the sensitivity of both models with respect to effluent predictions when the parameters in the equations are varied. He has found that the first-order equation is most sensitive to variations in K, the reaction rate constant, or in other words, changes in the biodegradability of the waste. The Kornegay and Andrews equation is affected to the greatest degree by variations in the constant $\frac{\mu_{max}(h)(X)}{Y}$ which is in turn affected considerably by changes in the data points which have been obtained. Relatively few variations in data points can alter the value of the constant $\frac{\mu_{max}(h)(X)}{Y}$ significantly. Campbell found that either equation was valid for relatively low substrate concentrations, however, only the Kornegay and Andrews equation should be used at higher waste strength concentrations.

In summary, then, both the first-order reaction equation and the Kornegay and Andrews mechanistic approach would be suitable for the design of a full-scale trickling filter plant, based on a prediction of effluent quality for daily operating conditions. If it is intended to produce a design for a certain effluent quality at all times throughout the day, considering the variation in influent BOD_5 concentration, then it would be best to employ the Kornegay and Andrews approach.

From the standpoint of basing design considerations on biological principles and the actual mechanisms involved in substrate removal, the Kornegay and Andrews approach is the better of the two models. If the present art of trickling filter design is to advance towards that of a science, then the mechanistic approach must be adopted as a suitable design tool.

7.0 TREATMENT PLANT PERFORMANCE

The performance of a biological treatment process is primarily a function of the nature and characterisitics of the wastewater being treated. The influence of parameters, such as COD, BOD_5, suspended solids, pH and nutrients which have been discussed in detail in previous sections of the report, are reviewed here. In addition, performance due to loading changes as a result of production schedules, the effects of grease, operating temperature, climatic conditions, and recirculation, which not only affect the performance of the plant but also its operation are discussed. Finally, factors, such as nuisances and sludge production, which are important to the operation of the process but not necessarily related to its performance are summarized in relation to the application of the trickling filter process to treatment of meat-packing wastes.

7.1 General Wastewater Characteristics

Detailed discussion of the wastewater characteristics at the J.M. Schneider Co. Ltd., has been presented in previous sections. Briefly, the wastewater has an average total BOD_5 of 550 mg/l, half of which is in the form of soluble organic material. The suspended solids concentration of the waste averages about 300 mg/l. Throughout the production day, the concentration of various parameters can vary by a factor of 8. This variation has a significant effect on the performance of the trickling filter. At high organic loadings, ranging from 200 to 800 lb. $BOD_5/1000\ ft.^3$/day, the total removal efficiency varied between 57 and 35% showing a decrease in efficiency as the loading increased.

Since the study was conducted to determine the capabilities of the trickling filter as a "roughing" treatment process, the hydraulic and organic loadings were quite high. A flow rate of 1.0 gpm/ft^2 produced an organic loading of approximately 400 lb BOD$_5$/1000 ft.^{3}/day. At these conditions, the trickling filter achieved a removal efficiency of about 50% and consistently produced an effluent BOD$_5$ concentration less than 300 mg/l. This meets the requirement for discharge to a municipal sewer system.

7.2 Production Week

The production schedule of an industrial plant is of major concern when determining the method of operation of a wastewater treatment facility for the industry. A biological treatment system for an industry working only a 5-day week is faced with several problems to overcome if the project is to be successful.

The J. M. Schneider Co. Ltd., plant operates on a 5 day production week. Generally the first production shift starts at 6:00 a.m. on Monday and the last shift ends about 11:00 p.m. Friday. The wastewater flow reached the primary treatment facility by 6:30 a.m. and takes approximately two hours to fill the flotation units before effluent is discharged. The diurnal flow pattern, discussed previously, then continues throughout the week until approximately 11:00 p.m. Friday. As final drainage and washup of tanks and equipment are being completed the flow gradually diminishes until about 7:00 a.m. Saturday. For the duration of the weekend, the flow is only a few gallons per minute from leakages in hoses or taps, at most an insignificant quantity for treatment.

The pilot-plant operation was begun on Monday mornings as soon as flow was discharged from the primary treatment plant. This operation generally continued until Friday afternoon. When the project was first begun, it was considered necessary to place the plant on recycle during the weekend period in order to maintain the biological slime surface in a wetted condition. Water was recycled from the final effluent tank through the filter at a flow rate of 1.0 gpm/ft^2 with some addition of the 450 gallons of wastewater which could be contained in the holding tank to supplement losses which occurred due to leakages in the system. This method of operation required that the pilot-plant be checked at least twice throughout the weekend, as the pumps were set to maintain flow in a closed system.

The continual recycle of wastewater over a 50 to 60 hour period resulted in a build-up of foam in the final effluent tank, leaving a black, sticky residue on the sides of tanks and walls of the substructure of the settling tank.

The problem of setting pump No. 4, which discharged to the clarifier, so that it would not get ahead of the recycle pump also proved to be difficult. On the several occasions when this happened there was an insufficient quantity of water in the holding tank to restart the plant. Consequently, the plant was shut down for periods up to 48 hours with no flow being passed over the filter media.

The results obtained on the performance, based on percent removal of COD or BOD_5 for the Monday operations when these shutdowns occurred, indicated that there was no detrimental effect to the treatment system. A summary of the average removal efficiencies for Monday operations as compared to the mean efficiency for all data points at each flow rate showed that the removal appeared to be higher on Monday. Statistically it was found that there was no significant difference in Monday operation as compared to the average performance of the plant.

The conclusion was then made that the trickling filter can be operated on a 5 day production week with no setback to performance efficiency of the system when the plant is restarted. This is an important consideration in terms of cost of operating the system with respect to both operating personnel and pumping costs. It would be necessary, however, to provide for drainage of tanks and washup prior to complete shutdown for weekends, but, the overall saving in operating costs would be substantial.

7.3 Grease

The very nature of the meat-packing operation itself leads to significant quantities of grease in the wastewater. The quantity of grease depends, to a degree, on in-plant housekeeping, nevertheless, with washing and process water, it is inevitable that a substantial quantity of grease will be discharged. The air flotation process will remove much of the grease and suspended particulate matter in the wastewater, however, there can still be rather high amounts of grease passed on in the wastewater discharged to the sewage system or in this study, to the trickling filter.

In the diurnal variation studies, it was found that the concentrations of grease or ether solubles, varied from 50 to 600 mg/l throughout the day with the peak strength occurring with the discharge of concentrated wastewater from the rendering system. On a 24 hour composite basis, the average grease concentration was about 150 mg/l.

This quantity not only exceeded the by-law limit of 100 mg/l but it was felt that there might possibly be some detrimental effect to the biological system of the trickling filter.

In order to determine the effect, if any, on the performance of the trickling filter, an experimental study was conducted in the laboratory. Since there was no realistic control over the concentrations of grease in the actual wastewater, a simulated waste was developed using "Difco" beef extract as an organic substrate and a 1:1 mixture of lard and tallow obtained from the meat-packing plant as the grease constituent.

A laboratory rolling-tube trickling filter unit, as shown in Figure 7.3.1, was started using meat-packing wastewater effluent from the primary treatment plant to develop a slime layer within four of the tubes.

The operation of this type of laboratory unit was first discussed by Gloyna (46). Basically, the tubes are acrylic plastic, 2 inches inside diameter and 30 inches long. They are mounted in aluminum

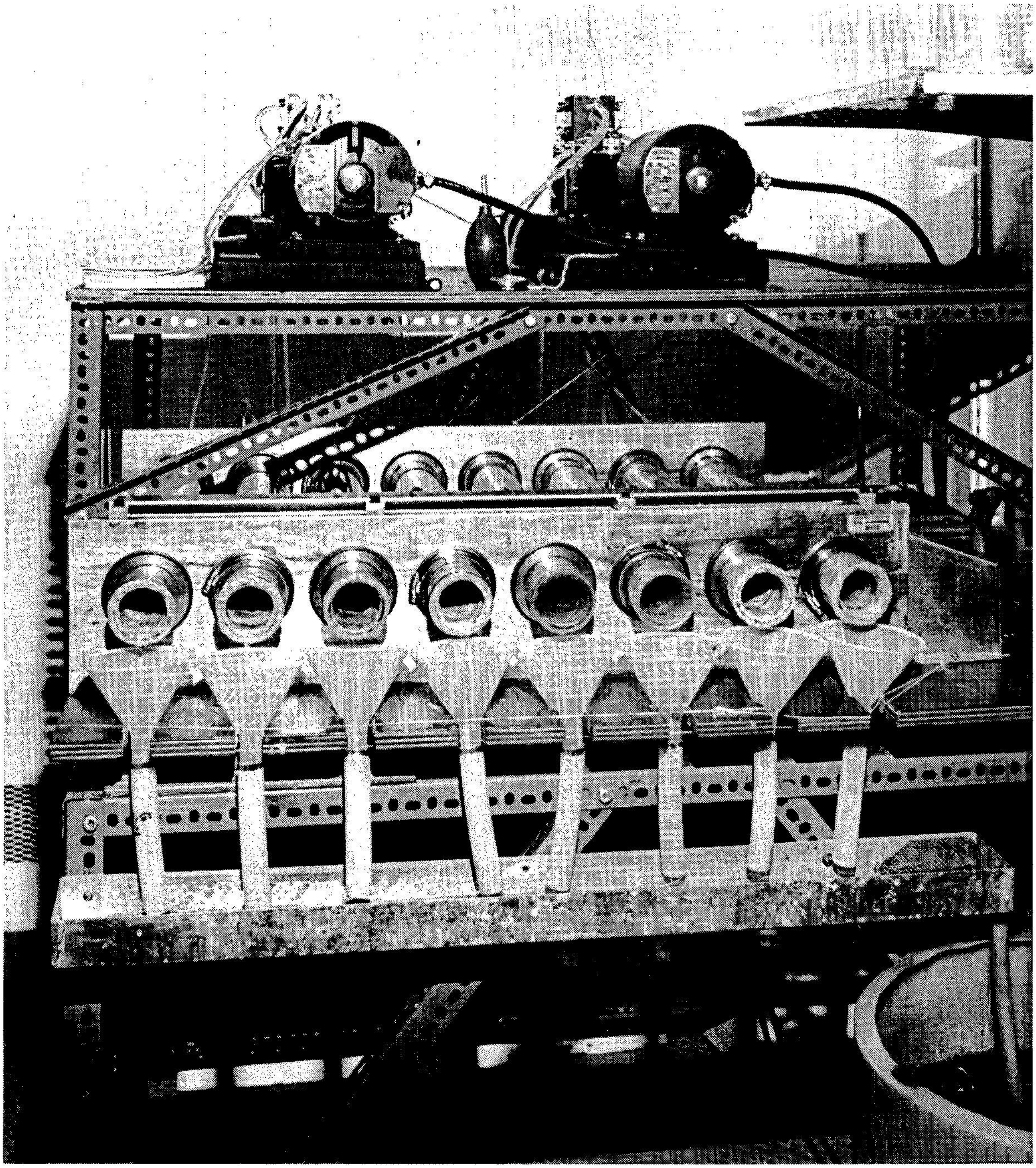


FIGURE 7.3.1

LABORATORY ROLLING-TUBE TRICKLING FILTER UNIT brackets set at a 1° slope to the horizontal and chain driven at a speed of 18.5 rpm. This allows the water to flow through the tube wetting the entire slime surface.

After about five days of operation a fairly even slime matrix had developed and the feed solution was gradually switched (over a period of three days) to the simulation feed which had a concentration of about 940 mg/l COD. A stable slime matrix was maintained and the feed solution was again switched, this time to four solutions containing 0, 50, 150 and 300 mg/l ether solubles in addition to the beef extract stock. Testing of influent and effluent samples continued over a period of two weeks. A summary of the results of the study is presented in Table 7.3.1.

The obvious fact from this study is that grease constitutes a considerable portion of the chemical oxygen demand. The increased COD to ether soluble ratio averages 2.65 for the three feed solutions containing grease.

The total removal of COD through the four tubes averages about 55% indicating that there is no overall difference in the performance as the grease concentration is increased. However, if the effluent COD is adjusted to consider only the original COD remaining, there is a significant drop in the removal efficiency as the grease concentration increases. The contribution to the COD of the grease in the final effluent is based on the COD/ether soluble ratio for the influent solutions, adjusted by 10 mg/l for the residual grease in the beef extract. These calculations are presented in Table 7.3.1.

TABLE 7.3.1.

GREASE LABORATORY STUDY RESULTS

Parameter	LABORATORY TRICKLING FILTER UNIT			
	1	2	3	4
Influent				
COD, mg/l	940	1060	1350	1790
Ether Sol., mg/l	0	50	150	300
Effluent				
COD, mg/l	400	500	600	800
Ether Sol. mg/l	10	30	40	80
Calculations				
Adjust. Effluent Ether Soluble (-10)	-	20	30	70
Effluent COD from Ether Solubles	-	55	80	185
Original COD in Effluent	400	445	520	615
% Removal of Soluble Substrate	57	52	45	35
Total % Removal	57	53	56	55

It appears then that there is some reduction in the removal of soluble organic substrate. However, since the total removal efficiency does not vary as the grease concentration is increased, there must be some physical adhesion of the slime particles which are sloughed from the filter surface into the effluent and which compensates for any decreased removal of soluble material.

Evidence of the reduction in grease throughout the pilot-plant process can not be expressed in quantitative terms as unfortunately the final effluent was never analysed for ether solubles. There was at no time throughout the operation of the pilot-plant, a froth or scum layer on the surface of the clarifier. This is in direct contrast to the appearance of both the holding tank and the distribution tray, where at any time throughout the production day, there was a significant quantity of grease.

7.4 Cold-Weather Operation Conditions

As in most experimentation into biological treatment processes for use in Canada, much consideration was given to the operation of the pilot-plant throughout cold weather periods. The nature of the pilot-plant equipment itself proved to be the only operational problem in this regard.

During the initial winter period in which the pilot-plant was in operation, the piping gallery between the manhole where the wastewater was obtained and subsequently discharged, was left open to the elements. The area between the instrumentation building and the filter tower was also left unprotected. The piping used was 1-1/2" ø black plastic piping and most of the connections were nylon couplings. Consequently, there were several occasions when pipes became frozen due to the fact that they were not properly drained for the weekend and/or became covered with snow and ice. This problem was overcome with the construction of plywood sheeting over the entire exposed piping area and the use of flexible rubber hosing on all joints which required uncoupling for the purposed of draining.

This freezing problem was the only operational problem that was encountered throughout two winters of operation. The use of a stationary distribution system at the top of the filter tower was a considerable advantage in this regard. In a permanent installation, the need for proper protection and insulation of the piping gallery would also have to be considered.

The effect of the colder winter temperatures on the performance of the pilot-plant was compared with that of the summer operation. An investigation of temperature effects has been carried out by Jank et al (23) using the same pilot-plant trickling filter at an installation at the Waterloo Sewage Treatemnt Plant. Variations of ambient temeprature between -11°F and 90°F were found to have only moderate effect on the filter efficiency. Temperature measurements at the packing surface indicated that heat loss at the slime and liquid interface was negligible in once-through applications. However, significant cooling of the waste occurred after it was discharged from the column of packing.

In this study of meat-packing wastes, the influent waste temperature was found to vary between 70°F and 95°F with an average daily temperature of about 85°F. Throughout the year, the ambient temperature varied between -10°F to 90°F. Throughout the milder temperature periods, there was a decrease in temperature of about 2 to 4°F between the influent wastewater to the filter and the effluent as it was pumped to the clarifier. This decrease in temperature ranged between 6 and 8°F during the coldest periods of the winter. Since there was some detention time for the effluent water in the square tank at the bottom of the filter tower, it was assumed that most of the decrease occurred at this point and not as the wastewater passed through the filter.

During the cold-weather period the removal efficiency was found to have decreased slightly for the lower flow rates. At the 1.0 gpm/ft^2 hydraulic loading rate there was a decrease of approximately 5 to 10% efficiency in comparing total BOD_5 data obtained in February with that collected in July. At the 1.5 and 2.0 gpm/ft^2 flow rates, there appeared to be no difference in the data collected during winter and summer. As has been discussed previously throughout this report, many of the differences in removal efficiencies may have partially resulted from changes in the treatability of the wastewater over the periods of the study.

In section 7.2 of this report, the operation of the pilot-plant over a 5-day production week was discussed. It was found that there was no significant difference in Monday's treatment performance as compared to the other production days even though the trickling filter was shut-down over the weekend. This same trend occurred throughout the winter months as well.

During the period December 17, 1971 to January 3, 1972, the pilot-plant trickling filter was not operated. This allowed the bios or slime on the media to become anaerobic and freeze. The results over the first week's resumption of operation of pilot-plant were as high as the removal efficiencies found prior to the plant shutdown. This result was predicted in laboratory experiments conducted by Jank in the previous study referred to in this section. The fact that the trickling filter biological treatment process can be shutdown and restarted a period of two weeks later without a major loss in performance is a most important consideration in an industrial waste application.

7.5 Recirculation

During this eighteen month study of trickling filtration, the pilot-plant was operated for approximately six months on recirculation. The data collected throughout this period has been evaluated by McGill (44) with a view to determining the relative value of employing recirculation to increase BOD_5 removal and ascertaining whether the Kornegay and Andrews mechanistic approach can be satisfactorily adapted for prediction of effluent quality when recirculation is employed. A brief summary of his findings are presented here as recirculation is one of the many factors which can affect the performance of a trickling filter.

The operating procedure basically involved recirculating water from the square tank at the bottom of the tower through Pump No. 3 at a controlled flow rate. Influent waste was fed by means of Pump No. 2. Samples of raw influent and tower effluent were collected and analysed as discussed in Sections 4.2 and 4.3. The various base flows and recirculation ratios evaluated are presented in Table 7.5.1

McGill, using values of the constants for the Kornegay and Andrews equation from the studies without recirculation, predicted effluent concentrations with the aid of computer simulation. These, he compared with the actual effluent concentrations under similar conditions of flow and influent concentration. The predicted substrate removal rates exceeded those achieved in the pilot-plant when recirculation was employed and he concluded that the Kornegay and Andrews model could not be used to predict substrate removal under the conditions encountered in this study.

Experiments showed that recirculation was more effective in increasing substrate removal rates at a total influent BOD_5 concentration of 1,000 mg/l than at 500 mg/l. Moreover, it appears that where the effluent concentration resulting from a single pass system, is below a certain limiting level (approximately 250 mg/l for this waste) recirculation will not improve the effluent quality significantly or, at least, enough to justify its use.

Possibly of most interest in this study, is the fact that for total BOD removal, there was an upper limit to the recirculation ratio beyond which effluent quality would deteriorate rather than

TABLE 7.5.1

HYDRAULIC LOADINGS EVALUATED

BASE FLOW, gpm	RECIRCULATION RATIOS N*	TOTAL APPLIED FLOWS, gpm
24	0, 1	24, 48
16	0, .5, 1, 1.5	16, 24, 32, 40
12	0, .5, 1, 1.5, 2	12, 18, 24, 30, 36
8	0, .5, 1, 1.5, 2, 3	8, 12, 16, 20, 24, 32
6	3	24
4	5	24

where $N = \frac{R}{Q}$ and Q = 1

continue to improve. This phenomenon occurred for base flows of 0.5 and 0.75 gpm/ft^2, at recirculation ratios of 1.5:1 and was linked to a reduction in the settleability of the effluent solids. Indeed the removal of soluble substrate improved beyond a recirculation ratio of 1.5:1, however, there was a drastic increase in the effluent suspended solids concentration. This was only one of the effects that was not predicted by the Kornegay and Andrews model.

In summary, then, McGill found that the Kornegay and Andrews model was unsatisfactory for effluent quality prediction when recirculation was employed. Recirculation was found to increase the effective substrate removal rate, although not to the extent predicted by the model. It was found that an upper limit of recirculation existed beyond which further recirculation began to have a detrimental effect upon the removal rate of total BOD$_5$. This effect was found to be related to a reduction in the settleability of the suspended solids in the effluent from the filter.

7.6 Nuisances

When discussing nuisances in respect to a waste treatment system, one refers to such factors as odours, noise, etc., for what might be loosely termed the aesthetic qualities of the operation.

The odours which usually eminate from a meat-packing plant and which are noticeable to the public occur from the barns or animal storage areas and the smoke houses. In addition, if the wastewater is exposed, as in most waste treatment systems, this can be another source of odours.

Throughout the operation of the pilot-plant, there no doubt were some odours released at the top of the filter tower. However, these were only noticeable when standing directly at the top of the tower on the catwalks. On several occasions, visitors remarked that there was only a slight odour when near the pilot-plant and that this was mainly from the primary treatment plant. In checking the plant on weekends when there was no flow from the primary facility, there was never any noticeable odour.

During the summer months, when the pilot-plant had been shutdown over the weekend, there was a definite odour during the period of sloughing of the anaerobic biomass when the pilot-plant was restarted. This lasted for about one hour and was not noticeable at distances more than ten feet away from the bottom of the filter tower.

There was also some odour whenever sludge was discharged from the bottom of the clarifier lasting only as long as it took to drain the sludge. This time period would be on the order of 10 to 15 minutes.

Throughout the mild weather periods when the pilot-plant was in operation colonies or masses of some type of fly-like organism developed on areas of the plastic sheeting surrounding the plastic media where leakages had occurred. The numbers of these insects would increase quite rapidly if they were not flushed from the plastic. There was also some indication that the plastic sheeting had apparently been chewed, not unlike the destruction of a plant-leaf by insects. Although there was no nuisance from these insects flying about the filter (they were never actually observed flying, as a common housefly) they did nevertheless cause a rather unsightly condition unless washed away on a regular (daily) schedule.

The occurence of the two types of nuisances discussed above are most probably due to the nature of the pilot-plant itself. As an example, the proper design of a sludge handling facility would not allow the exposure of raw sludge to the atmosphere before some treatment. The covering surrounding the plastic media would also be constructed in a manner in which there would be little chance for the insects to develop.

7.7 Sludge Production

The sludge production in a biological treatment system is an important consideration in terms of cost of operation. Although the main objectives of this study were to examine the operation and performance of the trickling filter itself, it was felt that some indication of the quantity and character of the sludge should be presented.

Unfortunately, the settling tank had not been designed for flows up to 32 gpm, having a maximum flow through rate of only 19.2 gpm. This resulted in quantities of suspended solids being discharged in the effluent. Once this fact was known, samples of final effluent were no longer considered for analysis. If these samples had been analysed for suspended solids alone, then this would have permitted accurate mass balance computations to have been made.

The quantity of sludge which was discharged each day varied with the flow rate as could be expected with an inadequate clarification system. Generally with the 16 gpm flow rate, approximately 65 gallons of sludge having a concentration of 10 to 15,000 mg/l were discharged each day. This quantity increased to about 100 gallons per day at the 8 gpm flow rate and decreased to the range of 40 to 50 gallons per day for the 32 and 24 gpm flow rates respectively.

It must be emphasized that these estimated quantities of solids are more a factor of flow rate through the clarifier than actual sludge production.

The quantity of suspended solids removed at each flow rate can be determined from the Daily Operation data presented in Tables 5.1.1 and 5.2.1. Using an estimated flow for this meat-packing plant as 1.5 MGD (Imp) results in a removal of 3,090, 2,460, 2,250 and 2,060 pounds of dry solids per day at the four flow rates 0.5, 1.0, 1.5 and 2.0 gpm/ft^2. This assumes that the removal achieved in a full-scale clarifier would be the same as that using quiescent settling in a graduated cylinder. Also, the change in this quantity due to the production of solids within the filter media is not accounted for in this calculation, as the removal is based on influent to final effluent reduction in suspended solids.

However, comparing mean values for unsettled influent and unsettled effluent TSS from Table 5.1.1, there appears to be no difference in the magnitude of the solids concentrations. This would tend to indicate that there is no net production of solids within the filter. The conversion of soluble organic material into biological cells must then occur at the same rate at which solids are hydrolyzed to soluble material before being assimilated.

The removal of suspended solids as calculated from influent to settled effluent then can be considered a reasonable estimate of the quantity of sludge to be treated for recovery or disposal.

There are possibly several solutions for the use of this biological sludge produced from process wastewater. It should contain sufficient protein to be suitable as a nutritive source in animal feed concentrate. However, the sludge would have to dewatered before it could be cooked. This might be accomplished by one of several methods such as vacuum filtration, centrifugation or thickening.

Limited laboratory studies, to obtain parameters for dewatering the sludge by vacuum filtration, indicated that although a specific resistance could be measured, attempts to perform filter leaf tests failed consistently as the sludge would not dewater sufficiently to form a cake on the filter leaf. Addition of chemicals to increase the dewaterability was not performed. These tests were preliminary, in nature, and the results may not be as negative as they appear.

Further study into the problem of sludge treatment for by-product recovery is required. The limited scope of this research has only uncovered an area where more information is necessary before the overall system can be optimized.

7.8 Summary

The trickling filter process has been shown to be an ideal roughing treatment process for the meat-packing industry. Satisfactory treatment in terms of organic removal can be achieved even though the wastewater being treated is subject to wide variation in characteristics throughout the day. The system can be operated according to the production schedule of the plant, and even shut down for periods up to two weeks, without significantly affecting the performance of the plant when it is restarted. The winter climatic conditions did not appear to upset either the operation or the performance of the pilot-plant. Maintenance required to keep the plant in operation throughout the study was minimal.

8.0 CONCLUSIONS

1. Plastic-media trickling filters operating at high organic loadings offer an attractive means for the pre-treatment of meat-packing wastewaters prior to discharge to municipal sewers.
2. At organic loading rates between 200 and 400 lb. BOD_5/1,000 ft^3/day, the system can be expected to remove in excess of 50% of the applied BOD_5. At loading rates up to 1,000 lb. BOD_5/1,000 $ft.^3$/day, the removal decreases to about 35%.
3. Both the first-order reaction equation and the Kornegay and Andrews approach can be used to predict the removal of soluble as well as suspended and colloidol BOD_5 by a trickling filter system. The expressions have been modified to account for settleable BOD_5 in the influent waste which could be removed prior to filtration. Values of the constants have been evaluated for both design equations for the meat-packing waste. It is recommended that Kornegay and Andrews approach be used at higher influent BOD_5 concentrations as it appears to be the more general of the two equations.
4. There is apparently no adverse effect on the biological system when the plant is shutdown over the weekends due to the meat-packing plant operating on a five-day production week.

5. While ambient temperatures varied between -5°F and 90°F during the data collection program, there was only a slight variation in BOD_5 removal efficiency occurring at the lower flow rates.

6. Freezing of the bios during week-end shut-down did not appear to affect the performance of the plant when operation was resumed. The bios was allowed to freeze for a period of two weeks and attained the original level of operating efficiency within 24 hours of start-up.

7. The trickling filter system successfully treated wastes with ether soluble levels of 50 to 600 mg/l and pH variations of 6.6 to 9.8 although a slight reduction in BOD_5 removal efficiency was observed at the more extreme values.

8. The value of recirculation as a means of improving trickling filter performance remains obscure and cannot be predicted from existing mathematical models. In this study, the use of recirculation when the influent BOD_5 was 1000 mg/l or greater resulted in a 20 to 50% increase in the rate of total BOD_5 removal the greater degree of improvement being obtained at the lowest base hydraulic loadings. The increase was attributed to an increase in the removal rate for soluble BOD_5. At recirculation ratios greater than 1.5:1 the overall rate of BOD_5 removal decreases.

   At low influent BOD_5 concentrations, about 500 mg/l, recirculation has no apparent effect upon trickling filter performance.

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10.0 SYMBOLS AND ABBREVIATIONS

The following is a list of symbols and abbreviations used throughout the text. Units have been omitted here but are included as required in the report.

Ap	specific surface area of filter medium
a/b	substrate concentration in the liquid film at one half the maximum substrate removal rate
1/b	maximum concentration of substrate removed per unit depth of filter
BOD, BOD_5	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
D	depth of filter media
gpm	gallons (imperial) per minute
gpm/ft^2	gallons per minute per square foot of filter surface area
h	thickness of the active portion of the slime layer
H	cross-sectional surface area of the trickling filter
K	reaction rate constant
K_c	substrate concentration in the liquid film at one-half the maximum removal rate
K_{10}	reaction rate constant (to the base 10)
K_{20}	reaction rate constant at 20° C
MGD	million gallons (imperial) per day
n	hydraulic loading rate exponent
Q	volumetric flow rate or hydraulic loading rate
s_o	influent substrate concentration

s_e	effluent substrate concentration
T	waste water temperature, °C
TSS	Total Suspended Solids
X	concentration of microorgamisms in the slime layer
x	substrate concentration
y	concentration of substrate removed per unit of filter depth or the mass flux of substrate across the slime-liquid interface
Y	yield coefficient
μ_{max}	maximum growth rate coefficient
$\frac{\mu_{max}(h)(X)}{Y}$	maximum mass flux of substrate at slime-liquid interface
θ	temperature coefficient

11.0

APPENDICES

APPENDIX A

DAILY OPERATION DATA

The headings on the data sheets which follow are based on the coding as shown below:

UN - UNSETTLED
SE - SETTLED
SO - SOLUBLE

IN - INFLUENT
EF - EFFLUENT

8 - Flow Rate
16 in
24 GPM
32

C - COD, mg/l
B - BOD_5, mg/l
T - Total Suspended Solids, mg/l
V - Volatile Suspended Solids, mg/l
P - pH

Example

SEEF8B - Settled Effluent BOD_5 at the 8 gpm flow rate

FLOW-RATE 0.5 GPM/FT^2

UNIN8C	SEIN8C	SOIN8C	UNEF8C	SEEF8C	SOEF8C	UNIN8B	SEIN8B	SOIN8B	UNEF8B	SEEF8B	SOEF8B
1143	825	448	1052	563	337	461	348	218	364	176	128
1099	1028	656	909	545	332	544	440	296	338	218	108
1035	925	427	680	482	308	383	369	230	263	167	141
964	808	419	717	600	412	480	398	216	282	261	168
1111	952	552	754	627	421	488	417	192	293	215	144
1040	910	431	918	618	374	503	417	219	382	219	147
1113	935	504	874	573	358	600	518	189	364	233	143
1028	784	504	1056	524	314	563	492	242	540	249	152
1156	892	413	793	475	231	634	604	266	383	288	138

UNIN8T	UNIN8V	SEIN8T	SEIN8V	UNEF8T	UNEF8V	SEEF8T	SEEF8V
392	326	238	192	464	382	144	114
272	246	222	206	340	292	114	106
296	258	234	208	252	224	102	94
340	280	244	210	190	168	116	108
340	284	248	216	234	200	124	110
314	258	228	184	330	280	122	114
304	276	210	188	322	280	116	108
322	268	200	164	466	386	116	106
364	310	238	208	326	270	134	120

FLOW-RATE 1.0 GPM/FT^2

UNIN16C	SEIN16C	SOIN16C	UNEF16C	SEEF16C	SOEF16C	UNIN16B	SEIN16B	SOIN16B	UNEF16B	SEEF16B	SOEF16B
817	722	421	587	440	262						
867	741	400	665	444	301	470	411	245	330	240	148
931	761	454	761	489	319	525	447	276	378	277	194
1049	947	544	805	722	544						
1270	834	453	897	540	326						
1003	798	482	833	541	332	555	423	227	417	286	157
1063	873	486	778	545	340	627	464	254	350	240	171
940	762	450	695	529	379						
1100	924	566	996	725	486						
1028	774	456	659	512	321						
840	720	386	918	513	274						
1051	854	443	917	577	332						
925	823	431	721	564	321						
929	762	452	762	468	286	510	439	236	361	209	141
1083	932	563	881	627	421	612	518	287	424	284	185
1122	937	514	1012	711	423	612	484	231	461	318	180
948	813	446	773	582	382	615	548	258	450	294	228
837	733	446	717	558	319	372	357	210	432	218	126
827	763	509	827	565	382	510	491	299	473	269	225
869	869	516	925	623	393	514	511	272	439	293	194
915	851	554	812	606	436	473	447	291	379	296	210

UNIN16T	UNIN16V	SEIN16T	SEIN16V	UNEF16T	UNEF16V	SEEF16T	SEEF16V	UN1N16P	SEEF16P
242	222	170	160	224	206	116	108	7.50	7.80
328	282	182	160	238	206	96	90	7.30	7.55
272	252	164	158	232	212	90	84	7.50	7.80
278	246	230	204	222	198	154	148	7.30	7.40
412	382	202	186	362	344	116	104	7.35	7.65
270	244	180	164	328	294	130	122		
298	290	182	178	260	248	102	102	7.30	7.60
306	286	174	170	210	198	112	112	7.40	7.60
280	266	202	190	338	302	122	118	7.05	7.30
310	276	180	166	194	186	86	84	7.35	7.65
282	234	194	156	416	350	150	122		
334	308	222	216	370	312	142	130	7.35	7.60
278	260	206	202	244	228	128	126	7.40	7.65
298	268	184	168	322	288	120	116	7.40	7.70
344	306	230	212	330	312	152	134	7.50	7.70
352	336	276	258	308	282	180	176	7.60	7.75
284	236	212	180	260	214	134	110	7.50	7.70
292	272	178	166	246	218	134	128	7.70	7.90
206	194	172	156	324	284	122	112	7.75	7.85
202	192	192	186	352	304	134	130	7.60	7.70
230	210	184	176	256	236	132	120	7.50	7.60

FLOW-RATE 1.5 GPM/FT2

UNIN24C	SEIN24C	SOIN24C	UNEF24C	SEEF24C	SOEF24C	UNIN24B	SEIN24B	SOIN24B	UNEF24B	SEEF24B	SOEF24B
738	651	389	603	484	310						
1019	894	502	949	713	416						
902	815	494	909	659	392						
1113	839	463	933	627	361						
1428	1135	563	1230	809	548						
909	782	466	767	585	340						
937	886	543	811	638	409	492	467	260	438	302	180
781	701	398	876	556	311						
789	725	402	725	558	299						
866	693	405	551	504	338						
875	725	447	667	514	361	456	362	206	300	222	156
952	800	439	838	592	396	535	404	195	408	282	167
938	724	420	794	556	370						
1000	770	413	1055	555	365						
1030	760	439	867	590	356						
1028	744	417	807	555	339	586	375	188	377	260	129
996	786	451	782	589	371	611	437	237	389	305	189
940	853	544	925	700	488	526	446	258	452	342	197
936	794	468	857	635	436	514	420	222	430	310	211
1087	885	486	960	707	470	600	465	251	469	338	243
1286	1207	737	1200	956	659						
862	782	419	680	514	348	463	434	206	322	246	168
1009	834	508	897	669	441	589	455	267	424	319	224
843	741	443	615	545	388	378	292	194	444	260	204
909	807	525	768	659	463	481	413	258	383	322	232

UNIN24T	UNIN24V	SEIN24T	SEIN24V	UNEF24T	UNEF24V	SEEF24T	SEEF24V	UN1N24P	SEEF24P
214	206	166	158	190	188	132	126	7.50	7.70
294	242	262	196	320	248	208	168	7.25	7.35
252	200	218	176	312	256	182	142	7.45	7.55
290	246	222	188	352	324	166	138	7.40	7.50
572	456	458	400	306	272	198	180	7.20	7.55
280	232	204	172	282	246	156	138	7.50	7.70
248	210	194	166	248	222	150	138	7.50	7.65
278	234	202	170	328	320	192	150	7.60	7.70
236	208	204	192	262	244	168	158	7.50	7.60
292	264	186	184	178	160	106	106	7.40	7.70
288	256	190	180	212	184	122	106	7.50	7.70
302	268	200	178	270	234	134	118	7.45	7.65
334	304	220	220	278	264	138	120		
326	326	224	224	428	396	124	124	7.30	7.50
270	344	208	178	362	282	154	134	7.60	7.70
306	358	220	206	302	272	186	184	7.40	7.60
328	312	224	208	250	234	174	168	7.35	7.65
264	252	202	196	276	260	150	148		
276	230	184	146	277	252	122	106	7.50	7.80
328	284	216	178	278	244	156	136	7.55	7.70
348	290	276	224	332	274	174	138	7.40	7.50
252	248	190	184	206	202	110	110	7.50	7.80
252	246	166	164	234	232	110	106	7.30	7.55
242	188	188	162	288	234	114	86	7.50	7.30
246	228	192	166	200	194	130	130	7.55	7.70

FLOW-RATE 2.0 GPM/FT^2

UNIN32C	SFIN32C	SOIN32C	UNEF32C	SFEF32C	SOEF32C	UNIN32B	SFIN32P	SOIN32B	UNEF32B	SFEF32B	SOEF32B
898	785	422	703	547	328						
943	787	413	756	585	351	559	425	219	405	292	188
965	762	452	754	607	397	446	393	207	351	291	192
948	806	431	854	672	387						
1143	929	476	1087	754	436						
783	689	366	614	492	287						
866	764	441	787	590	354						
861	765	414	773	590	359						
996	876	486	948	685	406						
1143	927	510	1081	772	425						
947	844	489	860	623	379	488	450	210	411	302	177
937	826	472	921	661	409	472	429	225	437	311	173
1062	921	559	1039	763	480						
738	698	429	647	552	349						
857	762	456	722	571	373						
964	794	458	980	640	403	480	396	198	440	297	150
790	664	387	696	514	308	377	338	153	290	217	125
962	836	489	797	663	434	544	452	261	433	347	213
1008	886	476	980	764	492	438	435	215	449	360	232
830	739	439	664	530	356	419	395	215	329	245	146
996	924	574	884	725	510	597	475	300	474	395	267
1051	869	474	960	695	435	646	582	273	585	375	260
893	703	419	743	577	395	435	352	177	318	260	175

UNIN32T	UNIN32V	SFIN32T	SFIN32V	UNEF32T	UNEF32V	SFEF32T	SFEF32V	UN1N32P	SEEF32P
292	278	204	198	224	212	122	114	7.30	8.00
336	290	208	174	238	206	152	130		
242	224	186	184	204	194	122	120	7.75	7.70
330	302	200	180	282	254	150	138	7.50	7.60
358	344	222	216	350	340	158	152	7.35	7.40
264	230	182	170	200	190	124	120	7.70	7.85
252	226	192	174	272	244	136	128	7.45	7.55
262	242	182	170	272	250	124	120	7.60	7.65
268	242	204	200	308	286	152	148	7.45	7.50
352	286	234	188	396	330	186	142		
266	216	210	170	276	228	152	116	7.60	7.80
280	242	202	178	344	308	154	144	7.50	7.60
286	264	206	194	316	286	134	132	7.15	7.35
186	178	152	148	180	176	148	146		
202	178	162	156	258	234	104	100	7.50	7.60
304	268	210	186	348	306	162	148	7.55	7.60
232	222	178	172	228	224	130	124		
284	268	190	182	260	256	136	136	7.40	7.40
298	280	242	224	278	262	194	182	7.60	7.60
242	220	202	198	216	208	100	70	7.35	7.50
254	230	210	186	256	224	162	148	7.40	7.50
332	292	244	222	294	264	166	152	7.45	7.50
322	310	176	170	222	206	120	118	7.80	7.85

APPENDIX B

DIURNAL VARIATION DATA

The headings on the data sheets which follow are based on the coding shown below:

C - COD, mg/l
T - Total Suspended Solids, mg/l
P - pH

UN - UNSETTLED
SE - SETTLED
SO - SOLUBLE

IN - INFLUENT
EF - EFFLUENT

16 - FLOW RATE
24 - in
32 - GPM

Example

CSO1N16 - COD of soluble Influent at 16 gpm Flow Rate

Note:

TIME represents hour for which each 1 hour composite sample was completed beginning from 12 midnight to 1 AM and continuing for 24 hours.

FLOW-RATE 1.0 *GPM/FT*^{2}

TIME	*CUNIN*16	*CSEEF*16	*CSOIN*16	*CSOEF*16	*TUNIN*16	*TSEEF*16	*PUNIN*16
1	1032	528	492	313	294	140	7.40
2	853	504	370	337	248	150	7.60
3	821	471	350	244	234	138	7.70
4	862	573	354	260	312	200	7.80
5	634	475	317	253	208	138	7.90
6	618	455	244	219	236	132	7.80
7	488	455	305	256	196	118	7.70
8	813	549	350	252	322	180	7.80
9	1036	792	699	480	348	184	7.70
10	2377	1991	1613	1431	326	248	7.30
11	1656	1483	1065	992	258	230	7.20
12	1219	1016	748	666	272	260	7.10
13	1065	821	626	545	250	196	7.30
14	878	732	520	415	230	238	7.20
15	894	585	520	374	260	174	7.20
16	983	683	577	431	246	180	7.20
17	904	655	562	394	216	172	7.00
18	843	574	498	349	200	160	7.10
19	1253	691	486	353	442	200	7.00
20	1052	687	438	406	302	200	7.20
21	1406	751	502	402	480	248	7.40
22	1249	659	450	329	440	212	7.60
23	1108	578	378	289	440	198	7.40
24	976	490	365	265	316	158	7.40

FLOW-RATE 1.5 *GPM/FT*^{2}

TIME	*CUNIN24*	*CSEEF24*	*CSOIN24*	*CSOEF24*	*TUNIN24*	*TSEEF24*	*PUNIN24*
1	390	311	239	143	104	102	7.90
2	327	247	207	120	84	80	8.50
3	311	235	199	155	86	80	8.60
4	295	263	227	167	70	84	9.35
5	343	303	263	183	92	92	9.60
6	382	303	327	207	134	86	8.75
7	462	351	367	255	110	90	7.65
8	865	458	347	239	344	160	7.55
9	1243	749	582	390	368	240	7.70
10	2031	1546	1327	1171	518	234	7.50
11	1506	1275	821	733	382	264	7.40
12	1195	964	661	582	374	292	7.35
13	1139	869	622	502	304	240	7.25
14	1044	773	534	446	282	230	7.30
15	956	773	510	406	300	254	7.25
16	1012	669	510	382	296	214	7.20
17	916	629	462	347	280	190	7.20
18	1000	641	502	382	328	194	7.30
19	884	590	478	359	284	176	7.30
20	845	526	414	303	286	166	7.50
21	869	530	374	279	292	170	7.80
22	825	498	335	231	270	190	7.60
23	741	502	311	215	268	200	7.50
24	526	406	303	191	150	148	7.50

FLOW-RATE 2.0 GPM/FT^2

TIME	CUNIN32	CSEEF32	CSOIN32	CSOEF32	TUNIN32	TSEEF32	PUNIN32
1	791	644	354	346	250	180	7.30
2	668	596	358	310	214	166	7.45
3	1773	755	302	302	732	246	7.30
4	1445	684	310	298	590	206	7.85
5	533	501	294	274	170	164	8.70
6	513	437	286	247	180	124	8.60
7	827	652	322	314	322	198	8.60
8	819	580	410	342	238	136	8.30
9	1730	1292	1105	859	420	210	7.85
10	2753	2117	1527	1455	648	314	7.40
11	2028	1541	1010	970	500	270	7.40
12	1364	1034	728	660	386	212	7.40
13	1217	922	600	521	314	198	7.25
14	1070	755	517	445	286	164	7.15
15	994	763	485	429	304	176	7.20
16	1169	891	584	533	370	228	7.10
17	1079	813	571	516	322	190	7.25
18	1016	778	579	492	252	176	7.40
19	976	770	567	500	242	148	7.30
20	988	714	472	429	270	162	7.50
21	1103	762	429	397	342	194	7.70
22	1087	722	381	349	396	210	7.80
23	1135	754	460	429	348	180	7.80
24	929	643	401	393	262	130	7.80

APPENDIX C

DEPTH STUDY DATA

All values are reported in mg/l BOD_5 for various depths of filter media from the top of the filter.

FLOW-RATE 0.5 *GPM/FT*^{2}

SOLUBLE	
0	18
653	537
636	514
610	484
550	458
422	383
589	443
570	420
428	390
361	304
240	177
218	159
246	165
222	141
233	132
209	126
248	132
275	165

FLOW-RATE 1.0 *GPM/FT*^{2}

UNSETTLED	*SETTLED*					*SOLUBLE*				
0	0	4	8	13	18	0	4	8	13	18
807	785	653	548	518	405	365	350	315	293	233
585	578	426	484	375	282	246	237	246	210	176
324	293	285	214	184	87	138	129	105	98	48
735	691	582	507	424	308	333	333	275	272	210
616	578	529	477	439	349					
464	464	462	410	360	291	218	169	188	147	121
376	308	278	267	244	188	135	132	132	120	84
923	863	855	788	738	668					
604	593	518	417	330	268					
1050	1018	1013	975	885	765	593	593	567	462	499
683	619	552	510	439	417	288	281	273	234	212
442	439	353	263	240	139	183	170	149	159	93
1815	1702	1613	1485	1425	1260	1159	1116	1163	1148	1050
1365	1358	1178	1088	885	840	915	915	840	724	690
1590	1508	1515	1410	1350	1223	1140	1133	1125	1092	998
930	848	735	698	705	675	468	420	378	394	387
1155	1140	940	870	743	810					
1043	938	840	773	638	638	488	432	405	409	360

FLOW-RATE 1.5 *GPM/FT*^{2}

UNSETTLED	*SETTLED*					*SOLUBLE*				
0	0	4	8	13	18	0	4	8	13	18
788	735	653	657	540	420	327	276	276	276	230
1078	960	915	878	780	735	529	495	528	495	477
593	573	540	473	428	330	218	214	218	210	181
465	462	391	432	349	323	204	201	189	204	141
1508	1298	1170	1133	1110	953					
728	660	615	570	630	465					
1365	1290	1215	1163	1170	1013	852	814	788	769	717
582	552	499	462	390	334	239	239	225	218	201
743	732	682	604	608	454					
803	750	638	570	548	503	413	394	368	345	319
773	743	601	492	391	360	201	201	192	186	158
616	563	439	398	327	308					
1185	1095	1005	1035	938	893					
1035	960	855	788	728	705					
1365	1275	1155	1110	1095	1050	792	720	698	687	675
1260	1170	1133	1073	1058	975	600	589	570	555	540

FLOW-RATE 2.0 GPM/FT^2

UNSETTLED	SETTLED					SOLUBLE				
0	0	4	8	13	18	0	4	8	13	18
578	537	499	499	383	387	221	221	221	189	173
1140	1140	975	1020	938	885					
481	473	432	394	376	316	237	228	192	189	177
387	330	304	274	267	210	138	129	117	120	93
623	593	563	540	480	450	285	283	237	233	248
1065	968	953	945	870	810	604	585	569	562	518
525	462	443	387	360	300	221	164	207	183	138
660	480	480	435	375	285	214	211	214	214	151
271	256	214	226	181	136					
327	270	255	240	225	214	106	99	95	86	81
1613	1418	1365	1298	1163	1138	1099	1017	1017	923	1005
683	649	510	477	420	409	239	224	227	204	203
1155	1155	930	825	780	745	480	413	383	416	409
1305	1178	1185	1125	1190	1125					
1477	1268	1163	1065	1080	998	840	702	745	646	667
1118	1088	1050	1020	870	713	518	439	424	481	450

APPENDIX D

TRICKLING FILTER PROCESS DESIGN

The acceptability of the trickling filter process for the treatment of meat-packing wastewaters has been shown in the body of this report. In general, it can be stated, that the trickling filter process is a very viable alternative for the pretreatment and/or "roughing" biological treatment of meat-packing wastewaters in situations where land areas may be limited for the construction of treatment facilities or where partial treatment to produce an effluent of a specified quality is required.

The results of this study have indicated that either the first order equation or the Kornegay-Andrews formulation, presented as equations 6-3 and 6-8 respectively are acceptable for the process design of a trickling filter system treating meat-packing wastes. In Section 6-3 of this report, a comparison of the two design formulations was presented based on the average daily operation results found during the study. To further illustrate the use of these equations, an example of a process design based on a substantially higher influent BOD concentration than the average daily concentration found in this study will be presented using both the design equations.

The following wastewater characteristics have been assumed for the purpose of this comparison.

Wastewater Flow = 2.0 MGD

Influent Total BOD_5 Concentration = 1000 mg/l

Required Effluent BOD_5 Concentration = 300 mg/l

Since the design equations developed in this study were established using "Flocor" plastic-media, values of Ap and η will be set at 29 ft^2/ft^3 and 0.5 respectively.

The first-order reaction equation found for removal of Total BOD_5 in a meat-packing wastewater is:

$$s_e = 0.927\ s_o\ e^{-\ 0.0256\ D/Q^{n}}$$

Substituting into this equation for the values stated above results in a relationship between D and Q as:

$$Q^{0.5} = \frac{0.0256}{1.13}\ D$$

Selecting a depth of 40 ft, would require a hydraulic loading rate of 0.95 gpm/ft^2. With a total waste flow of 2.0 MGD, a surface area of 1460 ft^2 would be necessary, giving a total volume of media of 58,500 ft^3.

The Kornegay-Andrews equation can be presented as:

$$(0.927\ s_o - s_e) + K_c \ln\left(\frac{0.927\ s_o}{s_e}\right) = \frac{\mu_{max}\ (h)(X)}{Y}\ \frac{Ap\ H\ D}{Q}$$

Selecting a flow rate as 1.0 gpm/ft^2, results in values of constants Kc and $\frac{\mu_{max}\ (h)(X)}{Y}$ of 0.747 and 7.14 respectively. The required surface area for the filter can be calculted directly as 1,390 ft^2.

Since all of the terms in the equation are known, except D, direct substitution results in a value of D of 46 ft. The total volume of media is then 64,000 ft^3.

It would appear then that to obtain the same effluent quality, about 10% more media volume is required as determined by the Kornegay-Andrews equation. Previously, it was shown that the first-order equation was the more conservative of the two at the lower concentrations.

In estimating the requirements for a full-scale trickling filter system, it has been assumed that adequate clarification facilities would follow the biological phase. Loading conditions on the pilot-plant clarifier precluded the use of any results for final effluent and consequently all laboratory analyses for effluent samples were based on simulated settling in a graduated cylinder. Thus, no design parameters could be determined for the clarification unit.

However, from observation of the settleability of the effluent suspended solids as shown in Figure 5.3.1, some comments on general considerations for the design of the clarifier can be made. It sould be noted from Figure 5.3.1, that most of the settling under quiescent conditions occurred in the first hour. Thus, a general range of detention times in the order of 1.75 to 2.25 hours with an overflow rate of 500 to 750 gallons per day per square foot (gpd/ft^2) of surface area should provide satisfactory settling conditions.

Overflow rates as high as 1400 gpd/ft^2 have been used successfully in the treatment of brewery waste trickling filter effluent (47) when the clarification unit was constructed directly under the filter media tower structure. Use of this process technique allows large particles of biomass to slough directly into the clarifier without being broken up from passing through a pumping mechanism.

The development of rational design procedures for the trickling filter process has been demonstrated using the data obtained in a pilot-plant study using the wastewater from a particular meat-packing plant. These developments should facilitate the design procedures used in future applications of the trickling filter process to the treatment of meat-packing wastewater.