EPA-600/2-78-013
February 1978

Environmental Protection Technology Series

BIOLOGICAL TREATMENT, EFFLUENT REUSE, AND SLUDGE HANDLING FOR THE SIDE LEATHER TANNING INDUSTRY

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-78-013
February 1978

BIOLOGICAL TREATMENT, EFFLUENT REUSE, AND SLUDGE HANDLING FOR THE SIDE LEATHER TANNING INDUSTRY

by

L. B. Polkowski
W. C. Boyle
Polkowski, Boyle & Associates
Madison, Wisconsin 53705

and

B. F. Christensen
S. B. Foot Tanning Company
Red Wing, Minnesota 55066

Grant Project 12120 DSG

Project Officer

Clarence C. Oster
Minnesota-Wisconsin District Office
U.S. Environmental Protection Agency Region V
Minneapolis, Minnesota 55423

Industrial Environmental Research Laboratory
Office of Research and Development
U. S. Environmental Protection Agency
Cincinnati, Ohio 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollution impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report presents the findings of an extensive study of the side leather tanning industry. The study was conducted to obtain information concerning side leather tanning wastewater and the performance of an aerobic biological treatment system upon the wastewater. Treated effluent reuse, pressure sludge dewatering and sludge disposal were also evaluated. The results of this study will be of interest to the entire leather tanning industry. For further information on the subject contact H. Kirk Willard, Chief, Food and Wood Products Branch, IERL-Cincinnati, Ohio 45268.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

An evaluation of the treatability of unsegregated, unequalized, and unneutralized wastewaters from a side-leather tanning industry utilizing the hair pulping process by primary and secondary biological treatment methods is presented. Primary treatment consisted of screening and gravity separation in clarifier-thickeners, whereas the secondary treatment method employed aerated ponds and final clarifiers with the capability of recycling biological solids. The system was operated over a wide range of detention times, with and without solids recycle, and nutrient (phosphorus) addition, and during seasonal variation representing mean monthly air temperature variations from -14°C to 30°C. The removal efficiencies were related to loading parameters associated with detention times and unit organic loading relationships as well as temperature variations. Although the study was conducted for purposes of research and demonstration, the results for various measured parameters were compared with Best Practicable Treatment (BPT) and Best Available Treatment (BAT) guidelines which served as a reference for the comparison. The tannery effluent guidelines have been remanded to the courts with possible revision as an outcome. Generally, the results indicated the inability of the system to meet these guidelines during low temperature operations and for some parameters even during warm weather periods.

The raw wastewater characteristics for this type of processing were within the EPA guideline limitations based on kg/1000kg of hide processed with the exception of oil and grease. Detailed source sampling indicated that the beamhouse operations represent by far the major source of most of the parameters measured with the hair pulp operation as the single greatest overall contributor.

Solids removed from the wastewater treatment processes were dewatered by pressure filtration wherein buffing dust (a material indigenous to the industry) was used as precoat with lime and $FeCl_3$ employed as the principal conditioning agents. The dewatered cake was landfilled under test conditions, singly and in combination with municipal refuse, and with and without earth cover. Leachate quantities and qualities were measured, internal temperature development was monitored, and changes in solids and moisture content were recorded.

The secondary treatment effluent was reused in the beamhouse operations under test conditions to evaluate the effects of water conservation practice on leather qualities as well as to determine the buildup of conservative substances in the wastewater effluent such as chloride.

This report submitted as partial fulfillment of the contract terms No. 12120DSG by S. B. Foot Tanning Co. under the sponsorship of the U. S. Environmental Protection Agency for the period August 1971 through November 1974.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGEMENTS

The authors are particularly indebted to Mr. William P. Martin, Project Research Engineer, who assumed the responsibilities for the conduct of this project, both in terms of plant operating requirements from start-up through establishing routine maintenance procedures, as well as supervision, participation in and evaluation of the total research effort. Mr. Martin formed and supervised the nucleus of personnel necessary for the conduct of the laboratory and field studies.

Excellent cooperation and assistance was provided throughout the course of the study from S. B. Foot Tanning Company laboratory and maintenance personnel. The studies related to the evaluation of wastewater effluent reuse were conducted by tanning company personnel under the direction of Mr. Richard G. Waite, Assistant Technical Director and Mr. N. Clifford Benrud, Chief Leather Chemist. Mr. Werner Lersch, Maintenance Engineer, provided the innovativeness and assistance essential to the modification or replacement of failing mechanical equipment essential to the functioning of the wastewater treatment plant.

Appreciation is given to the City of Red Wing for the use of laboratory space for certain analyses as well as for continuing assistance throughout the study. The authors are particularly grateful to Mr. Lawrence Monette and Mr. William Randall who were responsible for the laboratory analytical work during the course of the study. Mr. Randall is presently City of Red Wing Director of Public Utilities having responsibilities for the continuing treatment of wastewaters from the S. B. Foot Tannery.

Mr. George M. Osborn was the Financial Officer for the project who provided much needed assistance.

SECTION I

INTRODUCTION

GENERAL

This study was conducted to characterize the wastewaters and to determine the performance of an aerobic biological treatment system for the treatment of unequalized, unneutralized wastewater from a cattle side leather industry. In addition, pressure sludge dewatering and dewatered sludge disposal were evaluated along with reuse of the treated effluent in beamhouse operations.

A principal objective of the project was to demonstrate the amenability of biological treatment of side leather tannery wastewaters by aerated ponds and the feasibility of reusing the treated effluent in certain of the tanning processes. The tannery waste (beamhouse and tanyard utilizing hair pulping) was treated in parallel aerated pond systems to obtain performance information related to BOD removal, an evaluation of the importance of nutrient supplementation, oxygen requirements, transfer efficiencies, solids-liquid separation of the final effluent, the effect of recycle solids concentrations in the aerated ponds, and temperature on the BOD removal characteristics. The project demonstrated the value of the aerated pond process in treating discharges from a tannery excluding the wastewaters from finishing operations. The study was conducted during periods when the fleshings were and were not rendered on the site. When rendering was employed, the stickliquor resulting therefrom constituted a part of the wastewater characterized and treated.

The applicability of pressure filtration was demonstrated in the dewatering of tannery sludge with consideration given to the use of waste materials indigenous to the industry as filter aids in the dewatering process. Certain waste materials such as buffing dust and shavings were used as conditioning agents. The results were evaluated in terms of sludge filter abilities and yield with stability measurements of the dewatered sludge cake by land disposal methods. The latter was evaluated in terms of leachate production and changes in the solid waste material when disposed of separately or when combined with domestic refuse from a community.

The feasibility of the reuse of final effluent from the aerated ponds in the hair pulp beamhouse operations in the leather making process were demonstrated by measurements of the product important to the leather industry. In that approximately 18 percent of the total waste volume is derived from these processes, the reuse of water may constitute a reduction in costs associated with water pollution control.

The secondary objectives of the study included:

1) An evaluation was made of the gravity separation properties of the tannery waste without the use of equalization and neutralization in primary settling waste treatment processes. The studies were conducted in two primary clarifiers used for settling and thickening of the sludge.

2) The effect of chemical additives was evaluated on the solids-liquid separation of the biological floc in the final clarifier.

3) The influence of biological treatment was determined on the stabilization of the treated effluent with regard to the scale-forming properties of tannery wastes.

4) The removal of other constituents of tannery wastewater such as chromium, oil and grease, suspended solids, etc., in the various treatment processes was determined to evaluate the effectiveness of the treatment provided.

5) The bacterial die-off or regrowth of indicator organisms in the treatment processes was determined.

BACKGROUND

The side leather tanning industry represents a major wet industry in this country particularly in localized areas. The wastes from the industry are highly polluted with inorganic chemicals such as lime, chrome and sulfur compounds as well as organic substances, i.e., dyes, hair, grease, manure, protein, and protein degradation materials.

The tanning industry has made progress in wastewater treatment through laboratory pilot scale and a limited number of full-scale studies. However, there is a lack of technical information available related to the performance of such wastewater treatment facilities. Questions regarding the appropriate design criteria for treatment of wastes can be answered only after full-scale treatment units are evaluated. The problems related to scale-up of many of the unit processes used in treating tanning waste are best resolved by large scale investigations.

The most pronounced characteristic of tannery wastes that presents difficulty in treatment is the highly variable nature of the waste in terms of pH, solids, and organic content. The wastes from the beamhouse are predominantly high in pH, hair, sulfides, grease, manure and protein; the wastes from the tanyard are low in pH, high in chromes, dyes, and degraded proteins. Segregation of wastes from the tanyard and the beamhouse is normally recommended. Thus, wastes from the beamhouse may be settled separately resulting in a smaller investment in primary settling equipment. Since the beamhouse and tanyard wastes are considerably different in character, separate treatment of each is sometimes employed. Existing tannery process flowsheets and waste collection systems often make segregation a complex and expensive alternative, which makes the treatment of the combined wastewaters more attractive.

The biological stabilization of the unsegregated tannery waste by conventional methods has proven to be feasible but costly. Frequently biological waste treatment is more economically feasible if combined and diluted with domestic wastes. Trickling filters, activated sludge and facultative ponds are the biological processes which have been studied to a limited extent.

There is an interest in aerated lagoon treatment of tannery wastes, however, there is little information available for the design of lagoons. A pilot scale study was conducted in August, 1966, at the S. B. Foot Tanning Company, Red Wing, Minnesota, (1), wherein a 6.1 x 6.1 x 1.68 m deep (20 x 20 x 5 1/2 ft deep) aerated pond having a volume of 62.3 m^3 (2200 ft^3) treated settled tannery waste resulting from hair-save beamhouse and tanyard operations at an average rate of 57.7 m^3/d (15,250 gal/d).

The pilot study indicated a BOD reduction of 68 percent could be achieved in an aerated pond with a 1-day detention time during the month of August. The results indicated that biological stabilization of the tannery waste without segregation, equalization and neutralization was possible. However, additional information was needed to provide sufficient performance information such as the effects of detention time, temperature, nutrient addition and sludge recycle.

Dewatering and handling of tannery sludges were of interest. The vacuum filter studies of sludge dewatering at S. B. Foot Tanning Co.

(1, 2) were conducted primarily in the laboratory. Specific resistance and filter leaf tests were made using sludges collected in continuous flow clarifiers. Use of cationic polyelectrolytes improved the filtration rate but not in a consistent way. The data available for the design of vacuum filters for tannery sludges in general is inadequate.

Previous laboratory studies at S. B. Foot Tanning Co. (2) indicate that centrifugation does not appear to be feasible. The wet oxidation of tannery sludges hold some possibilities in terms of chrome recovery but capital and operating costs are high, and problems associated with chrome toxicity in the filtrate make this method less desirable.

Pressure filtration of tannery sludges is not widely practiced in the United States. Pressure filtration produces a cake of low moisture content and a filtrate of high quality, both characteristics desirable in sludge dewatering. The ultimate disposal by landfilling of dewatered sludge cake is of particular interest because the practice represents the most economical and practical procedures available.

Treatment of tannery wastes to a high degree can provide the opportunity for in-plant water reuse. Of the total water used, approximately 18 percent is used in the beamhouse when hair pulping operations are employed. The influence of the reuse of secondary treated effluent on the tanned hide quality and on the tannery processes has not been previously documented but is part of the findings herein.

PROJECT DEVELOPMENT

The facilities were constructed to enhance the evaluation of the performance of the various unit processes. The employment of piping and associated appurtenances permitted separation of parallel operations as well as permitted the units to operate through a wide range of conditions. It was possible to vary the flow and resulting detention times simultaneously from one day to approximately 20 days by altering the flow and number of aerated ponds in service. The ponds were lined with concrete, and floating surface type aeration equipment was employed. The aerated pond effluent from each parallel system passed to a corresponding clarifier provided with an inlet chamber and chemical additive capability. The sludge collection equipment and piping permitted the solids to be returned to the aerated ponds or to be wasted to the primary clarifier. The combined waste effluent was discharged to a chlorine contact tank and subsequently discharged into Hay Creek. Pumping and piping were provided to convey the treated wastewater effluent to the process site for the water reuse evaluation.

The thickened sludge from the primary clarifier-thickeners, consisting of primary and waste secondary sludges, was conditioned and dewatered by pressure filtration and disposed as landfill.

An extensive sampling program was carried out during the study. Sampling was keyed to the process and objectives of the study. Sampling stations were located in the new influent, primary effluent, pond effluents, secondary effluents and chlorinated effluent lines. Continuous, proportional to flow samples were collected. Flow was measured and recorded via a magnetic flowmeter preceding the clarifier-thickeners. Flow measurement at the division box for individual pond treatments were made. The waste was characterized at times throughout the study by intensive 24-hour surveys. Individual units were analyzed as dictated by the study.

The following analyses presented throughout report contents were performed at unit influent and effluent locations to evaluate the performance and provide information for the interpretive analysis:

1) BOD

2) COD

3) Nitrogens: NH_3, NO_3, Organic N

4) Phosphorus; total, ortho and condensed

5) Chromium

6) Solids: total, settleable, suspended; volatile and fixed

7) Oil and grease

8) Chlorides

9) Sulfides

10) pH

11) Effluent Langelier Index

12) Coliforms; total and fecal

13) Alkalinity

14) Calcium

15) Temperature

To assist in obtaining information useful to the development of design criteria for this method of treatment, additional measurements were made of oxygen uptake, oxygen transfer rates, solids accumulations within the pond and sludge production, and quiescent settling analysis of the pond contents. The results were evaluated to determine relationships between removal and loading parameters in terms of detention times, organic loadings, volumetric loadings and sludge production. Although ancillary in nature, an evaluation of indicator organism die-off through the treatment processes was made.

Characteristics commonly associated with tannery wastes from the beamhouse are high pH, high total solids, high calcium concentrations, and high alkalinities. Often CO_2 neutralization of the waste is practiced to minimize the effects of high pH on subsequent biological processes. The long detention time aerated pond systems minimize the effects of pH variation and provide CO_2 from biological respiration to produce an effluent which is stable with respect to $CaCO_3$ equilibrium. The effectiveness of the aerated pond system under various operating conditions concerning the effluent stability was evaluated.

An evaluation was made of the sludge handling system to obtain information concerning the applicability of pressure filtration in tannery sludge dewatering. The use of available waste materials indigenous to the tanning industry as filter aids and for filter precoat was of particular interest. However, commercial chemical conditioning agents such as lime and $FeCl_3$ were used routinely. The effectiveness of the conditioning agents was evaluated in terms of sludge filterability, specific resistance, filter media blinding, filtrate quality, and cake moisture.

In order to evaluate cake stability, control test plots were used for storage of the dewatered residues, both separately and in combination with municipal refuse. The test plots were designed to permit collection of leachate resulting from cake drainage and/or natural precipitation on the disposal site. Consolidation rates, internal temperatures and cake moisture and solids analyses were performed to evaluate cake stability and provide criteria for ultimate disposal of solids from the tanning industry.

During the study period the secondary effluent was used in representative drums of the leather making process and the results were compared with similar operations using fresh water. Quality and production control tests were performed such as rehydration factors, leather quality and physical strength properties of the finished product in evaluating the applicability of reusing treated tannery waste effluents for beamhouse operations. An engineering analysis was made to evaluate the applicability of water reuse on a full-scale basis and predict wastewater treatment performance with a full-scale water reuse program in the side leather tanning industry.

The overall study was conducted in the following general phases:

1) A study of detention times in the aerated ponds, from 1 to 20 days, conducted in parallel in the four -3600 m3 (1 M gal) ponds. This study was conducted over a sufficiently long period of time to obtain reliable information on BOD, solids, chrome and sulfide reduction under a given period of aeration.

2) A nutrient study was conducted with phosphorus supplementation to the aerated ponds. This study was conducted in parallel aerated ponds to permit the non-phosphorus supplemented system to serve as a control.

3) The recycle of sludge from the secondary settling tanks to the aerated ponds was employed to determine the value of continual reseeding particularly during low temperature operations and short detention times.

4) Seasonal influence was evaluated throughout the study.

5) Aerated pond effluent reuse was studied during a period when effluent qualities were typical of good performance for the aerated pond system. The effect of the waste effluent quality on hide processing and the effect of the reuse measures on the treatment system were evaluated.

SECTION II

CONCLUSIONS

1) In the acid chromium tanning of cattleskins, the major source of wastewater pollutants derive from the beamhouse operations with the exception of ammonia-nitrogen, total chrome and sulfates. With the exception of chloride, the hair pulp operation contributed the majority of the pollutants measured in the beamhouse.

2) Wastewater flows from this tannery varied with the process formulations for hair pulping employed representing the season the hides were flayed. The greatest wastewater flows per unit weight of green hide were obtained when the summer formula was employed at 46.4 l/kg (5.56 gal/lb). Mean wastewater flows based on all flow data was 43 l/kg (5.21 gal/lb) of hide processed with a range of 32.2 to 53 l/kg (3.86 to 6.35 gal/lb). The mean flow was below the U.S. Environmental Protection Agency's Development Document for Effluent Limitation Guidelines for the Leather Tanning and Finishing Point Source Category for Category I of 53.4 l/kg (6.4 gal/lb) of hide processed. The study reported herein did not include leather finishing wastes which represented 1.7 percent of the total wastewater flow. Wastewater flow variation throughout a 24-hour process day in this tannery produced a maximum flow approximately 130% of the average and 200% of the minimum flow.

3) With the exception of oil and grease, the mean values for the raw wastewater characteristics from this tannery, i.e., BOD_5, COD, total solids, total suspended solids and total chromium, in terms of kg/1000 kg of hide processed were lower, even when rendering was employed, than the values reported for Category I in the U.S. EPA Point Source Guidelines Document. The amount of oil and grease was higher than the Guidelines even when rendering was not employed. With the exception of total phosphorus, the raw wastewater quality in terms of kg/1000 kg of hide processed for BOD_5, COD, total solids, total volatile solids, total suspended solids, oil and grease and total chromium, was higher when rendering was employed as compared to when rendering was not employed. No significant difference was found in the various raw wastewater characteristics representing the different seasonal process formulations.

4) The results of the primary settling analysis indicate the highly variable nature of primary tank performance in terms of percent removals and the ability of this unit operation to reduce the variation of the wastewater characteristics from raw to primary effluent. The mean percent removals obtained for the range of overflow rates of 12 to 18 m^3 d/m^2 were BOD 39%, COD 45%, total suspended solids 58%, oil and grease 67% and total chromium of 38%. The range of removals obtained for 9, 24-hour intensive surveys with overflow rates ranging from 13.4 to 18.7 m^3 d/m^2 were as follows: BOD_5 33-72%, COD 34-52%, total suspended solids 43-84%, and total chromium 30-63%. No correlation could be developed relating primary sedimentation performance to the overflow rates experienced in this study.

5) The biological treatment of settled, unneutralized and unsegregated acid chrome tannery wastewaters was studied over a two-year period under a variety of loading conditions in four series/parallel aerated lagoons followed by secondary sedimentation. Primary variables of control included mixed liquor solids concentrations, hydraulic residence time and phosphorus addition. Uncontrolled variables included temperature and wastewater characteristics. Based on these studies the following conclusions can be drawn.

a) Settled, unneutralized, unsegregated chrome tannery wastewaters are biologically treatable at long detention times or low F/M (kg BOD applied per day/kg MLVSS under aeration) loadings in aerated lagoons.

b) The percent removal of BOD_5 in aerated lagoons is dependent upon F/M loading and temperature. Greater than 90% of the BOD_5 in the primary treated wastewater can be removed at F/M loadings as high as 0.25 kg/kg-D, but there is substantial evidence to suggest that at the lower temperatures (less than about 14°C) the F/M values should not exceed 0.15 kg/kg-D. The U. S. Environmental Protection Agency best practicable treatment (BPT) guidelines for BOD_5 effluent values were achieved at temperatures greater than 13°C at F/M loadings less than 0.14 kg/kg-D. The U. S. Environmental Protection Agency best available treatment (BAT) guidelines for BOD_5 were achieved only under one lagoon condition based on mean values, at 20°C, for an F/M loading of 0.13 kg/kg-D.

c) Of the other parameters identified by the U.S. EPA guidelines for the category I tannery, total suspended solids, total chrome, total Kjeldahl nitrogen and sulfides, the aerated lagoon treatment was not able to achieve BPT or BAT guideline values under the conditions tested except for sulfide. At 20°C and at a F/M loading of 0.13 kg/kg-D, total chrome was reduced to an acceptable BPT level but the BAT level was not achieved.

d) The addition of ferric chloride as a coagulant to the biologically treated effluent prior to secondary clarification, produced acceptable effluent quality with respect to BOD_5, total suspended solids, total chrome and sulfides for BPT and BOD_5, total chrome and sulfides for BAT. This coagulant also reduced fecal coliform MPN below 200/100 ml without the need for disinfection.

e) Total Kjeldahl nitrogen (TKN) reductions in the lagoons ranged from 17-30%. Nitrification within the lagoon was significant only at low F/M loadings (less than 0.14 kg/kg-D) under high temperature conditions. Reductions in TKN were not high enough to meet BAT effluent guideline requirements for Category I tannery wastewaters.

f) The settled secondary effluent contained substantial amounts of finely divided suspended solids even when secondary clarifier overflow rates and solids loadings were low, however, the addition of ferric chloride greatly improved the removal of these solids.

g) Solids production data from the biological lagoon system was highly complicated by the nature of the influent solids and the mixing regime within the lagoons. Solids deposition did occur during the entire study period and the accumulations were measured periodically but only rough estimates could be made for the solids produced in the process. A range of 1.09 to 1.72 kg TSS/kg BOD_5 removed was calculated with substantial reduction in the solids produced during periods when phosphorus additions were being made.

h) The BOD/P ratio in the influent to the lagoons suggested a deficiency in phosphorus to the biological system. Phosphorus additions under selected lagoon conditions indicated greater biological activity was occurring, however, no significant improvement in effluent quality could be demonstrated over the test period.

i) Oxygen consumption data for the aerated lagoons was estimated for selected operating conditions. Oxygen requirements of 0.9 to 2.0 kg O_2/kg BOD_5 removed were calculated with the higher values occurring at the lower F/M loadings. Under two conditions occurring in the spring, oxygen requirements were estimated to be 2.6 and 3.5 kg O_2/kg BOD_5 removed possibly due to more active biological conditions at the higher temperatures after the dormant winter conditions.

6) The surface aeration of the shallow lagoons proved to be a problem with respect to mixing of the lagoon contents. A large number of lower powered high speed aerators rather than fewer number of higher powered low speed aerators was found to produce the most satisfactory mixing and oxygen transfer conditions although solids deposition occurred throughout the test period. Estimates of aeration efficiency, which included a correction for oxidation of sulfide to sulfate, ranged from 2.7 to 5.9 lb O_2/hp-hr under standard conditions.

7) Chlorination of the final effluent was usually required in the summer months to meet the fecal coliform objective of 200/100 ml. Chlorine dose to achieve the objective was dependent upon effluent quality and ranged from 3 to 18 mg/l in 1973. In the following year these levels had to be increased due to the accumulation of solids in the chlorine contact tank.

8) The recycling of biologically treated tannery wastewater as process water for the beamhouse operations was studied to determine the effect of this practice on leather quality and physical strength characteristics. The results of the test showed that the only adverse effect on the treated hide properties was the production of a slightly darker shade of leather over the controls which were processed with well water as a supply source. The importance of this effect would be dependent upon the individual tannery capability for water recycle and product quality control.

9) A chloride balance was made to determine the impact of treated effluent recycle for beamhouse operations which account for 17.7% of the total tannery flow. The equilibrium chloride concentration calculated when 100% recycle to the beamhouse would be practiced was about 4700 mg/l as compared with 3900 mg/l without recycle. This increase should not have serious effect on the wastewater treatment process.

10) The tannery wastewater sludges were dewatered by the pressure filtration process and studies related thereto produced the following conclusions.

a) Analyses of the primary sludge over the study period showed the sludge to have the following characteristics: total solids 10.5% mean, range 7.0 to 16.1%; oil and grease 2.1% mean, range 1.0 to 4.0%; volatile suspended solids 70.4% mean, range 63-81%.

b) Buffing dust, a solid waste material indigenous to the industry, was successfully used as a filter precoat material throughout the study but required filter cloth cleaning after 30 to 40 cycles of operation.

c) With proper conditioning, biological waste sludges and sludge mixtures with high proportions of oil and grease as scum were filterable by the pressure filtration process.

d) Multiple linear regression analysis of full scale operating data utilizing three dependent variables, filter time, mean filtration rate, and a first order constant for the filtrate volume-time relationship was used with independent variables of specific resistance, sludge feed and cake characteristics and conditioning chemicals and amounts as well as with the independent variables of the Jones equation which resulted in the following conclusions.

1) The specific resistance values represent the consistent single factor significantly correlated to full scale filter performance.

2) Increases in ferric chloride dose for sludge conditioning had a pronounced effect on the improvement of filter performance in the range of concentrations employed, 3.67 to 8.18% weight of dry solids.

3) Increase in lime dose for sludge conditioning resulted in a detriment to the filter performance in the range of concentrations employed, 7.4 to 18.7% weight of dry solids.

4) The feed sludge solids concentration or the final dewatered sludge cake solids did not prove to be significantly correlated with filter performance measures.

11) Controlled studies were conducted to evaluate the effects of landfilling dewatered tannery sludge cakes alone or in combination with municipal refuse in covered and uncovered cells. Results of these tests conducted over a two year period produced the following conclusions.

a) The landfilling of dewatered sludge cake without earth cover was a more desirable procedure than covering the cakes with soil because the exposed or uncovered cake had greater opportunity to undergo aerobic decomposition resulting in higher internal temperatures, more rapid evaporation of moisture, greater rates of settlement and consolidation and lower quantities of leachate generated. Some odors are associated with the fresh dewatered cakes but were not considered to be significant.

b) In the first 60 days after placement, the 100% sludge cake cells had an initial settling rate of between 0.08 to 0.16 m/m height-month depending on whether they were covered or uncovered. Refuse and combinations of refuse and sludge cake produced initial settling rates substantially lower than these values.

c) Analyses of sludge cakes approximately 3 months after placement showed a reduction in volatile solids of 35.2% for earth covered cakes and 55.7% for uncovered cakes. Percent dry solids over this period increased by 3.6% in the covered cakes and 23.2% for the uncovered cakes.

d) Collection of leachate from the test cells indicated that between 20 to 23% of the total rainfall resulted in leachate for the covered sludge cakes, whereas only 7 to 9% of the total rainfall resulted in leachate in the uncovered cells. Covered refuse produced about 10% of the incident rainfall as leachate.

e) Analyses of leachate quality from the test cells indicated that higher masses of pollutants were generated from covered sludge cakes and lowest amounts were produced by refuse or mixed refuse-sludge cake cells.

f) Greatest amounts of total chromium in leachate were produced from covered sludge cakes than for uncovered sludge cakes. Approximately 0.001 g chrome/1000 kg dry cake placed was released over the test period for covered sludge cakes (approximately 0.04% of the total chrome placed) as compared with a range of from 0.003 to 0.00004 g chrome/1000 kg dry cake for uncovered cakes (approximately 0.0017% of the chrome placed).

SECTION III

RECOMMENDATIONS

1) In-plant efforts to reduce wastewater pollutants in an acid chrome tannery should be directed primarily to the beamhouse operations except for total chrome, ammonia and sulfate which come primarily from the tanyard. The beamhouse hair pulp operation is the principal source of sulfides and protein degradation products and efforts should be directed to sulfide recovery and reuse as well as the employment of methods for the removal and enrichment of the protein degradation products for subsequent marketing.

2) The treatment of unsegregated chrome tannery wastewater by aerobic lagoons will provide a high degree of treatment but supplemental treatment with chemical coagulation is necessary to reduce the finely divided particulate matter and the pollutants associated therewith to more acceptable levels. However, the addition of ferric chloride as a coagulant to the secondary effluent did reduce the levels of fats and greases and total Kjeldahl nitrogen to meet the requirements of Best Available Treatment (BAT). However, these results were obtained only under high temperature or warm weather conditions. The results from these studies show that the nitrogen in the wastewater does not undergo transformation and oxidation to the extent required by BAT guidelines even under the low organic loading and high temperature conditions evaluated in this demonstration study. It would be necessary to provide substantially longer sludge ages (lower F/M values) than utilized in these studies. Even under these conditions, there is no evidence that biological processes will reduce the total Kjeldahl nitrogen to acceptable limits for this wastewater and further research is needed to substantiate this process. The reduction of fats and greases to meet acceptable requirements will be likely achievable through more effective oil and grease removals by preliminary and primary processes, such as electro-floatation techniques, as well as by the employment of chemical assists in the secondary processes. Further evaluation of the effectiveness of selected methods for fat and grease removal would be desirable.

3) When aerobic lagoons are employed to treat acid chrome tanning wastewaters, it is recommended that the process be designed to

provide maximum flexibility. In cold climates, it is recommended that the lagoon system be provided with and operated with sludge return so that detention times may be reduced during cold periods to minimize the cooling effects without seriously affecting performance. Consideration should be given to deeper ponds and submerged aeration devices to minimize the problems attendant with cold weather operation.

4) The results of the biological treatment systems represent relatively brief periods of testing under a variety of operating conditions. It is recommended that treatment performance be evaluated over an extended period to fully ascertain the effects of seasonal variations on the capability of the treatment system employed and to statistically evaluate the performance data relative to recommended effluent guidelines.

5) Research efforts should be conducted to ascertain the health hazards associated with the discharge of unchlorinated wastewaters from tannery processes when sanitary wastes are not included. It is unlikely that the fecal coliform requirement currently acceptable for municipal wastewater discharges is realistic for tannery process wastes.

6) Odor problems in tannery wastewater unit operations derive principally from the evolution of hydrogen sulfide from the wastewater attendant with a decrease in pH, from the presence of volatile nitrogen bearing substances generated in the treatment of hides and through biochemical reaction with hide protein, and from gaseous biochemical endproducts generated in unit operations, which are likely to be anaerobic including sedimentation operations and sludge handling processes. The addition of ferric chloride to the raw wastewater is recommended during periods when sulfide bearing discharges to the treatment plant occur which will likely enhance odor control through the precipitation of sulfide as the iron salt. This procedure also may provide benefits of improved suspended solids separation through coagulation mechanisms. In other areas of the treatment process where anaerobic conditions may evolve or pH adjustments to sludge before dewatering, consideration should be given to enclosure of the unit process with appropriate ventilation and waste air treatment.

7) In designing treatment facilities for tannery wastes, considerable effort should be made to account for the peculiar properties of this wastewater, such as wide pH fluctuations, ability to cause encrustations, corrosivity and the presence of hair and scraps. The operational difficulties that were encountered with this treatment facility and suggestions to alleviate some of these problems, both for design and maintenance, are provided in Appendix C of this report.

8) To minimize the secondary pollutional effects in the land disposed of dewatered tannery sludge from the pressure filtration process (solids content from 40 to 50% by weight) it is recommended that the cakes be placed in uncovered fill in 1 meter depths for a 12-month period before covering. It may be necessary to provide odor control by topical applications on the freshly dewatered disposed cakes to minimize odors for certain locations.

Section IV

WASTEWATER TREATMENT PLANT FLOWSHEET

The unsegrated, unequalized, unneutralized wastewater is conveyed to the treatment plant wetwell through a 61 cm sewer. Three main intercepting sewers provide the in-plant wastewater collection system for process waters. In addition, roof drainage, during times of rainfall, enters the process wastewater streams for subsequent treatment. The influent channel to the pumping station wetwell was provided with bar type screening in the primary channel with provisions to grind the scraps in place without the need for removal from the wastewater stream. During periods of clogging or power outage provisions were made for flow to be directed to a secondary channel equipped with a bar screen with 1.59 cm clear openings with manual cleaning. The grind in-place device was ineffective and was replaced with a bar screen with 0.96 cm openings and mechanical rake. The bar screen in the secondary channel was also equipped with a mechanical raking device. Screenings were disposed of as landfill.

The screened wastewater entered a wetwell with an operating volume of about 18.9 m^3. In addition to the raw wastewater flow, filtrate from the sludge dewatering facility as well as waste activated sludge from the secondary clarifiers, reentered the waste at this point. The wastewater from the wetwell was pumped to the primary settling tanks with two variable speed pumps under normal operation and one constant speed pump for peak flows. The pumps are physically arranged in parallel and activated by a control system for prescribed water levels in the wetwell.

The pumps discharge into a 36 cm main equipped with a magnetic flowmeter capable of measuring and recording instantaneous flows as well as totalized flows. The flow was divided between the two clarifiers with roughly an equal portion passing to each, although these individuals flows were not metered (Figure 1).

The circular primary settling units, each 10.7 m in diameter, were equipped with two sludge collectors and a single surface scum collector (Figures 2 and 3). The flow was introduced through a center well 0.91 m in diameter about 0.46 m below the liquid surface and the tanks served as clarifiers with baffled peripheral discharge over a flat crested weir. The

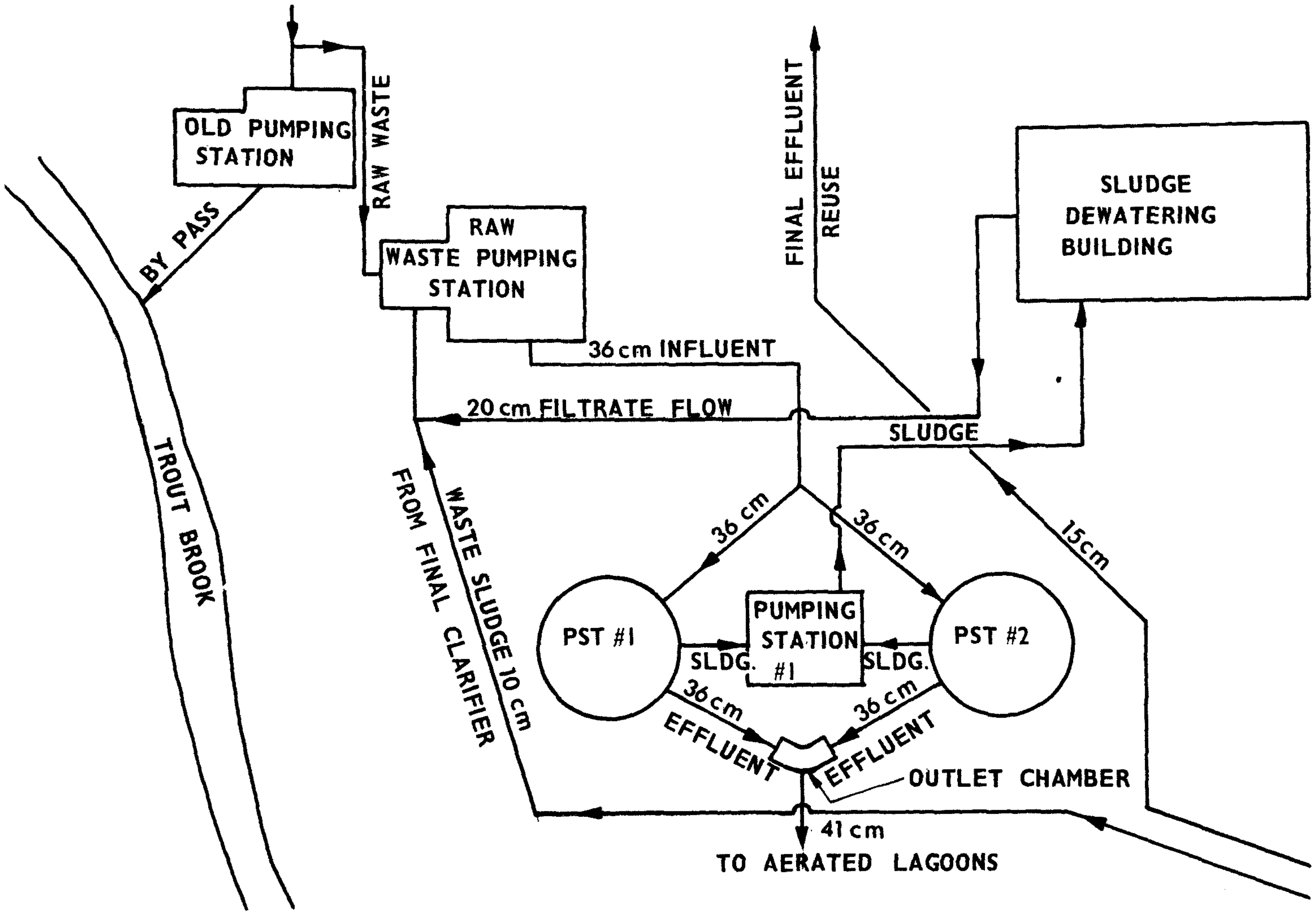

Figure 1. Primary treatment flowsheet.

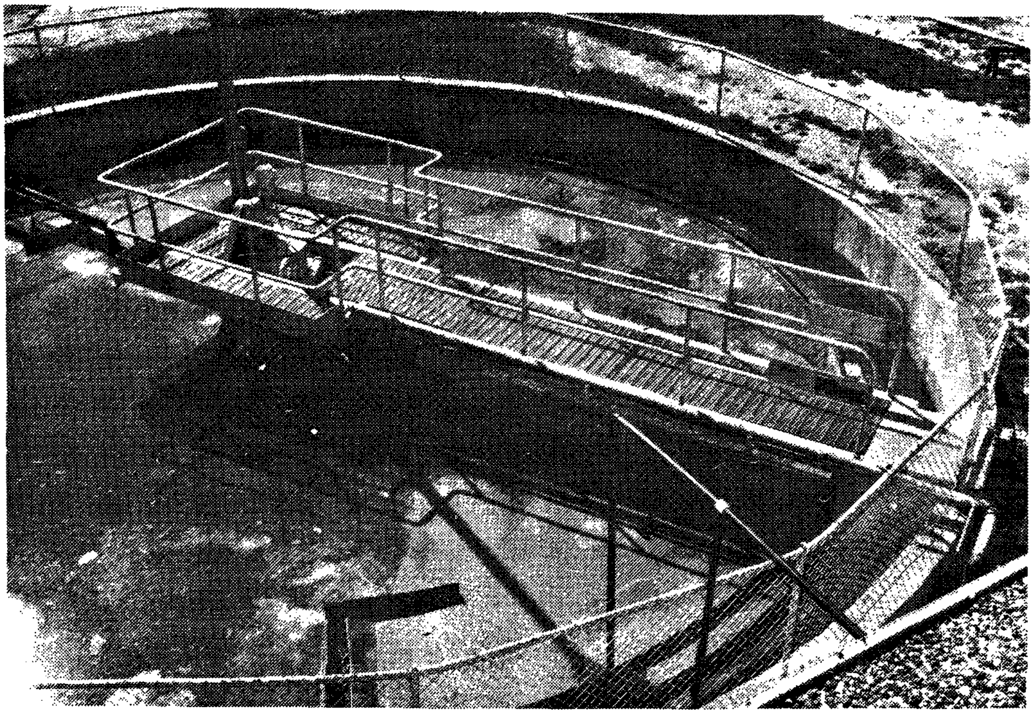

Figure 2. Primary settling tank.

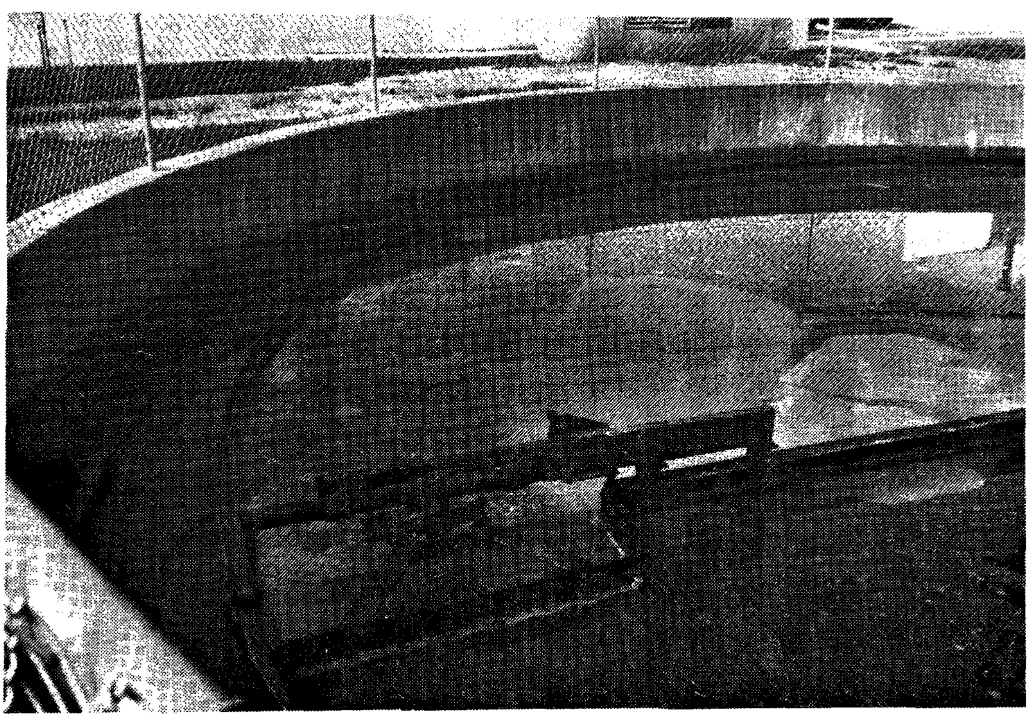

Figure 3. Primary settling tank scum collector.

settled solids passed into a thickening zone in the lower portion of the tank with sludge discharge through a sump 1.01 m x 1.98 m - 1.22 m deep near the center of the settling tank. The settling tank sidewall depth of 3.66 m provided a volume of about 327 m^3. The floatable material was discharged to a scum manhole adjacent to each tank and measured 1.52 m x 1.52 m x 4.27 m deep with a capacity of about 6.44 m^3 each. The scum was stored and concentrated before disposal off-site. Each scum manhole was equipped with a pump for dewatering the chamber.

The settled effluent from each clarifier passed into a weir controlled outlet chamber before the two streams were conveyed by gravity to the secondary treatment facilities. The outlet chambers served as sampling points for evaluating the performance of the primary clarification.

The thickened primary settled sludge solids were conveyed through a 15 cm line to three positive displacement pumps for subsequent discharge to the solids dewatering building as required.

The combined primary effluent was discharged to a distribution chamber capable of dividing the primary effluent to the various aerated lagoons or lagoon systems for each test condition (Figure 4). In addition, the distribution chamber received the return activated sludge from the final clarifiers as separate streams to be directed appropriately to the desired aerated pond treatment system (Figure 5). Two parallel treatment systems could be employed with or without return sludge as independent secondary treatment systems (Figure 4). The primary effluent flow, pond influent flow, was proportioned to the appropriate treatment system or individual lagoon by use of shear gates thus providing complete flexibility.

The four aerated lagoons (Figure 6) were concrete lined with ground level top dimensions of 99.4 m x 26.2 m, two of which were 2.13 m deep providing volumes of 3691 m^3 each (lagoons 1 and 2) and a 1.83 m operating depth for two with a 3524 m^3 each (lagoons 3 and 4). The side walls were sloped 2:1, horizontal to vertical, for bottom dimensions of 90.8 m x 17.1 m for lagoon numbers 1 and 2 and bottom dimensions of 90 m x 16.8 m for lagoon numbers 3 and 4. The primary effluent-return sludge mixture was conveyed to the lagoons through a 36 cm pipe and introduced at mid-width and depth at the influent end of the lagoon. The outlet structure was located at the opposite end of the lagoon at mid-width and extended 3.66 m into the lagoon providing 9.14 m of weir length. Each outlet weir controlled the liquid depth at 2.13 m and 1.83 m for lagoons 1 and 2, and 3 and 4, respectively (Figure 7).

The physical piping arrangement with associated valves and shear gates for the four lagoons is shown in Figure 4. The flow patterns utilized in

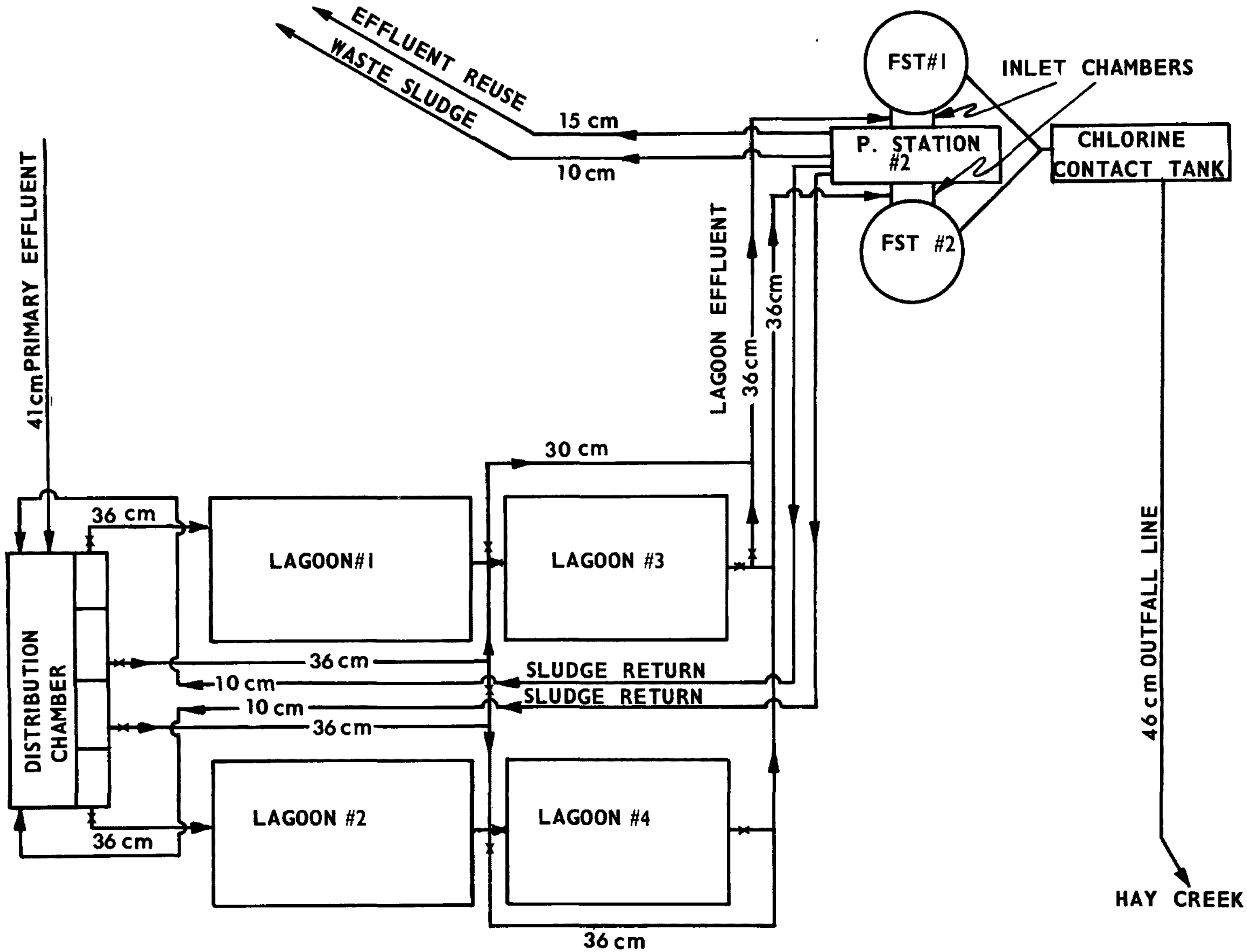

Figure 4. Biological treatment process flowsheet.

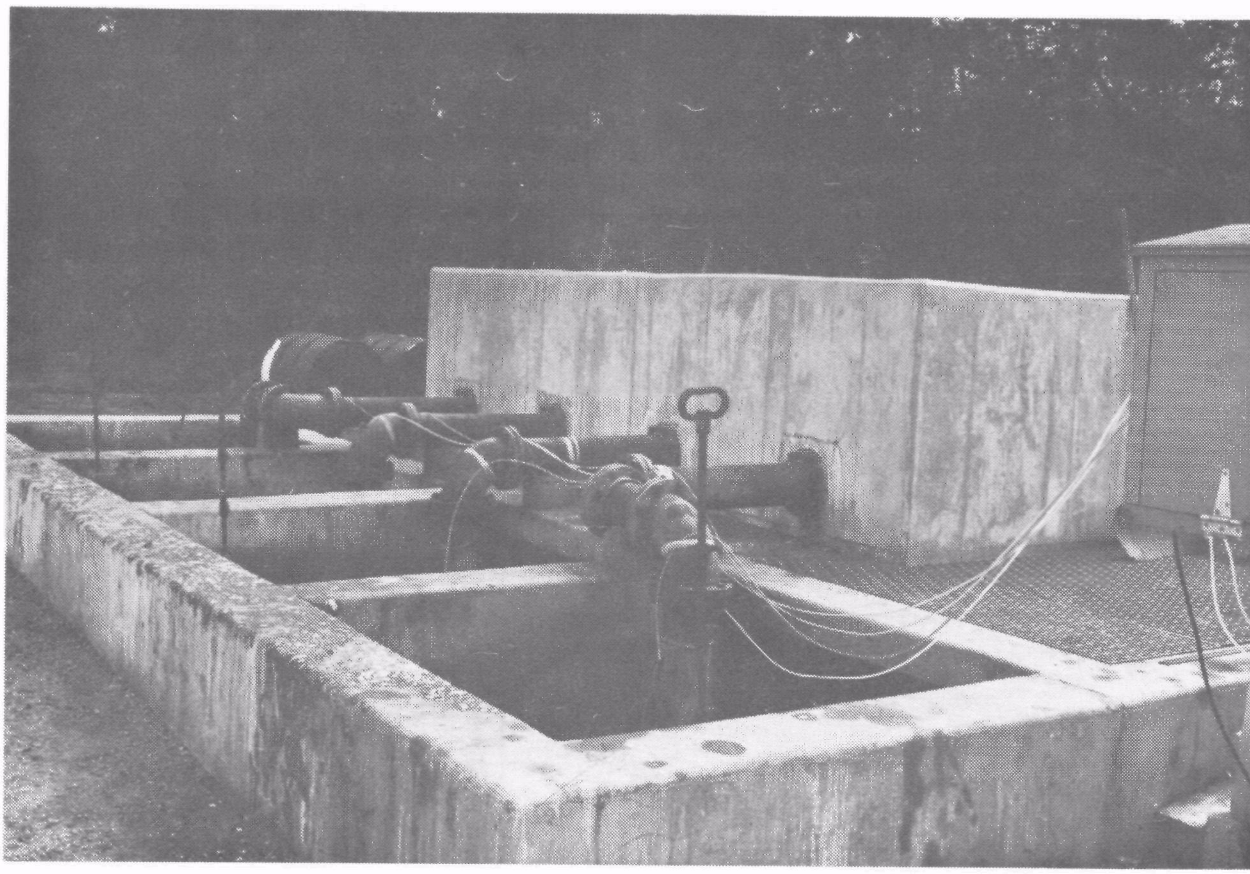

Figure 5. Flow distribution chamber.

Figure 6. Aerated lagoons.

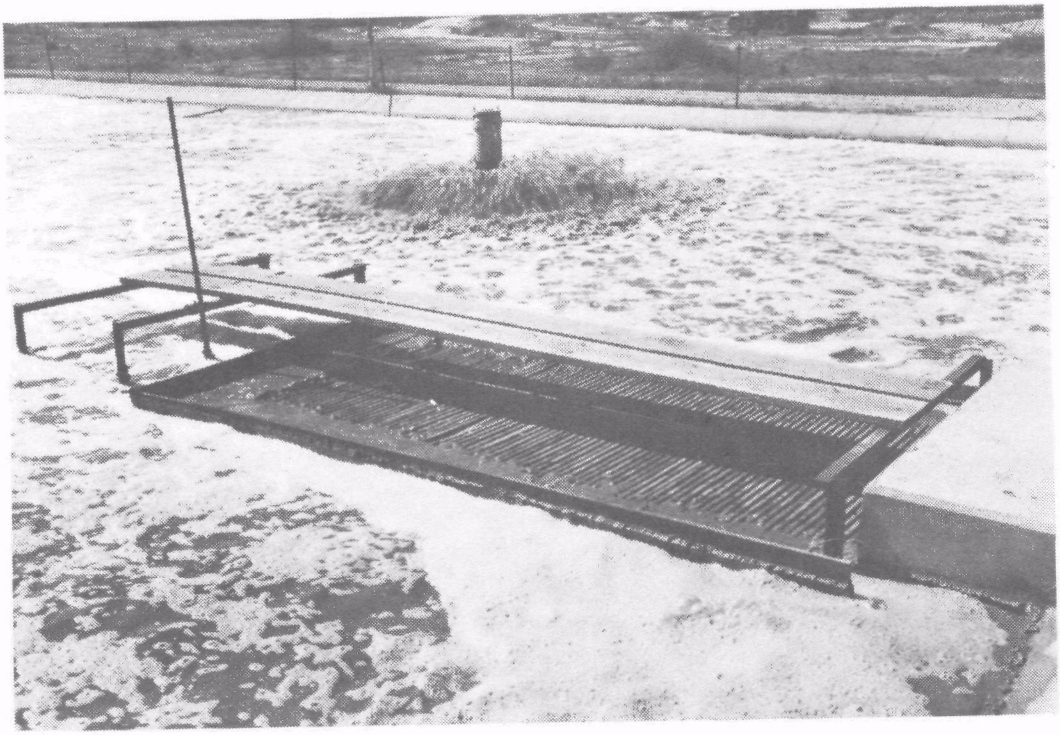

Figure 7. Lagoon effluent structure.

the study were as follows:

A. Parallel--Equal flow was directed to each of the four lagoons with the effluent directed to the final clarifiers.

B. Series--Equal flow was directed to each of the front lagoons (numbers 1 and 2) and then in series with the rear lagoons (numbers 3 and 4 respectively), the effluent from the rear lagoons to each of the two final clarifiers.

C. Parallel-Series--Equal flow was directed to each of the front lagoons (numbers 1 and 2). The effluent from lagoon number 2 was divided for flow into the rear lagoons (numbers 3 and 4). The effluent from lagoon number 1 and effluents from lagoons 3 and 4 were directed to one of the two final clarifiers respectively.

The valve arrangement at the discharge end of the lagoons offered some flexibility as to which final clarifier received the flow. By proper arrangement at the distribution chamber, it was possible to direct the return sludge to the second lagoon in series and bypass the first lagoon, if desired.

Mechanical floating surface aerators were provided for the biological oxygen requirements and to keep the solids in suspension. The original 750 kg m/sec aerators did not meet specifications regarding circulating velocities and were replaced with 375 kg m/sec high speed aerators, 12 in each lagoon, which improved the ability to maintain solids in suspension but did not eliminate the problem of solids separation in the aerated lagoons completely.

The aerated pond effluent with associated biological solids were conducted to an inlet chamber, 1.83 m x 1.83 m x 3.66 m deep, with a usable volume of 12.7 m^3, which served as a mixing compartment for the addition of chemical coagulants for a test condition in September-October, 1974 (Figure 8).

The mixed liquor, after passing through the inlet chamber, entered the 12.2 m diameter final clarifiers through a center well feed about 0.46 m below the surface and was deflected downward by a baffle. The clarified effluent passed over a flat crested weir at the tank periphery and the settled solids were conveyed by the sludge collector to a 1.68 m x 0.61 m x 0.91 m deep sump located near the center of the tank for continuous removal. The final clarifiers were not equipped with scum retention baffles or skimming devices. Each final clarifier tank volume was approximately 282 m^3 with a sidewall depth of 2.44 m (Figures 9 and 10).

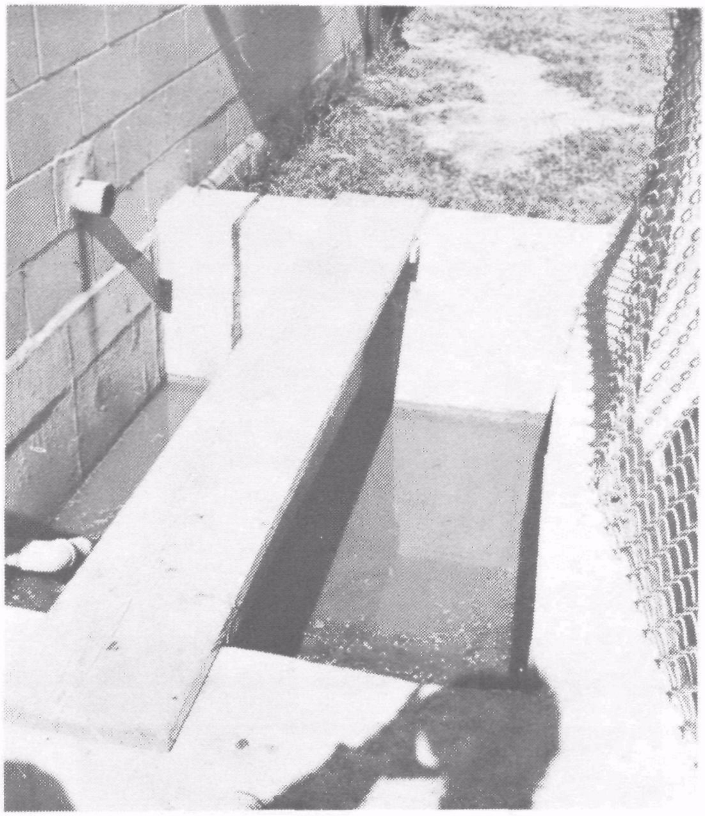

Figure 8. Final clarifier inlet chamber

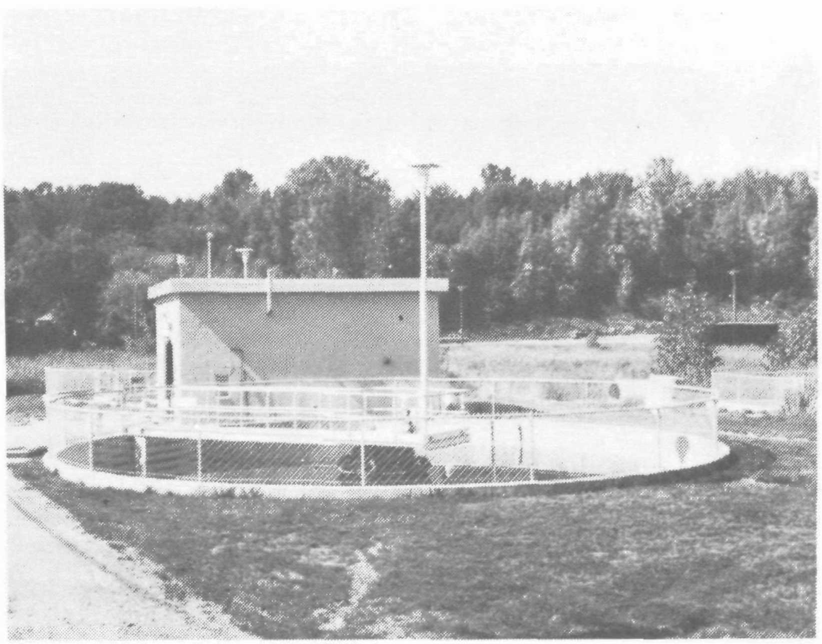

Figure 9. Final clarifier.

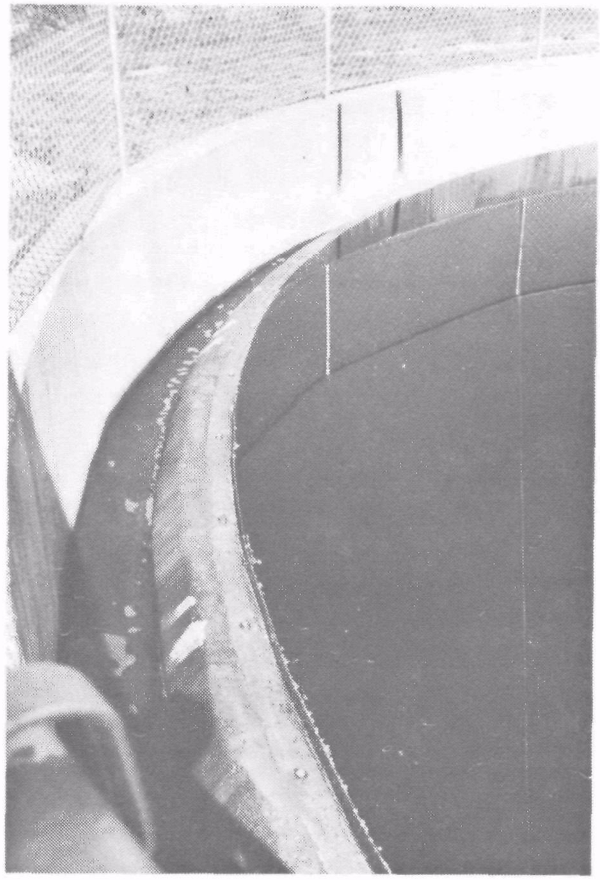

Figure 10. Final clarifier overflow weir.

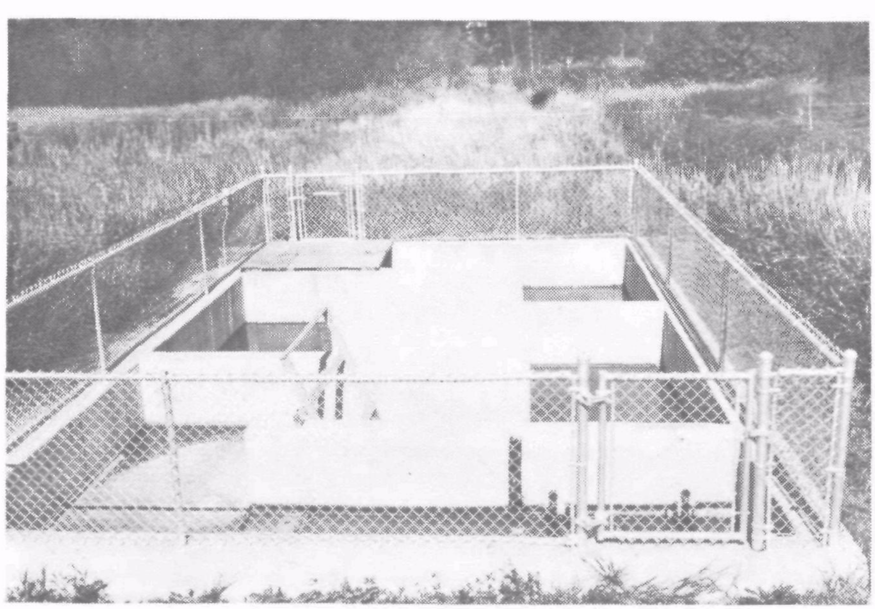

Figure 11. Chlorine contact chamber.

The settled secondary sludge was removed from the clarifiers by three variable speed centrifugal pumps (0-757 l/min), two of which were used to return the sludge to the distribution chamber via a 10 cm line, one for each clarifier and parallel treatment system. The third pump was used to waste sludge from either clarifier to the wetwell via 10 cm line. Each pump discharge was provided with flowmeters for process control.

The secondary clarifier effluents were combined and discharged to a baffled rectangular chlorine contact tank 9.45 m x 5.79 m x 3.05 m deep (Figure 11). Chlorine feed equipment apportioned the chlorine feed rate from 0 to 90.7 kg per 24 hours. The chlorine gas was combined with the tannery water supply as a carrier and the solution was introduced to the chlorine contact tank via a 2.54 cm PVC pipe. The chlorine solution, introduced through a diffuser, and final effluent were combined in a 1.52 m x 1.52 m section at the inlet to the contact tank. The contact time was about 50 minutes for the flows experienced. An additional pump was provided to return final settling tanks effluent from near the influent end of the chlorine contact tank to various tanning operations for an effluent reuse study.

The chlorinated effluent was discharged to Hay Creek via a 366 m, 46 cm outfall sewer.

SECTION V

SLUDGE DEWATERING FLOWSHEET

The sludge from the primary settling tanks was dewatered by the pressure filtration process housed in the sludge dewatering building (Figure 12), wherein the conditioned sludge was pumped under pressures up to 15.8 kg per cm^2 into a 45 chamber, 1.52 m x 1.52 m by 3.18 cm thickness filter press. The filter chambers were lined with a mono-filament nylon filter cloth and a precoat of buffing dust, a waste-material indigenous to the tanning industry, was applied just prior to commencement of the filtration cycle. The system was designed to produce a filter cake of 45% solids with a cycle time of 70 to 100 minutes, thus dewatering 1315 kg to 1406 kg of sludge solids, with associated chemical conditioners, per cycle. Chemical conditioning utilizing $FeCl_3$ and lime in the amount of up to 227 kg per cycle was employed to aid filtration.

A schematic flow diagram in Figure 13 shows the ancillary equipment and sidestreams associated with this dewatering process. The thickened sludge was pumped from the primary clarifiers through a sludge grinder to reduce the size of large pieces of hide or scrap that may interfere with subsequent operations. The sludge passed into a rapid mixing or reaction tank, 1.72 m^3 capacity, where liquid ferric chloride and slaked lime were added to the sludge before entering the contact tank. The contact tank, an effective volume of about 15.9 m^3 was provided with slow mixing paddles to insure uniform mixing and serve as the sludge reservoir for pumping sludge to the filter press. The filter press operated on a batch basis and each filter cycle was preceded by precoating the filter cloth with a slurry of buffing dust from the precoat tank, applying the precoat solution using a 4500 kg m/sec pump, over a 4 minute time interval. Filtrate water was used as the makeup water for the precoat slurry as well as for wetting the filter cloth before the precoat operation. The contents of the equalization tank containing conditioned sludge was introduced to the filter press immediately after precoating, prior to initiation of the filter feed pumps, to hold the precoat materials in place. The filter feed pumps, two positive displacement hydraulic powered pumps, were activated and conditioned sludge was pumped to the filter press from the contact tank. The solids were retained on the filter cloth and the liquid filtrate was conducted to the filtrate storage tank to serve as makeup water for subsequent filter runs. The excess filtrate overflowed and returned to the wetwell. The

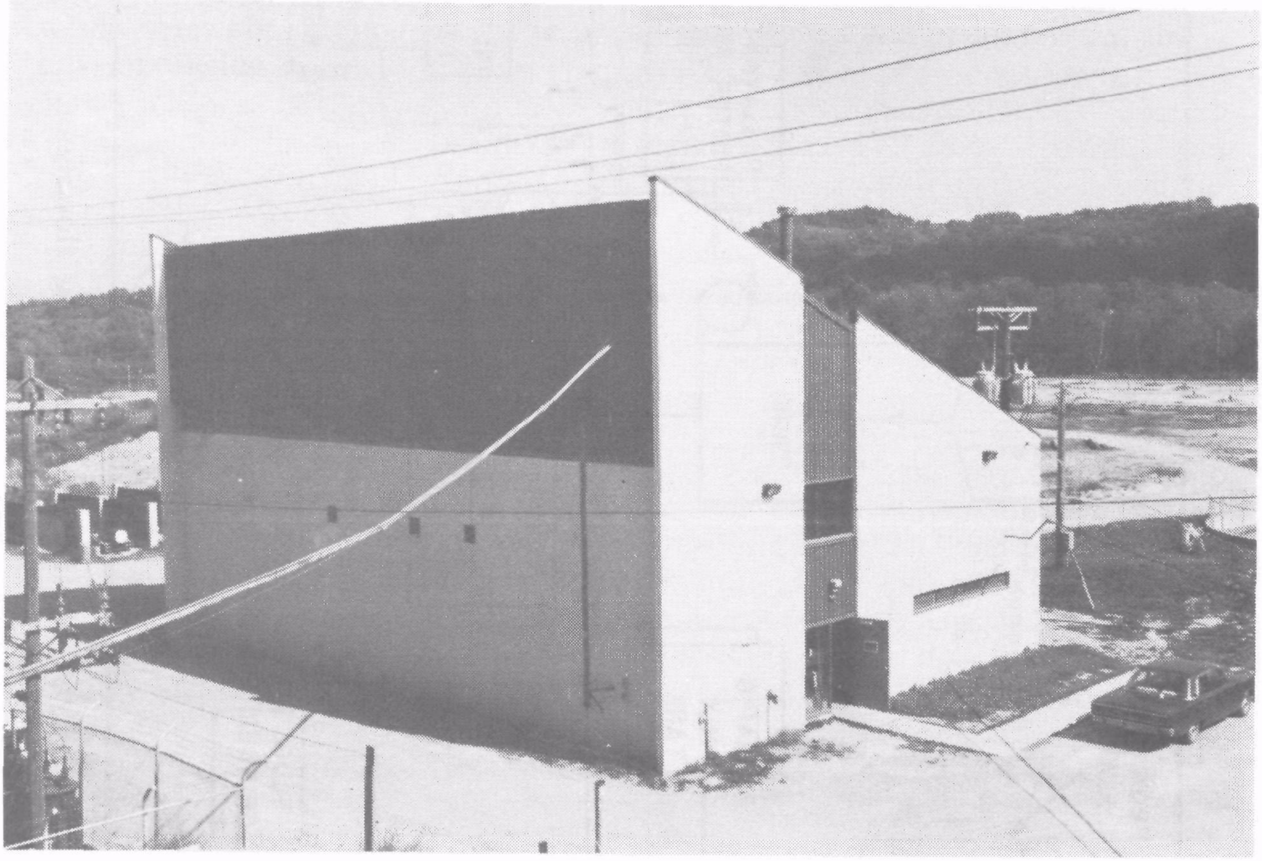

Figure 12. Sludge dewatering building.

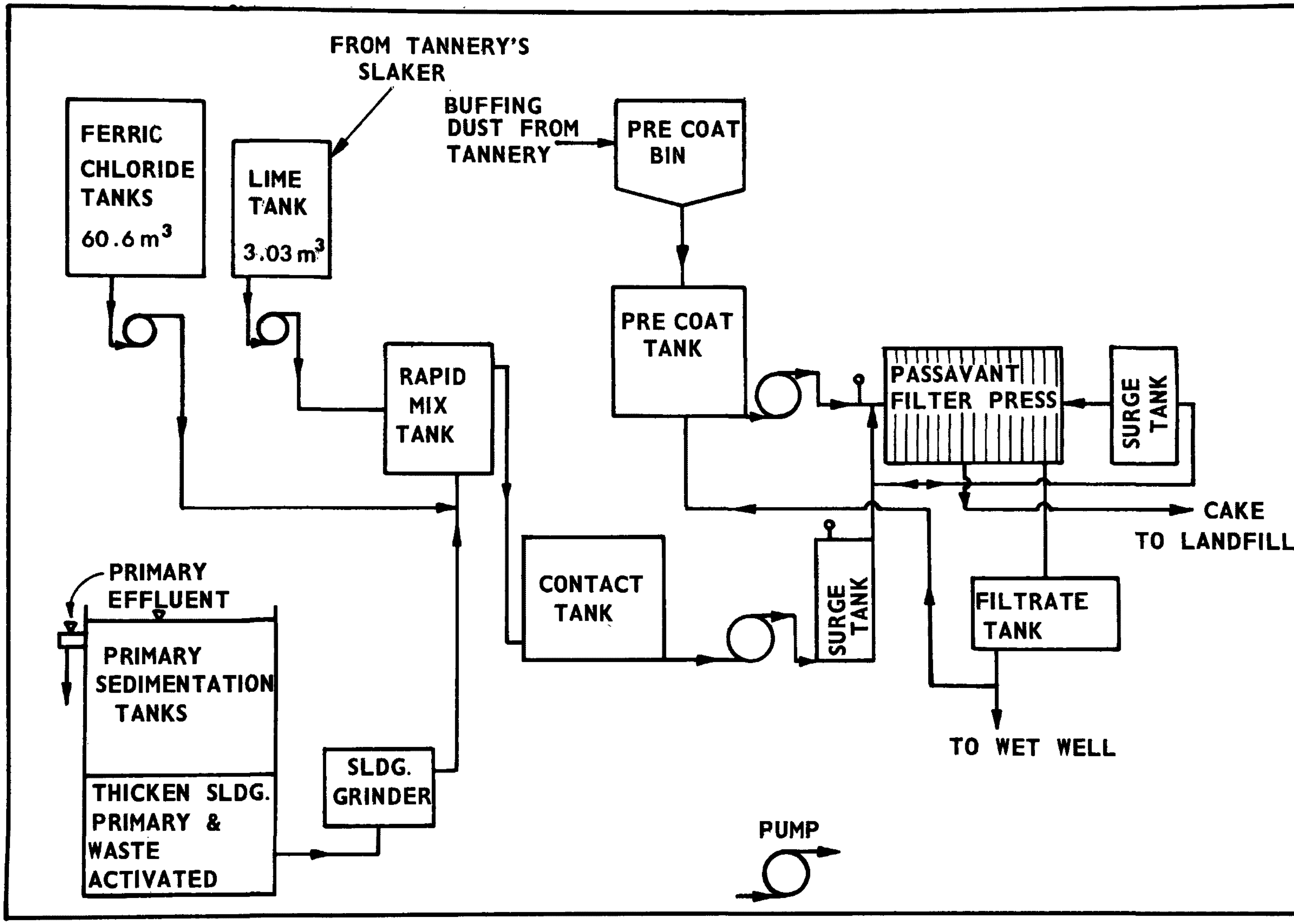

Figure 13. Sludge dewatering flowsheet.

hydraulic powered feed pumps operated at declining rates from the start of the filter cycle as the resistance to filtration increased, a result of the solids deposited. The cycle was terminated when operating pressures approached 15.1 to 15.8 kg/cm^2 and the filtrate rate decreased to 19 to 53 l/min. The remaining unfiltered sludge in the piping and core of the filter press was pneumatically forced back into the contact tank. The press was opened so as to release one cake at a time. The cakes were dropped into a chute equipped with three bars to break the cakes as they were discharged to a dump truck. The truck was capable of receiving the cakes from a single cycle for disposal onsite. The filter cakes were dumped on the ground. Subsequent landfilling and covering, was undertaken in one to two week intervals (Figure 14). The press was closed and prepared for the next operating cycle.

Figure 14. Dewatered sludge cake.

SECTION VI

CHARACTERIZATION OF PROCESS DISCHARGES

The waste products generated for the various manufacturing operations result from the tanning of cattleskins by the acidic chromium process. The series of batch operations employed are shown in Figure 15 wherein "beamhouse", "tanyard", and "color and fat liquoring" are the principal unit processes. In addition, the fleshings have been rendered since March, 1974, by acidic heat treatment resulting in a stickliquor which was discharged to the wastewater treatment plant. The leather, grain sides, was not finished at a location which contributes to the treatment works; however, wastewaters generated from the source were characterized and reported herein.

Prior to 1971 the industry employed a "hairsave" operation and thereafter converted to "hair pulping". The results reported herein represent the hair pulping operations typical of current technology in the tanning industry.

The hides received for processing were 60-70% green salted and 30-40% prefleshed on an average. The raw waste load from the rendering process depends heavily on the amount and nature of the flesh material associated with the hide as received. The lime-sulfide formula used in the beamhouse varied with the nature of the hide received, and had a significant effect on the raw waste load. During the cold winter months the hides received would have longer hair and, conversely, during the summer months shorter hair, thus the hair pulping formula employed would reflect these differences in hair length. In that hides are purchased and stored before processing, the calendar periods may not coincide with the processing formula employed.

The beamhouse and tanyard departments constitute a series of individual scheduled batch drainages to the wastewater treatment plant. The purpose of the beamhouse operation is to remove manure, blood, salt, flesh and hair to prepare the hides for tanning. The tanyard converts the hide to leather by a series of steps, principally chemical in nature, followed by the physical process of splitting the side into a grain layer of uniform thickness and a split layer or "splits" of variable thickness.

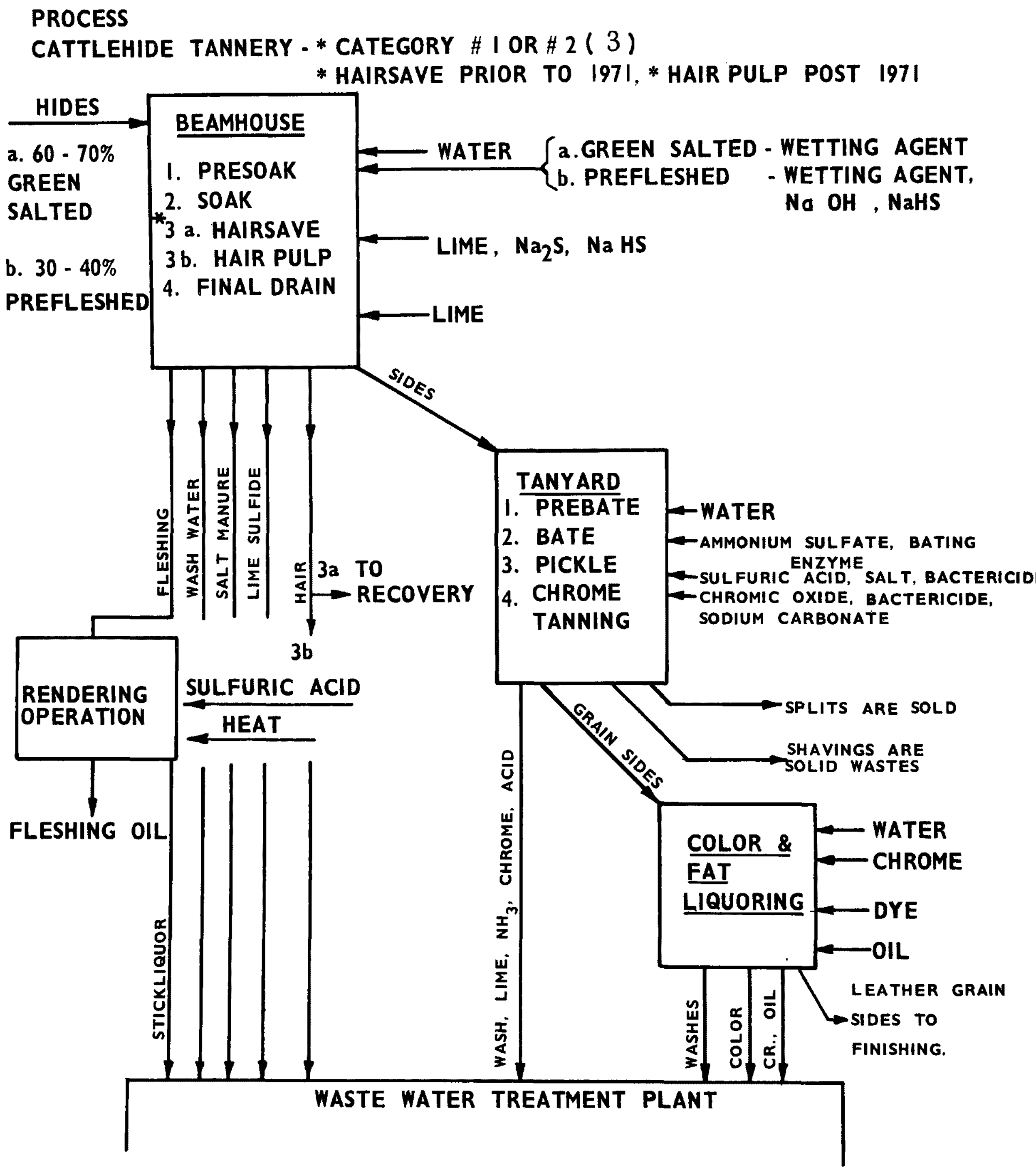

Figure 15. Process diagram of raw material, product and waste flows.

The splits are not processed further at this tannery. The grain layer is subjected to a mechanical process of shaving to provide a smooth surface and the resulting shaving residues are disposed of as a solid waste.

The color and fat liquoring operations are employed to impart the desired color to the leather with the aid of synthetic dyes and to restore oils that are lost in the preliminary processing step. The leather sides are dried and subjected to a finishing operation wherein various substances are applied topically to the grain side to produce the desired finished leather surface.

A series of samplings were conducted of the individual drainages representing the major process operations as well as composite sampling of the combined operations, i.e., beamhouse, tanyard, color and fat liquoring, during the summers of 1973 and 1974, when the summer formula (short hair) was used in the beamhouse. A summary of these results for the various parameters are presented as kg/1000 kg of hides processed(as received) in Table 1 and as a percentage of the total waste contribution from these sources in Table 2.

It is noted that with the exception of ammonia nitrogen, sulfate and chromium, that the beamhouse contribution for a given wastewater parameter varied from 50 to 99% with the largest percentage of waste materials resulting from the hair pulping operation. This is evident with the exception of chloride where the major source results from the soak operation in the beamhouse (Figure 16).

It is readily apparent that efforts for in-plant reduction of wastes should be directed principally to the beamhouse operations. Where ammonia and total chrome effluent concentrations are of concern, additional in-plant recovery or chemical substitution should be directed to the tanyard operations.

The beamhouse formulations employed for the hair pulping depends on the nature of the hide, principally hair length, for the relative amounts of chemicals used. The principal concern is associated with the sulfide usage wherein greater amounts are employed with winter hides or hides having longer hair. The effect of this is summarized in Table 3 with the designated formulations.

The finishing wastes were characterized separately in that the leather finishing operations are conducted at another industrial site. A summary of these results are presented in Table 4.

It is readily apparent that the finishing wastes represent an insignificant portion of the total wastewater characteristics.

TABLE 1. RAW WASTE LOAD FROM MAJOR TANNERY DEPARTMENTS AND SUBOPERATIONS *
(Kg/1000 Kg HIDE PROCESSED)

Parameter	Beamhouse					Tanyard					Color & Fat Liquor	Total
	Pre-Soak	Soak	Hair Pulp	Relime	Total	Pre-Bate	Post Bate	Pickle	Chrome	Total		
Total solids	38.2	63.4	176.1	31.1	308.8	7.9	14.8	13.9	50.9	87.5	140	536.3
Volatile solids	3.3	18.0	90.7	9.3	121.3	2.1	7.9	2.7	7.3	20.0	23	164.3
Fixed solids	34.9	45.4	85.4	21.8	187.5	5.8	6.9	11.2	43.6	67.5	117	372.0
Suspended solids	3.6	11.7	76.9	7.9	100.1	2.3	2.4	1.4	3.0	9.1	10	119.2
Volatile solids	1.0	9.6	56.9	3.3	70.8	1.2	0.7	1.1	2.7	5.7	5	81.5
Fixed suspended	2.6	2.1	20.0	4.6	29.3	1.1	1.7	0.3	0.3	3.4	5	37.7
BOD_5	2.5	8.9	36.7	7.3	55.4	2.1	3.1	1.2	1.8	8.2	12	75.6
COD	4.3	18.1	160.0	19.1	201.5	4.2	6.0	4.0	6.3	20.5	32	254.0
Oil and grease	0.4	5.0	10.8	2.0	18.5	0.6	0.5	0.66	1.18	2.94	5	26.14
Kjeldahl-N	0.09	0.34	27.1	0.85	28.38	0.38	0.77	0.15	0.31	1.61	1.5	31.49
Ammonia-N	0.02	0.11	0.16	0.07	0.36	0.10	0.55	0.09	0.17	0.91	0.5	1.77
Organic-N	0.07	0.23	27.0	0.78	28.08	0.29	0.21	0.06	0.14	0.70	1.0	29.78
Calcium Total	0.19	0.18	10.6	2.78	13.75	0.91	0.77	0.20	--	1.88	5	20.63
Dissolved	0.11	0.13	7.7	1.23	9.17	0.37	0.60	0.08	--	1.05	4	14.22
Chloride	3.2	38.2	31.5	5.2	78.1	1.54	0.26	5.9	13.7	21.4	20	119.5
Sulfide	--	0.31	5.5	0.57	6.38	0.06	--	--	--	0.06	--	6.44
Sulfate	--	--	--	--	--	0.54	4.6	1.7	11.8	18.64	14	32.64
Chromium	--	--	--	--	--	--	--	--	1.4	1.4	0.5	1.9

* Results are based on summer formula without rendering operation.

TABLE 2. RAW WASTE LOAD FROM MAJOR TANNERY DEPARTMENTS EXPRESSED AS A PERCENTAGE OF THE TOTAL CONTRIBUTION*

Parameter	Beamhouse					Tanyard						
	Pre-Soak	Soak	Hair Pulp	Relime	Total	Pre-Bate	Post Bate	Pickle	Chrome	Total	Color & Fat Liquor	Total
Total solids	7.12	11.82	32.84	5.80	57.58	1.47	2.76	2.59	9.49	16.32	26.10	100
Volatile solids	2.01	10.96	55.20	5.66	73.83	1.28	4.81	1.64	4.44	12.17	14.00	100
Fixed solids	9.38	12.20	22.96	5.86	50.40	1.56	1.85	3.01	11.72	18.14	31.45	100
Susp. solids	3.02	9.82	64.51	6.63	83.98	1.93	2.01	1.17	2.52	7.63	8.39	100
Volatile susp.	1.23	11.78	69.82	4.05	86.87	1.47	0.86	1.35	3.31	6.99	6.13	100
Fixed susp.	6.90	5.57	53.05	12.20	77.72	2.92	4.51	0.80	0.80	9.02	13.26	100
BOD_5	3.31	11.77	48.54	9.66	73.28	2.78	4.10	1.59	2.38	10.85	15.87	100
COD	1.69	7.13	62.99	7.52	79.33	1.65	2.36	1.57	2.48	8.07	12.60	100
Oil & grease	1.53	19.13	41.32	7.65	69.62	2.30	1.91	2.52	4.51	11.25	19.13	100
Kjeldahl-N	0.29	1.08	86.06	2.70	90.12	1.21	2.45	0.48	0.98	5.11	4.76	100
Ammonia-N	1.13	6.21	9.04	3.95	20.34	5.65	31.07	5.08	9.60	51.41	28.25	100
Organic -N	0.24	0.77	90.66	2.62	94.29	0.97	0.71	0.20	0.47	2.35	3.36	100
Calcium Total	0.92	0.87	51.38	13.48	66.65	4.41	3.73	0.97	--	9.11	24.24	100
Dissolved	0.77	0.91	54.15	8.65	64.49	2.60	4.22	0.56	--	7.38	28.13	100
Chloride	2.68	31.97	26.36	4.35	65.36	1.29	0.22	4.94	11.46	17.91	16.74	100
Sulfide	--	4.81	85.40	8.85	99.07	0.93	--	--	--	0.93	--	100
Sulfate	--	--	--	--	--	1.65	14.09	5.21	36.15	57.11	42.89	100
Chromium	--	--	--	--	--	--	--	--	73.68	73.68	26.32	100

*Results are based on summer formula without rendering operation.

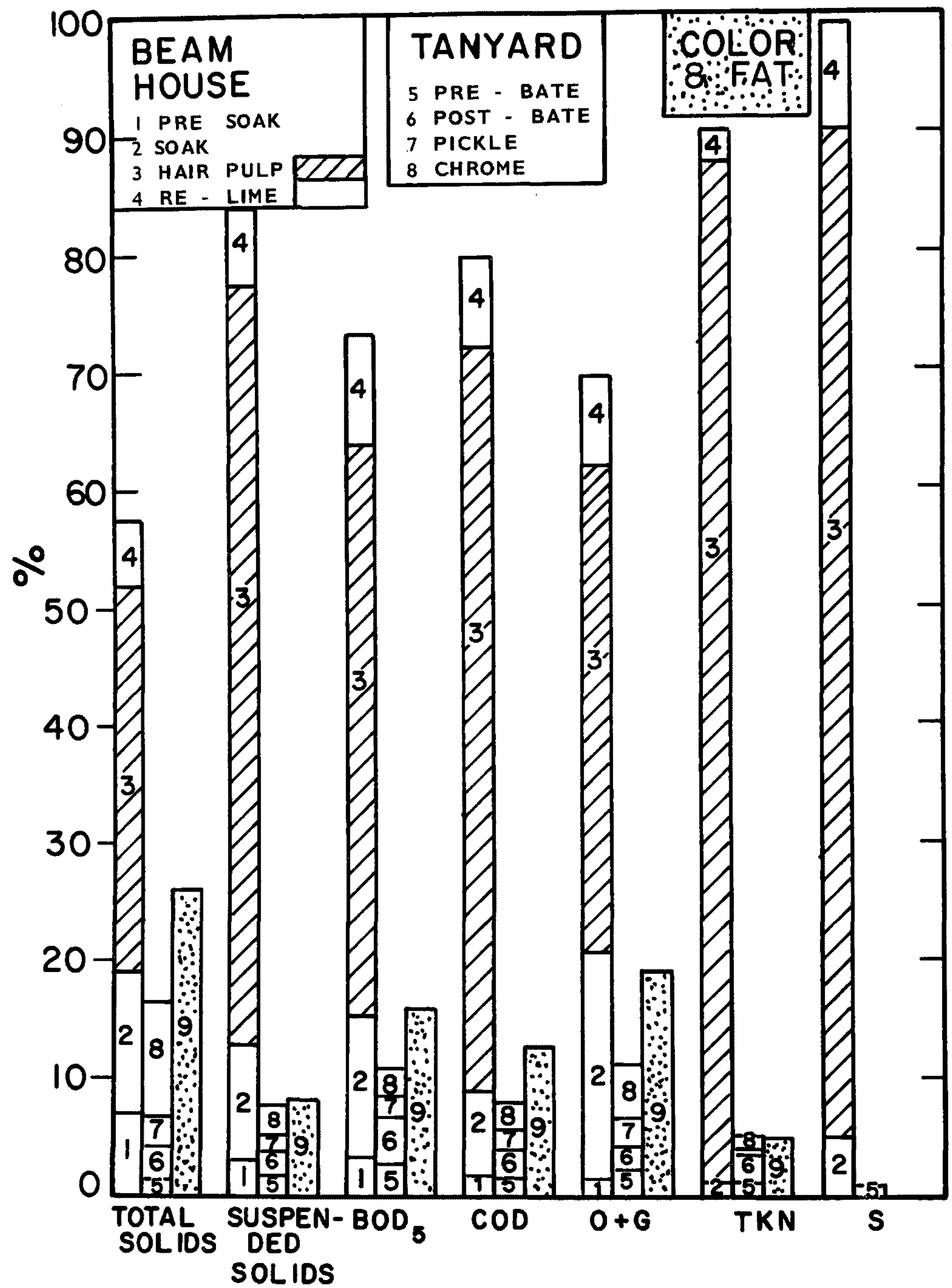

Figure 16. Raw wastewater characteristics.

TABLE 3. SULFIDE USE BY PROCESS FORMULA

Season	Estimated Hide weight kg/hide	Sulfide used kg/d*	Sulfide in raw waste kg/1000 kg hide
Summer	23.6	384	5.01
Spring-Fall	25.0	484	5.96
Winter	26.3	580	6.78

* Based on 3250 hides.

TABLE 4. FINISHING WASTEWATER CHARACTERISTICS

Parameter	Finishing waste load kg/1000 kg	Raw waste load kg/1000 kg*	Ratio of finishing waste to total raw waste load, % +
Total solids	1.6	536.3	0.30
Suspended solids	0.5	119.2	0.42
BOD_5	1.0	75.6	1.30
COD	3.8	254.0	1.47
Oil and grease	0.2	26.1	0.76
Kjeldahl nitrogen	0.04	31.5	0.13
Chromium	0.001	1.9	0.05
Sulfide	nil	6.44	--
Flow, l/kg	0.762	43.35	1.73

* Includes beamhouse, tanyard, color and fat liquoring.

+ Includes beamhouse, tanyard, color and fat liquoring, and finishing wastes.

SECTION VII

WASTEWATER FLOW VARIATIONS

Considerable data were collected regarding the 24-hour wastewater flows. In addition, hourly flow data were determined on numerous occasions to characterize the flow variations associated with the processing modes in the tanning operations.

Table 5 summarizes hourly flow data collected in 1972 for 24-hour periods on the dates indicated. As one would expect, on the average the wastewater flows were greatest for the early morning (first) shift, 6:00 a.m. to 2:00 p.m. (associated with beamhouse operations), and the minimum flows were experienced during the third shift, 10:00 p.m. to 6:00 a.m. A plot of the accumulative percent of wastewater flow versus hour of the day from midnight for the average results obtained (Figure 17) illustrates the relationship between peak to average rates. Maximum flows are approximately 130% of the average day flow and approximately 200% of the minimum flow.

Further characterization of the wastewater flow variations based on 24-hour flows and related to the unit weight of hide processed per day are illustrated in Figure 18. The results of numerous surveys, corresponding to days when 24-hour surveys were conducted, show the flows to range from 32.2 to 53 l/kg (3.86 to 6.35 gal/lb) with a value of 43 l/kg (5.16 gal/lb) representing the median and 43 l/kg (5.21 gal/lb) the mean. All flows are less than the value cited by the U.S. Environmental Protection Agency in the Development Document for Effluent Limitation Guidelines for the Leather Tanning and Finishing Point Source Category (3) of 53.4 l/kg (6.4 gal/lb) of hide for category 1. The waste flows measured do not include finishing wastes representing 1.73% of the total flow. The resulting flows in gallons per pound of hide processed for the various seasonal processing formulas are presented in Figure 19 and all flow results are summarized in Table 6.

TABLE 5. 24-HOUR COMPOSITE SAMPLINGS OF RAW WASTE DURING 1972
HOURLY FLOW PERCENTAGES

Time	Composite sampling dates						Average
	February 23-24	March 7-8	March 23-24	August 8-9	Sept. 25-26	Dec. 11-12	
Flow, m^3	2786	2953	2884	3346	2989	3028	
Flow, gal	736000	780000	762000	884000	789600	800000	
Midnight-1 a.m.	3.1	3.1	1.6	1.7	2.3	2.1	2.31
1 a.m.-2 a.m.	2.6	2.7	1.7	2.7	2.8	3.4	2.65
2 a.m.-3 a.m.	3.5	3.3	3.7	4.0	3.1	4.8	3.73
3 a.m.-4 a.m.	2.5	3.2	2.5	2.9	2.9	2.0	2.66
4 a.m.-5 a.m.	2.9	2.8	1.8	2.9	2.2	2.6	2.53
5 a.m.-6 a.m.	4.1	2.4	4.2	3.2	4.4	4.1	3.73
6 a.m.-7 a.m.	7.3	5.5	5.8	5.2	6.5	4.3	5.76
7 a.m.-8 a.m.	5.9	5.4	7.3	6.7	5.8	4.8	5.98
8 a.m.-9 a.m.	5.9	6.2	4.6	5.2	4.1	5.4	5.23
9 a.m.-10 a.m.	6.4	5.1	5.8	6.6	6.1	7.5	6.23
10 a.m.-11 a.m.	4.2	5.8	5.0	5.4	3.5	5.0	4.81
11 a.m.-Noon	6.1	5.8	5.4	5.0	4.8	4.3	5.23
Noon-1 p.m.	4.9	5.3	6.6	5.4	6.4	5.8	5.73
1 p.m.-2 p.m.	6.5	5.9	4.6	5.7	4.8	5.6	5.51
2 p.m.-3 p.m.	4.4	4.6	5.5	5.0	4.1	4.0	4.60
3 p.m.-4 p.m.	3.4	3.7	3.7	3.7	3.9	4.1	3.75
4 p.m.-5 p.m.	3.7	3.5	3.9	3.5	4.4	3.4	3.73
5 p.m.-6 p.m.	4.1	4.0	3.8	4.5	6.7	4.6	4.61
6 p.m.-7 p.m.	3.8	4.9	4.3	3.1	4.7	3.0	3.96
7 p.m.-8 p.m.	4.5	3.1	3.7	3.1	2.9	3.1	3.40
8 p.m.-9 p.m.	3.3	4.2	4.7	3.6	4.1	4.5	4.06
9 p.m.-10 p.m.	3.3	3.0	4.3	3.8	3.8	4.4	3.76
10 p.m.-11 p.m.	1.9	3.8	2.5	3.6	3.3	2.8	2.98
11 p.m.-Midnight	2.0	2.8	3.3	3.5	2.9	3.4	2.98
First shift (6 a.m.-2 p.m.)	47.1	44.8	44.7	45.2	41.8	43.5	44.52
Second shift (2 p.m.-10 p.m.)	30.5	30.9	34.0	30.3	34.8	31.4	31.98
Third shift (10 p.m.-6 a.m.)	22.4	24.3	21.3	24.5	23.4	25.1	23.50

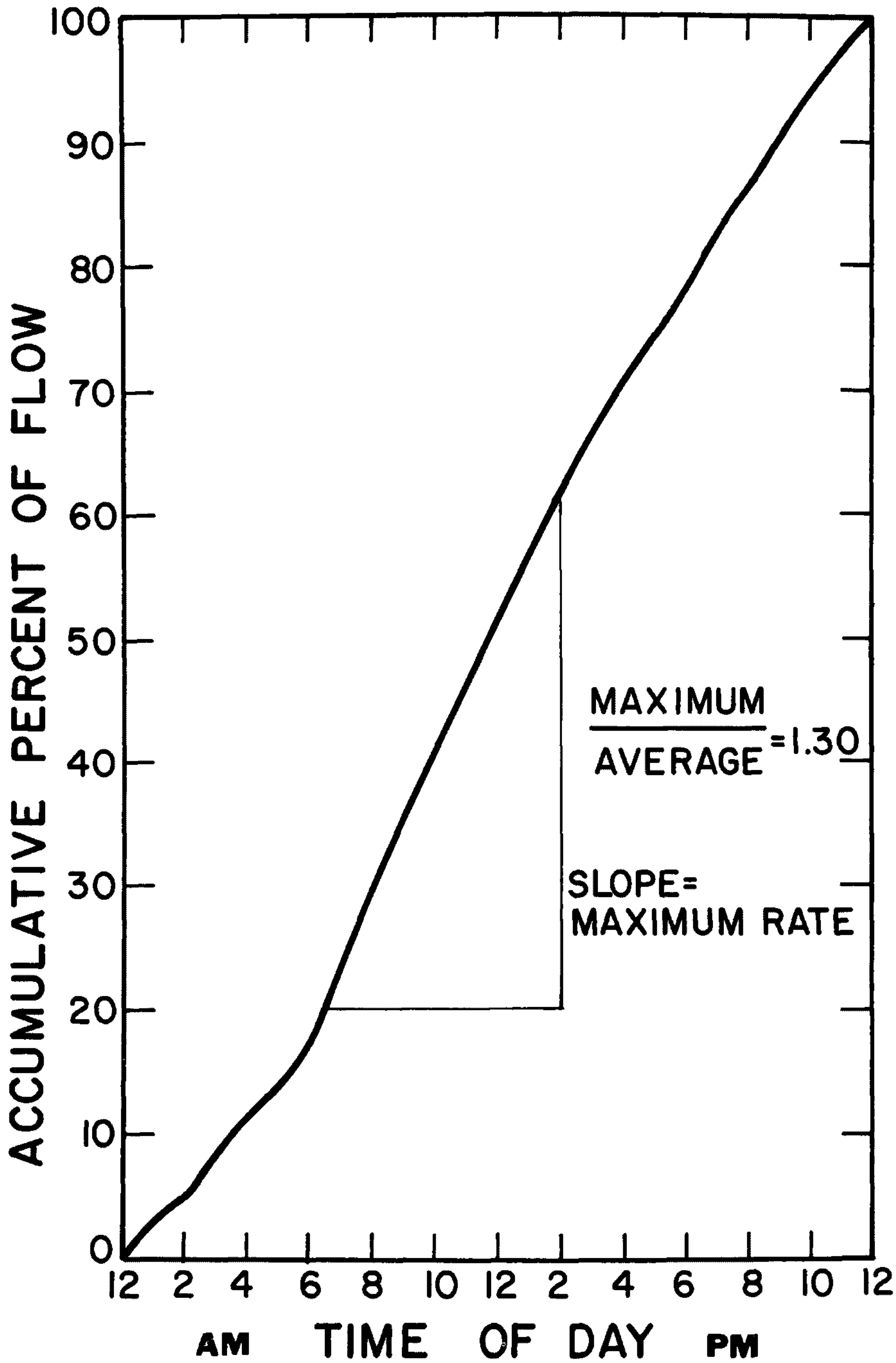

Figure 17. Raw wastewater flow average 24 hour variation.

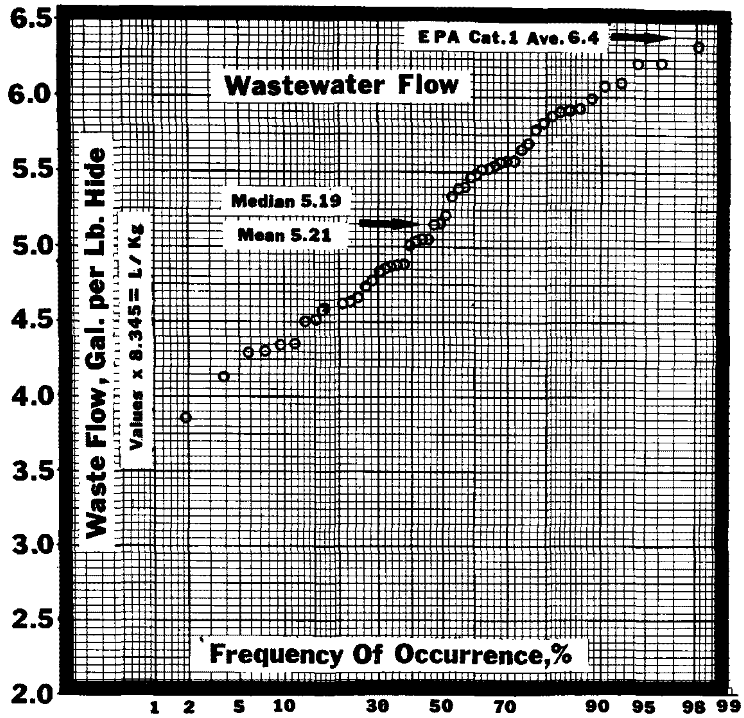

Figure 18. Raw wastewater flow per unit weight of hide.

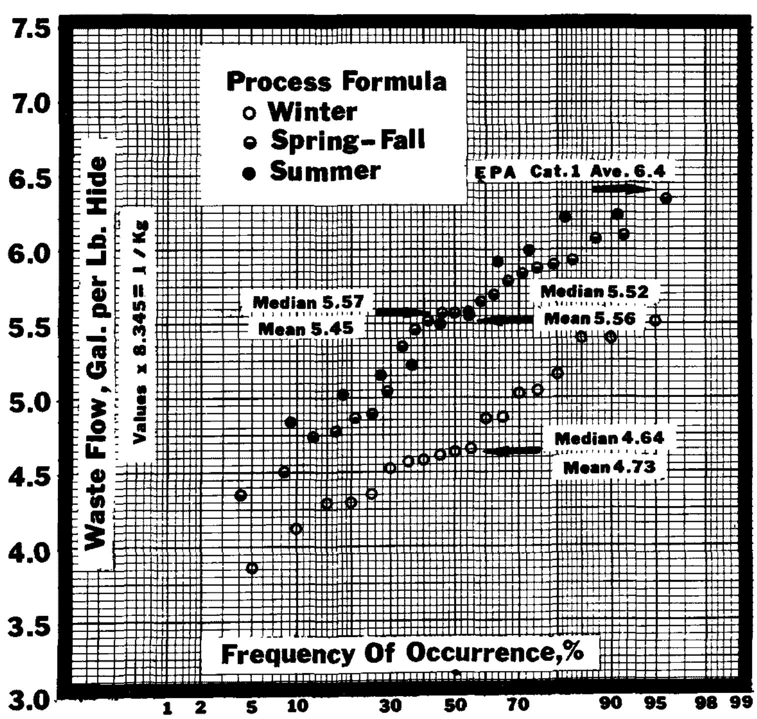

Figure 19. Raw wastewater flow by process formula per unit weight of hide.

TABLE 6. DAILY WASTEWATER FLOW VARIATIONS.

Date	Number of days	Range gal/lb hide*	Median gal/lb hide*	Mean gal/lb hide*	Standard deviation
All	52	3.86-6.35	5.19	5.21	0.619
Winter	19	3.86-5.51	4.64	4.73	0.450
Summer	10	4.84-6.23	5.52	5.56	0.510
Spring-Fall	23	4.35-6.35	5.57	5.45	0.546

*Values times 8.345 give results in l/kg.

SECTION VIII

WASTEWATER CHARACTERIZATION

The combined raw wastewater discharges were characterized by the analyses of fifty 24-hour composited samples over the course of the project. The wastewater represents the process waters of a side leather tanning industry utilizing a hair pulping operation but does not include the wastewaters resulting from leather finishing operations. As demonstrated in the section on characterization of process discharges, the finishing wastes would represent only 1.73 percent of the total flow and 0 to 1.47 percent of the total wasteload contribution (Table 4) for the parameters measured. Consequently, the raw waste characterization was compared to those values reported in category 1 of the U.S. Environmental Protection Agency Development Document (3).

The results of the surveys were analyzed in several ways to demonstrate the effect of rendering flesh as compared to not rendering and also in terms of the process formula employed for pulping representing winter, summer, and spring-fall hides. In addition, all of the 24-hour survey data were evaluated without regard to the employment of or lack of employment of rendering or with regard to process formula.

The results have been summarized in various ways for easy reference. Tabular results of each of the measured parameters have been summarized as to concentration in mg/l as well as in the form of kg per 1000 kg of hide processed. For each measured parameter the range, median, mean and standard deviations are presented for the number of sample results available.

Table 7 represents the summary of all 24-hour survey raw wastewater data regardless of process formulation or the employment of rendering. Table 8 summarizes the data regardless of process formulation, but when the practice of rendering was not employed, whereas Table 9 reports similar data during the period when rendering was employed. Table 10 summarizes the data according to hair pulping process formula during the period when no rendering of the flesh was employed.

A summary of mean values, in terms of kg/1000 kg of hide, for the various combinations of raw wastewater data are presented in Table 11.

TABLE 7. RAW WASTEWATER CHARACTERISTICS
24-HOUR COMPOSITES--ALL DATA*

Parameter	Number of analyses	Concentration, mg/l				Kg/1000 kg hide			
		Range	Median	Mean	Standard Deviation	Range	Median	Mean	Standard Deviation
BOD_5	48	1093-2560	1624	1656	351.7	38.6-115	68.8	71.8	17.7
COD	50	2730-9942	4488	4523	1070	131-487	186.8	195.8	55.1
Total solids	50	7200-13750	11080	10920	1538	313-625	469.2	471.0	73.5
Total volatile solids	49	1630-5330	2756	2824	689	75.8-207	116	122	28.9
Total suspended solids	50	1470-5970	2568	2730	863	61.6-232	113	117	33.0
Oil and grease	37	404-1604	728	763	235	17.0-72.3	29.8	33.5	12.2
Total chromium	42	20.8-80.0	49.8	50.6	14.2	1.09-3.95	2.32	2.22	0.71
Total phosphorus	33	1.52-21.4	5.6	6.0	3.5	0.07-0.81	0.25	0.26	0.14
Total Kjeldahl nitrogen	19	105-582	285	332	129	3.55-26.8	13.5	14.6	6.28

* Includes data collected with and without rendering under all process formulations, no finishing wastes.

TABLE 8. RAW WASTEWATER CHARACTERISTICS
24-HOUR COMPOSITES--ALL DATA, NO RENDERING*

Parameter	Number of analysis	Concentration, mg/l				Kg/1000 kg hide			
		Range	Median	Mean	Standard Deviation	Range	Median	Mean	Standard Deviation
BOD_5	29	1093-2235	1478	1501	296	38.6-103	60.5	63.2	14.5
COD	31	2730-6620	4220	4284	841	131-278	176	182	37.8
Total solids	31	7200-13360	10910	10540	1520	313-580	430	443	63.9
Total volatile solids	30	1628-3936	2472	2570	545	75.8-161	103	108	19.4
Total suspended solids	31	1468-5200	2460	2579	787	61.6-180	104	108	27.3
Oil and grease	18	404-816	595	601	103	17.0-36.9	24.7	25.1	5.6
Total chromium	24	20.8-68.4	45.4	46.8	13.3	1.08-3.21	1.97	2.02	0.64
Total phosphorus	20	4.3-21.4	6.7	7.4	3.6	0.21-0.81	0.29	0.33	0.14

*Includes data collected when rendering was not employed and represents all process formulations, but no finishing wastes.

TABLE 9. RAW WASTEWATER CHARACTERISTICS
24-HOUR COMPOSITES--ALL DATA, RENDERING *

Parameter	Number of analysis	Concentration, mg/l				Kg/1000 kg hide			
		Range	Median	Mean	Standard Deviation	Range	Median	Mean	Standard Deviation
BOD_5	19	1308-2560	1929	1893	298	65-115	84	85	13.9
COD	19	3735-9942	4618	4913	1296	153-487	215	219	70.7
Total solids	19	8836-13750	11490	11540	1390	387-625	510	517	65.0
Total volatile solids	19	2224-5328	3080	3225	714	103-207	140	144	27.8
Total suspended solids	19	1872-5972	2872	2974	944	87-232	125	132	36.3
Oil and grease	19	480-1604	898	916	222	22.3-72.3	42.2	41.4	11.4
Total chromium	18	24.5-80.0	50	55.6	14.2	1.10-3.95	2.5	2.51	0.75
Total phosphorus	13	1.52-6.73	3.2	3.7	1.6	0.07-0.26	0.14	0.16	0.07

*Includes data collected when rendering was employed and represents all process formulations but no finishing wastes.

TABLE 10. RAW WASTEWATER CHARACTERISTICS RELATED TO PROCESS FORMULA
24-HOUR COMPOSITES--ALL DATA, NO RENDERING

Process Formula & Parameter	Number of analysis	Concentration, mg/l				Kg/1000 kg hide			
		Range	Median	Mean	Standard Deviation	Range	Median	Mean	Standard Deviation
Winter									
BOD_5	13	1122-2235	1452	1514	342	39-94	57	59	15.2
COD	13	3169-6619	4671	4659	934	131-278	183	180	38.9
Total solids	13	7428-13360	11170	11280	1516	313-560	426	435	64.5
Total vol. sol.	12	1800-3936	2931	2926	623	76-162	110	113	24.9
Total susp. sol.	13	1468-5200	2888	2991	1035	62-180	110	114	37.2
Summer									
BOD_5	8	1093-2109	1360	1424	333	54-103	60	67	16.4
COD	10	2730-5380	3665	3730	745	131-244	165	174	38.9
Total solids	10	7196-11252	9061	9283	1157	372-498	428	428	40.7
Total vol. sol.	10	1628-2413	2166	2100	221	84-111	95	97	8.5
Total susp. sol.	10	1612-2606	2144	2155	294	84-115	99	100	11.2
Spring-Fall									
BOD_5	8	1227-1717	1573	1558	168	58-87	65	67	10.0
COD	8	3957-4800	4330	4356	321	156-264	188	194	36.3
Total solids	8	9512-12016	11100	10906	915	376-580	481	473	82.3
Total vol. sol.	8	2464-2879	2636	2625	150	96-138	110	113	15.2
Total susp. sol.	8	1850-2880	2462	2442	339	73-137	109	106	22.0

TABLE 11. SUMMARY RAW WASTEWATER CHARACTER: MEAN OF 24-HOUR COMPOSITES

Source	Rendering	Flow l/kg(gal/lb) hide	BOD_5	COD	Total solids	T. susp. solids	Oil & grease	Total chromium
			kg/1000 kg hide					
EPA Cat. 1 Cattleskin Tannery*	No	53.4(6.4)	95	260	525	140	19	4.3
Project data+	No	#	63.2	182	443	108	25.1	2.02
	Yes	--	84.9	219	517	132	41.4	2.51
Formula								
Winter	No	39(4.7)	58.6	180	435	114		
Summer	No	47(5.6)	66.8	174	428	99.8		
Spring-Fall	No	45(5.4)	67.1	194	473	106		

* EPA Development Document--includes finishing wastes.

+ Finishing wastes excluded.

A mean flow of 43.5 l/kg (5.21 gal/lb) hide was obtained for all project flow data including data for rendering and no rendering.

In addition, the values for category 1 on the U.S. Environmental Protection Agency Development Document (3) are presented for purposes of comparison.

Several observations are noted:

1) For the parameter measured, with the exception of total phosphorus, the results during the period when the rendering operation was employed resulted in higher mean levels than when no rendering was employed (Tables 8 and 9).

2) With the exception of oil and grease, the mean values for all parameters reported, i.e., BOD_5, COD, total solids, total suspended solids, and total chromium, were less than reported as category 1 in the U.S. Environmental Protection Agency Development Document (3)(Table 11).

3) The mean value for oil and grease in the survey data even when rendering was not employed was greater than the EPA category 1 (Table 11).

4) With the exception of total suspended solids, the winter formula utilized during the period when the hides have the longest hair did not result in the maximum mean value for the other reported values of flow, BOD_5, COD and total solids (Table 11).

The results of the 24-hour surveys were presented graphically to illustrate the variability of the measured parameters or qualities. These variations are of particular significance as they may related process design to minimize the variability of the effluent. The concentration in mg/l or mass kg/1000 kg hide processed for some of the parameters versus frequency of occurrence (as a percent of the observations) are presented in Figures 20 to 29. For a given level of the stated parameters, one is able to determine the percent of time (24-hour composites) or percent of samples that were equal to or less than the stated level or the percent of samples that exceeded the stated value. It is understood that the results of hourly composites or samples collected over shorter time intervals would result in a greater range of values from low to high. The EPA category 1 value in terms of kg/1000 kg hide is indicated, as well as the median and mean values. If the plotted data result in linearity on the probability plot, the results conform to a normal rather than skewed distribution whereas nonlinearity of the plotted data would indicate a skewed distribution of results. The information is useful in setting guideline values.

RENDERING WASTES

A batch process utilizing sulfuric acid and water was employed to render

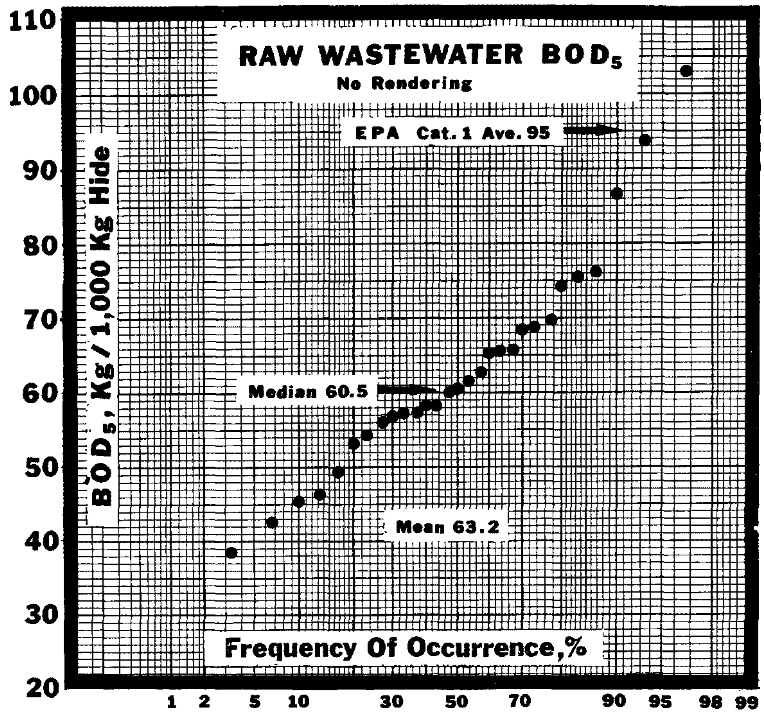

Figure 20. Raw wastewater BOD_5 of 24 hour composites per unit weight of hide.

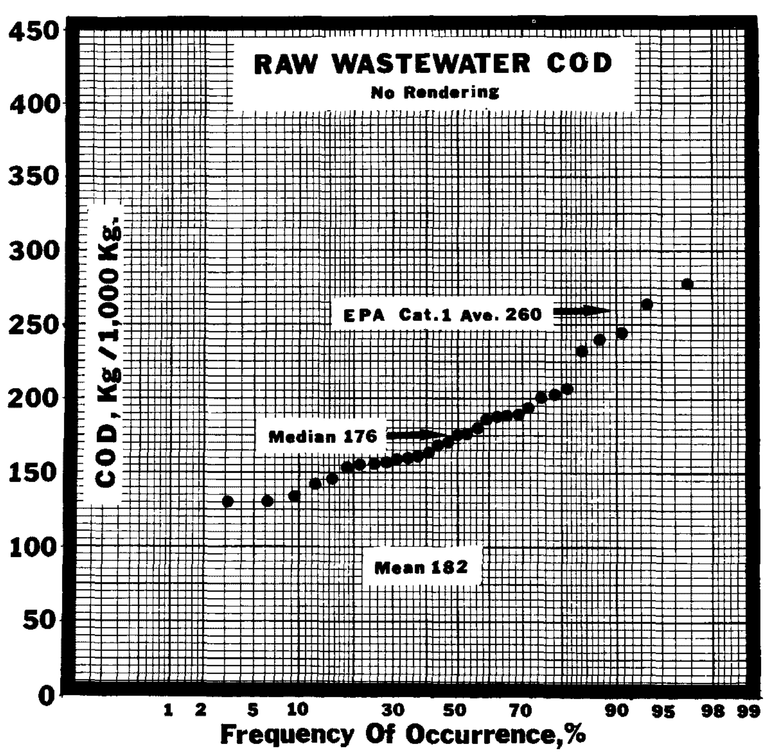

Figure 21. Raw wastewater COD of 24 hour composites per unit weight of hide.

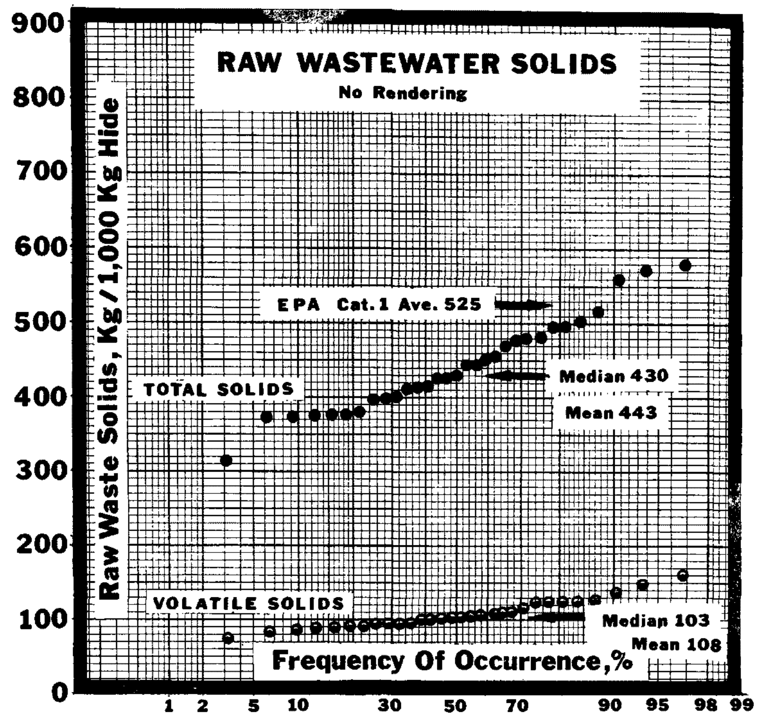

Figure 22. Raw wastewater total and volatile solids of 24 hour composites per unit weight of hide.

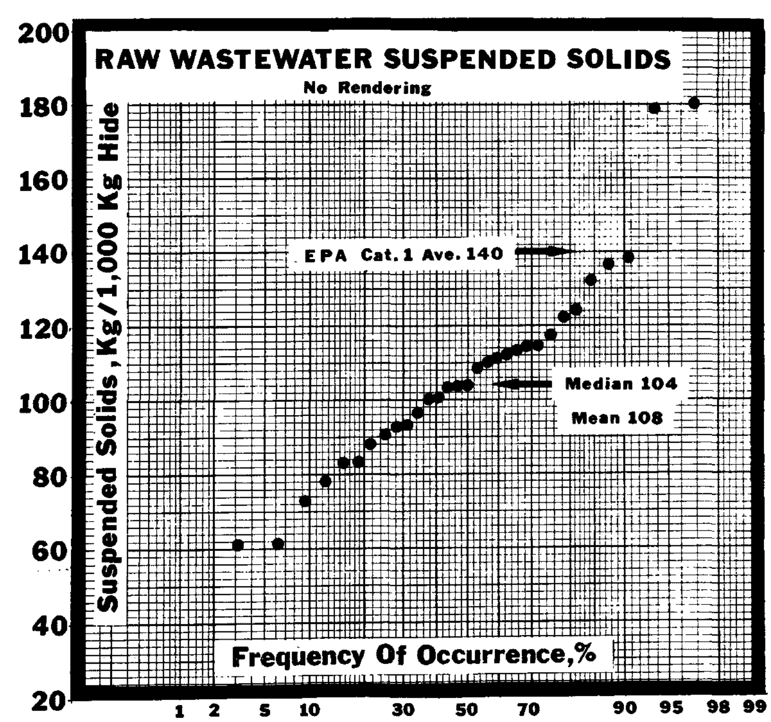

Figure 23. Raw wastewater suspended solids of 24 hour composites per unit weight of hide.

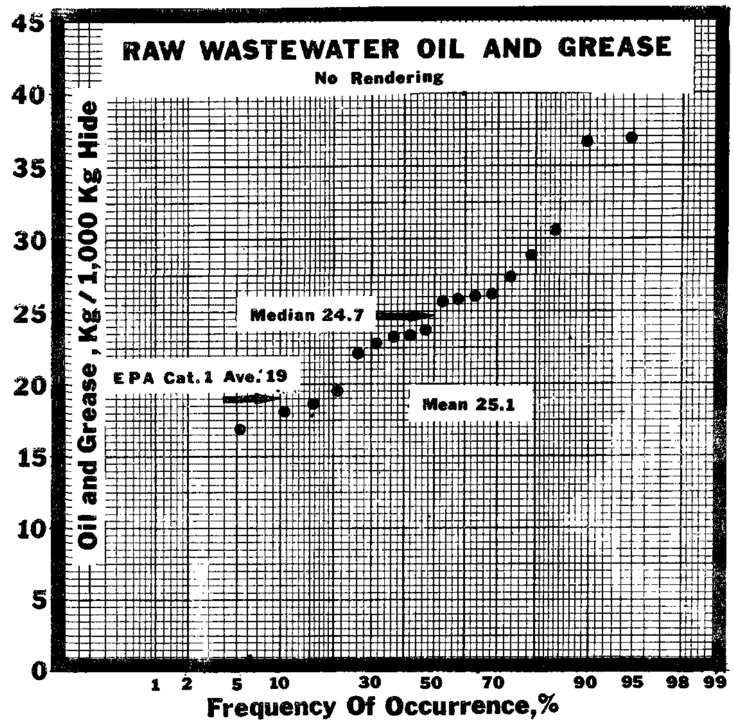

Figure 24. Raw wastewater oil and grease of 24 hour composites per unit weight of hide.

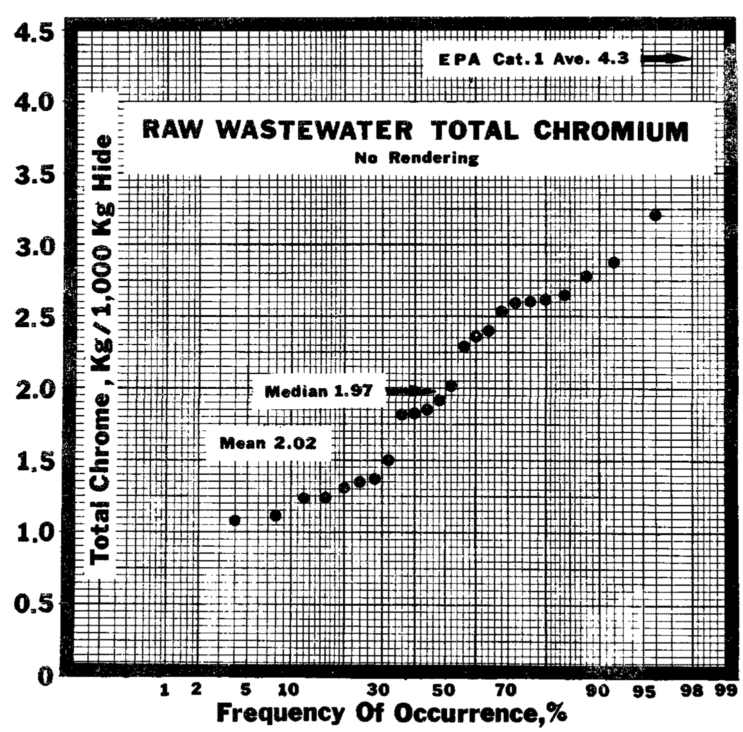

Figure 25. Raw wastewater total chrome of 24 hour composites per unit weight of hide.

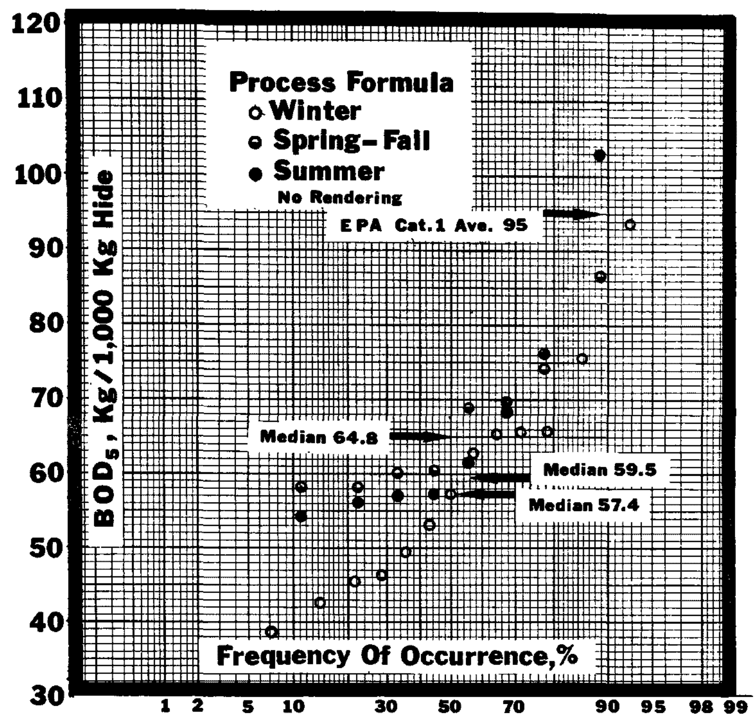

Figure 26. Raw wastewater BOD_5 related to process formula for 24 hour composites per unit weight of hide.

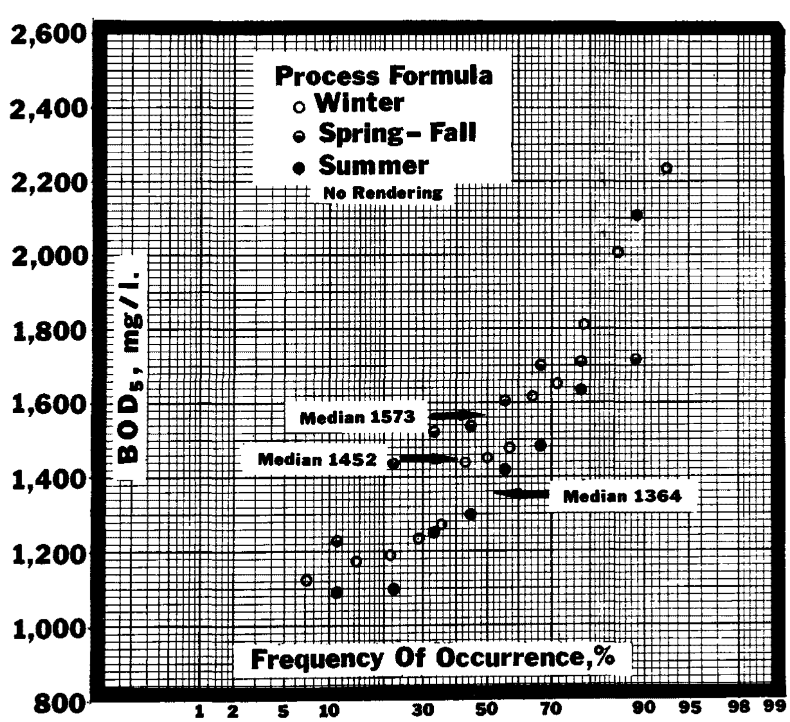

Figure 27. Raw wastewater BOD5 concentrations related to process formula for 24 hour composites.

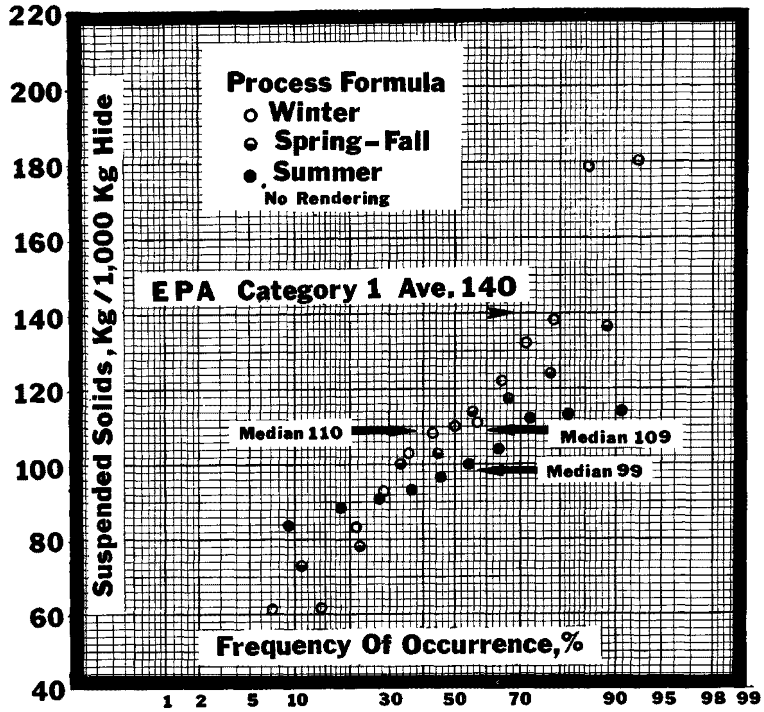

Figure 28. Raw wastewater suspended solids related to process formula for 24 hour composites per unit weight of hide.

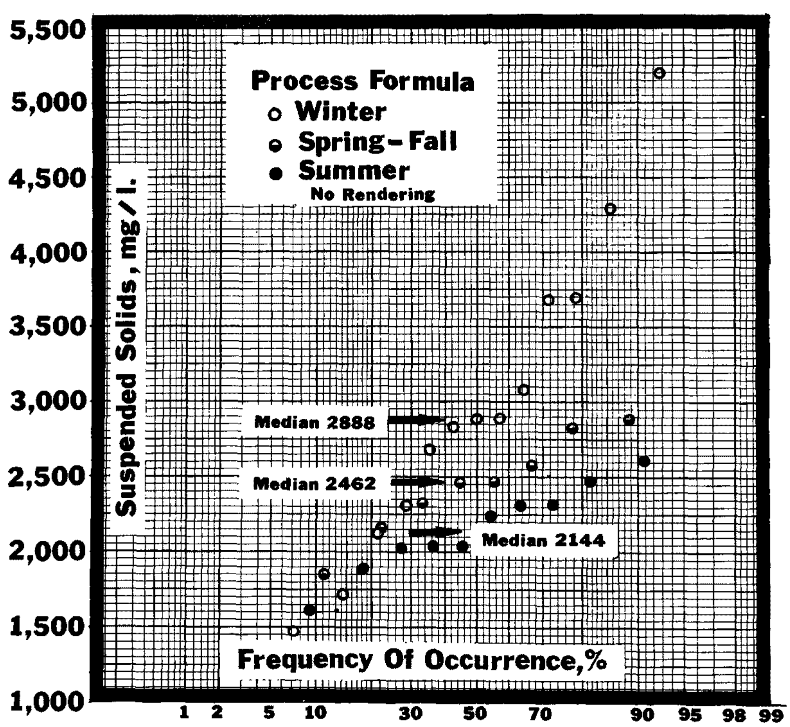

Figure 29. Raw wastewater suspended solids concentration related to process formula for 24 hour composites.

the ground fleshings for the separation of oil. The remaining stick-liquor was discharged to the wastewater treatment system and was characterized as a component of the raw wastewater discharge.

The amount of fleshings processed would depend upon the relative proportion of unfleshed (green salted) hides to prefleshed hides for the process day. For example, a green salted hide would yield approximately 6 kg of flesh per hide; whereas a prefleshed hide would yield from 20 to 50% of that of a green salted hide.

The resulting waste characteristics of the rendering operation based on processing 100% green salted hide are presented in Table 12.

TABLE 12. SUMMARY OF RENDERING PROCESS AVERAGE WASTE LOAD TO THE TREATMENT PLANT MARCH TO NOVEMBER 1974

Parameter	Load, kg/1000 kg hide based on processing 100% green salted hide
Total solids	53.5
Volatile solids	39.1
Fixed solids	14.4
Suspended solids	23.9
Volatile suspended solids	21.1
Fixed suspended solids	2.8
Total Kjeldahl nitrogen	4.1
Organic nitrogen	4.1
Ammonia nitrogen	Negligible
BOD_5	20.5
COD	43.1
Oil and grease	15.9

SCRAP SOLID WASTES

Although the scrap loading is not generally a part of the raw wastewater flow in that dry operations are employed for trimming, some scrap material will enter the wastewater stream and be screened. All raw wastewater sampling was accomplished after screening because the size of scrap would not permit representative sampling.

Two periods of 3 and 4 weeks for October of 1973 and July of 1974 respectively were sampled for scrap load. The results of these surveys are summarized in Table 13. It is apparent that the waste load is small in terms of kg of dry solids per 1000 kg of hide processed and the scrap is disposed of as a solid waste by a private refuse contractor which does not contribute to the wastewater flow.

TABLE 13. SCRAP WASTE CHARACTERIZATION

Item	Sampling Period October 1973	Sampling Period July 1974
Length of study, weeks	3	4
Barrels scrap per week	6 to 7	13
Total weight per barrel, kg (lbs)	81.6 (180)	89.8 (198)
Density, kg/m^3 (lb/ft^3)	753-961 (47-60)	865(54)
Total volume of scrap per week, m^3 (ft^3)	0.677 (23.9)	1.35 (47.8)
Dry solids, percent (range)	24 (17 to 29)	24 (15 to 35)
Dry solids per week, kg (lbs)	141 (312)	280 (618)
Dry solids per operating day, kg (lbs)	28.3 (62.4)	55.8 (123)
Volatile solids, percent of dry solids (range)	78.6(72.4-85.6)	81 (79.2-84.5)
Dry solids, kg/1000 kg hide	0.4	0.7

Neither test period included winter hide stock. The expected scrap loadings would be higher during the processing of winter hide stock.

PROCESS RAW WATER SUPPLY CHARACTERIZATION

The water used as process water for the tannery is obtained from the industry's well and has the following raw water characteristics.

The water is considered to be hard and no pretreatment of the water is provided.

TABLE 14. TANNERY WELL WATER SUPPLY OCTOBER 25, 1975

Constituent	Concentration, mg/l
Alkalinity	275
Calcium, Ca	95
Chloride, Cl^-	177
Total chrome, Cr	0.002
Nitrogen	
Total Kjeldahl nitrogen	8.0
Ammonia nitrogen	5.0
Nitrate nitrogen	4.0
BOD_5	5.0
COD	12.0
Total phosphorus	0.04
Sulfate	190
Total solids	852
Volatile solids	144
Percent volatile solids	16.9
Total suspended solids	6

SECTION IX

PRIMARY SETTLING

The raw wastewater from the beamhouse, tanyard, and color and fat liquoring operations were combined and subjected to gravity separation in two settling tanks arranged in parallel. The wastes were unequalized and unneutralized, receiving coarse screening as the only preliminary treatment. Waste biological solids from the secondary treatment system and sludge dewatering filtrate were combined with the raw wastewater flow as influent to the settling tanks at various times throughout the study.

The removal effectiveness of primary settling on various wastewater characteristics were determined by the evaluation of routine 24-hour composite results as well as for samples composited over shorter time intervals within a 24-hour period. In the latter, sampling was conducted to allow for the detention time in primary settling units. The results are summarized as the primary effluent quality, percent removals of various wastewater characteristics, and the evaluation of possible relationships of removals with clarifier overflow rates.

PRIMARY EFFLUENT QUALITY

The results of the 24-hour composite surveys are summarized in Tables 15 to 17 and in Figures 30 to 34.

It is apparent from Table 15 of primary effluent concentrations for all data available for the various quality parameters measured the highly variable nature of the results. The number of observations, standard deviations, mean and median are presented for each quality parameter.

Table 16 and Figures 30 to 34 show the primary effluent concentrations expressed in mg/l for all data when no rendering operations were employed. In addition, Figures 30 to 34 show the raw wastewater concentrations for the various parameters measured. The results are presented as the number of measurements included in the statistic, range of values, median, mean and standard deviation for BOD_5, COD, total volatile solids, total suspended solids, oil and grease, total chromium and total phosphorus. The mean values when rendering is not employed are less for all quality

TABLE 15. PRIMARY EFFLUENT CHARACTER: 24-HOUR COMPOSITES -- ALL DATA

Parameter	N*	Concentration, mg/l			
		Range	Median	Mean	Standard Deviation
BOD_5	42	308-1561	1046	1029	283
COD	44	1490-3460	2508	2509	535
Total volatile solids	44	944-2412	1602	1577	358
Total suspended sol.	44	252-1838	1097	1133	373
Oil and grease	32	128-370	236	242	69.6
Total chromium	35	12.1-42.1	21.6	23.2	6.97
Total phosphorus	27	1.87-6.15	3.22	3.39	1.16

* The number of 24-hour composite results used to determine statistics.

TABLE 16. PRIMARY EFFLUENT CHARACTER 24-HOUR COMPOSITES--ALL DATA, NO RENDERING

Parameter	N*	Concentration, mg/l			
		Range	Median	Mean	Standard Deviation
BOD_5	28	308-1286	874	907	235
COD	30	1490-3460	2173	2319	501
Total volatile solids	30	944-2412	1328	1455	335
Total suspended sol.	30	252-1838	1097	1091	382
Oil and grease	18	128-282	202	207	50.1
Total chromium	21	12.4-85.7	21.6	28.9	19.6
Total phosphorus	20	2.05-6.15	3.28	3.51	1.11

* The number of 24-hour composite results used to determine statistics.

TABLE 17. PRIMARY EFFLUENT CHARACTERISTICS RELATED TO PROCESS FORMULA 24-HOUR COMPOSITES ALL DATA, NO RENDERING

Process formula and Parameter	N*	Concentration, mg/l Range	Median	Mean	Standard Deviation
Winter					
BOD_5	12	308-1286	918	894	326
COD	12	1939-3460	2696	2692	519
Total volatile solids	12	1264-2412	1688	1752	298
Total suspended sol.	12	589-1838	1341	1320	349
Oil and grease	7	138-278	226	230	50.1
Total chromium	8	16.8-30.5	21.4	22.5	4.47
Total phosphorus	4	3.33-6.15	4.7	4.72	1.17
Summer					
BOD_5	8	744-1078	832	855	102
COD	10	1490-2174	1970	1916	199
Total volatile solids	10	944-1276	1176	1161	104
Total suspended sol.	10	573-1384	1087	1062	237
Oil and grease	4	162-282	202	212	50.3
Total chromium	6	12.1-27.6	18.2	18.6	5.58
Total phosphorus	9	2.05-5.60	3.17	3.39	1.03
Spring-Fall					
BOD_5	8	787-1158	980	978	166
COD	8	1895-2746	2235	2262	302
Total volatile solids	8	1194-1743	1328	1378	173
Total suspended sol.	8	252-1172	892	781	371
Oil and grease	7	128-253	164	182	44.3
Total chromium	7	12.4-25.2	18.6	18.1	4.45
Total phosphorus	7	2.14-3.99	2.96	2.96	0.65

*The number of 24-hour composite results to determine statistics.

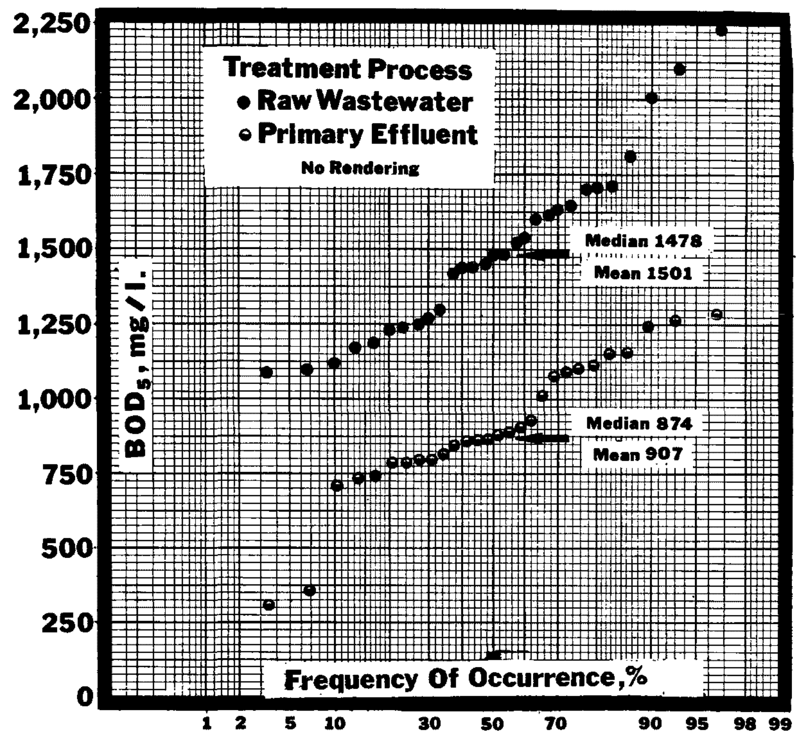

Figure 30. Raw wastewater and primary effluent BOD_5 concentration for 24 hour composites.

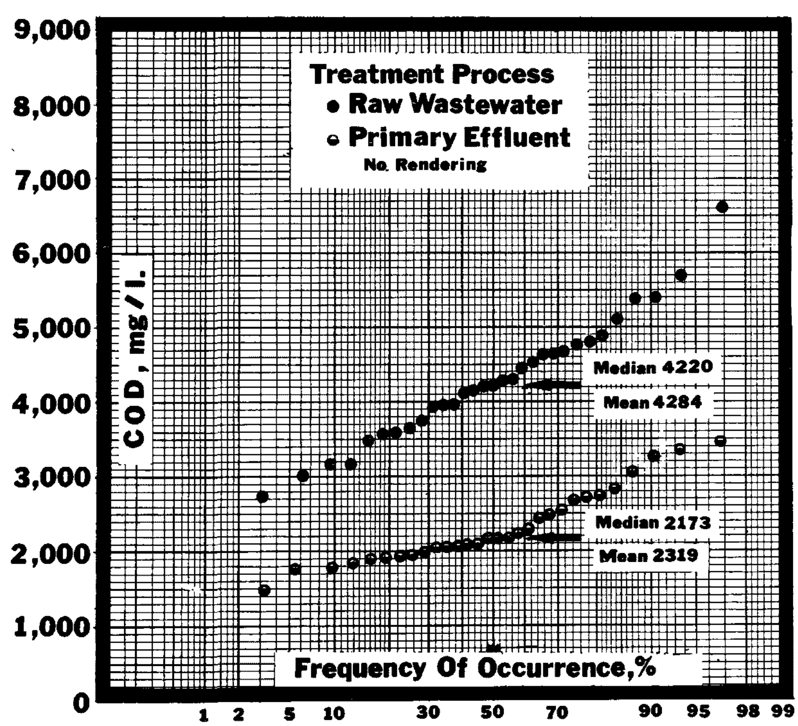

Figure 31. Raw wastewater and primary effluent COD concentrations for 24 hour composites.

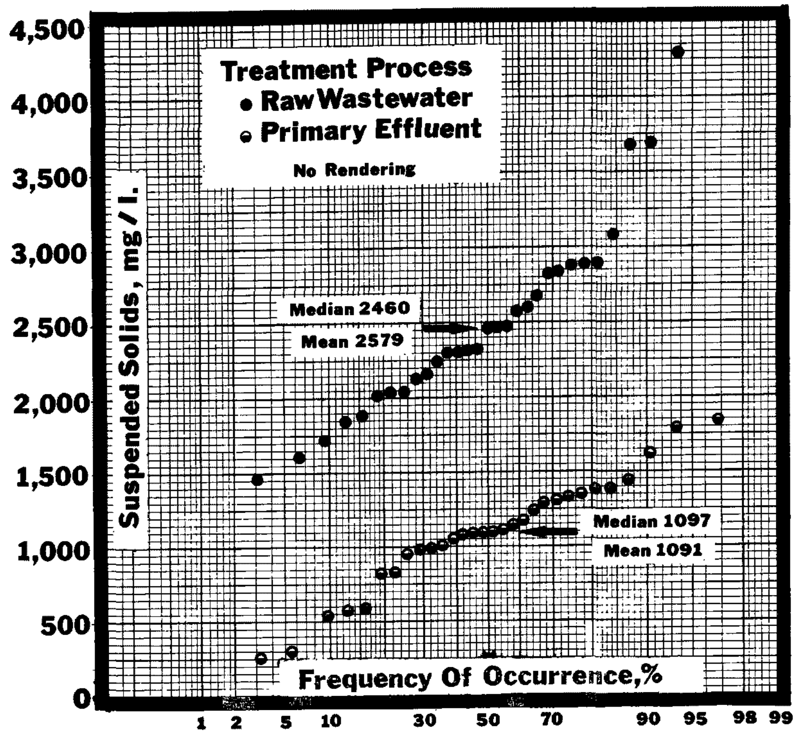

Figure 32. Raw wastewater and primary effluent suspended solids concentrations for 24 hour composites.

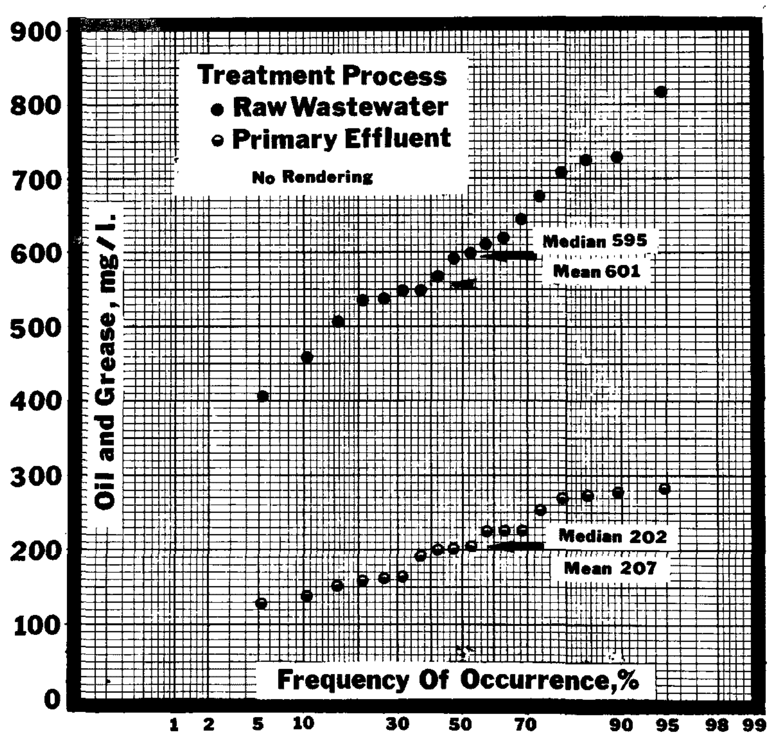

Figure 33. Raw wastewater and primary effluent oil and grease concentrations for 24 hour composites.

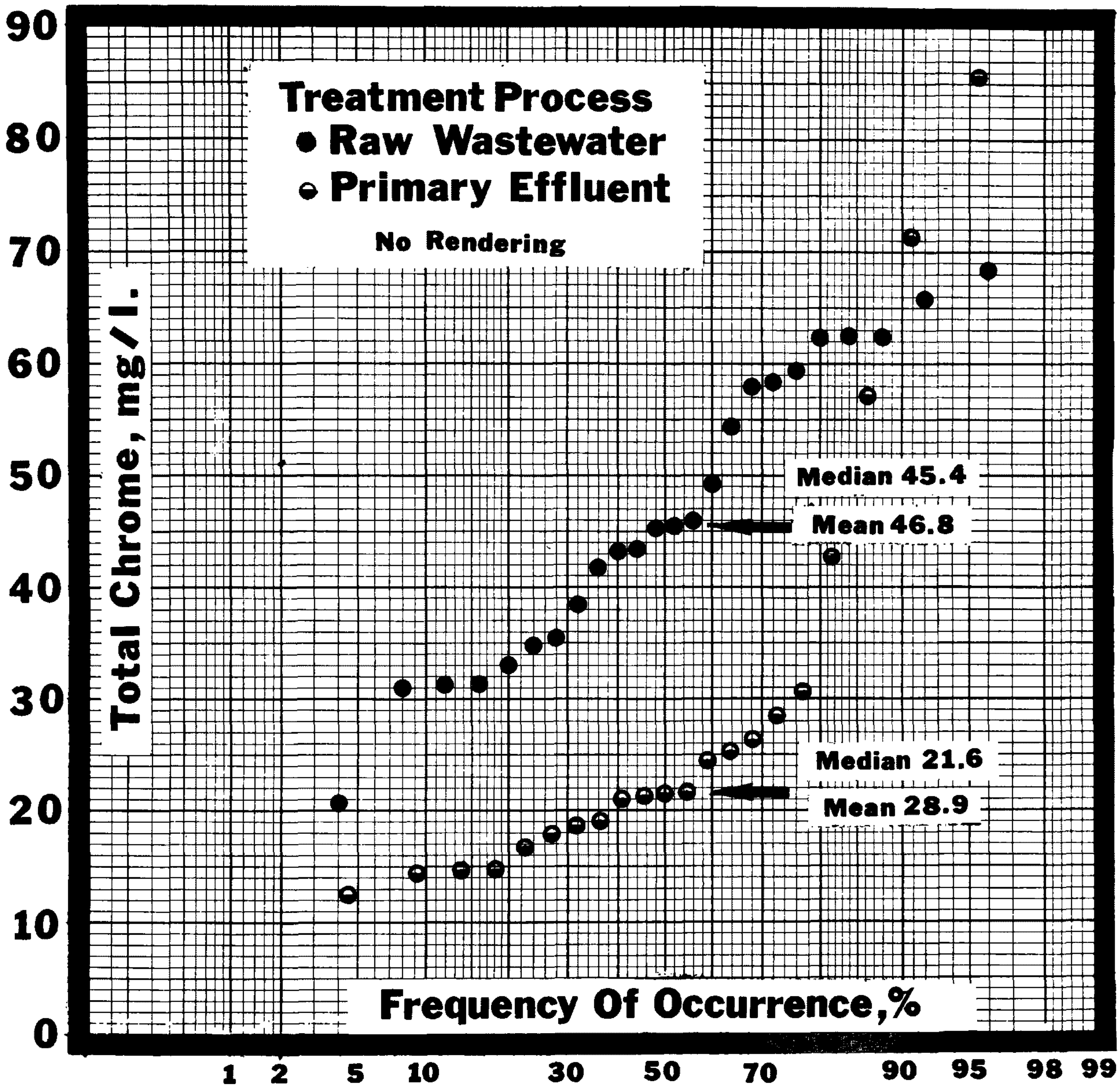

Figure 34. Raw wastewater and primary effluent total chrome concentrations for 24 hour composites.

parameters except for total chrome and total phosphorus than when all data are included as presented in Table 15. These differences are not significant for the error variances associated with the results.

A similar summary of results are presented in Table 17 for primary effluent when the three process formulas were employed. Also, these results represent sampling during periods when rendering was not employed. With the exception of BOD for the spring-fall formula, all the mean values for the winter formula are higher than for summer and spring-fall formulas. Although these differences are not statistically significant, the higher results for winter hides may be expected on the basis of hair length and the relative greater amounts of associated pollutional material attached to the hair for winter hides.

PRIMARY SETTLING EFFICIENCY

On several occasions the performance of the primary settling tanks was evaluated by taking effluent and influent 4-hour composite samples with the effluent composite samples lagging by 2 hours to allow for tank detention times. This was to assess the variation of the influent and effluent for the quality parameters measured regarding the percent of the total daily contribution for each 4-hour composite and the removal efficiencies experienced.

The results of two surveys are presented in Table 18 and Table 19 for August 8-9, 1972, and September 25-26, 1972, respectively. Figures 35 to 37 show the influent-effluent results for suspended solids, chemical oxygen demand, and total chrome for the August 8-9 survey. Based on the results of the 4-hour composites and the influent flow for the composite interval, the variations for each quality parameter are presented as mass rates in pounds per hour. The percent removal of a given constitutent varies markedly throughout a 24-hour period.

The influent variation reflects the practices of batch discharges from various departments within the tannery depending upon the quality parameters observed. For example, the high contribution of suspended solids in the raw wastewater for midday through early afternoon reflects the batch discharges from the beamhouse operations, similarly one may use the total chrome values to reflect the periods for principal discharges from the tanyard (Figures 36 and 37). The primary effluent variation is less pronounced as one may expect but the variation in the effluent parallels influent quality with higher values noted in the effluent when high values of a given quality parameter are present in the influent.

Table 18 presents the percent of total mass for each 4-hour influent composite and each quality parameter. Although the variations from hour

TABLE 18. PRIMARY SETTLING EFFICIENCY, AUGUST 8-9, 1972

Time	Sample	Raw waste flow m^3	Total solids Conc. mg/l	Total solids Percent of total*	Total suspended solids Conc. mg/l	Total suspended solids Percent of total	COD Conc. mg/l	COD Percent of total	Total chrome Conc. mg/l	Total chrome Percent of total
7 a.m. to 11 a.m.	Raw	799	6240	17.8	1040	9.7	2070	16.8	17.0	13.2
9 a.m. to 1 p.m.	Primary		7300		820		1410		12.5	
	% Removal		+17		21		32		26	
11 a.m. to 3 p.m.	Raw	704	11680	29.1	5400	44.2	4290	30.5	9.0	6.1
1 p.m. to 5 p.m.	Primary		9110		1040		2580		4.7	
	% Removal		22		81		40		48	
3 p.m. to 7 p.m.	Raw	496	9390	16.1	3110	17.5	4190	20.5	37.5	17.5
5 p.m. to 9 p.m.	Primary		8140		1000		2340		12.7	
	% Removal		13		68		44		66	
7 p.m. to 11 p.m.	Raw	473	6510	10.6	1060	5.7	1700	7.9	56.4	25.1
9 p.m. to 1 a.m.	Primary		6180		730		1190		17	
	% Removal		5.1		31		30		70	
11 p.m. to 3 a.m.	Raw	397	7350	9.9	2120	9.4	2240	8.6	69	25.3
1 a.m. to 5 a.m.	Primary		7400		786		1415		18.5	
	% Removal		+ 0.7		63		37		73	
3 a.m. to 7 a.m.	Raw	477	10040	16.5	2490	13.5	3360	15.7	28.5	12.8
5 a.m. to 9 a.m.	Primary		8680		580		1730		11.0	
	% Removal		13		77		48		61	
24-hour composite	Raw	3346	8565	100	2606	100	3005	100	31.4	100
	Primary		7879		826		1774		12.1	
	% Removal		8		68		41		61	

*Percent of total is based on concentration and flow or mass of the stated quality parameter.

TABLE 19. PRIMARY SETTLING EFFICIENCY, SEPTEMBER 25-26, 1972

Time	Sample	Waste flow, m^3	BOD_5 Conc. mg/l	BOD_5 Percent of total	COD Conc. mg/l	COD Percent of total	Total susp. sol. Conc. mg/l	Total susp. sol. Percent of total	Susp. vol. solids Conc. mg/l	Susp. vol. solids Percent of total	Total chromium Conc. mg/l	Total chromium Percent of total	Total calcium Conc. mg/l	Total calcium Percent of total
8 a.m. to noon	Raw	559	1160	14.3	2445	11.6	1520	15.4	775	10.0	21.5	12.9	147	8.1
8 a.m. to noon	Waste sl.	50	528		1410		916		448		17.2		192	
10 a.m. to 2 p.m.	Primary		852	21.1	1750	18.3	200	13.2	48	7.9	8.8	7.9	195	16.6
Noon to 8 p.m.	Raw	1156	2130	54.2	6260	61.2	2515	52.6	1960	52.1	17.0	21.0	445	50.4
Noon to 8 p.m.	Waste sl.	100	474		1430		830		416		18.8		193	
2 p.m. to 10 p.m.	Primary		998	43.5	2500	46.0	320	36.9	120	34.9	13.3	21.2	311	46.4
8 p.m. to 2 a.m.	Raw	550	573	6.9	1270	5.9	546	5.4	377	4.8	59.0	34.8	152	8.2
8 p.m. to 2 a.m.	Waste sl.	75	471		1310		616		300		12.0		180	
10 p.m. to 4 a.m.	Primary		452	9.2	1070	9.2	304	16.4	136	18.5	47.0	34.9	170	11.8
2 a.m. to 8 a.m.	Raw	723	1550	24.6	3490	21.3	2035	26.6	2000	33.2	40.5	31.4	471	33.3
2 a.m. to 8 a.m.	Waste sl.	75	457		1300		624		280		15.4		171	
4 a.m. to 10 a.m.	Primary		705	26.2	1680	26.4	340	33.5	156	38.7	26.5	36.0	198	25.2
Raw waste composite		2989	1522		3957		1850		1456		31.2		342	
Influent composite			1426		3720		1748		1356		30.0		327	
Primary effluent composite			795		1895		300		119		21.7		232	
Percent removal			48.1		49.0		84.0		91.7		31.9		29.2	

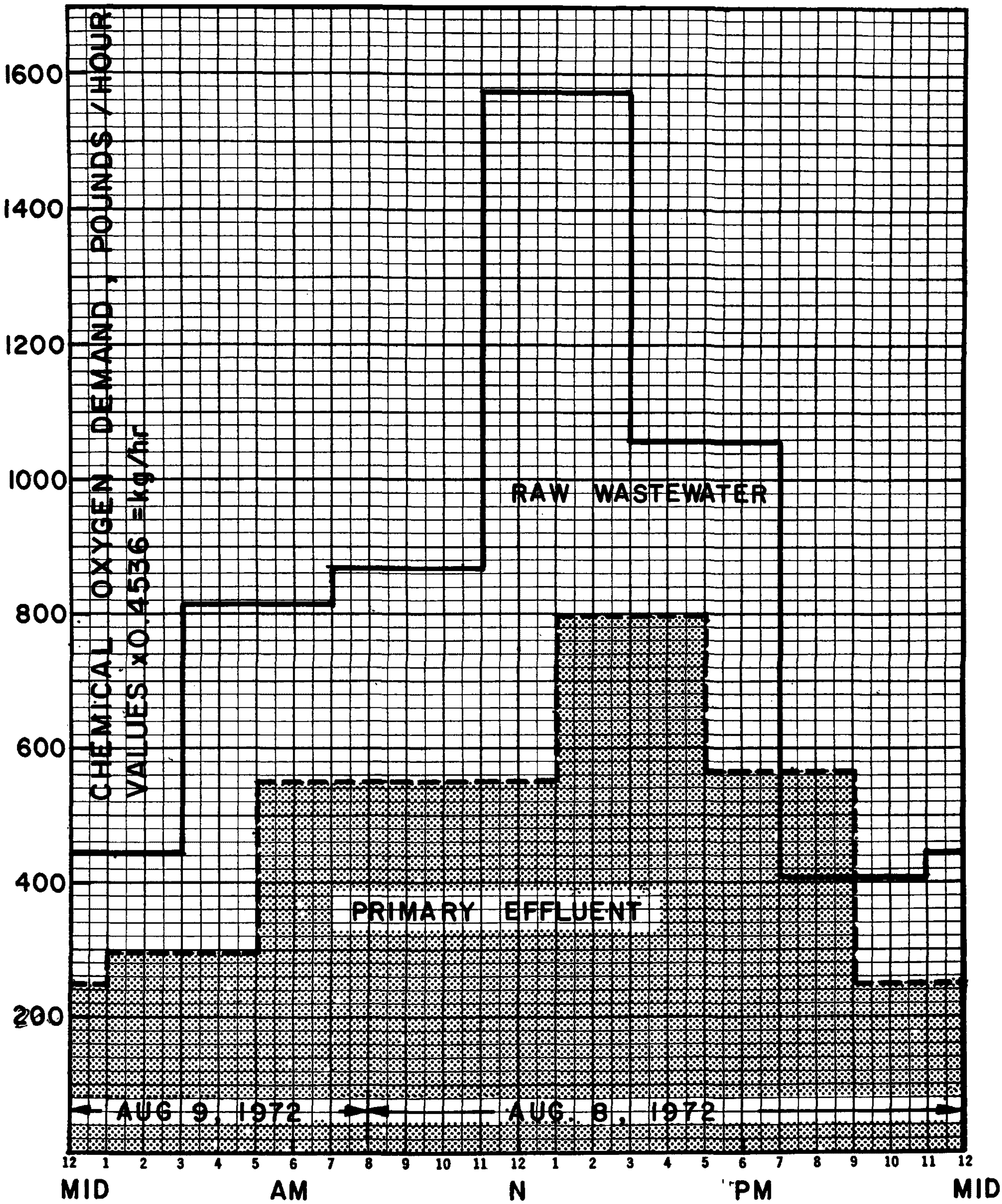

Figure 35. Primary sedimentation COD performance: 4 hour composites.

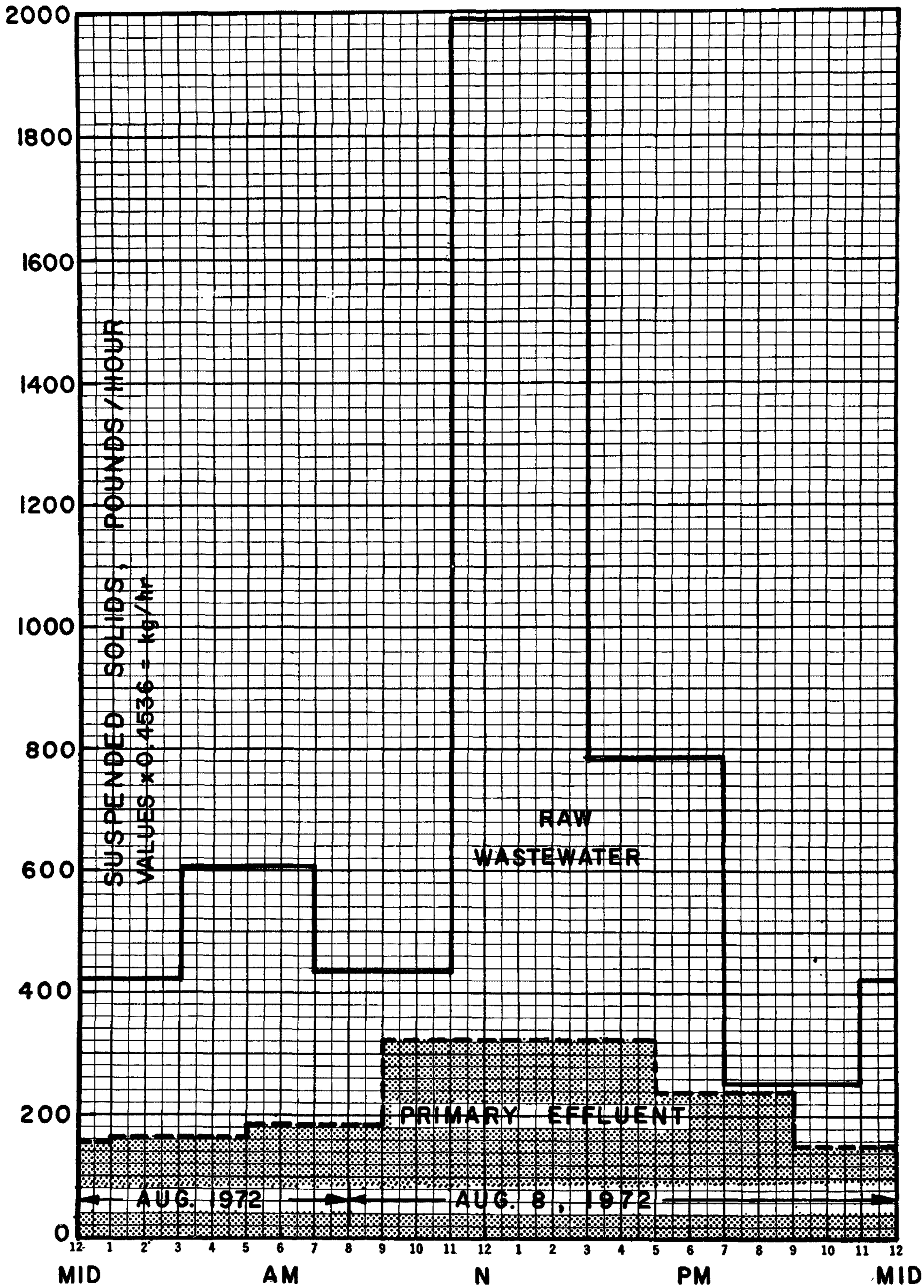

Figure 36. Primary sedimentation suspended soilds performance: 4 hour composites.

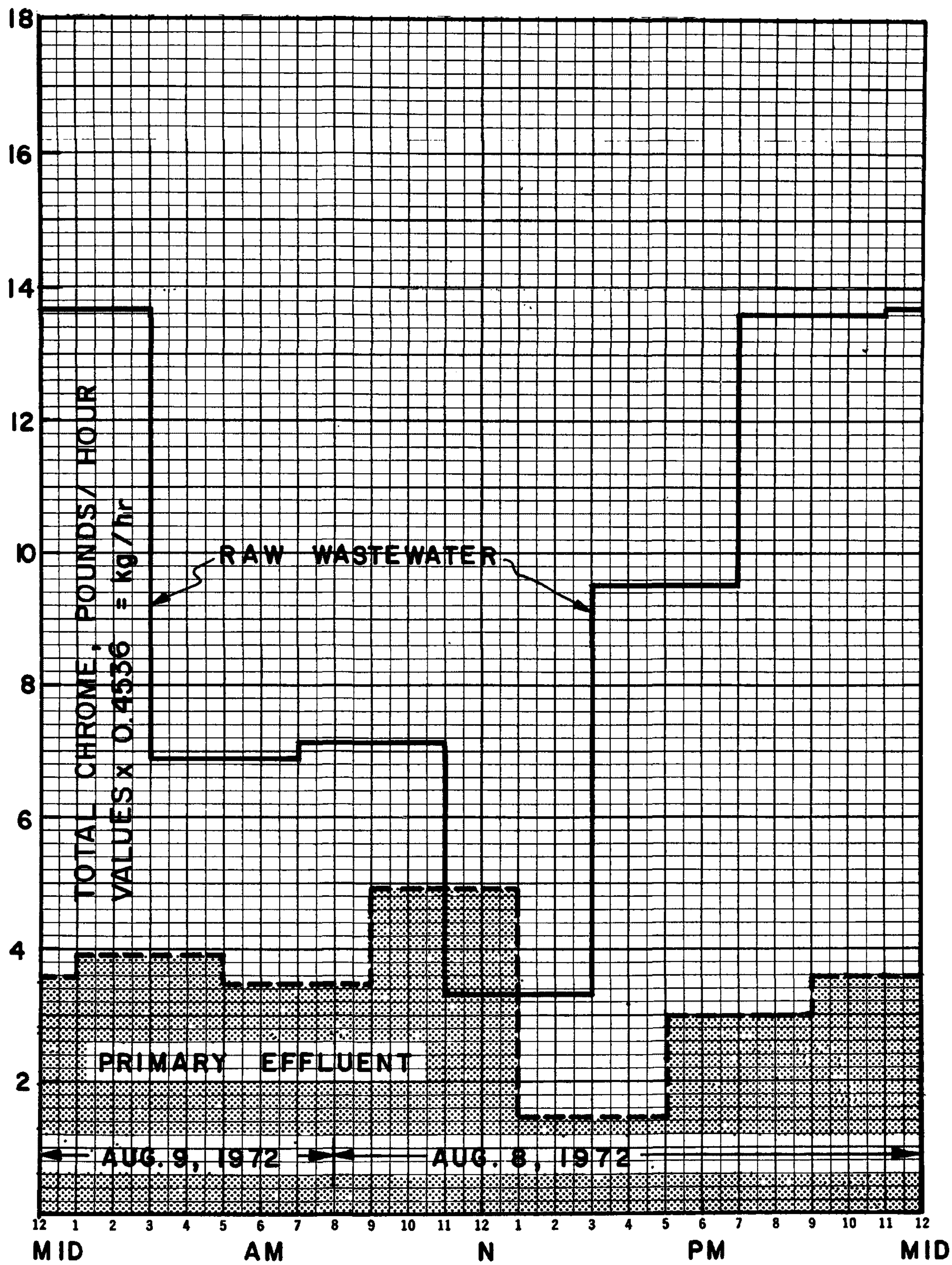

Figure 37. Primary sedimentation total chrome performance: 4 hour composites.

to hour or for shorter periods of time would be more pronounced, the 4-hour interval dampens the variation as would the resident time of the wastewater in the settling units. The percent total solids removals vary from increases in effluent concentrations to reductions with an overall removal for the 24-hour period of only 8 percent. The high dissolved solids and the variation thereof as part of the total solids accounts for this apparent anomaly. The removal of suspended solids is more indicative of the portion of total solids amenable to gravity separation with removals ranging from 21 to 81 percent for the 4-hour composites and an overall removal of 68 percent.

The results of the September 25-26, 1972, primary settling survey are presented in Table 19 with the compositing intervals for influent and effluent indicated. The results also reflect the influence of wasting biological or secondary sludge to the primary settling tanks. With few exceptions the concentrations of the wasted biological solids stream for the various quality parameters and composites were lower than for the corresponding raw wastewater qualities. The raw wastewater flow was 2989 m^3/d and the waste secondary sludge was 300 m^3/d or approximately 10% of raw wastewater contribution. The influent composites for the 24-hour period compared with the primary effluent composites were used to determine the percent removals for the various parameters presented in Table 19. The BOD_5, suspended volatile solids, and total calcium were included as the measured quality parameters and the relative contribution or percent of total contribution on a mass basis for the composite period for each parameter and for both raw wastewater and primary effluent are presented also.

The results show, on this date, that high removals of suspended and volatile suspended solids were experienced at 84 and 92 percent respectively, whereas BOD and COD removals were 48 and 49 percent. It is apparent that although high removals of suspended solids were experienced, the removal of total calcium was only 29% indicating a high fraction of dissolved or particle sizes too small to be affected by gravity separation. Part of this calcium is indigenous to the carriage water or process water supply.

Additional one-day surveys were conducted to evaluate the performance of the primary settling tanks and the results for the 24-hour composite, for both raw and primary effluents, flows and overflow rates are presented in Table 20. A summary of the percent removal results are presented at the bottom of the table showing the number of values used, range, mean and standard deviation. In addition, all the raw wastewater and primary effluent data for the 24-hour composite surveys and corresponding percent removals are presented in Table 21. The data were grouped according to

TABLE 20. INTENSIVE PRIMARY SETTLING SURVEYS

Date	Raw wastewater flow mgd	Overflow rate* gal/d/ft^2	BOD_5	COD	Total solids	Total volatile solids	Total suspended solids	Volatile suspended solids	Total chrome	Percent secondary waste solids to raw wastewater solids: Total suspended solids	Percent secondary waste solids to raw wastewater solids: Volatile suspended solids
Feb. 23-24, '72	0.736	351									
Raw			1122	4510	12030	3062	5200	2700			
Primary effluent			308	2680	9610	1682	1330	765			
Percent removal +			72.5	40.6	20.1	45.1	74.4	71.7			
Mar. 13-14, '72	0.949	459									
Raw			1411	3567	10020	2436	2308	1436	58		
Primary effluent			929	2173	8039	1417	992	534	21.2		
Percent removal			34.2	39.1	19.8	41.8	57.0	62.8	63.4		
Aug. 8-9, '72	0.884	421								5.67	
Raw				3005	8565		2606		31.4		
Primary effluent				1774	7879		826		12.1		
Percent removal				41.0	8.0		68.3		61.5		
Sept. 25-26, '72	0.869	423								4.06	2.49
Raw			1522	3957	9512	2628	1850	1456	31.2		
Primary effluent			795	1895	7482	1194	300	119	21.7		
Percent removal			47.8	52.1	21.3	54.6	83.8	91.8	30.4		
Dec. 11-12, '72	0.800	402									
Raw			1174	3169	7428	1800	1468	956	43.5		
Primary effluent			711	2098	7422	1264	589	271	21.1		
Percent removal			39.4	33.8	0.08	29.8	59.9	71.6	51.5		
Jan. 16-17, '73	0.718	330									
Raw			1273	4280			1721	938	65.9		
Primary effluent			856	2712			717	224	24.5		
Percent removal			32.8	36.6			58.3	76.1	62.8		
May 8-9, '73	0.742	417								1.50	1.75
Raw			1478	4308	11102	2349	2128	1334			
Primary effluent			703	2233	9429	1679	1057	559			
Percent removal			52.4	48.2	15.1	28.5	50.3	58.1			

(continued)

TABLE 20. (CONTINUED)

Date	Raw wastewater flow mgd	Overflow rate* gal/d/ft^2	BOD_5	COD	Total solids	Total volatile solids	Total suspended solids	Volatile suspended solids	Total chrome	Percent secondary waste solids to raw wastewater solids: Total suspended solids	Percent secondary waste solids to raw wastewater solids: Volatile suspended solids
June 6-7, '73	0.697	393								14.3	11.2
Raw			1653	4438	10063	2614	2405	1575			
Primary effluent			975	2192	8995	1320	1108	520			
Percent removal			41.0	50.6	10.6	49.5	53.9	67.0			
June 12-13, '73	0.779	420								15.5	10.1
Raw			1635	4117	9123	2215	1882	1287			
Primary effluent			799	2060	8710	1160	1080	464			
Percent removal			51.1	50.0	4.53	47.6	42.6	63.9			
Percent removal summary											
N, Number of values			8	9	8	7	9	8	5		
Range			32.8-72.5	33.8-52.1	0.08-21.3	28.5-54.6	42.6-83.8	58.1-91.8	30.4-63.4		
Mean			46.4	43.6	12.4	42.4	60.9	70.4	53.9		
Standard deviation			12.8	6.75	7.90	9.88	12.6	10.4	14.0		

* Overflow rate represents primary effluent flow rate which is equivalent to raw wastewater inflow plus waste activated sludge plus filtrate from the solids dewatering less primary sludge withdrawal.

\+ All percent removals represent raw wastewater influent to primary effluent.

TABLE 21. SUMMARY OF PRIMARY REMOVAL BY SETTLING

Identification	Mean concentration, mg/l Raw	Primary effluent	Percent removal
Project data--all			
BOD_5	1656	1029	37.9
COD	4523	2509	44.5
Total volatile solids	2824	1577	44.2
Total suspended sol.	2730	1133	58.5
Oil and grease	763	242	68.3
Total chromium	50.6	23.2	54.2
Total phosphorus	5.96	3.39	43.1
Project data--all--no rendering			
BOD_5	1501	907	39.6
COD	4284	2319	45.9
Total volatile solids	2570	1455	43.4
Total suspended sol.	2579	1091	57.7
Oil and grease	601	207	65.6
Total chromium	46.8	28.9	38.2
Total phosphorus	7.43	3.51	52.8
Process formula--no rendering--winter			
BOD_5	1514	894	41.0
COD	4659	2692	42.2
Total volatile solids	2926	1752	40.1
Total suspended sol.	2991	1320	55.9
Process formula--no rendering--summer			
BOD_5	1424	855	40.0
COD	3730	1916	48.6
Total volatile solids	2100	1161	44.7
Total suspended sol.	2155	1062	50.7
Process formula--no rendering--spring-fall			
BOD_5	1558	978	37.2
COD	4356	2262	48.1
Total volatile solids	2625	1378	47.5
Total suspended sol.	2442	781	68.0

process formula, all data, and as all data when rendering was not employed. The only major differences in percent removal between the various groupings of 24-hour composite data occur for the parameters of total chromium and total phosphorus for 'project data all' and 'project data all no rendering', with the lower removals of chrome and higher removals of phosphorus for the 'project data all no rendering'.

PRIMARY REMOVALS VERSUS SURFACE SETTLING RATES (OVERFLOW RATES)

Linear regression and correlation analyses of the data were performed to determine if a relationship between percent removal or primary effluent concentrations and clarifier overflow rate existed. Generally, one may expect lower removals with higher overflow rates for certain of the quality parameters measured and particularly so for those parameters representing particulate matter large enough to be affected by gravitational forces. The parameter suspended solids which represents the non-filterable residue, is frequently used to evaluate the performance of settling units. Only a portion of the suspended solids are settleable which would be subject to separation in the primary settling units.

The results for percent removals for BOD and total suspended solids presented in Table 20 were plotted against overflow rate in gpd/ft^2 to determine the extent to which overflow rate may affect removal for the limited range of overflow rates experienced. These results are plotted on Figure 38. Linear regression correlation statistics, based on the intensive primary settling surveys (Table 20), were calculated for the BOD and total suspended solids removals separately, both of which indicated that there was a decrease in removal with an increase in overflow rate, however, the correlation coefficients, were only -0.213 and -0.132 for percent BOD and total suspended solids removals respectively (Table 22). The range of overflow rates were from 13.4 to 18.7 m^{3}d/m^2 (330 to 459 gal d/ft^2) based on primary effluent flows which reflected the raw wastewater flow adjustments for primary sludge pumping and solids dewatering filtrate return.

Additional linear regression and correlation analyses were performed for the routine 24-hour composite data which permitted the evaluation to be made over a wider range of overflow rates 13.4 to 40.9 m^{3}d/m^2 (330 to 1003 gal d/ft^2) and a wide range of percent removals and primary effluent concentrations. Also, 45 separate removals and overflow rates were available for the BOD evaluations and 48 available for the TSS evaluations. The results presented in Table 22 show lack of correlation between percent removals and overflow rates for both BOD and TSS with correlation coefficients of -0.139 and 0.124 respectively. The primary effluent BOD

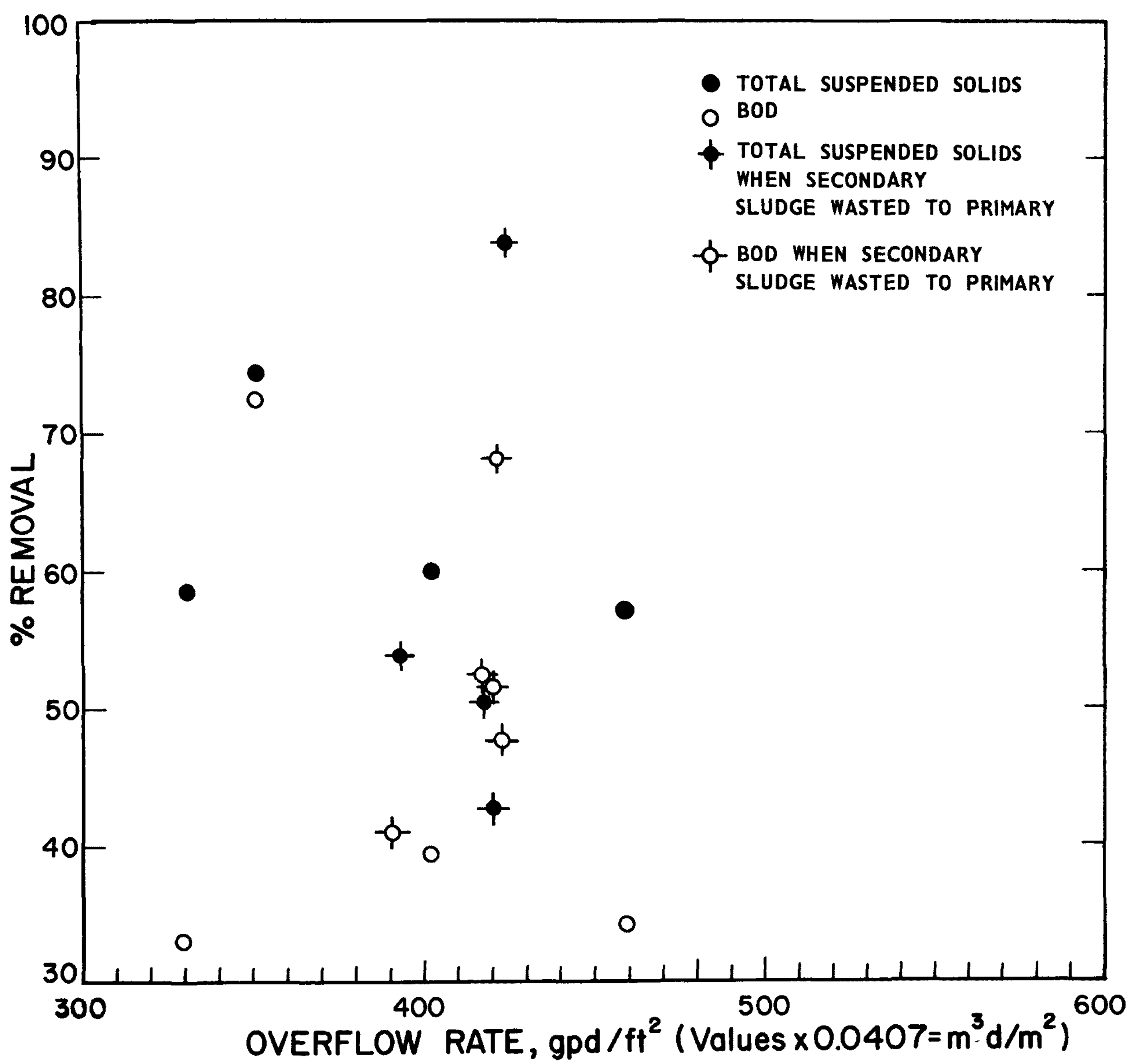

Figure 38. Primary settling percent removal versus overflow rate based on 24-hour composites.

TABLE 22. SUMMARY OF LINEAR REGRESSION-CORRELATION ANALYSES FOR PRIMARY SETTLING PERFORMANCE

Data Source	Linear regression equation	Correlation coefficient (r)
Table 20	$\% BOD_r = -0.0659V_o + 72.74$ Range $\% BOD_r = 32.8$ to 72.5 Range $V_o = 330$ to 459	-0.213
Table 20	$\% TSS_r = -0.0423V_o + 77.94$ Range $\% TSS_r = 42.6$ to 83.8 Range $V_o = 330$ to 459	-0.132
24-Hour composites, all data	$\% BOD_r = -0.00801V_o + 41.66$ Range $\% BOD_r = 13.2$ to 72.5 Range $V_o = 330$ to 1003	-0.139
24-Hour composites, all data	$BOD_{PE} = 0.516V_o + 733.0$ Range $BOD_{PE} = 308$ to 1561 Range $V_o = 330$ to 1003	0.404
24-Hour composites, all data	$\% TSS_r = 0.00925V_o + 50.23$ Range $\% TSS_r = 10.9$ to 89.8 Range $V_o = 330$ to 1003	0.124
24-Hour composites, all data	$TSS_{PE} = 0.274V_o + 995.2$ Range $TSS_{PE} = 252$ to 2108 Range $V_o = 330$ to 1003	0.151

where:

$$\% BOD_r = \left(\frac{\text{BOD influent} - \text{BOD effluent}}{\text{BOD influent}}\right) 100$$

$$\% TSS_r = \left(\frac{\text{TSS influent} - \text{TSS effluent}}{\text{TSS influent}}\right) 100$$

BOD_{PE} = BOD Primary Effluent, mg/l

TSS_{PE} = TSS Primary Effluent, mg/l

V_o = Overflow rate, gal/d/ft^2

concentrations appeared to correlate with overflow rates to a greater extent than for TSS concentrations as evidenced by the correlation coefficients of 0.404 and 0.151 respectively. The only inconsistent result obtained from this analysis was the apparent increase in percent TSS removal with an increase in overflow rate for the range of overflow rates experienced. The data were not uniformly distributed over the range of overflow rates experienced with a preponderance of data in the 12.2 to 18.3 m^3d/m^2 (300 to 450 gal d/ft^2) range when two primary clarifiers were in operation. The high range of overflow rates occurred when only one of the two clarifiers were in operation.

The results of the primary settling analysis indicate the highly variable nature of primary tank performance for the treatment of this wastewater. This variability was evident both for removals over 4-hour compositing periods within a 24-hour period as well as for comparison of results based on 24-hour composited samples. The relationship between percent removal clarifier overflow rates show a lack of correlation with no apparent indication of the overflow rate best suited for the design of primary clarifiers. The percent removals obtained by primary clarification for overflow rates primarily in the range of 12 to 18 m^3d/m^2 (300 to 450 gal d/ft^2) is best summarized in Table 21 wherein the percent removals for the various parameters with the exception of total chrome are essentially the same when all 24-hour composite data are compared with all 24-hour composite data when rendering was not practiced. The removals obtained were 39% BOD, 45% COD, 58% total suspended solids, 67% oil and grease, and 43% for total volatile solids. Regarding total chrome, the removals were 54% when flesh rendering was practiced, whereas, only 38% removals were obtained when all project were included in the summary. It would appear that the chrome is somehow associated with the particulate fractions that are subject to separation to a greater extent when rendering is employed.

SECTION X

LAGOON ANALYSIS

The primary objective of the lagoon studies was to evaluate the effectiveness of this biological process in treating unneutralized, unequalized, presettled tannery wastewaters. Effectiveness was defined in terms of meeting Best Practicable Effluent Limitations (BPT) and Best Available Effluent Limitations (BAT) requirements as established by the U.S. Environmental Protection Agency and as set forth in the Development Document for Effluent Limitation Guidelines and New Source Performance Standards for the Leather Tanning and Finishing Point Source Category (3). The BPT and BAT guidelines from this source are given in Tables 23 and 24. These effluent guidelines have been remanded to the court for revision, however, they serve for purposes of comparison for treatment performance in this study. In addition, effective treatment was evaluated in terms of process stability and operation maintenance. Since wide variations exist in chrome tannery wastewaters, no attempt was made to establish a design criteria for the industry, but rather to demonstrate whether such a process with known loading relationships would achieve the desired level of treatment within the range of design constraints normally employed in wastewater treatment practice.

In designing the full-scale demonstration plant at the S. B. Foot Tanning Company, design data was taken from pilot plant studies conducted in 1966 (1). Sufficient flexibility was built into the design of the lagoon systems so that a wide range of wastewater loadings could be evaluated. As noted earlier, substantial changes in the in-plant tannery processes limited this flexibility to some extent.

Sufficient data are available in the literature to suggest that aerated lagoons operated at low solids concentrations are highly temperature sensitive. Since this facility is located in a region of the country where wide fluctuations in ambient air temperature occur (average monthly temperature range -14° to 25° C), it was determined that the lagoons should be provided with recirculation capability to that high solids could be maintained during the cold winter months. In addition, piping was provided so that the four lagoons could be operated in a number of different flow patterns with independent clarification and sludge return. Thus two different

TABLE 23. BEST PRACTICABLE EFFLUENT LIMITATIONS (CONTROL TECHNOLOGY CURRENTLY AVAILABLE) MAXIMUM THIRTY DAY AVERAGE, 7/1/77

Parameter*	Subcategory+					
	1	2	3	4	5	6
BOD_5	4.0	4.6	3.8	1.6	4.8	2.8
Total chromium	0.10	0.12	0.05	0.10	0.06	0.10
Oil & grease	0.75	0.90	0.75	0.25	0.90	0.35
TSS	5.0	5.8	4.8	2.0	6.0	3.4

* For all subcategories pH should be between 6.0 and 9.0 at any time.

\+ Classification related to in-plant processes employed with all values reported in kg/1000 kg hide.

TABLE 24. BEST AVAILABLE EFFLUENT LIMITATIONS (TECHNOLOGY ECONOMICALLY ACHIEVEABLE), 7/1/83

Parameter*	Subcategory+					
	1	2	3	4	5	6
BOD_5	1.40	1.60	1.30	0.50	1.60	0.70
Total chromium	0.05	0.06	0.05	0.02	0.06	0.03
Oil & grease	0.53	0.63	0.50	0.24	0.63	0.34
Sulfide	0.005	0.006	0.005	0.002	0.006	0.003
TSS	1.5	1.8	1.4	0.6	1.8	0.8
TKN	0.27	0.32	0.25	0.10	0.31	0.14

* For all subcategories pH should be between 6.0 and 9.0 at any time. For all subcategories Most Probable Number (MPN) of Fecal Coliform should not exceed 400 counts per 100 ml.

\+ Classification related to in-plant processes employed with all values reported in kg/1000 kg hide.

configurations could be examined simultaneously. Also chemical addition facilities were available to provide pretreatment or post-treatment of the wastewater.

LAGOON OPERATING CONDITIONS AND PROCEDURES

A number of process flowsheets were initially proposed for study of the lagoon system. Preliminary investigations on the lagoons were started in the fall of 1971. As indicated earlier in this report, difficulties were encountered with the aeration equipment. It was late in the summer of 1973 before the appropriate aeration facilities were installed and operated. Although some lagoon configurations were studied prior to that time, meaningful data was not available until the fall of 1973. A listing of the lagoon conditions are presented in Table 25. Four other conditions which were operated between the fall of 1973 and early spring of 1974 are not listed nor were they analyzed as a result of mechanical failures.

Sampling for the lagoon studies was accomplished with automatic flow proportioned samplers on the primary sedimentation effluent and secondary clarifier effluent, or by grab sampling of lagoon effluent proportioned to flow. The details of the sampling procedures are discussed in Appendix A. It should be emphasized, however, that where two lagoon configuration flow sheets employed the same final clarifier, it was necessary to grab composites of treated lagoon wastewater effluent before discharge to the clarifier. Samples were grabbed and composited proportionally to flow over a 12- or 24-hour period. Settling of the composite was then performed in the laboratory using a 1000 ml cylinder and all settled effluents were then analyzed. Samples settled in this manner were denoted on the data tables.

Effluent analyses included BOD_5; COD; solids, total and dissolved; chrome, total and dissolved; oil and grease; all nitrogen; total, ortho and suspended phosphorus; total, suspended and dissolved calcium; sulfide, sulfate, chloride and alkalinity. Analytical procedures used are outlined in Appendix A. Measurements in the lagoon included continuous recording of pH, temperature and dissolved oxygen, and periodic determinations of lagoon mixed liquor solids, oxygen uptake rates, and accumulated sludge deposits. Recycle flow rates and sludge wasting rates were also recorded.

LAGOON PERFORMANCE

Analysis of the data from the lagoon study was performed for each condition over a period of time selected to be representative for that condition. An allowance of about two sludge retention periods (estimated) was normally made. All data collected after that time interval was then

TABLE 25. LAGOON EXPERIMENTAL DESIGN

Condition	Dates	Mode	P addition mg/l P	Recycle	Percent Flow*	Lagoon No.+
1	8/7/73-9/17/73	Single	No	No	5	1
2	9/17/73-10/29/73	Single	No	No	10	1
3	10/29/73-2/18/74	Single	No	Yes	25	3
4	2/6/74-3/25/74	Single	Yes	Yes	25	3
5	2/6/74-3/25/74	Single	Yes-10	Yes	75	2
6	4/1/74-5/13/74	Single	Yes-10	Yes	50	1
7	4/8/74-5/13/74	Single	Yes-10	No	50	4
8	5/13/74-6/17/74	Single	No	Yes	50	4
9	5/13/74-6/17/74	Series	Yes-10	Yes	50	1,3
10	7/8/74-8/12/74	Single	Yes-10	Yes	33.3	4
11	7/8/74-8/12/74	Series	Yes-10	No	33.3	1,3
12	8/12/74-9/9/74	Series	No±	Yes	33.3	1,3
13∓	9/9/74-11/1/74	Single	No	No	30	1
14∓	9/9/74-11/1/74	Single	Yes-7	No	30	3
15∓	9/9/74-11/1/74	Single	Yes-7	Yes	30	4
15A	11/1/74-1/2/75	Single	Yes-7	Yes	33	4

* Percent of total tannery flow to that lagoon system.

\+ See Figure 4.

± Phosphorus carryover in sludge from condition 11 was likely.

∓ Chemical additions were practiced during these condition as follows:
Condition 13: $FeCl_3$ added to raw wastewater, CO_2 added to raw wastewater;
Condition 14: $FeCl_3$ added to secondary effluent.

used except in the case of the winter condition 3 when aerator freeze-up occurred.

The results of the operational conditions for the 15 lagoon conditions analyzed appear in Table 26. The design parameters employed in this study were F/M, SΘ, and Θ defined as follows:

$$F/M = \frac{\text{kg BOD applied/d}}{\text{MLVSS under aeration}}$$

$$\Theta = \text{hydraulic retention time} = \frac{\text{volume}}{\text{flow rate}} \text{ (days)}$$

$$S\Theta = \text{g/l MLVSS} \times \frac{\text{volume}}{\text{flow rate}} \text{ (days)}$$

The use of solids retention time was not possible owing to the difficulties in obtaining satisfactory solid balances on the lagoon systems. This will be discussed more fully elsewhere.

The values estimated for these design parameters and the percent reduction calculated were based on primary effluent data for process days only. Very little data was collected over the weekends when only partial processing of hides was undertaken. The best weekend data was collected during 1974 after rendering was instituted. Based on an analysis of weekend BOD_5 data, it was estimated that the average daily waste loading for a 7-day week versus an average daily loading for a process week (used in all subsequent calculations) would be 86 percent of the daily value for the process week. The 86 percent value represented the period prior to the employment of rendering operations (before March, 1974, and for conditions 1, 2, and 3), and a value of 81 percent was obtained during the period when rendering was employed (conditions 4 - 15A). Thus for the F/M ratios reported herein they would be reduced 86 to 81 percent of those values reported if based on a 7-day week. Corresponding reductions would be made in the BOD_5 percent removal values as well.

Biochemical Oxygen Demand

Analysis of all 15 conditions with respect to BOD removal, both total and soluble fractions, appear in Table 27. Soluble BOD values were estimated by performing a least squares linear regression on total BOD versus volatile suspended solids (VSS) for the effluent. The soluble BOD_5 value obtained where the line of best fit intercepted the y-axis or at zero VSS. One graphical example of this estimating procedure

TABLE 26. LOADING CONDITIONS OF LAGOON SYSTEMS*

Condition	Dates+	Lagoon Temp °C Mean	Range	F/M kg/kg	S θ g/l day	θ days	MLVSS mg/l	Comment
1	8/7/73-9/9/73	20	16-26	0.13	12.30	50.0	246	Low D.O.
2	10/5/73-10/29/73	13	10-16	0.14	9.90	21.0	474	
3	11/16/73-12/31/73	4.4	0-14	0.15	4.61	3.3	1396	
4	3/8/74-3/24/74	7	6-12	0.16	4.87	2.5	1973	
5	3/8/74-3/24/74	11	8-14	0.41	3.21	1.0	3248	
6	4/19/74-5/13/74	16	14-19	0.21	7.76	2.1	3733	
7	4/19/74-5/13/74	16	13-19	0.89	2.51	2.7	921	
8	5/21/74-6/17/74	19	18-24	0.87	1.38	2.2	644	
9	5/21/74-6/17/74	18	16-24	0.23	4.79	4.0	1202	
10	7/26/74-8/11/74	21	19-26	0.10	15.17	3.0	5127	Low D.O.
11	7/26/74-8/11/74	21	18-24	0.26	9.80	9.8	1002	L.S.±
12	8/30/74-9/9/74	15	11-20	0.05	20.50	7.0	2980	
13	9/20/74-11/1/74	14	9-20	0.34	6.48	5.5	1179	$FeCl_3$
14	9/26/74-11/1/74	14	7-19	0.34	6,68	5.6	1187	L.S.
15	9/27/74-11/1/74	13	8-17	0.12	13.41	3.8	3507	L.S.
15A‡	11/1/74-1/2/75	8	4-16	0.09	7.96	2.1	3875	

*All values represent averages.

+Dates through which lagoon performance was estimated.

±L.S. -- Lab Settled.

‡Estimated values after project period.

TABLE 27. LAGOON PERFORMANCE--EFFLUENT BOD_5*

Condition	BOD_5 mg/l	BOD_5 Removal percent	Soluble+ BOD_5 mg/l	BOD_5 Suspended fraction mg BOD_5/mg VSS
1	37	96		
2	51	93		
3	194	80		
4	171	85	146	0.30
5	397	76	320	0.51
6	171	85	50.0	2.40
7	489	70		
8	293	70	70.4	0.82
9	56	94	18.9	0.54
10	169	87	79.8	0.65
11	62	96	38.4	0.33
12	8.8	99	5.8	0.36
13	67	95	41.8	0.54
13A±	182	85		
14	107	91	57.1	0.26
15	129	88	56.9	0.31
15A	34	97		

* All values are average.

+ See, for example, Figure 37; linear least squares estimate.

± Without $FeCl_3$ coagulation of final effluent.

appears in Figure 39. In several instances, insufficient data were available to produce a meaningful regression analysis. The slope of the least squares line of best fit, expressed as mg BOD/mgVSS, is also presented in Table 27. Note that there is a trend of increased contribution of BOD by the volatile solids fraction as the F/M ratio increases. Oxygen deficiencies in lagoons (conditions 6 and 10) also produced higher BOD per weight of VSS.

The results of the BOD analysis are presented in Figure 40 wherein the percent removal of BOD as a function of F/M ratio is shown. Regression lines are shown for percent removal as a function of F/M ratio for results representing temperatures less than 11°C and for the results of the temperature range 15-21°C, both for F/M ratios ranging from 0.05 to 0.4. It is evident that the BOD removal results are temperature dependent with lower removals at the lower temperatures, particularly at the higher F/M ratios which suggests that low F/M ratios be employed during winter conditions. Also it can be noted the influence of D.O. deficiency on lagoon performance as represented by conditions 6 and 10. The importance of chemical coagulation of the lagoon effluent is apparent from the condition 13 (see also condition 13A--laboratory settled without $FeCl_3$ addition). Finally, the addition of phosphorus as an essential nutrient in the biological stabilization of tannery waste is not clearly delineated in this analysis. The primary effluent produced a BOD:N:P ratio averaging 100:24:0.30 suggesting a phosphorus deficiency. Addition of phosphoric acid for selected lagoon conditions in the amount of 10 mg/l (7 mg/l was added to lagoons under conditions 14 and 15) indicated a higher oxygen uptake rate over lagoons without phosphorus addition. This increase, in several cases, produced an oxygen deficiency, yet examination of the data did not clearly show a demonstratable increase in performance. Since environmental conditions varied so much from condition to condition and since there was no effective way to establish an absolute control, it is likely that the effect of phosphorus addition was obscured.

Data on the continuation of condition 15 beyond the project period into the winter of 1974 are also plotted on Figure 40 to indicate the effectiveness of this particular flowsheet through the colder winter months. Although colder temperatures were experienced for condition 15A, than for condition 15, the BOD_5 removals were higher, however, the F/M ratio was lower for the lower temperature condition 15A. Freeze-up of some aerators by mid-January occurred bringing about a very substantial deterioration of the process. Similar problems occurred in the winter of 1973. Further discussion of this operational problem will be presented later.

For a more detailed analysis of lagoon performance, several lagoon conditions were selected. These conditions were used because:

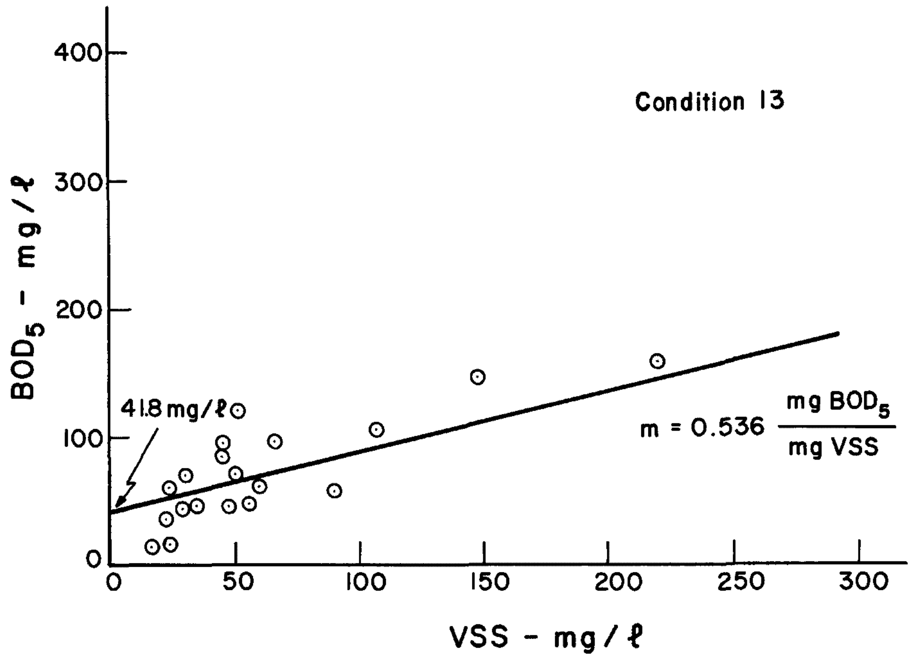

Figure 39. Lagoon performance--correlation of effluent BOD_5 and VSS concentrations.

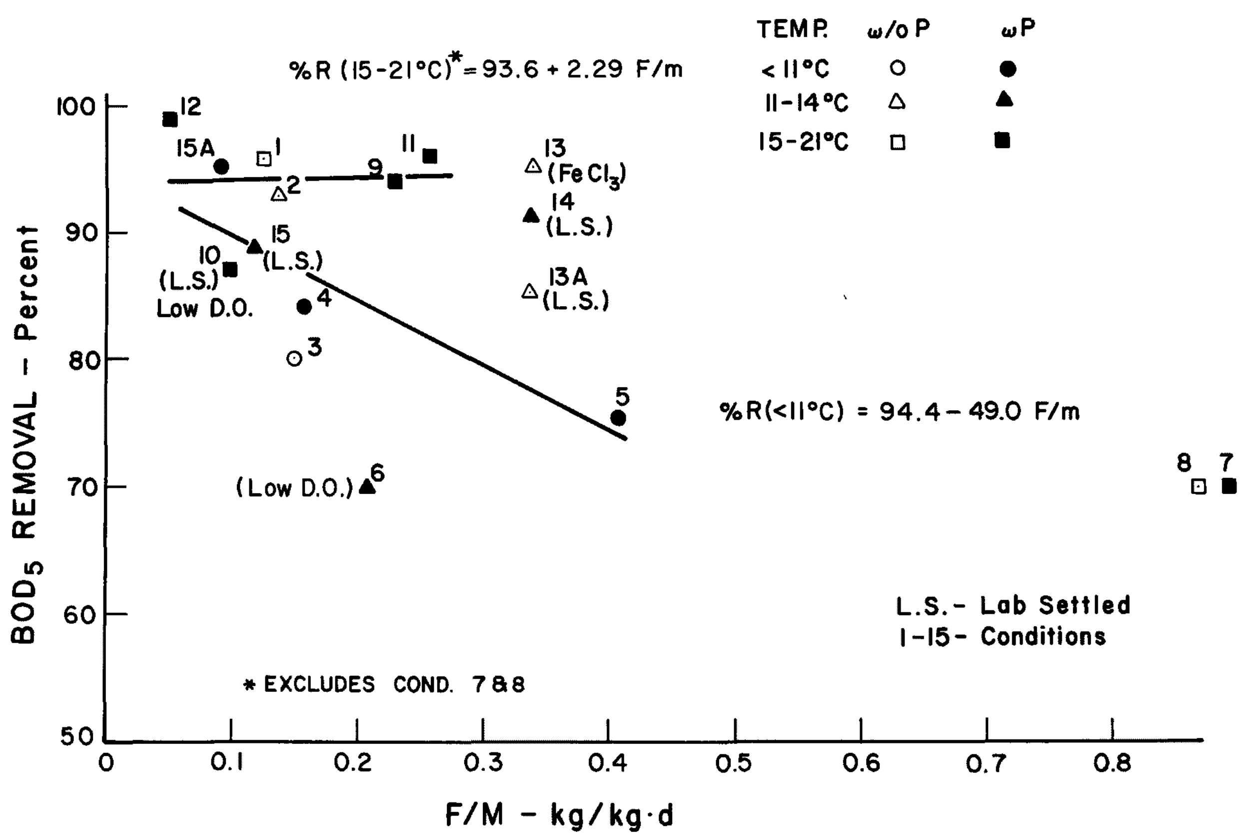

Figure 40. Lagoon performance--BOD_5 removal versus F/M ratio.

first, there was sufficient data collected to provide a meaningful statistical analysis; second, they represented a flowsheet considered to be more acceptable for design than others; and, third, they provided a means of comparison between different flow configurations. The conditions selected were 3, 15, and 15A (the high solids systems) and 1, 2, 13, and 14 (the low solids systems). Condition 3 is contrasted with 15 and 15A to show effect of phosphorus addition. Both conditions were operated during the early winter months. Conditions 1 and 2 were contrasted with 13 and 14 to show the influence of phosphorus addition in low solids operation. All four conditions were operated in the late summer and early fall.

Results of the performance of the lagoons under these selected conditions appear in Figures 41 through 70 and Tables 28 through 35. Probability plots of the 24-hour composite samples taken over the test period for each condition for BOD, COD, TSS and VSS, both in terms of mg/l and kg/1000 kg hide, are employed to illustrate variability of the process. The primary influent data for the appropriate time period for a given condition can be seen in Figures 41 through 70 and are summarized in Table 36. The mean BOD and COD values of the primary settled influent were considerably lower for lagoon conditions 1 and 2, than for 3, 13, 13A, 14, and 15, which can be attributed to process formula in part and the practice of rendering (Table 36). Although conditions 13, 13A, 14, and 15 had the benefit of $FeCl_3$ addition to the raw wastewater for control of sulfides and attendant odor problems, the primary effluent values for BOD and COD were the highest when presumably the $FeCl_3$ could serve as a coagulant to improve primary tank performance. The differences between summer and spring-fall process formulas, comparing conditions 1 and 2 with 3, shows the higher values of BOD and COD for condition 3 when spring-fall formula is used, however, the TSS concentrations do not follow. Rendering the practices employed in conditions 13, 13A, 14, 15, as compared to conditions 3, result in higher BOD, TSS and VSS values, but essentially no change in COD. In reviewing the results of the lagoon treatment, the primary influent characteristics should be noted and are depicted on Figures 41-70.

The results of the various lagoon conditions are reported as probability plots, each point representing a 24-hour composite of the secondary effluent. The BPT limits presented in Table 23 represent discharge limitations based on a maximum 30-day average. In that the data presented herein for each condition represented the results over a very limited period of time, 1 to 2 months, at a given season of the year, the interpretation of the results with reference to the BPT values is limited. Nonetheless a comparison of the BPT limits with the results

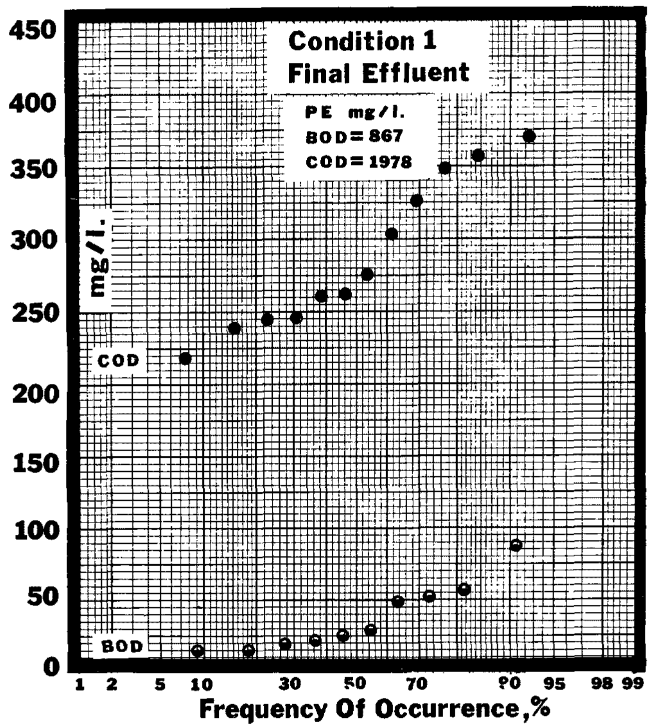

Figure 41. Final effluent concentrations for BOD and COD for condition 1.

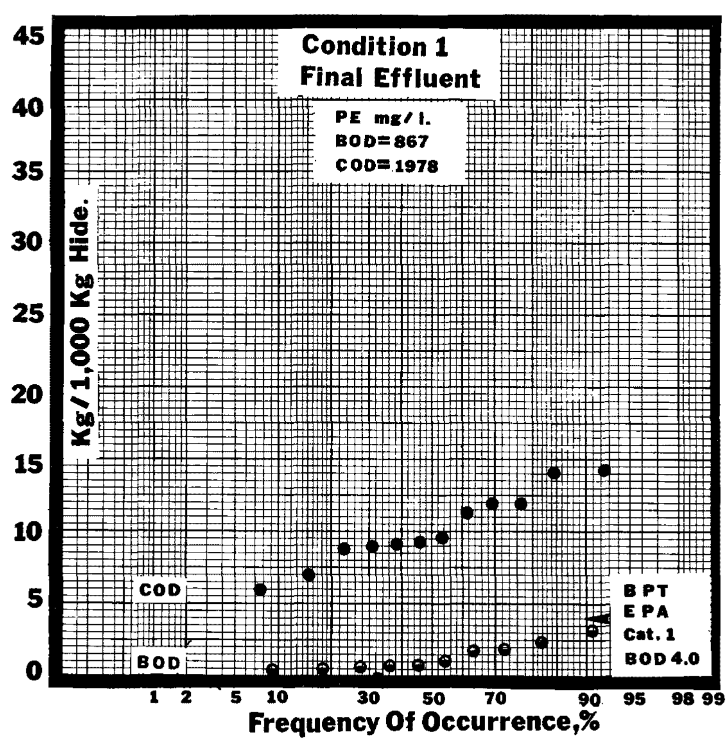

Figure 42. Final effluent mass ratios for BOD and COD for condition 1.

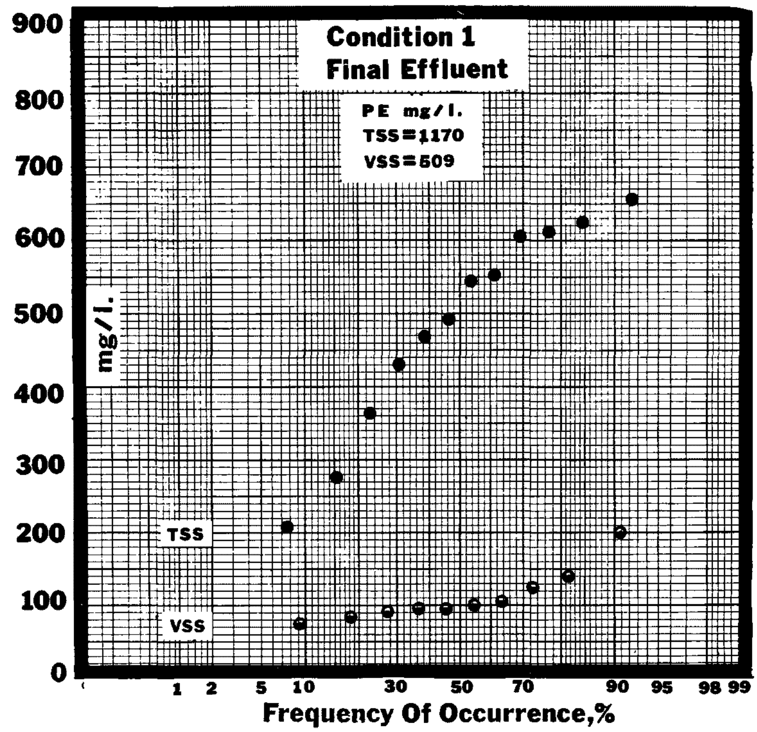

Figure 43. Final effluent concentrations for TSS and VSS for condition 1.

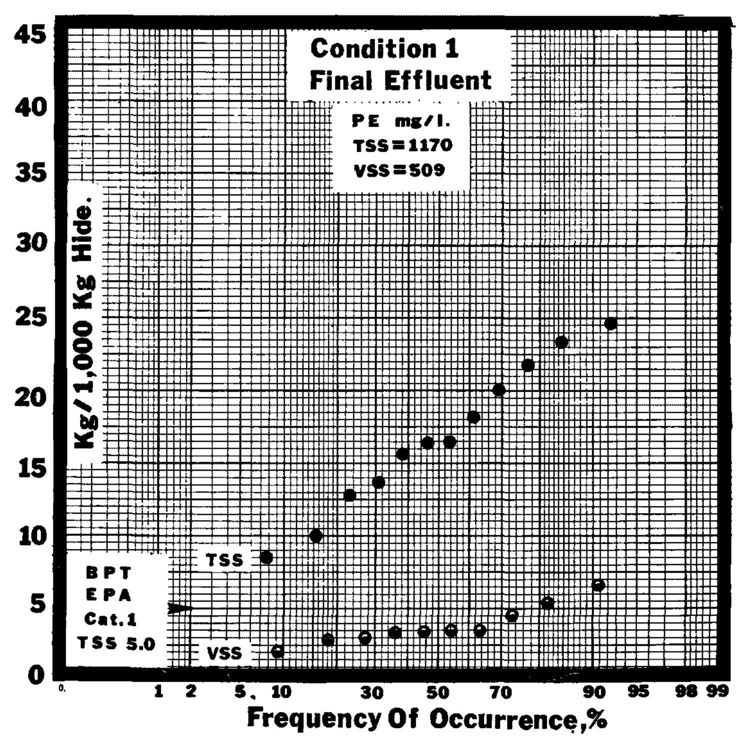

Figure 44. Final effluent mass ratios for TSS and VSS for condition 1.

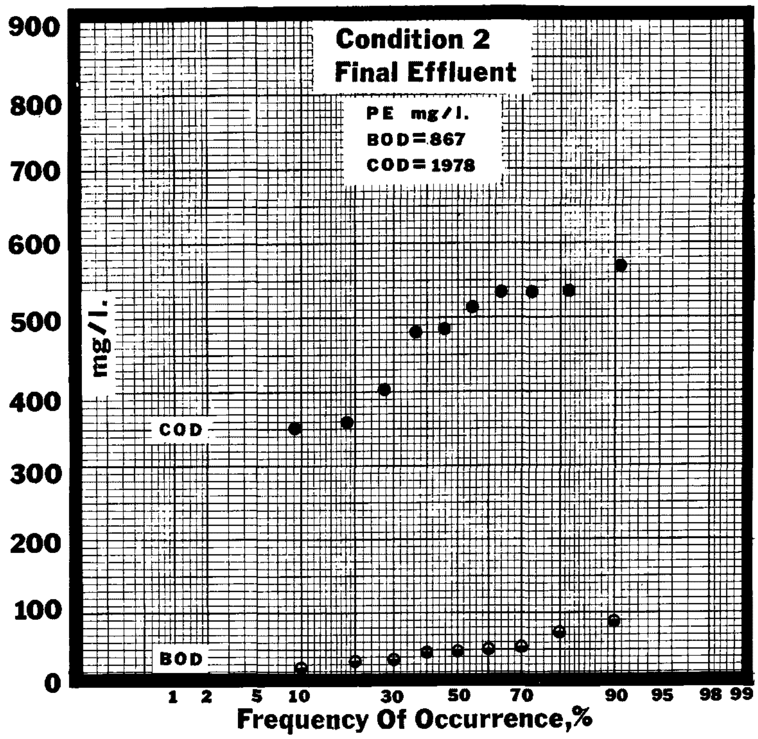

Figure 45. Final effluent concentrations for BOD and COD for condition 2.

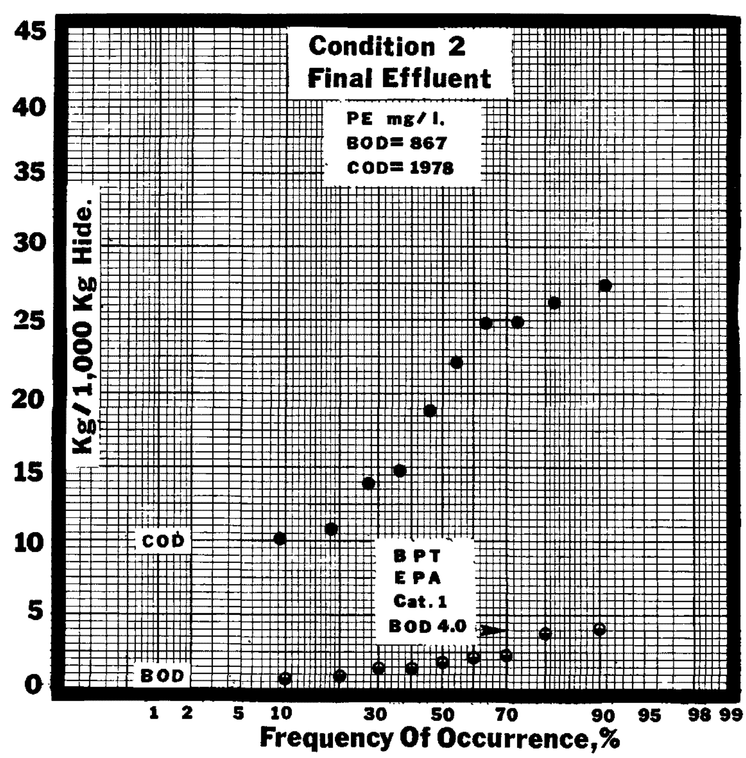

Figure 46. Final effluent mass ratios for BOD and COD for condition 2.

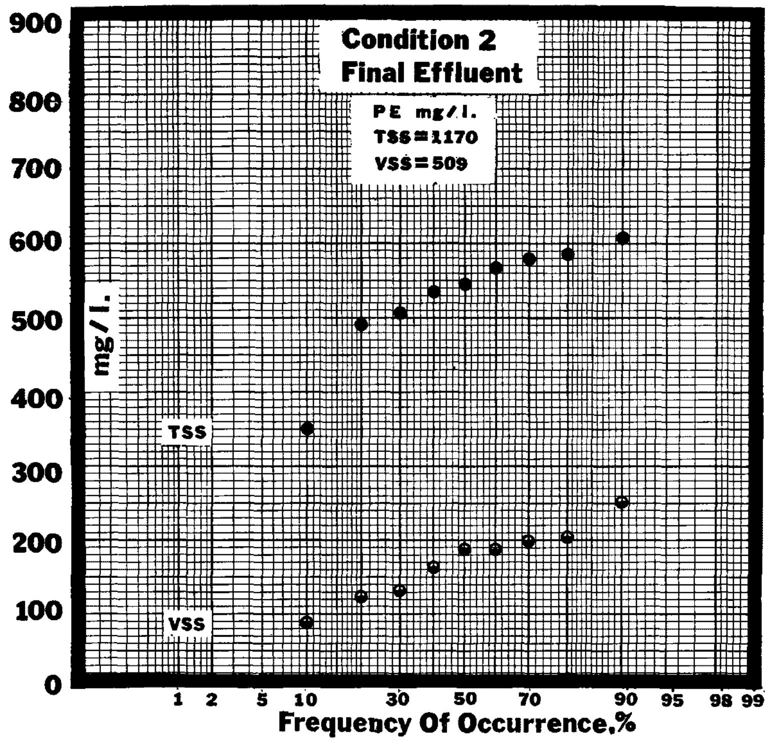

Figure 47. Final effluent concentrations for TSS and VSS for condition 2.

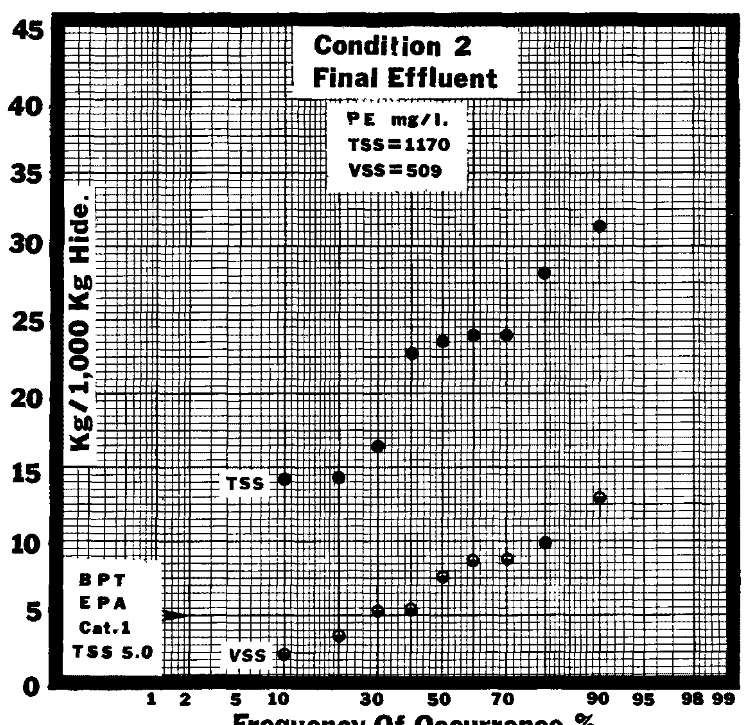

Figure 48. Final effluent mass ratios for TSS and VSS for condition 2.

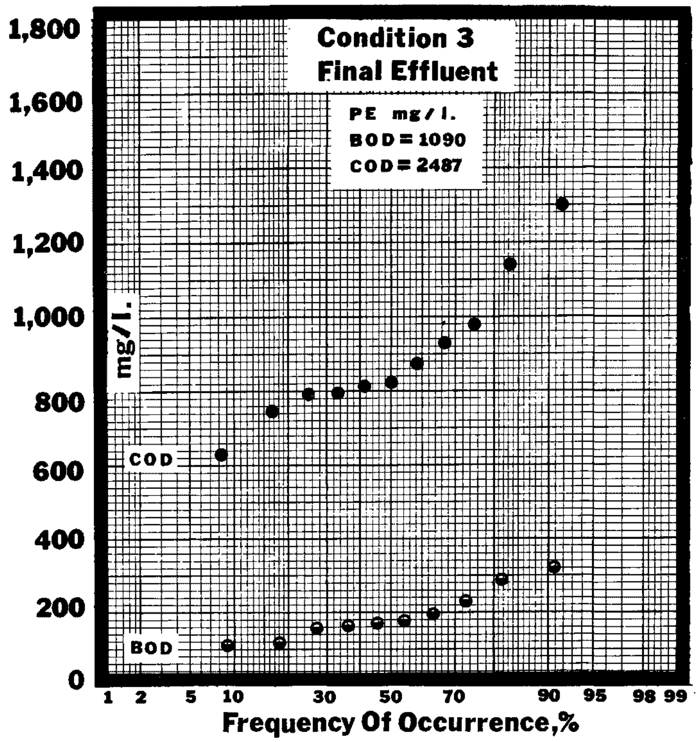

Figure 49. Final effluent concentrations for BOD and COD for condition 3.

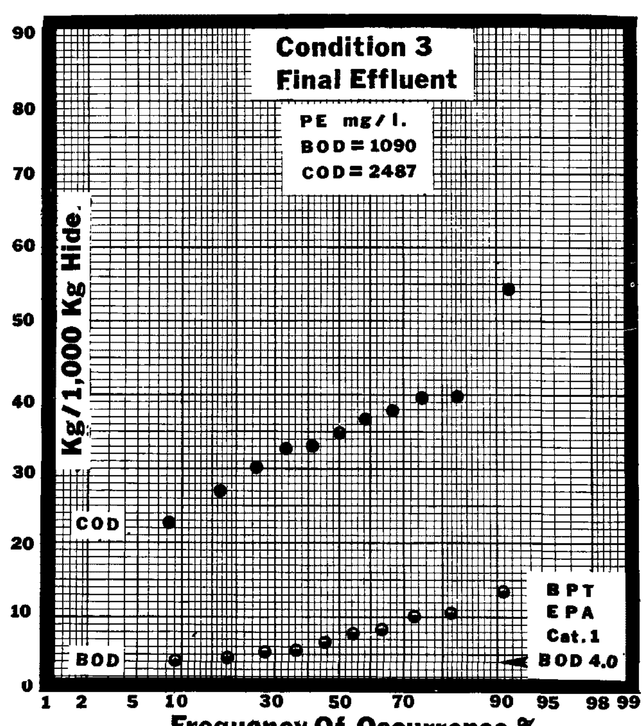

Figure 50. Final effluent mass ratios for BOD and COD for condition 3.

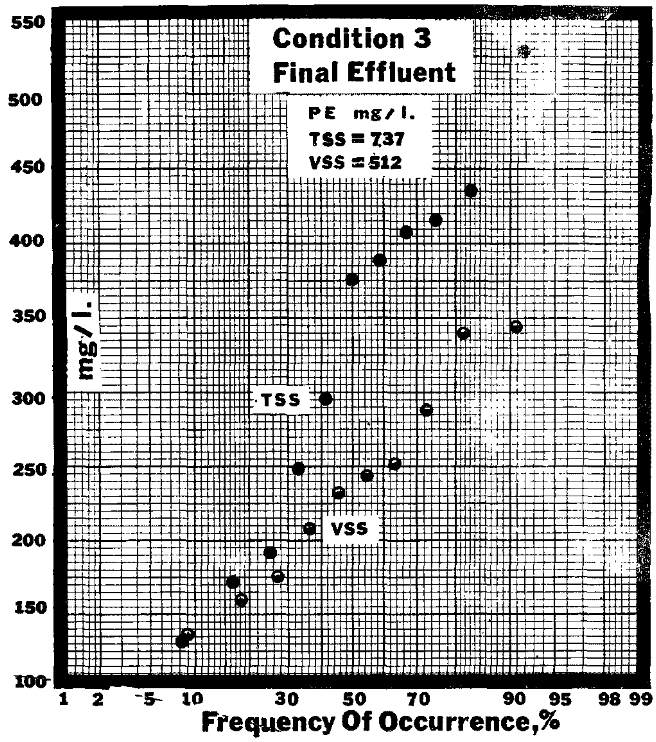

Figure 51. Final effluent concentrations for TSS and VSS for condition 3.

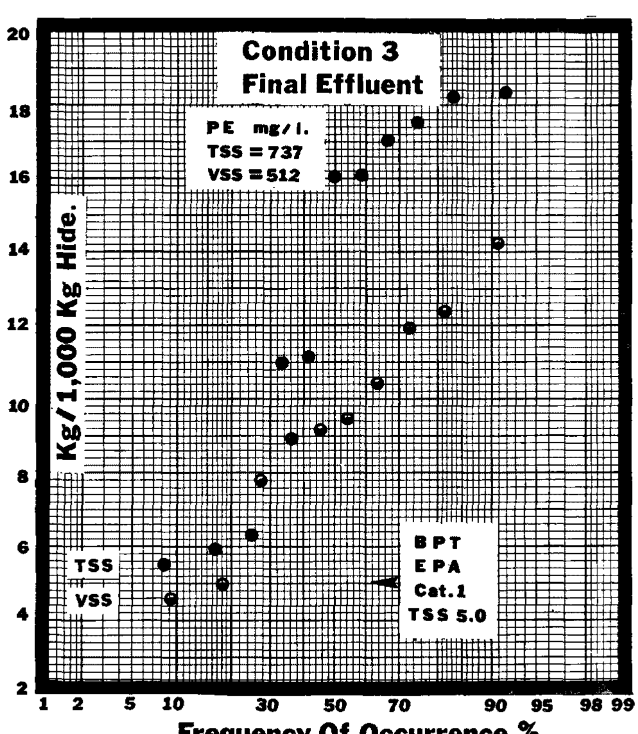

Figure 52. Final effluent mass ratios for TSS and VSS for condition 3.

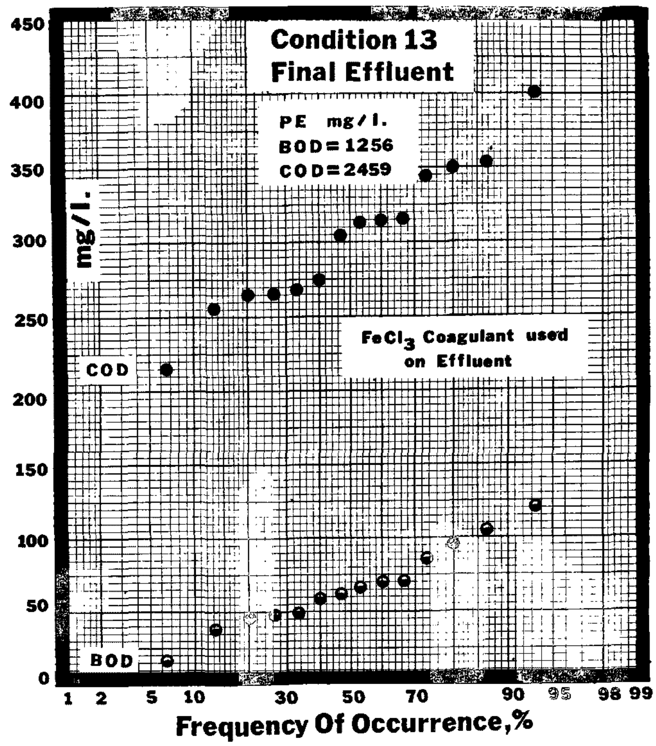

Figure 53. Final effluent concentrations for BOD and COD for condition 13.

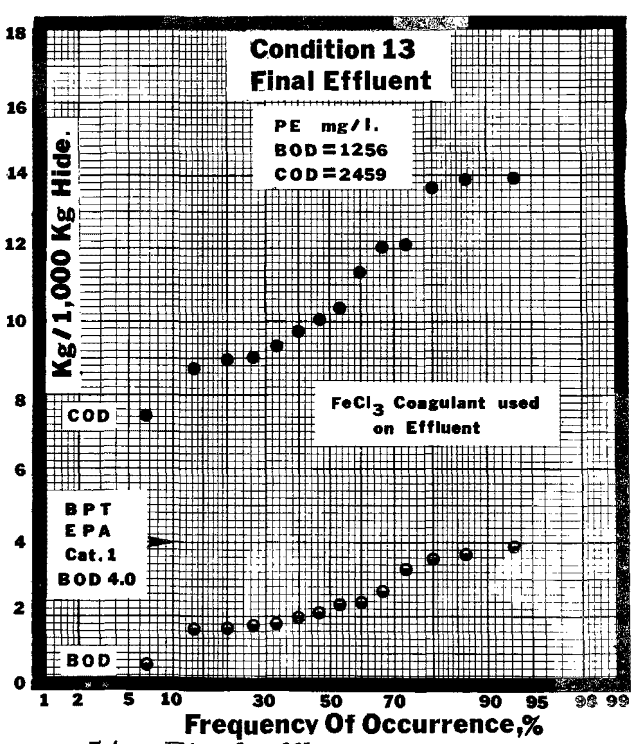

Figure 54. Final effluent mass ratios for BOD and COD for condition 13.

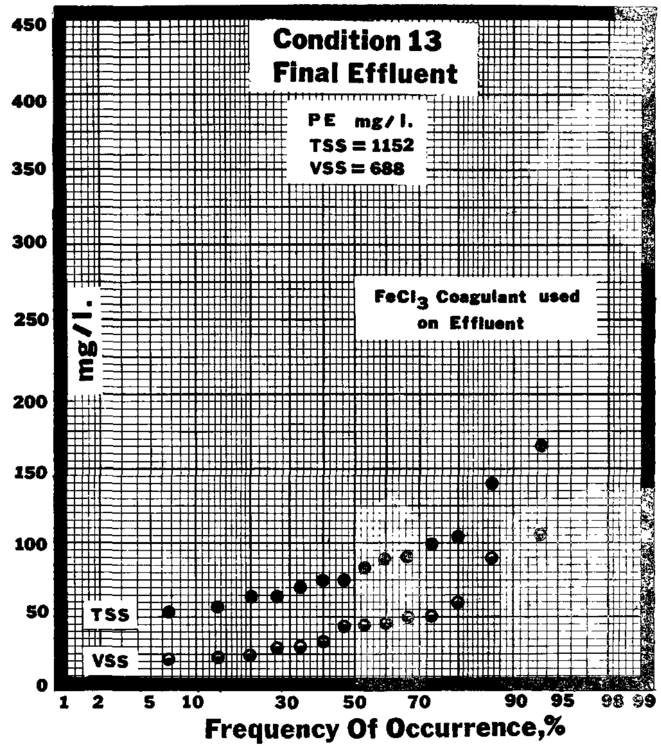

Figure 55. Final effluent concentrations for TSS and VSS for condition 13.

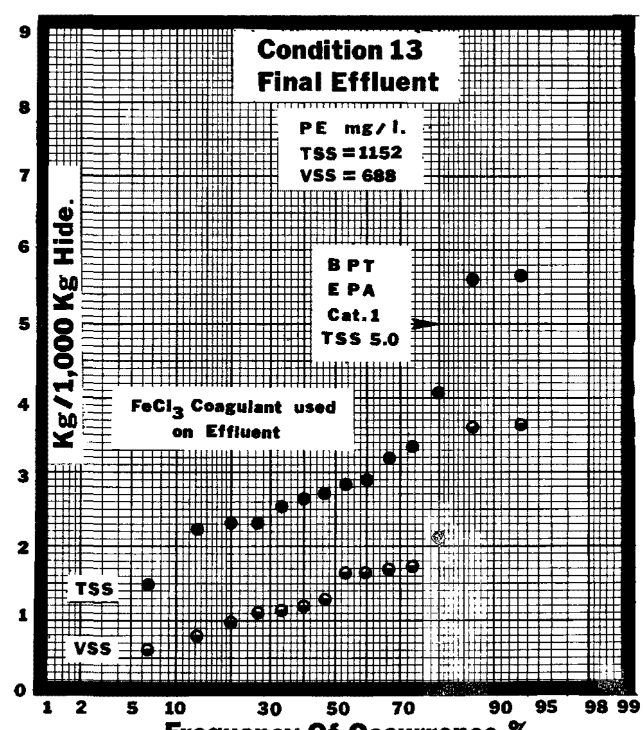

Figure 56. Final effluent mass ratios for TSS and VSS for condition 13.

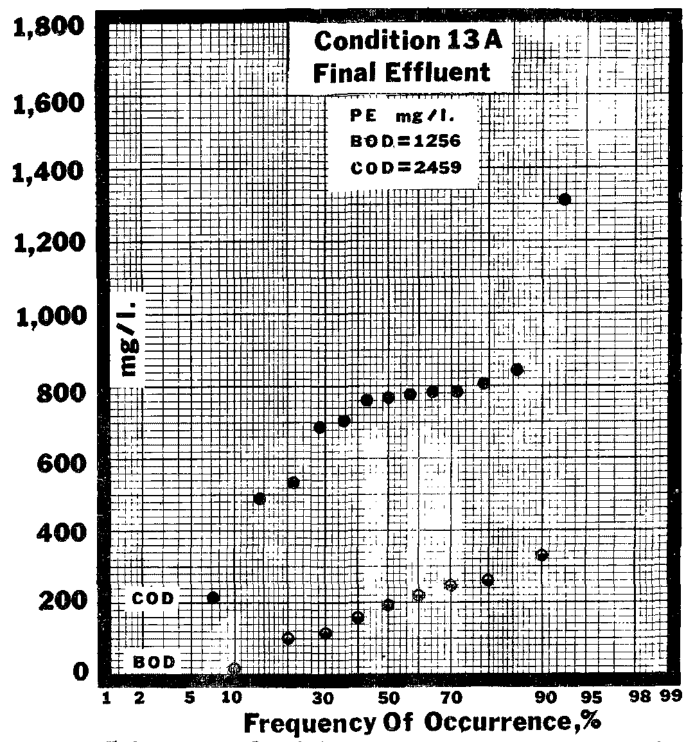

Figure 57. Final effluent concentrations for BOD and COD for condition 13A.

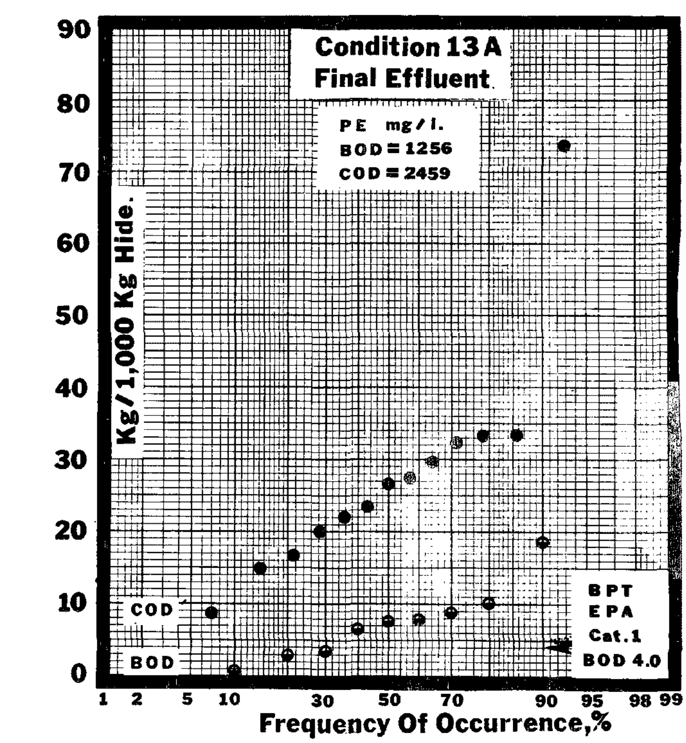

Figure 58. Final effluent mass ratios for BOD and COD for condition 13A.

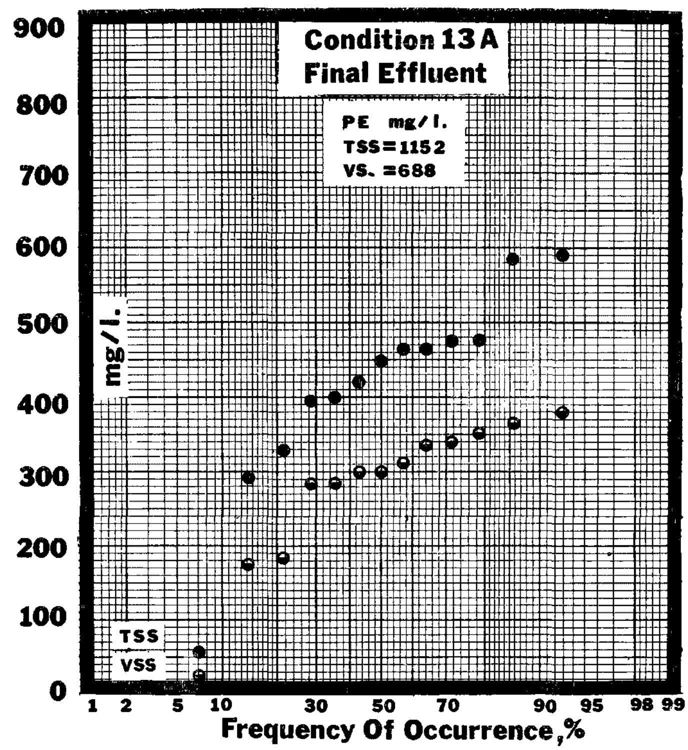

Figure 59. Final effluent concentrations for TSS and VSS for condition 13A.

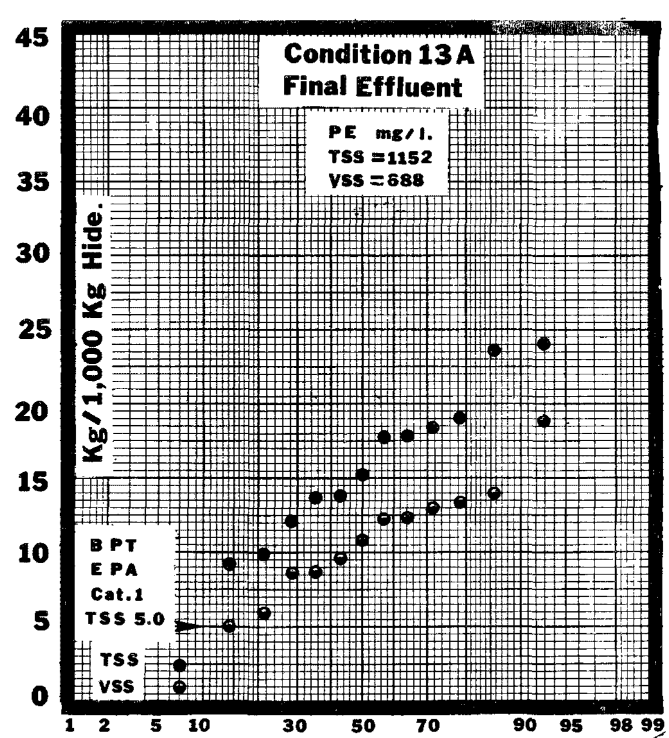

Figure 60. Final effluent mass ratios for TSS and VSS for condition 13A.

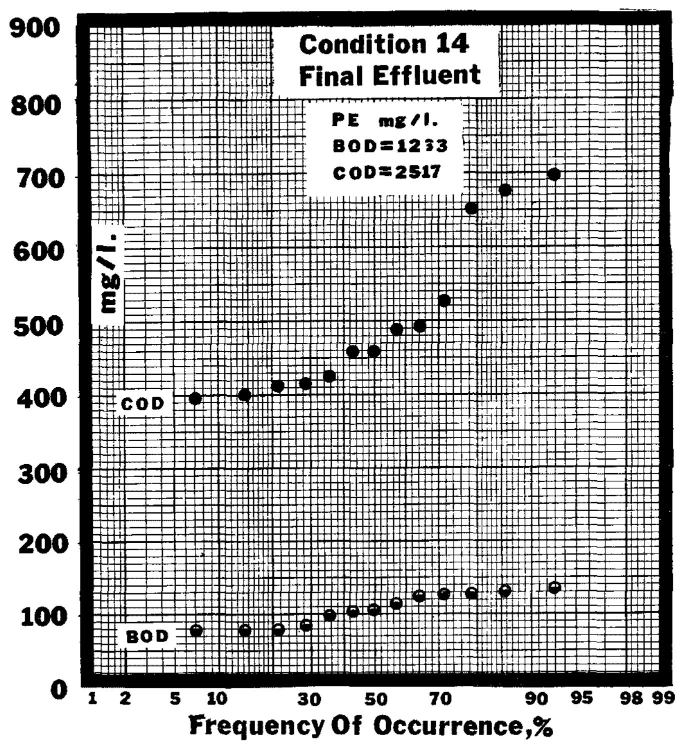

Figure 61. Final effluent concentrations for BOD and COD for condition 14.

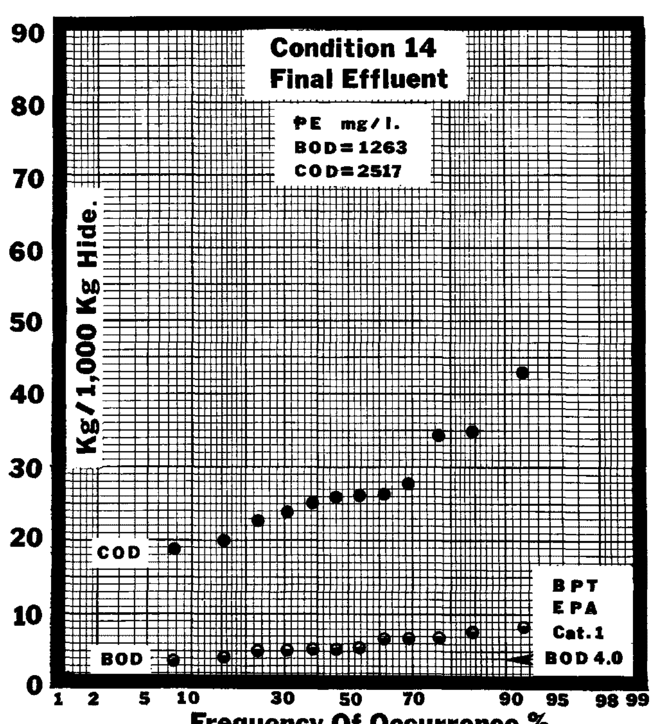

Figure 62. Final effluent mass ratios for BOD and COD for condition 14.

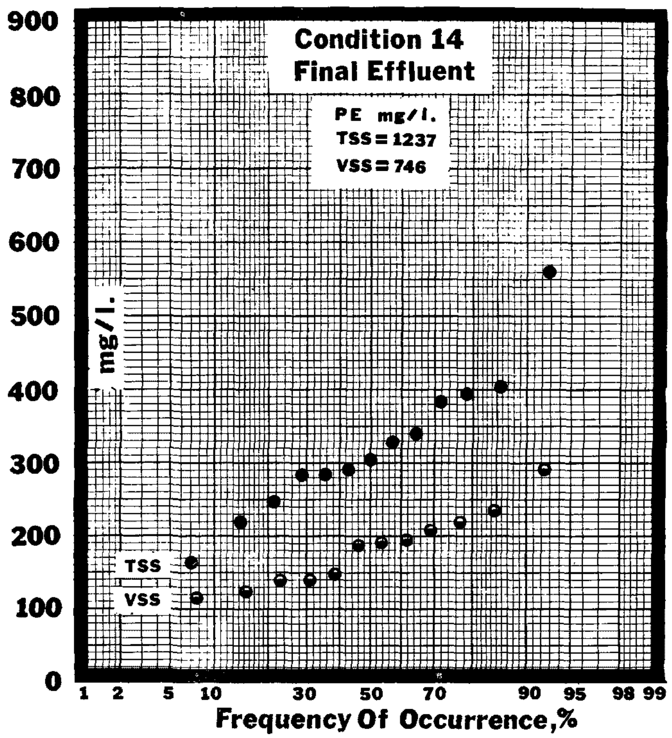

Figure 63. Final effluent concentrations for TSS and VSS for condition 14.

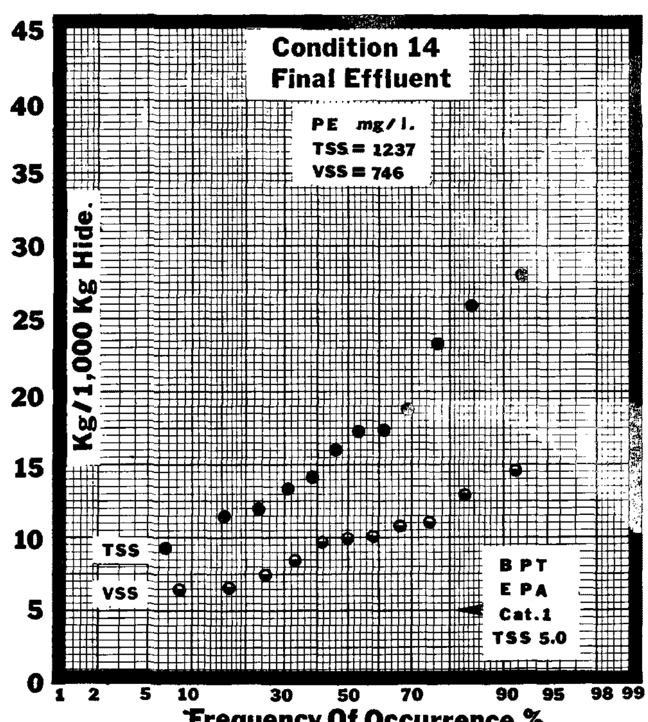

Figure 64. Final effluent mass ratios for TSS and VSS for condition 14.

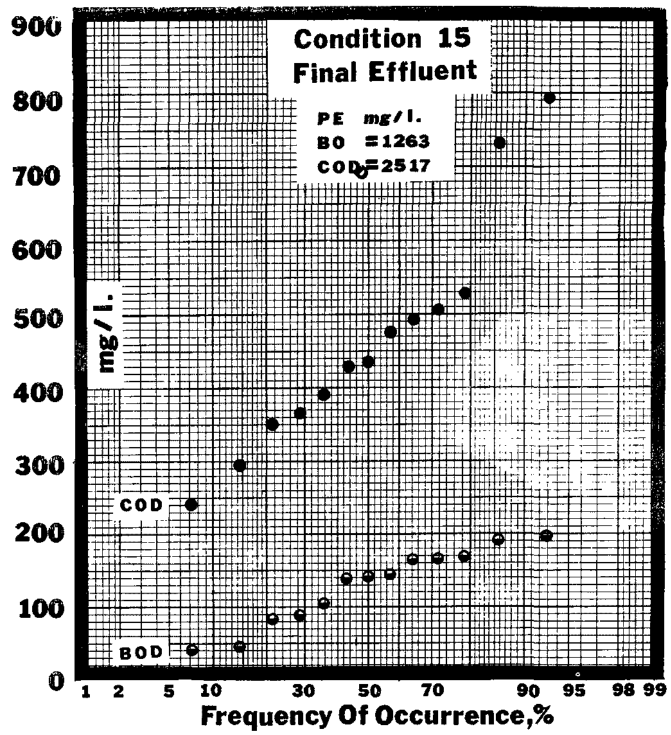

Figure 65. Final effluent concentrations for BOD and COD for condition 15.

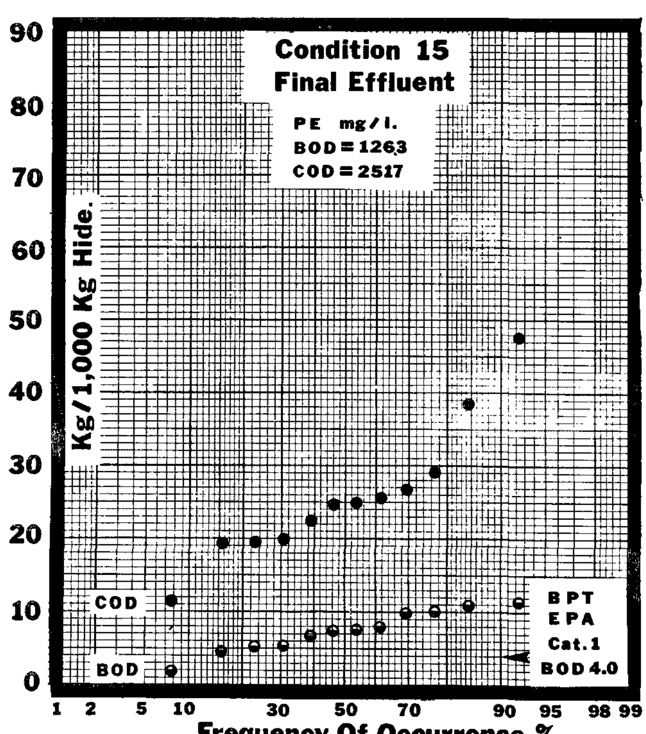

Figure 66. Final effluent mass ratios for BOD and COD for condition 15.

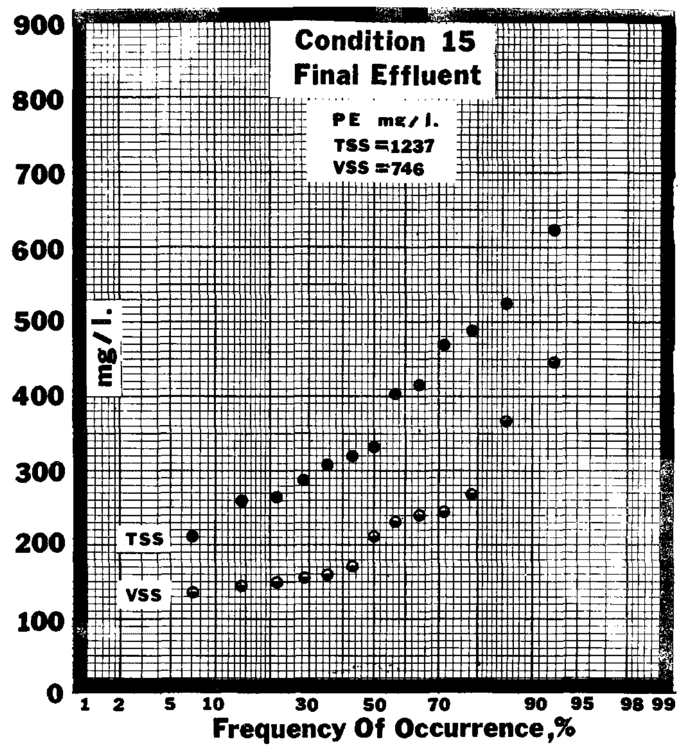

Figure 67. Final effluent concentrations for TSS and VSS for condition 15.

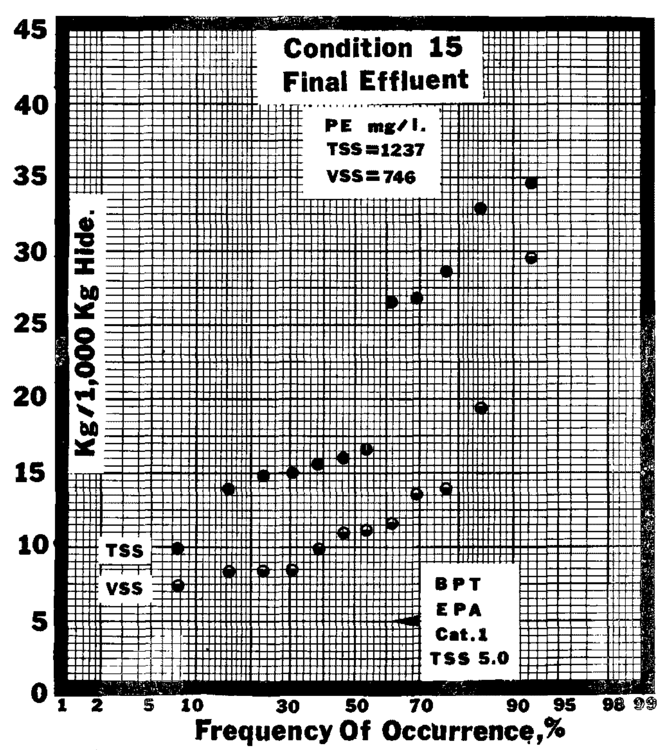

Figure 68. Final effluent mass ratios for TSS and VSS for condition 15.

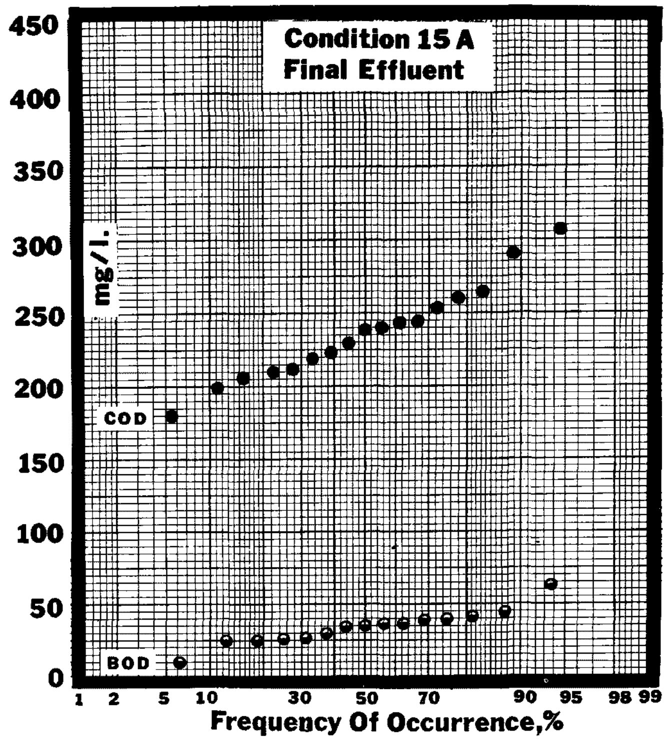

Figure 69. Final effluent concentrations for BOD and COD for condition 15A.

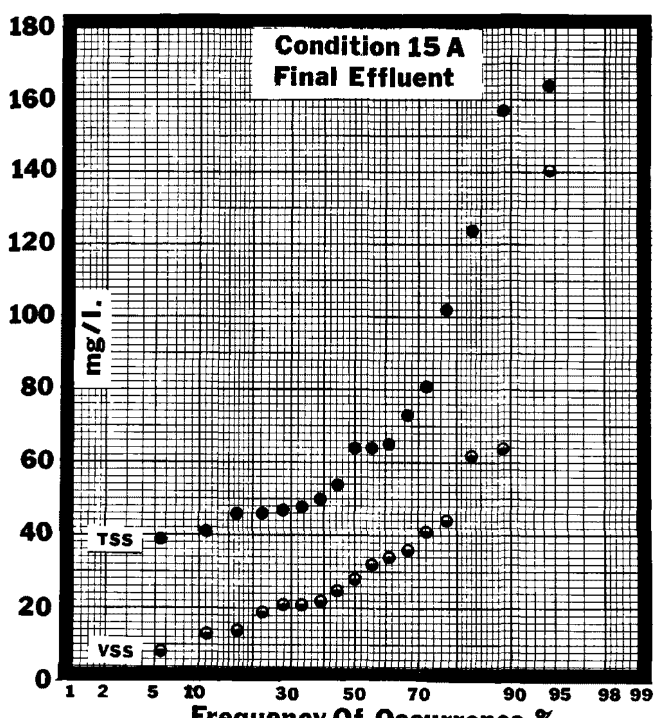

Figure 70. Final effluent concentrations for TSS and VSS for condition 15A.

TABLE 28. LAGOON PERFORMANCE: CONDITION 1

Parameter	Number of data points	Concentration, mg/l Mean	Concentration, mg/l Standard deviation	Concentration, mg/l Range	kg/1000 kg* Mean	kg/1000 kg* Standard deviation	kg/1000 kg* Range
BOD_5	10	36.7	22.4	15-87	1.31	0.87	0.41-3.16
COD	10	287.4	49.4	218-370	10.15	2.47	5.94-14.24
TSS	10	486.0	136.9	208-656	16.80	4.87	8.51-24.72
VSS	10	111.2	34.4	76-200	3.81	1.26	2.07-6.64
Total chrome, Cr	1	2.14	-	-	0.08	-	-
Oil and grease	4	30	20.3	8-62	1.05	0.77	0.22-2.26
Sulfide, S	2	Trace	-	-	Trace	-	-
Total phosphorus, P	6	1.02	0.25	0.66-1.49	0.03	0.01	0.02-0.06
Total organic nitrogen, N	-	-	-	-	-	-	-
pH, standard units	6			7.6-8.3			

* Weight per weight of hides processed.

TABLE 29. LAGOON PERFORMANCE: CONDITION 2

Parameter	Number of data points	Concentration, mg/l Mean	Concentration, mg/l Standard deviation	Concentration, mg/l Range	kg/1000 kg Mean	kg/1000 kg Standard deviation	kg/1000 kg Range
BOD_5	9	51.0	18.8	25-89	2.09	1.11	0.72-4.10
COD	9	476.4	74.0	361-569	19.41	6.22	10.15-27.48
TSS	9	530.2	72.1	352-608	22.06	5.62	14.23-31.29
VSS	9	171.1	46.8	88-252	7.15	3.13	2.36-12.97
Total chrome, Cr	6	3.06	2.09	0.64-6.38	0.26	0.24	0.03-0.75
Oil and grease	3	65.3	43.2	28-126	1.14	0.01	1.13-1.15
Sulfide, S	1	Trace	-	-	0.009	-	-
Total phosphorus, P	3	0.98	0.01	0.96-0.99	0.043	0.004	0.04-0.05
Total organic nitrogen, N	-	-	-	-	-	-	-
pH, standard units	6			7.8-8.1			

TABLE 30. LAGOON PERFORMANCE: CONDITION 3

Parameter	Number of data points	Concentration, mg/l			Kg/1000 kg		
		Mean	Standard deviation	Range	Mean	Standard deviation	Range
BOD_5	10	193.6	64.8	113-322	7.68	2.84	4.25-13.46
COD	10	893.2	180.1	632-1140	35.41	7.82	22.78-54.37
TSS	10	326.5	120.7	132-548	13.02	4.94	5.95-18.35
VSS	10	238.0	67.5	136-344	9.40	2.91	4.61-14.22
Total chrome, Cr	8	5.99	2.49	1.43-9.20	0.28	0.12	0.05-0.40
Oil and grease	6	84.7	35.3	10-120	3.65	1.59	0.44-5.33
Sulfide, S	5	0.08	0.07	0.05-0.19	<.002	-	0.01-<0.001
Total phosphorus, P	10	1.14	0.32	0.62-1.58	0.05	0.01	0.03-0.06
Total organic nitrogen, N	-	-	-	-	-	-	-
pH, standard units	10			7.6-8.2			

TABLE 31.. LAGOON PERFORMANCE: CONDITION 13*

Parameter	Number of data points	Concentration, mg/l			Kg/1000 kg		
		Mean	Standard deviation	Range	Mean	Standard deviation	Range
BOD_5	14	66.8	26.9	17-121	2.39	0.89	0.69-3.91
COD	14	303.3	47.3	215-401	10.76	2.01	8.75-13.93
TSS	14	87.8	30.5	57-165	3.13	1.17	1.49-5.66
VSS	14	46.5	24.0	23-106	1.66	0.89	0.80-3.64
Total chrome, Cr	16	0.77	0.50	0.24-1.67	0.03	0.017	0.01-0.07
Oil and grease	13	29.9	17.3	3.5-53	1.08	0.66	0.12-2.43
Sulfide, S	14	0.07	0.14	Tr-0.53	<.001	-	Tr-0.02
Total phosphorus, P	9	0.37	0.16	0.13-0.65	0.012	0.006	0.01-0.02
Total organic nitrogen, N	16	198.5	43.5	80-260	7.26	2.19	1.83-11.18
pH, standard units	10			6.9-7.5			

* $FeCl_3$ coagulation preceding sedimentation.

TABLE 32. LAGOON PERFORMANCE: CONDITION 13A*

Parameter	Number of data points	Concentration, mg/l			Kg/1000 kg		
		Mean	Standard deviation	Range	Mean	Standard deviation	Range
BOD_5	9	182.4	90.0	17-331	7.40	4.90	0.69-18.61
COD	9	728.8	237.5	215-1313	27.80	15.09	8.75-73.83
TSS	9	415.1	131.5	57-592	15.15	5.76	2.32-24.08
VSS	9	297.7	94.6	24-364	10.30	4.39	0.98-18.89
Total chrome, Cr	12	6.09	2.00	3.71-10.50	0.21	0.04	0.14-0.27
Oil and grease	2	67.5	16.5	51-84	2.51	0.36	2.17-2.87
Sulfide, S	-	-	-	-	-	-	-
Total phosphorus. P	-	-	-	-	-	-	-
Total organic nitrogen, N	9	232	33.8	190-320	8.43	2.08	5.62-12.31
pH, standard units	-			-			

* Without $FeCl_3$ coagulation--laboratory settled.

TABLE 33. LAGOON PERFORMANCE: CONDITION 14

Parameter	Number of data points	Concentration, mg/l			Kg/1000 kg		
		Mean	Standard deviation	Range	Mean	Standard deviation	Range
BOD_5		107.1	20.3	79-134	5.89	1.35	3.71-8.39
COD		500.1	103.0	401-697	27.43	6.58	18.83-43.01
TSS							
VSS							
Total chrome, Cr	10	3.80	1.36	0.96-5.04	0.20	0.07	0.05-0.29
Oil and grease	8	70.80	36.5	30-139	3.50	1.93	1.41-7.47
Sulfide, S	5	Trace	-	-	Trace	-	-
Total phosphorus, P	6	1.67	0.52	0,98-2.65	0.08	0.03	0.05-0.13
Total organic nitrogen, N	13	209.2	14.7	184-238	11.31	1.31	9.05-14.27
pH, standard units	10			7.7-7.8			

TABLE 34. LAGOON PERFORMANCE: CONDITION 15

Parameter	Number of data points	Concentration, mg/l			Kg/1000 kg		
		Mean	Standard deviation	Range	Mean	Standard deviation	Range
BOD_5	13	128.8	49.7	41-197	7.39	2.72	1.92-11.29
COD	13	464.1	150.7	241-793	25.82	9.10	11.32-47.77
TSS	13	377.5	116.7	212-624	20.97	8.01	9.95-34.63
VSS	13	285.2	89.9	136-448	12.74	5.99	7.32-29.61
Total chrome, Cr	10	5.73	2.59	1.42-9.19	0.33	0.13	0.07-0.53
Oil and grease	10	62.2	34.8	13-124	3.14	1.92	0.61-7.0
Sulfide, S	7	0.05	0.05	Tr -0.07	<.001	-	-
Total phosphorus, P	6	1.90	0.55	1.50-3.06	0.10	0.03	0.60-0.15
Total organic nitrogen, N	13	177.1	19.9	146-198	9.50	1.48	7.24-12.03
pH, standard units	11			7.5-7.9			

TABLE 35: LAGOON PERFORMANCE: CONDITION 15A*

Parameter	Number of data points	Concentration, mg/l	
		Mean	Range
BOD_5	15	34.3	10-63
COD	15	236.6	180-307
TSS	15	74.4	39-164
VSS	15	36.7	8-140
Total chrome, Cr	17	0.98	0.39-2.51
Oil and grease	17	31.6	7-176
Sulfide, S		-	
Total phosphorus, P		-	
Total organic nitrogen, N	17	204.1	170-236
pH	26	7.7	7.2-7.9

* After project period.

TABLE 36. MEAN PRIMARY EFFLUENT PARAMETERS FOR LAGOON CONDITIONS

Condition	Dates *	Process formula	Rendering	Coagulant addition to raw waste	Number of data	Primary effluent, mg/l			
						BOD	COD	TSS	VSS
1	8/7/73-10/29/73	Summer	No	None	14	867	1978	1170	509
2	8/7/73-10/29/73	Summer	No	None	14	867	1978	1170	509
3	11/15/73-12/31/73	Spring-Fall	No	None	9	1090	2487	737	512
13	9/20/74-11/1/74	Spring-Fall	Yes	$FeCl_3$	20	1256	2459	1152	688
13A	9/20/74-11/1/74	Spring-Fall	Yes	$FeCl_3$	20	1256	2459	1152	688
14	9/26/74-11/1/74	Spring-Fall	Yes	$FeCl_3$	18	1263	2517	1237	746
15	9/26/74-11/1/74	Spring-Fall	Yes	$FeCl_3$	18	1263	2517	1237	746

*Dates through which primary settling effluent was evaluated. Data for conditions 1, 2; 13, 13A; 14, and 15 were averaged over the same periods respectively.

obtained can serve to provide some relative measure of the performance of the systems.

Biochemical Oxygen Demand and Total Suspended Solids

In viewing the BOD mass ratio plots for conditions 1 and 13 (Figures 42 and 54), it is apparent that all of the 24-hour composite samples had values less than the BPT limitation of 4.0 kg/1000 kg. Obviously if all effluent values are less than this limitation, the 50% or mean value of all effluent values are less than the stated BPT value. Condition 13 represented an effluent that had received $FeCl_3$ addition as a coagulant to the secondary effluent. Neither condition represented a period when cold weather conditions prevailed, therefore, the results likely do not demonstrate performance during the poorest 30-day period corresponding to the BPT maximum monthly average limitation reported.

For condition 2 (Figure 46), approximately 85% of the 24-hour composite values was within the BOD limitations as well as the 50% of mean value for this period. The same restrictions apply as above concerning the season when the pond system was operated for this condition. In conditions 3, 14 and 15 (Figures 50, 62 and 66, respectively), 90% of the 24-hour composite BOD values exceeded the BPT limitation and likewise for the mean value. One can conclude that these operating conditions would not meet the BPT limitation regardless of season. In condition 13A (Figure 58), identical to 13 but without the benefit of $FeCl_3$ coagulation of the secondary effluent, 70% of the 24-hour composite BODs exceeded the BPT limitation as well as the mean or 50% value. Although the value of utilizing $FeCl_3$ as a coagulant under operating condition 13 is evident, no inference can be made concerning the ability of the lagoon systems to meet BPT requirements if a coagulant is employed, however, higher removals are expected with the use of the coagulant.

With the exception of condition 13, none of the 24-hour composite values reported meet the BPT limitation for TSS of 5.0 kg/1000 kg hide (see Figures 44, 48, 52, 56, 60, 64 and 68). In condition 13 (Figure 56), 85% of the 24-hour composite values were less than the 5.0 kg/1000 kg hide limitation, as was the mean or 50% value. The limitation as applied to the BOD results concerning cold weather operating conditions must be applied to the TSS results as well.

Low solids systems operating during the warmer weather periods conditions 1 and 2 can make the BPT requirement for BOD_5 but coagulant is definitely required to achieve the requirement with respect to TSS. Even more significant is the fact that PBT requirements for BOD and TSS could not be met 100 percent of the time during the colder months of the year (Figures 66 and 68), even with high solids operation condition 3 (Figures 50 and 52), and condition 15 (Figures 66 and 68). The high effluent solids from these processes and the contribution of BOD by the VSS would suggest that proper coagulation might achieve the BPT requirements for BOD and TSS but no long term data is available on the stability of a coagulant dosed high solids system over the winter months. The average $FeCl_3$ dosage of 214 mg/l to the low solids lagoon effluent for condition 13 (Figures 53-56) did readily achieve a vast improvement in effluent quality.

Examination of BAT effluent limitations with respect to BOD and TSS indicate that only condition 1 (Figure 42) was able to achieve the BOD requirement greater than 50 percent of the time. No condition studied could achieve the TSS requirement, even with coagulant dose.

Total Chrome, Oil and Grease, TKN, Sulfide, and pH

Tables 28 through 35 summarize the effluent quality characteristics for the selected conditions discussed above. A scarcity of data for a number of the quality parameters precluded probability plots. Examination of these tables and the BPT effluent limitations as set forth in Table 23 would produce the following conclusions.

With the exception of a single value reported for condition 1 (Table 28), the total chrome requirement can be met for BPT situations only with addition of coagulant (condition 13, Table 31). All other conditions studied produced total chrome levels in excess of 0.1 kg/1000 kg on an average basis.

In no condition studied could the requirement on oil and grease of 0.75 kg/1000 kg hide be met, even with the addition of coagulant aid. Significant decreases in oil and grease were achieved by chemical coagulation (condition 13 -- 1.08 $\pm$ 0.66 kg/1000 kg versus condition 14 -- 3.50 $\pm$ 1.93 kg/1000 kg). Lower values noted for conditions 1 and 2 were due primarily to lower oil and grease loadings to the lagoons since no rendering was practiced during these operational periods.

In no condition studied could the requirement on TKN of 0.27 kg/1000 kg of hide be achieved for BAT (Table 32). The TKN values expressed as kg/1000 kg were excessively higher than established in the Guidelines Report (3). TKN, values ranged from 7.3 to 11.3 kg/1000 kg on an average and no apparent correlation existed between this parameter and a chemical coagulant addition or lagoon loading rate.

The data in Tables 28-35 show that sulfide levels in the lagoon effluents will fall below BAT requirements of 0.005 kg/1000 kg of hide. Only when aerator failure occurred (or under severe overload where oxygen transfer rate was exceeded by uptake rates throughout the lagoon) did sulfide appear in significant amounts in the effluent.

The pH values in the lagoon effluents were dependent upon tannery process formula, temperature and lagoon loading conditions. As was noted in the discussion of the raw wastewater, alkalinities and pH were highly variable. This variation was greatly attenuated in the lagoon effluents. Normally pH varied from 7.5 to 8.3 except for condition 13 where $FeCl_3$ additions lowered pH values in the range of 6.9 to 7.5. All values of pH reported were in the range of values 6.0 to 9.0 for BPT and BAT effluent limitations. Alkalinity was reduced through the lagoons, likely as precipitated carbonates. Langlier Saturation Index dropped from a range of +1.8 to +2.5 in the primary effluent to +0.3 to +0.6 in the lagoon effluents suggesting that the waste was sufficiently stabilized against carbonate precipitation.

Fate of Nitrogen

The fate of nitrogen through the pond system is best depicted by results obtained for conditions 13, 14, and 15 (Table 37). Scant data were available on conditions 1, 2, and 3.

TKN reductions through the lagoon system were significant ranging from about 17′ to 30%. This reduction was likely due to adsorption and precipitation of colloidal materials although some biological oxidation and deamination may have occurred. Nitrification did occur to a limited extent in all three systems. The greatest degree of nitrification occurred under condition 15 at an F/M of 0.12 where the average nitrate concentration increased from 25 mg/l to 41 mg/l. Ammonia reduction was noted under this condition as well from 99 to 73 mg/l. At the higher F/M loading of 0.34 (conditions 13 and 14) only slight nitrification occurred and ammonia concentrations remained constant through the system.

Fate of Chlorides and Sulfate

As would be expected, the conservative element, chloride, did not undergo change in the lagoon system. Effluent chloride concentrations varied with process formula, normally ranging from 1500 to 3000 mg/l without rendering and from 3000 to 4000 mg/l with rendering. Sulfates did not reduce during the process since it was normally aerobic. Oxidation-reduction potentials did not drop sufficiently even in the secondary clarifiers to allow any significant conversion of sulfate to reduced sulfur

TABLE 37. LAGOON PERFORMANCE: NITROGEN ANALYSES

Condition	TKN mg/l avg	TKN mg/l sd	NH_3-N mg/l avg	NH_3-N mg/l sd	NO_3-N mg/l avg	NO_3-N mg/l sd	Temp. range °C
13pe*	251	90	99	10	25	5.8	9-20
13fe	198	43.6	104	10	28	7.5	
14pe	251	90	99	10	25	5.8	7-19
14fe	209	14.2	102	8.5	29	5.1	
15pe	251	90	99	10	25	5.8	8-17
15fe	177	19.9	73	12.9	41	16.6	

*Primary effluent (pe); final effluent (settled)(fe).

TABLE 38. LAGOON PERFORMANCE: COLIFORMS

Condition	Number of data	Θ Days	F/M kg/kg	Total* coliforms MPN per 100 ml	Fecal* coliforms MPN per 100 ml
6	5	2.1	0.21	561,390	1,949
7	4	2.7	0.89	582,343	3,646
8	6	2.2	0.87	133,147	1,582
9	6	4.0	0.23	112,248	1,106
10	5	3.0	0.10	13,506	1,533
11	5	9.8	0.26	1,118	108
12	3	7.5	0.05	1,233	220
13	6	5.5	0.34	855	113
14/15	6	5.6/3.8	0.34/3.8	2,411	229

* Geometric means.

compounds. Effluent concentrations ranged from 1100 to 1500 mg/l as $SO_4^=$ during the last year of the study when rendering was employed.

Fate of Bacteria

Bacterial studies were conducted on the lagoons during the experimental period. A detailed study on the microbiology of the lagoons was conducted in the summer of 1972. In brief, this study found six bacterial genera: Pseudomonas, Bacterium, Flavobacterium, Achremobacter, and Alcaligenes, the first three being dominant genera during the late summer months. Protozoa were also examined on a few occasions. Flagellated protozoa were predominant with some ciliated forms being found in low numbers. No other protozoa forms were observed in this study.

Coliform and fecal coliform analyses were conducted throughout the study period on lagoon effluents, chlorinated and unchlorinated. Table 38 presents the geometric means of coliform counts from secondary settling tanks for 10 different lagoon conditions. Several points can be made from these data. The fecal coliform MPN requirement of 200/100 ml could be met in only two lagoon conditions without chlorine addition based on geometric means. Condition 13 with $FeCl_3$ precipitation did achieve fecal coli reductions below 200 MPN/100 ml 85 percent of the time. Higher coliform counts were observed at the higher organic loading rates and/or shorter hydraulic detention times. Hydraulic retention time may be more significant as contrasted by counts from condition 11 (108 MPN/100 ml) versus condition 9 (1106 MPN/100 ml) and condition 9 (1106 MPN/100 ml) versus condition 6 (1949 MPN/100 ml). One added complication in this analysis was the absence of data on primary effluent coliforms. The higher effluent coliform might have been influenced by higher influent coliform counts.

One brief analysis of the die-off of coliforms in lagoons was conducted in September and October. As shown in Table 39 there appeared to be a very substantial increase rather than die-off in both total and fecal coliforms through the lagoon system. It is unlikely that this represented real growth, but rather release of coliforms from larger particle masses during the aeration process or the toxic characteristics of the raw wastewater may have produced analytical underestimates of the coliform group. The lagoon counts are about two orders of magnitude higher than settled effluents by comparing these counts to those of conditions 13 and 14 on Table 38.

TABLE 39. LAGOON PERFORMANCE: COLIFORM DIE-OFF

Date	Raw Waste Total Coliform MPN/100	Raw Waste Fecal Coliform MPN/100	Lagoon 1 (Condition 13) Total Coliform MPN/100	Lagoon 1 (Condition 13) Fecal Coliform MPN/100	Lagoon 3 (Condition 14) Total Coliform MPN/100	Lagoon 3 (Condition 14) Fecal Coliform MPN/100
9/27/74 7am-noon	400	<50	49,500	200	49,300	1,700
10/11/74 7am-noon	42,000	420	48,000	5,800	340,000	2,000

SVI of Mixed Liquor

The solids settling ability of the mixed liquor from the lagoons was characterized by finely divided solids which readily carried over the weirs even at the relatively low overflow rates and solids loading rates employed in the secondary clarifiers. The bulk of the solids did settle cleanly, even for the high mixed liquor conditions (5, 6, 12, and 15) with SVI values always well below 100. The granular characteristics of the sludge containing high concentrations of inert precipitated salts likely contributed to this.

SECONDARY CLARIFIER PERFORMANCE

The solids loading to the clarifiers were normally low ranging from 0.49 to 4.9 $kg/d/m^2$ (0.1 to 1.0 $lb/d/ft^2$) for the low solids systems to values of 9.8 to 58.6 $kg/d/m^2$ (2.0 to 12.0 $lb/d/ft^2$) for the high solids systems. No correlation appeared to exist between effluent suspended solids and solids loadings within this range. Bulking was never apparent during the study, and absence of heavy protozoan populations may have accounted to some extent for the discharge of large amounts of finely divided solids. The effect of chemical addition on removal of these solids is apparent from examination of condition 13 (with $FeCl_3$ coagulant, Figure 55) versus condition 13A (no coagulant added, Figure 59).

The underflow solids from the clarifiers were highly variable, varying from 3000 to 27,000 mg/l for the high solids system and from

2000 to 8000 mg/l for the low solids systems. Sampling difficulties and operational problems led to the wide variation on these values.

Examples of settling curves for typical mixed liquor sludges for condition 15 are depicted in Figures 71 and 72. Figure 71 shows the zone settling interface for various concentrations of TSS with respect to time. The rate of settling of the sludge water interface for each sludge concentration is used to construct the flux concentration curve shown in Figure 72. For the sludge loading on that day, 47.4 $kg/d/m^2$ (9.72 lb/ d/ft^2) the maximum underflow solids would have been 9100 mg/l on that date. Values as high as 27,000 mg/l were achieved for condition 15 under solids loadings ranging from 39.1 to 58.6 $kg/d/m^2$ (8 to 12 lb/d/ ft^2).

LAGOON SOLIDS MEASUREMENTS

The estimation of biological sludge production by the lagoon systems studied was complicated by the influent wastewater characteristics and the physical characteristics of the lagoons. Efforts were made to perform material balances on the systems studied but results were not meaningful.

The primary effluent contained high concentrations of non-settleable suspended solids of which 50-70 percent were volatile. A portion of these finely divided suspended solids, such as protein substance, had an opportunity to be precipitated with the reduction in pH within the lagoon. Analysis of the accumulated solids within the lagoon indicated that 55-60 percent of the solids were fixed. The organic suspended solids may have been (1) adsorbed into these inorganic precipitates, (2) biodegraded in suspension or within the precipitated sludge, (3) bioflocculated, or (4) simply carried through the process.

Accumulation and Resuspension and/or Resolution of Lagoon Solids

Since the lagoons were not well mixed, accumulation or resuspension of solids was noted throughout the period of this study. Table 40 summarizes the results of lagoon accumulation studies. The measurements were made according to the procedure outlined in Appendix A. These data are presented for given lagoon conditions after the appropriate number and location of aerators had been established. Since chemical and biochemical reactions are both pH and temperature dependent, a plot of lagoon pH and temperature was made to examine the importance of these variables in sludge accumulation. Figure 73 illustrates that, for the systems studied, accumulations were most

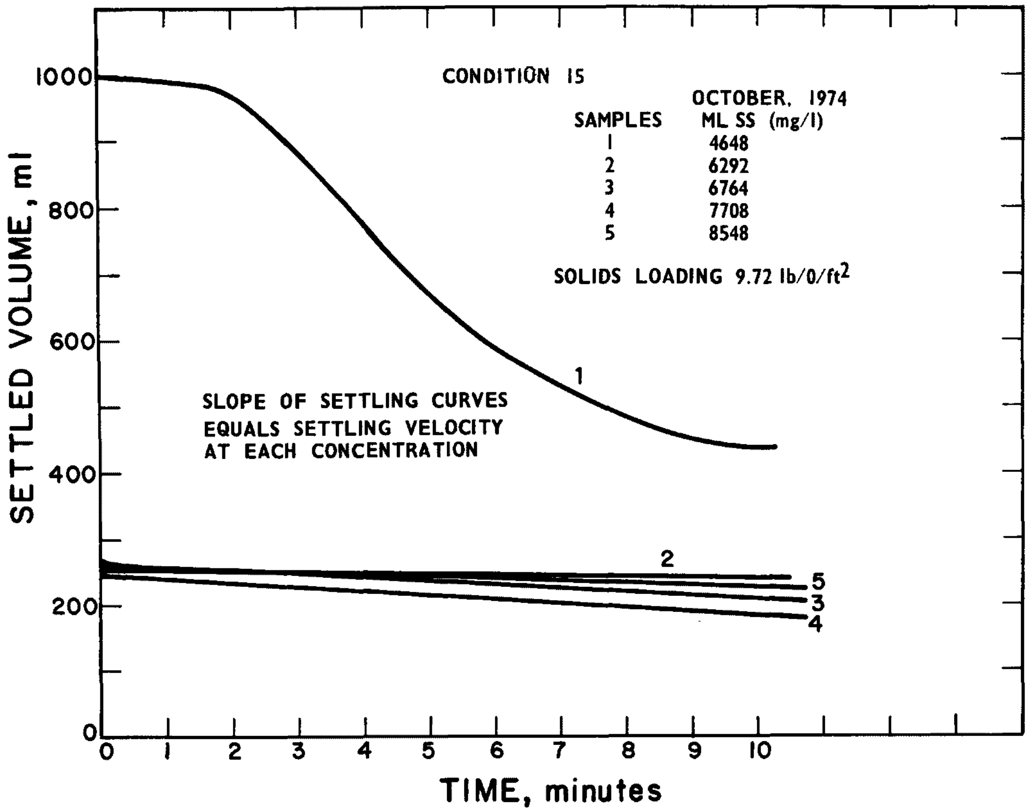

Figure 71. Mixed liquor settling curves for condition 15.

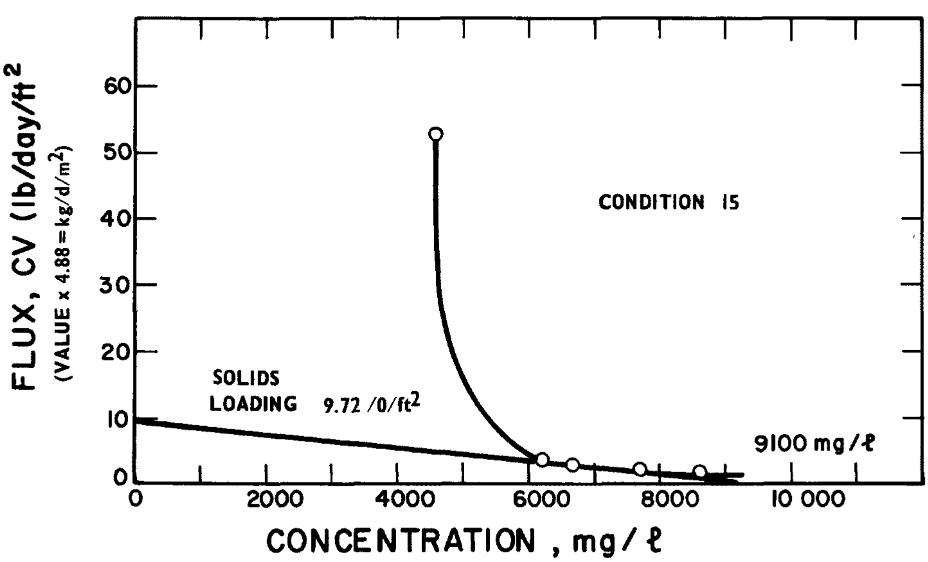

Figure 72. Flux concentration curve for mixed liquor condition 15.

TABLE 40. SLUDGE ACCUMULATION IN LAGOONS

Condition	Net sludge++ volume change gal/d	Sludge accumulation↓* sludge solution↑ TS lb/d	VS lb/d	COD lb/d	TKN lb/d	Ca^{++} lb/d	Lagoon temp °C	Lagoon pH	Phosphorus addition	Sludge return
3	700↓	600↓		400↓	35↓	125↓	4.4	7.7	No	Yes
4	346↓	331↓		209↓	20↓	58↓	7	7.65	Yes	Yes
8	1350↓	1535↓		1083↓	107↓	220↓	19	8.1	No	Yes
9	505↓	442↓		490↓	30↓	54↓	19	8.1	Yes	Yes
10	140↓	127↓	8	319↑	9↑	84↓	21	7.9	Yes	Yes
11+	770↑ / 560↑	460↑ / 590↑	278 / 334	574↑ / 665↑	80↑ / 40↑	173↓ / 83↑	24 / 21	7.9 / 7.5	Yes	No
12+	700↑ / 80↑	460↑ / 100↑	250 / 51	400↑ / 75↑	40↑ / 3↓	159↓ / 60↑	21 / 15	7.7 / 7.5	No	Yes
13	607↑	457↑	242	359↑	10↑	223↑	14	7.7	No	No
14	76↑	103↑	51	72↑	3↓	41↑	14	7.7	Yes	No
15	60↑	29↑	2	171↓	31↓	14↑	13	7.7	Yes	Yes

* ↓ Indicates deposit or accumulation of material, ↑ indicates resuspension and/or resolution of materials.

\+ Series operations, top figure represents first lagoon in series, lower figure represents second lagoon in series.

++ Values represent either the net sludge volume increase or decrease as an average over the operating period.

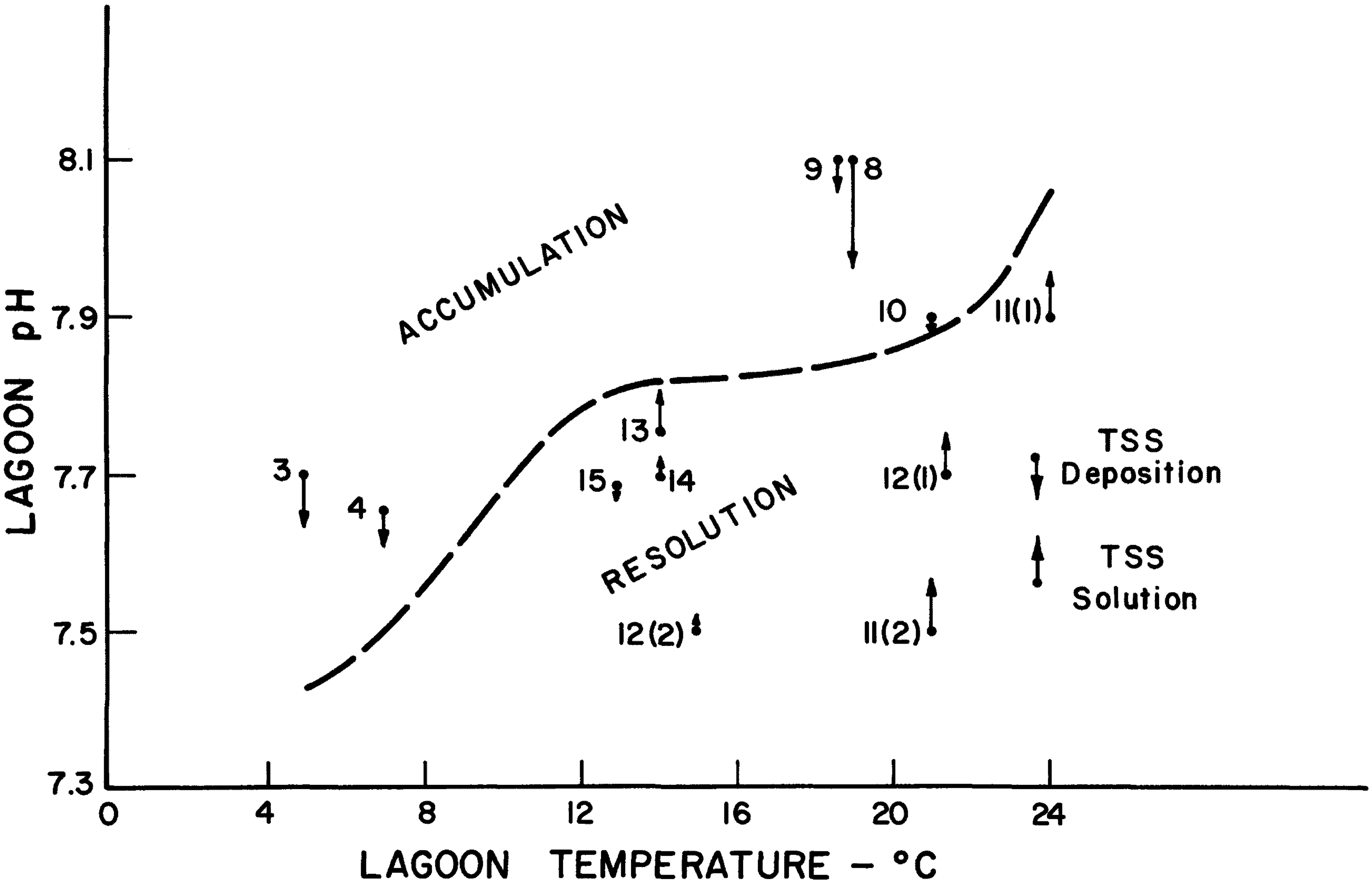

Figure 71. Sludge solids (total solids) accumulation (increase) or solution (decrease) in lagoon systems.

predominant in colder temperatures or at the higher pH values. Solution of sludges or loss of solids from the lagoon sludge layer occurred in the warmer periods and at the lower pH values.

Carbonates are less soluble at the higher pH values, accounting for in part the sludge accumulations. The anaerobic degradation of the accumulated organics will be more rapid at the higher temperatures resulting in a greater loss of organic solids at the higher temperatures.

Sludge Solids Production in Secondary Treatment

The discussion above makes it clear that any effort to account for biological solids production by employing a material balance around the lagoon system is simply too complex and that estimates of fixed, non-degradable solids carryover is not realistic. Crude estimates of gross solids "production" were made in those instances where data was sufficient to estimate solids "loss" from the system. In these instances, the change in mixed liquor suspended solids plus accumulated sludge plus wasted effluent suspended solids were employed to calculate a gross solids "production" per unit of BOD removal. These values appear in Table 41. There are several trends noted in this data. Generally as F/M loading increases, net solids production increases, a phenomenon well documented in the literature. No immediate effect of temperature is apparent. Most significant, however, is the substantial reduction in solids production with the addition of phosphorus. Direct comparisons may be made between conditions 7 and 8 and conditions 2, 3 and 4. The reduction in "produced" solids with phosphorus addition may be attributed to more active biological respiration which could produce higher rates of endogenous respiration. Phosphorus poor conditions did not produce significantly poorer effluents, however, but oxygen uptake rates were noted to rapidly increase upon addition of that element. One might also attribute lower apparent solids "production" in phosphorus treated wastes to greater BOD reductions in proportion to the fixed fraction of recalcitrant suspended solids which would carryover. Thus the ratio of TSS to BOD removal would decrease primarily because of the increase in the denominator.

The range of production values from 1.09 to 1.72 kg TSS/kg BOD removal are higher than those normally reported for biological systems. But, again, it should be emphasized that these values include carryover of non-degradable organic and inorganic suspended solids. Since steady state was never ideally achieved within the lagoons with respect to a solids balance, it is not realistic to predict whether the "production" values cited are valid over a long period of time.

TABLE 41. LAGOON SLUDGE PRODUCTION

Condition	Sludge return	Phosphorus addition	F/M kg/kgd	Lagoon temp. °C mean	range	Sludge* production kg TSS/kg/BODr
2	No	No	0.14	13	10-17	1.42
3	Yes	No	0.15	4.4	0-14	1.35
4	Yes	Yes	0.16	7	6-12	1.09
5	Yes	Yes	0.41	11	8-14	1.26
7	No	Yes	0.89	16	13-19	1.15
8	Yes	No	0.87	19	18-24	1.72
12	Yes	No	0.05	15	11-20	1.27

*Determined as the sum of (1) the change in mixed liquor suspended solids, (2) sludge accumulations in the lagoon system, and (3) sludge solids wasted and in the settled effluent.

That these "produced" solids contain a variety of constituents including biological solids and inorganic and organic residues that have been carried through the process is apparent. Since all of these solids must be handled as a sludge eventually, the source of the solids is perhaps not critical at this point.

OXYGEN REQUIREMENTS

The consumption of oxygen in the biological stabilization of organic matter within the lagoons was estimated by monitoring oxygen uptake rates within the lagoon system on several occasions during each condition. In order to most effectively estimate the oxygen requirement, it was necessary to monitor oxygen uptake at a number of grid points within the lagoon system over a representative period of time. Since organic loading to the lagoon was variable throughout the day, it was very difficult to assess oxygen consumption rates as a function of BOD_5 removed. Because of the time required to do these surveys properly only limited data was collected. Extensive field studies were performed for conditions 2, 3, and 5, during a period when oxygen transfer analyses were being made. Details of the method employed appears in Appendix B.

In analyzing the routine data collected on oxygen uptake rates within the lagoons. It was determined that representative data was also available for conditions 1, 4, 11, 14, and 15. These calculations have been included in the subsequent analyses although it must be recognized that the data base is not as rigorous as that for conditions 2, 3, and 5.

In assessing oxygen uptake rates, efforts were made to negate the influence of immediate chemical oxygen demand due to the presence of sulfides. Early uptake studies showed a pronounced break in the uptake curves, the uptakes being very rapid initially, followed by a substantial reduction in rate. The diphasic uptake response was due to sulfide oxidation and laboratory studies verified this. Modification of the uptake analysis was subsequently performed wherein samples collected for uptake measurements were vigorously aerated for 15 minutes to oxidize reduced compounds prior to actual uptake measurements. Thus, oxygen uptake values reported herein reflect only biological consumption.

Results of the oxygen uptake studies are presented in Table 42. The values reported are expressed in terms of mass of oxygen consumed per mass of BOD_5 removed. The uptake values were also corrected to 20°C for comparison purposes. The temperature coefficient, Θ, employed was 1.08 (4). Values of the uptakes reported ranged from as high as 3.51 to 0.9 kg O_2/kg BOD_5 removed.

The effect of lagoon loading on these oxygen uptake values is depicted in Figure 74. No trend is apparent from these few data points. It does not appear that phosphorus addition has affected uptake rates appreciably.

Most significant in Figure 74 are the higher uptake values reported for conditions 4 and 5. These conditions were both operated in early spring when lagoon temperatures began to increase. Since substantial deposition of solids had occurred over the winter months due to reduced biological activity in the anaerobic sludge layer and due to aerator failure, the solubilization of biodegradable organics in the spring from these underlying anaerobic sludge deposits likely increased oxygen demand. Consequently, the oxygen consumption per mass of BOD_5 removed from the influent would be high in comparison with values estimated for conditions operated during the late summer and fall. This phenomenon is common in incompletely mixed lagoons in the north where sludge deposition plays an important role. Supply of sufficient oxygen during the critical spring period can be a very signficant operational problem for such lagoons.

Long term BOD studies were performed on several occasions

TABLE 42. BIOLOGICAL OXYGEN CONSUMPTION IN LAGOONS

Condition	Dates	Recycle	Phosphorus addition	F/M kg/kg	T °C	$\frac{\text{kg O2}}{\text{kg BOD}_5}$ at T	$\frac{\text{kg O2}}{\text{kg BOD}_5}$ at 20°C *
1	8/7-9/17	No	No	0.13	20	2.18	2.18
2	10/5-10/29	No	No	0.14	13	0.90	1.54
3	11/16-12/31	Yes	No	0.15	4.4	0.63	2.01
4	3/8-3/24	Yes	Yes	0,16	7	1.29	3.51
5	3/8-3/24	Yes	Yes	0.41	11	1.77	2.60
13	9/2-11/1	No	No	0.34	14	0.58	0.92
14	9/26-11/1	No	Yes	0.34	14	0.56	0.89
15	9/27-10/31	Yes	Yes	0.12	13	1.16	1.98

* Calculated by $k_T = k_{20}\Theta^{T-20}$; $\Theta = 1.08$.

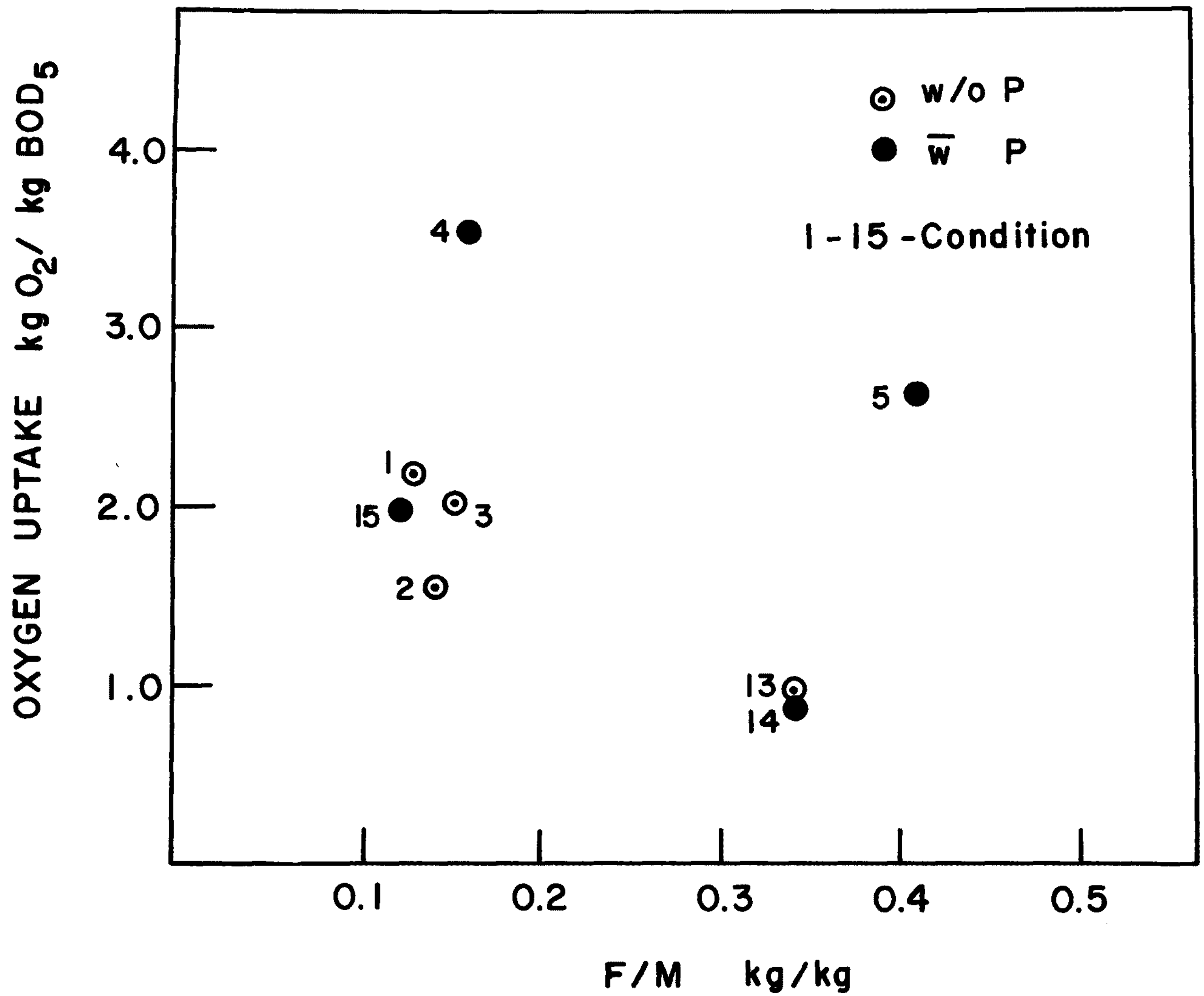

Figure 74. Biological oxygen consumption at 20^{o}C relative to F/M ratio.

during the study period. The ratio of ultimate carbonaceous BOD to BOD_5 on primary effluent ranged from 1.42 to 2.25 averaging 1.86. Provided that nitrification does not play an important role in the lagoon systems, one would assume that minimum oxygen consumption per mass of BOD_5 removed would fall within this range. The values recorded in Table 42 did appear to be consistent with this finding with the exception of conditions 4 and 5 previously discussed. As noted in Table 37, nitrification did occur to some extent in conditions 13 and 15. The oxygen demand estimated for ammonia oxidation in these systems amounted to less than 5% of the total oxygen demand.

The oxygen consumption values reported in this study are higher than those for domestic wastewaters, but this is not unusual. There is no reason to expect that such a relationship should be universal for all wastewaters. It should be re-emphasized, as well, that one must add to these figures the chemical oxygen demand exerted by sulfides as well as the oxygen consumed by ammonia oxidation. The oxygen consumed by sulfide may range from 0.75 to 2.0 kg per kg sulfide oxidized depending upon the end product of oxidation (thiosulfate and sulfate respectively). Oxygen demand by ammonia is approximately 4.5 kg per kg ammonia oxidized to nitrates.

OXYGEN TRANSFER

From the beginning of the demonstration project it was apparent that the aerators provided under the contract were inadequate in maintaining solids in suspension. Three low speed 10 HP aerators were provided in each lagoon providing a power input of 31 HP/mg (0.23 HP/1000 ft^3). Demonstrations, both at the manufacturers test facility and in the lagoons at S. B. Foot Tanning Company, indicated that for these very shallow lagoons, 1.83 m (6 ft) water depth, the low speed aerators were totally inadequate in maintaining the solids in suspension. A detailed report on these studies over a two year period are on file at the S. B. Foot Tanning Company. In summary, these studies showed that high speed aerators were more effective in mixing the shallow lagoons. Furthermore, employment of a large number of small aerators was more effective than a few larger ones. The final aerator configurations were installed and in operation by the late summer of 1973. Twelve HP high speed aerators were arranged as shown in Figure 6. These aerators were capable of providing adequate oxygen transfer under most lagoon conditions studied, although high oxygen demands occurring under certain lagoon conditions studied did deplete oxygen levels to zero. At no time were the lagoons ideally mixed and accumulations of sludge were evident (Table 40).

Oxygen transfer studies were conducted on occasion from October of 1973 through August of 1974. The studies were conducted by collecting six samples (two per each third of the lagoon) and determining oxygen uptake rates, oxygen transfer capacity --α(Kla waste/Kla tap), oxygen saturation ratio -- β (Cs waste/Cs tap), D.O., sulfide concentration, temperature and mixed liquor solids. Oxygen transfer rates were estimated by the following equation:

$$N_o = \frac{N}{\alpha} \quad \frac{C_s}{(C_{sw} - C)} \quad 1.02^{20-T}$$

where: N_o is the oxygen transferred per HP-hr at 20°C and 0.0 mg/l D.O.;

N is the oxygen transferred per Hp-hr at lagoon conditions;

C_s is the saturation of oxygen in tap water at 20°C - 9.2 mg/l;

C_{sw} is the waste oxygen saturation value (βC_s); and

C is the measured D.O.

The value of N was calculated based on complete oxidation of sulfide to sulfate.

$$S^{=} + 2O_2 \rightarrow SO_4^{=}$$

plus the oxygen uptake rate at that sample point.

Values of alpha (α) were obtained in the laboratory employing air diffusers within a vessel and comparing lagoon samples against tap water under identical conditions. It should be noted that this procedure was not completely valid since oxygen transfer in the lagoons was provided by mechanical aeration rather than by diffused air. There is sufficient data in the literature to suggest that differences do exist in alpha measurements employing bubble aeration versus mechanical shearing of the liquid surface. The beta correction was based primarily upon appropriate salinity or dissolved solids correction.

Results of the oxygen transfer studies are summarized in Table 43. (Calculations appear in Appendix B.) Values estimated for the standard aeration efficiency (N_o values) appear to be higher than normally expected for this type of device. This may be attributed to some extent to the sulfide oxidation correction which was not completely verified. (Note that

TABLE 43. OXYGEN TRANSFER STUDIES

Date	Lagoon number	Oxygen uptake rate mg/l/hr	Aerators HP	Lagoon volume mg	T °C	Alpha	Beta	C mg/l	Sulfide oxidized lb/d	N* $\frac{LBO_2}{HP\text{-}hr}$	N_o+ $\frac{LBO_2}{HP\text{-}hr}$
10/4/73	2	21.4	60	0.845	20	0.74	0.90	1.70	530	3.26	6.22
10/4/73	3	10.95	60	0.855	17	0.78	0.90	5.23	0	1.29	4.77
10/4/73	4	7.45	60	0.870	17	1.0	0.90	8.00	0	0.90	4.88
10/17/73	2	21.5	60	0.845	18	0.75	0.90	1.51	530	3.26	5.88
10/23/73	1	2.3	55	0.971	14	0.91	0.90	8.50	50	0.43	5.60
12/19/73	3	4.7	60	0.849	5	0.86	0.90	9.83	150	0.76	6.40
8/6/74	3	7.5	60	0.896	18	0.74	0.97	4.58	0.8	0.95	2.58

* N is the oxygen transferred per nameplate HP-hr at lagoon conditions.

+ N_o is the oxygen transferred per nameplate HP-hr at 20°C and 0.0 mg/l D.O., assuming consumption by sulfide.

oxygen uptakes measured were pre-aerated for 15 minutes to avoid measurement of sulfide oxidation, and therefore measure biological uptake only.) More important may simply be the errors in measurement and assumed distribution of oxygen uptake. The analysis of alpha may also produce some error, although the values measured seem reasonable and, if anything, may be a little high.

SECTION XI

CHLORINATION STUDIES

Owing to the relatively high concentrations of total and fecal coliforms in the wastewater and the potential presence of pathogens from the cattle hides, the plant was designed to provide chlorination of the final effluent. No sanitary wastewaters were admitted to the facility however. A description of the chlorination facilities appears elsewhere.

SAMPLING AND ANALYSES

Routine analyses of the final effluent for total and fecal coliforms as well as total bacteria were performed during the months of May through November when chlorination was required by the State of Minnesota Pollution Control Agency. Analyses were performed in both 1973 and 1974.. Details of the bacterial analyses are outlined in Appendix A. During the chlorination period, routine data was also collected for chlorine dose and effluent characteristics. Analyses for bacteria were obtained from grab samples taken from the final effluent discharge weir and from the two final clarifiers. Grab sampling was normally performed in the morning. Instantaneous flow rates and chlorine dosage were read during the grab sampling period.

Special studies were also conducted on occasion with grab samples collected from the primary clarifiers, the lagoons, and from the final clarifiers.

Chlorine was analyzed by the DPD ferrous titrimetric method as outlined in Appendix A. This method provided an accurate means of differentiating free and combined chlorine residuals.

BREAK POINT STUDIES

Chlorine demand studies were performed on samples from the primary sedimentation tanks, laboratory settled lagoon effluent and final settling tank effluent receiving $FeCl_3$ coagulation each representing different degrees of treatment. Aliquots of samples, 250 ml, were added to 600 ml glass beakers and appropriate doses of sodium hypochlorite were added. Samples were gently stirred in a Phipps-Bird gang mixer for 15 minutes and then residuals were analyzed. Results of these studies are depicted in Figures 75, 76, and 77. Characteristics of the treated samples are delineated in Table 44.

Break points were visible for all three wastewaters analyzed. It is apparent that demand increased with increased organic strength. The primary had a break point chlorine value of 2390 mg/l (COD = 2740) as compared with settled final effluent with a value of 870 mg/l (COD = 490). Ferric chloride coagulation improved this chlorine requirement to some extent. High sulfide, NH_3-N, and oil-grease concentrations likely produced the high demand for chlorine in the primary effluent.

BACTERIAL DISINFECTION

Results of the two summers of analyses on chlorination appear in Table 45. A relationship appears to exist (as should be expected) between chlorine dose to achieve a particular objective and wastewater quality. A rough graphical depiction of this relationship for the 1973 data appears as Figure 78. The COD was used as the measure of wastewater quality and the line roughly describes a condition which achieved a total coliform reduction to less than 200/100 ml. In the second year, 1974, heavy deposits of sludge which had accumulated in the chlorine contact chambers decidedly changed this relationship. No provisions were made to allow for cleaning of this tank and high washouts of solids from the clarifiers added significantly to the chlorine demand. As noted in Figure 78, substantially higher doses of chlorine (greater than 10 mg/l) were therefore required during the 1974 test period to achieve the same objective for bacterial kill as that for the 1973 test period.

As discussed earlier, certain conditions of lagoon operation, as well as the addition of $FeCl_3$ as a coagulant, often reduced the need for chlorine at all in order to achieve the current EPA effluent value of 200 fecal coliforms per 100 ml. This level can be achieved, when needed, by the addition (3-18 mg/l) of chlorine. Further study might be desireable to delineate whether there is any need for chlorinating this industrial watewater which contains no sanitary wastewaters.

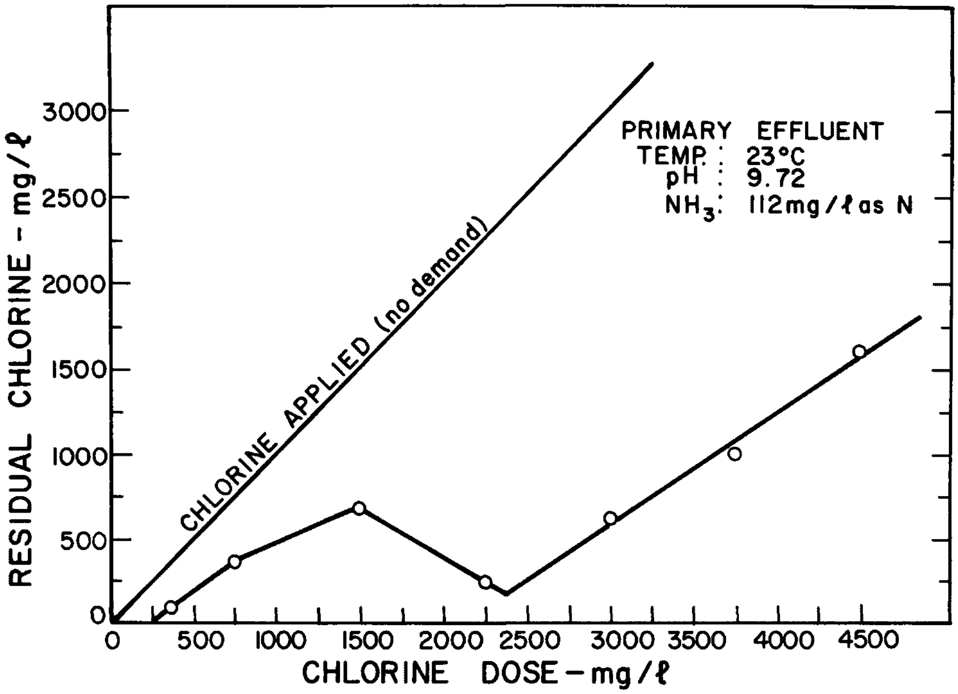

Figure 75. Breakpoint chlorination of primary effluent.

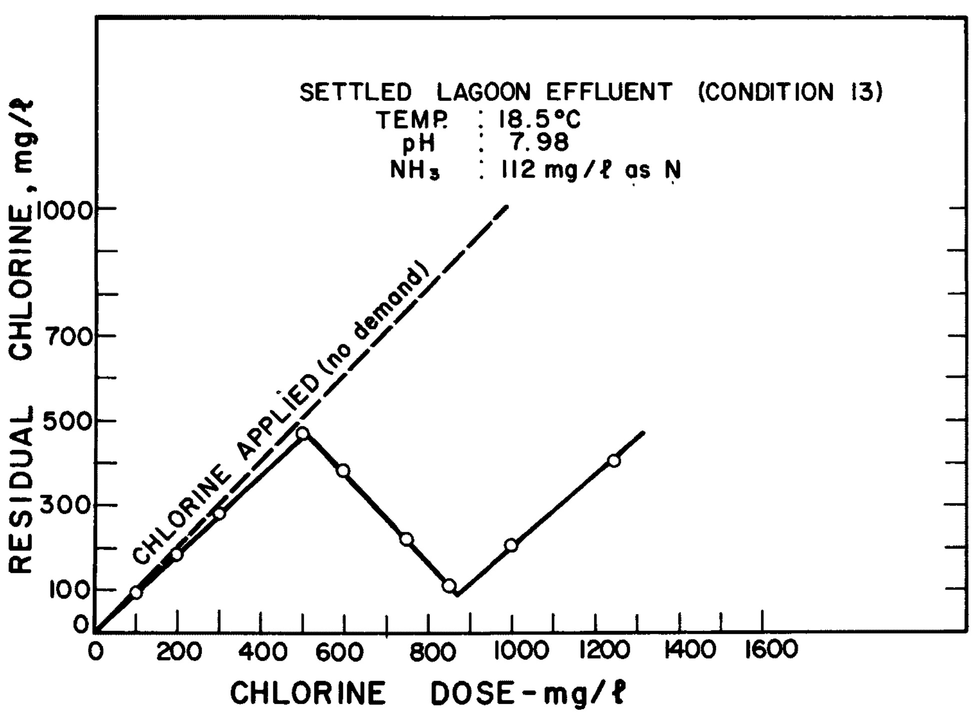

Figure 76. Breakpoint chlorination of settled lagoon effluent (condition 13).

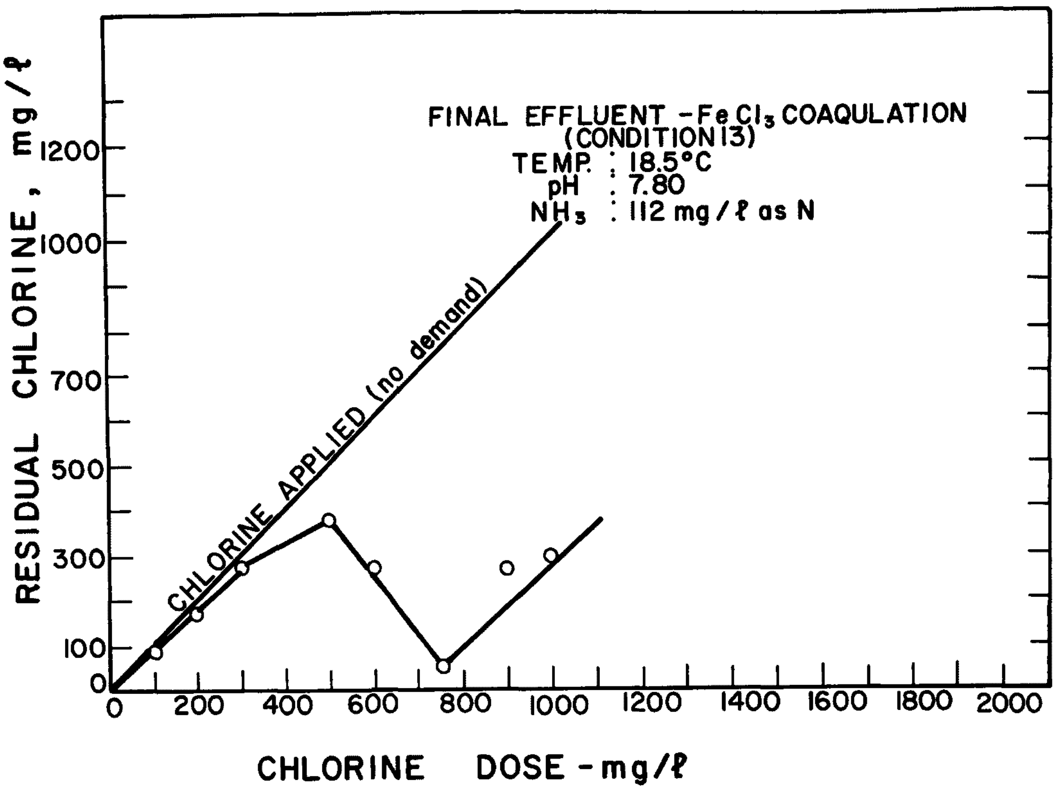

Figure 77. Breakpoint chlorination of $FeCl_3$ coagulated final effluent (condition 13).

TABLE 44. CHLORINE DEMAND STUDIES WASTEWATER CHARACTERISTICS

Analysis	Primary effluent* (10/17/74)	Lagoon effluent+ Condition 13 (9/25/74)	Final effluent± Condition 13 (9/25/74)
BOD(mg/l)	1180	100	49
COD(mg/l)	2740	490	265
NH_3-N(mg/l)	112	112	112
TKN-N(mg/l)	236	190	180
Nitrate-N(mg/l)	22	21	20
FOG(mg/l)	270	15	4
TS(mg/l)	10190	8272	8072
TVS(mg/l)	1700	584	464
SS(mg/l)	1170	292	75
VSS(mg/l)	624	176	33
pH	9.7	8.0	7.8
Temp(°C)	23.0	18.5	18.5

* 24-hour composite from primary sedimentation tanks.

\+ 24-hour composite settled in laboratory for one hour.

± 24-hour composite from final settling tank -- $FeCl_3$ dose 180 mg/l.

TABLE 45. CHLORINATION OF FINAL EFFLUENT

Date	Chlorine dose mg/l	pH	COD mg/l	NH_3-N mg/l	Total coliforms ($x10^3$/100 ml)	Total coliforms ($\frac{No-N}{No}$ x 100)	Fecal coliforms ($x10^3$/100 ml)	Fecal coliforms ($\frac{No-N}{No}$ x 100)	Total bacteria ($x10^6$/ml)	Total bacteria ($\frac{No-N}{N}$ x 100)
7/13/73	11.1	7.9	784		<1	97			.029	99.99
8/8/73	13.3	7.8	424		<0.1	90			.21x10^{-3}	99.99
8/16/73	12.5	7.6	435		<0.1	99			.013	99.94
8/23/73	10.4	7.9	290		<0.1	99.6			0.4x10^{-3}	99.99
8/30/73	8.2	7.8	360		<0.1	97.4			.012	99.93
9/6/73	5.8	7.9	437		0.2	96.5			8.3x10^{-3}	99.95
9/13/73	5.5	7.9	466						0.023	99.75
9/20/73	2.5	7.9	558		0.4				5.8	77.9
9/27/73	2.8	7.9	447		<0.1	97.1			0.029	99.9
10/4/73	2.8	7.7	588		21.1	54.1			2.0	91.4
10/10/73	5.6	7.8	522		<0.1	99.5			.085	98.7
10/17/73	5.1	7.8			<0.1	99.7			0.11	98.7
10/25/73	5.1	7.6	789		1.4	97.9			19.9	69.4
10/31/73	5.5	7.4	1054		2.4	32.4			18.4	75.3
5/8/74	15.9	8.0			300	88.1	2.0	-6.1		
5/16/74	18.0	7.9	1288	171	1300	99.1	1.5	45.5		
5/22/74	14.7	7.5	980	152			1.4	31.7		
5/29/74	9.4	7.6	705	158	67	70.2	1	48.2	1.0	96.1
6/5/74	8.9	7.5	649	157	30	31.0	<0.2	>70.6	7.2	90.6
6/12/74	12.4	7.6	631	162	27	58.5	0.08	93	2.6	73.5
6/19/74	6.0	7.8	570	144	<1	>97	<0.05	>77.8	0.026	99.7
7/10/74	~6.	7.4	330	102	0.4	79.3	0.04	88.2	0.051	89.5
7/17/74	8.8	8.4	396	121	1.3	88.5	0.025	87.0	0.083	99.3
7/24/74	5.2	7.7	409	105	17	5.8	2.8	-25.6	6.9	-14.3
7/31/74	6.4	8.5	490	68	10	46.1	1	41.5	35	3.1
8/7/74	18.1	7.7	537	94	9.4	43.5	2.2	44	1.3	58.2
8/14/74	17.8	7.7	561	120	1.9	42.8	0.2	46.9	6.2	33.4
8/22/74	18.3	7.1	340	123	2.2	-23.0	0.65	22.1	6.6	9.0
9/4/74	11.9	7.6	296	91	6.4	54.8	1.8	57.9		
9/18/74	10.1	7.4	302	85	0.15	97.3	<0.1	>61.5	0.22	91.1
9/25/74	13.4	7.6	1348	96	6.5	8.1	0.12	58.1	12	-74.4
10/2/74	14.2	7.6	1022	72	2.8	7.6	0.4	20.0	1.2	65.6
10/9/74	11.4	7.1	1474	80	0.6	61.4	0.1	47.4	0.6	91.3
10/17/74	10.9	7.1	346	107	0.05	94.5	0.025	67.8	0.05	99.5
10/25/74	10.1	7.3	282	95	0.01	97.2	0.005	98.3	0.8	93.9

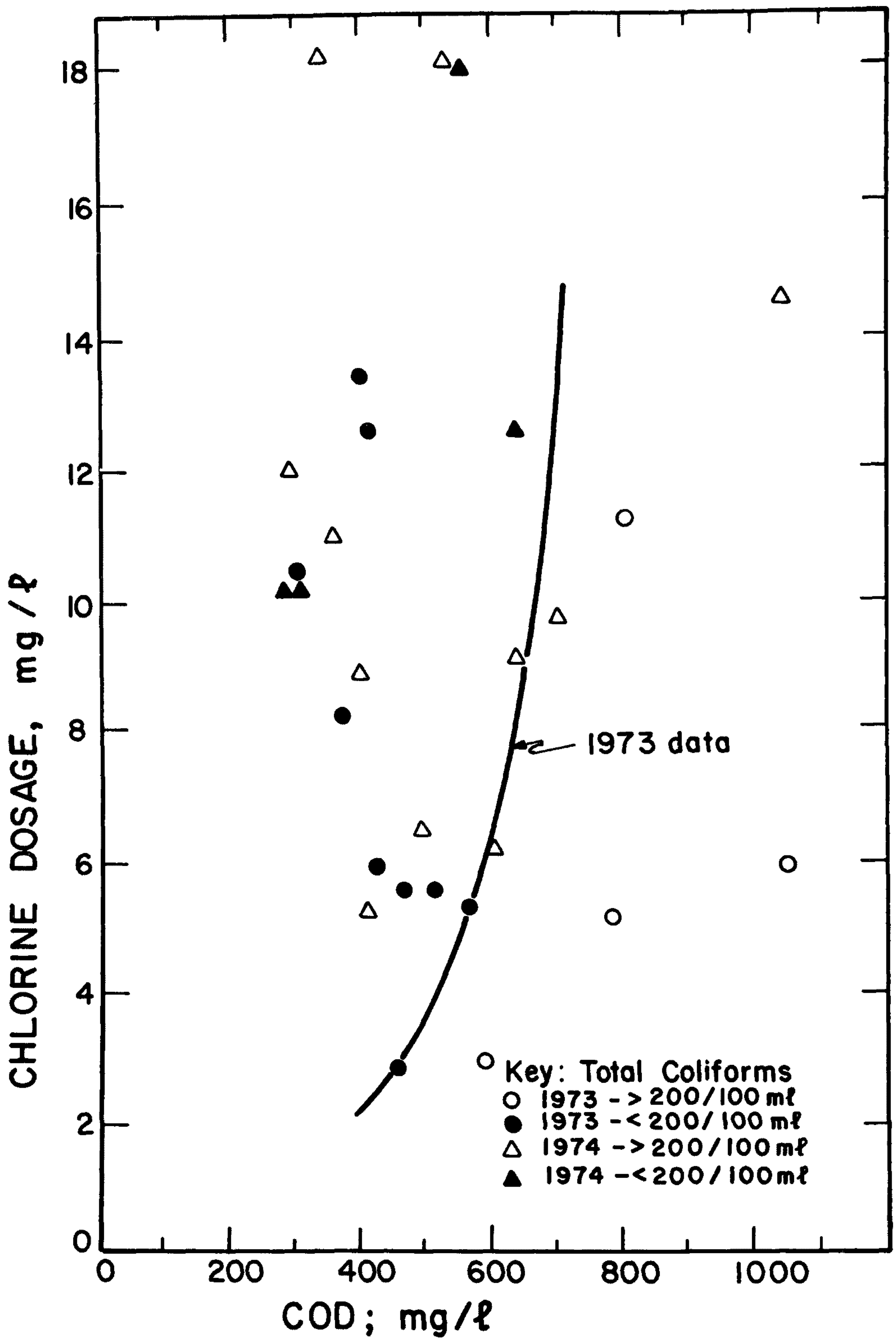

Figure 78. Effect of wastewater quality on chlorine requirements.

SECTION XII

WASTEWATER EFFLUENT REUSE

As part of the objectives of this demonstration study, the feasibility of using wastewater treatment plant effluent for certain in-plant process waters was to be evaluated. Preliminary analyses indicated that the likely area for water reuse would be associated with the beamhouse operations of soaking, hairpulping, and reliming rather than use the well water supply. In that the water use in the beamhouse represents approximately 17 to 18 percent of the total requirements, the reuse of effluent could result in a signficant reduction of wastewater volume for ultimate disposal. However, certain conservative substances, such as dissolved mineral matter, would result in higher wastewater effluent concentrations but would not increase the mass of substances discharged to the environment.

Several studies were conducted to evaluate the feasibility of effluent reuse, first from the results of experiments related to hide processing and the quality of the product, and second, from a mass balance of chloride concentrations buildup in the wastewater effluent by the employment of this practice.

EFFECT ON PRODUCT

Final wastewater effluent from the secondary wastewater treatment plant was used as process water for the beamhouse operations as compared to the use of the well water supply representing normal operating procedures.

Twenty cattle hides were sided down the backbone, numbered, and odd left and even right sides were taken as the test and the corresponding sides were taken as the control. The twenty 'test' sides were processed with a production lot in which the wastewater treatment secondary effluent was used as the sole water source from soaking through reliming, whereas the twenty 'control' sides were processed to the same point with well water which is the normal production procedure. After the beamhouse operations, the two lots, test and control, received similar treatments from tanning through finishing.

The results for the matched sides are presented in Table 46 for the leather analyses and in Table 47 for the standard physical tests. All analyses and physical tests were performed by tanning company personnel by routine ASTM, Federal Test Method Standard 311 and Society of Leather Trades' Chemists (see Appendix A).

The physical strength characteristics (Table 47) were about equal as well as such qualitative measures as leather break and temper. It appears that the yield figures favor the controls as well as the uptake of chrome and fats, however, the values are not statistically signficant. The test sides were slightly darker in shade than the controls which represents the only adverse circumstances affecting the desirability of recycling wastewater treated effluent. The degree to which this may be of concern would depend on the individual tannery and product quality control.

TABLE 46. LEATHER ANALYSIS*

	As received		Water free		H.S. Basis+	
	Test	Control	Test	Control	Test	Control
	(All values expressed as percent)					
Moisture	12.40	12.04	--	--	18.45	18.32
Fat	7.54	8.45	8.61	9.61	11.22	12.86
Hide substance	67.22	65.71	76.74	74.70	100.00	100.00
Ash	5.00	5.46	5.71	6.20	7.44	8.31
Organic(by diff.)	7.84	8.34	8.95	9.48	11.66	12.69
Cr_2O_3	3.49	3.88	3.98	4.41	5.19	5.90
pH	3.2	3.2	--	--	--	--

* Test sides treated with wastewater effluent for beamhouse procedure made in 742 Fairway. Control matched sides, well water used in beamhouse process. Test and control sides processed together from tanyard.

\+ Hide substance basis.

CHLORIDE BUILDUP BY EFFLUENT REUSE

In that chloride concentration represents a substance unaffected by the wastewater treatment processes employed and is a substance of high solubility, the effect of water reuse in the beamhouse operations on the

TABLE 47. PHYSICAL LEATHER PROPERTIES

	% Yield			Satra grain crack* force-kg/ exten-mm		Mullen grain* burst-lbs		Tensile strength - psi			% Tensile elong.		
	Test	Control	Diff. T-C	Test	Control	Test	Control	Test	Control	Diff. T-C	Test	Control	Diff. T-C
1.	87.5	89.1	-1.6										
2.	115.1	119.2	-4.1										
3.	100.8	103.0	-2.2										
4.	98.0	100.6	-2.6										
5.	110.1	110.7	-0.6	80+/10.8	80+/11.5	700+	700+	4590	4480	110	38	50	-12
6.	102.9	105.5	-2.6										
7.	90.5	92.9	-2.4										
8.	91.1	94.8	-3.7	43/9.2	40/9.3	590	700	2460	2595	-135	42	45	-3
9.	111.9	114.5	-2.6	47/9.9	39/8.6	700+	590	3795	5385	-1590	50	55	-5
10.	93.9	89.2	+4.7	27/8.1	39/9.3	520	635	2220	2560	-340	40	55	-15
11.	95.6	94.3	+1.3										
12.	107.7	105.7	+2.0	80/11.8	62/10.4	700+	700+	5495	4055	+1440	47	47	0
13.	86.4	87.4	-1.0	55/10.4	47/10.6	700+	700+	3280	2895	+385	47	49	-2
14.	103.5	101.9	+1.6	25/7.8	18/7.7	265	325	1350	1200	+150	35	37	-2
15.	91.3	92.0	-0.7	80+/11.9	77+/11.0	700+	700+	3810	4320	-510	50	47	+3
16.	112.2	111.9	+0.3										
17.	89.6	92.3	-2.7										
18.	104.0	100.4	+3.6										
19.	93.3	93.8	-0.5	20/8.1	16/7.2	300	310	825	825	0	31	31	0
20.	98.3	96.5	+1.8	32/8.2	37/8.7	525	525	3050	2675	+375	43	45	-2
Mean	99.2	99.8	-0.6	49/9.6	46/9.4	570	589	3090	4000	-10	42	46	-4

* Values with a superscript of + indicate the measurement was above the scale range of the instrument.

resulting wastewater effluent concentrations was of particular interest. In addition, most of the chloride found in the wastewater effluent is the result of the beamhouse operations with a substantial increase in effluent concentrations even without water reuse.

Table 48 showed the contributions of chloride from the various tanning operations with the major portion, in excess of 80%, resulting from the beamhouse. The well water supply has a chloride concentration of 177 mg/l but in the wastewater effluent, without recycle, the chloride concentration would increase to about 3,900 mg/l. Table 48 summarizes the water use and the resulting chloride concentrations and estimated pounds of chloride for each process operation. It should be noted that chlorides result from the tanyard operations as well, however, recycle of the effluent appears only to be feasible for the beamhouse operations at this time.

If one considers the chloride balance with the effluent reuse only for the beamhouse operations and the additional chlorides that would result from the sludge filtrate returned to the wastewater stream when using $FeCl_3$ as a sludge conditioner, the wastewater effluent chloride concentration would approach 4,700 mg/l. This would represent the equilibrium chloride concentration for the wastewater effluent which would be used in the beamhouse operations rather than the chloride levels of 3,900 mg/l as performed in the tests on leather quality represented in Tables 46 and 47. A calculation of the chloride balances with respect to reuse cycle are presented in Table 49. These results are based on a water use of 534 m^3/d (0.141 mgd) for the beamhouse and a total wastewater flow of 3028 m^3/d (0.8 mgd) or a 17.7% of the total effluent water reuse in the beamhouse operations. The percent increase in chloride concentration in wastewater treatment effluent as a result of recycle would be 21.4% which would be representative of a soluble conservative substance. Non-conservative substances, removable by the treatment process, would not increase in the wastewater treatment effluent to as high a degree.

Levels of chloride concentration in excess of 10,000 mg/l in the process water for the beamhouse operation are assumed to be unacceptable by tannery personnel. Consequently wastewater effluent reuse for 100% of the beamhouse operation appears to be feasible and acceptable providing that the resulting slightly darker shades of product can be properly adjusted. The overall increase in chloride concentration would likely have no significant effect on the treatability of the wastewaters so generated. Effluent limitations would require adjustment to account for the water conservation measures realized by effluent recycle when expressed as a concentration. However, effluent limitations expressed

TABLE 48. CHLORIDES IN WASTEWATER BY TANNERY PROCESS

Department	Process	Chloride concentration mg/l	Number of drums	Estimated gallons/drums	Total gallons	Estimated pounds of chloride/day
1. Beamhouse	a. Presoak	24900	9	2200	19800	4112
	b. Soak	22200	9	6600	59400	10998
	c. Hairpulp					
	drain	21800	9	1100	9900	1800
	wash	13440	9	3600	32400	3632
	d. Hairpulp final drain	5100	9	2200	19800	842
	Subtotal				141300	21384
2. Tanyard	a. Prebate	200	9	2000	18000	30
	b. Bate	200	9	4000	36000	60
	c. Pickle	36600	9	500	4500	1374
	d. Chrome	6300	9	3000	27000	1419
	Subtotal				85500	2883
3. Color and fatliquoring and other departments		177*			573200	846
	Total	3764+			800000	25113

* Chloride concentration of well water source of supply.

\+ Mean chloride concentration for the process waters excluding sludge dewatering filtrate recycle.

TABLE 49. CHLORIDE BALANCE FOR WATER REUSE SYSTEM IN THE BEAMHOUSE

Number of effluent reuse cycle	Chloride, kg/day, (pounds/day)				Chloride conc. mg/l T. plant effluent	% Increase in chloride conc. in wastewater effluent
	Beamhouse					
	Process addition	Final effluent reuse	Other	Total		
No reuse	9700(21384)	none	2060(4542)	11760(25926)	3886	2095*
1st	9700(21384)	2077(4579)	2060(4542)	13837(30505)	4572	17.65
2nd	9700(21384)	2444(5388)	2060(4542)	14204(31314)	4693	2.64
3rd	9700(21384)	2508(5530)	2060(4542)	14268(31456)	4715	0.47
4th	9700(21384)	2520(5556)	2060(4542)	14280(31482)	4718	0.06
5th	9700(21384)	2522(5560)	2060(4542)	14282(31486)	4719	0.02

*Increase percent compared to chloride concentration in water supply, all others compared to preceding effluent quality.

Other: Tanyard, sludge filtrate, chloride level in well water for color and fat department.

Flows:

Beamhouse	535 m^3/d	(0.1413 mgd)
Tanyard	324 m^3/d	(0.0855 mgd)
Color & Fat	2170 m^3/d	(0.5732 mgd)
Total	3029 m^3/d	(0.800 mgd)

in kg/1000 kg hide would be unaffected by the practice of effluent recycle.

SECTION XIII

SLUDGE DEWATERING

SLUDGE CHARACTERISTICS

The solids removed by gravity separation in the primary clarifiers was dewatered by the pressure filtration process.

The primary sludge contained settled raw wastewater solids and biological solids from time to time wasted from the secondary treatment system throughout the study. The sludge solids were thickened in the lower portions of the primary clarifiers. The thickened sludge was pumped to the sludge dewatering building where sludge grinding was affected and the sludge solids were discharged to a contact tank for chemical conditioning and subsequent pumping to the filter press.

The primary sludge (i.e., primary sludge and waste activated sludge at times), was analyzed routinely prior to grinding and chemical conditioning. The results of the analyses for various dates and operating conditions with associated chemical parameters are presented in Tables 50 and 50A. In addition, the extent to which waste activated sludge contributed to the number of filtered cycles per week is included as a relative reference. The average results for the sludge analyses for the period July to October, 1974, are shown in Table 51.

The sludge was dewatered on a 5-day basis Monday through Friday.

SPECIFIC RESISTANCE

The specific resistance measurements used in this study were after the recommendations of Passavant Corporation, Birmingham, Alabama. The stainless steel cylindrical specific resistance meter was capable of operating through a wide range of pressures by the use of nitrogen gas for the driving force. Filtrate volumes are measured with respect to time in a fashion similar to the standard specific resistance test operated under pressures less than 1 atmosphere.

The procedure involved the placement of 100 ml of the conditioned

TABLE 50. PRIMARY SLUDGE ANALYSIS

					Total				Suspended			
Date	Cycle no.	Waste act. sludge	Extent of waste filtered* cycles/wk.	pH	Total solids mg/l	Volatile solids mg/l	Fixed solids mg/l	Volatile %	Suspended total solids mg/l	Volatile suspended mg/l	Fixed suspended mg/l	Volatile %
10/16/73		yes	< 5		90832	53980						
10/23		no	none		129840	78800	51040	60.7	116240	75520	40720	65.0
10/24		no	none	8.15	110700	69400	41300	62.7	98300	67600	30700	68.8
10/25		no	none	7.5	125500	75500	50000	60.2	109600	72600	35000	66.2
10/31		no	none	7.68	132600	81700	50900	61.6	92000	61000	31000	66.3
11/1/73		no	none	9.48	79100	45600	33500	57.6	60300	43000	17300	71.3
11/2		no	none	7.48	79000	44300	34700	56.1	6500	42000	23000	64.6
11/6		no	none	10.25	110280	71280	39000	64.6	94560	68280	26280	72.2
11/7		no	none	10.5	142240	95200	47040	66.9	124320	92320	32000	74.2
11/8		no	none	10.68	117840	74880	42960	63.6	100720	72960	27760	72.4
11/13		no	none	9.79	135200	92500	42700	68.4	120700	90300	30400	74.8
11/14		no	none	7.69	116320	77920	38400	67.0	102320	76000	36320	74.3
11/15		no	none	10.7	109040	71360	37680	65.4	94960	69440	25520	73.1
11/27		no	none	7.68	158720				144480			
11/28		no	none	8.4	91520	56400	35120	61.6	78960	54080	24880	68.5
11/29		no	none	8.99	65520	38720	26800	59.1	50400	37840	12560	75.1
12/4/73	3	no	none	8.35	122160	77840	44320	63.7	105280	75040	30240	71.3
12/5	2	no	none		94160	57120	37040	60.7	78080	55280	22800	70.8
12/11	2	no	none	7.74	120720	79440	41280	65.8	105360	76560	28800	72.7
12/12	2	no	none	6.9	159040	105280	53760	66.2	142800	101280	41520	70.9
12/12	3	no	none	8.67	103680	69120	34560	66.7	89360	66960	22400	74.9
12/13	3	no	none	9.07	81120	52080	29040	64.2	69440	51120	18320	73.6
12/18	3	no	none	9.32	106640	71920	34720	67.4	91200	70560	20640	77.4
12/21		no	none	7.28	158640	115840	42800	73.0	142480	111680	30800	78.4
7/9/74	1	no	none	8.82	160920	118920	42000	73.9	142240	115640	26600	81.3
7/10	2	no	none	6.88	159160	114760	44400	72.1	135640	110400	25240	81.4
7/10	4	no	none	7.18	119000			77.5				

(Continued)

TABLE 50. (CONTINUED)

					Total				Suspended			
Date	Cycle no.	Waste act. sludge	Extent of waste filtered* cycles/wk.	pH	Total solids mg/l	Volatile solids mg/l	Fixed solids mg/l	Volatile %	Suspended total solids mg/l	Volatile suspended mg/l	Fixed suspended mg/l	Volatile %
7/11	4	no	none	6.52	108724	69244	39840	63.7	89004	66204	22800	74.4
7/24		yes	<10	7.36	97040	65880	31160	67.9	83560	62560	21000	62.7
7/26		yes	<10	7.08	110080	75760	34320	68.8	98480	72800	25600	73.9
7/29	2	yes	<10	7.48	91160	61920	29240	67.9	79400	58240	21160	73.4
7/31		yes	<10	6.68	100880	64880	36000	64.3	88480	61760	26720	69.8
8/6/74		yes	<10	6.78	101440	65440	36000	64.5	88640	61920	26720	69.9
8/7		yes	<10	7.54	123120	77680	45400	63.1	108760	73000	35100	67.7
8/9		yes	<10	7.74	113520	74440	39080	65.6	100200	70760	29440	70.6
8/16		yes	<10	6.62	136680	93120	43560	68.1	120320	88560	31760	73.6
8/20		yes	<10	6.82	108920	69160	39760	63.5	95150	66160	28960	69.6
8/26		yes	<10	7.15	125904	80856	45042	64.2	113064	78264	34800	69.2
9/3/74	3	yes	<10	7.02	120040	66680	53360	55.5	95160	64160	31000	67.4
9/6		yes	<10	9.01	88520	53680	34840	60.4	77400	52640	24760	68.0
9/10		yes	>10	8.26	85880	54080	31800	63	74480	52480	22000	70.5
9/16		yes	>10	7.64	105760	65520	40240	62	90300	62320	27980	69
9/18	5,6,7	yes	>10	7.61	89640	52680	36960	58.8	73800	49920	23880	67.6
9/20	6,7,8	yes	>10	7.32	85560	49400	36160	57.7	69840	46640	23200	67.8
9/25	2	yes	>10	7.3	104720	68600	36120	65.5	90360	65120	25240	72.1
9/26		yes	>10	6.99	77400	46760	30640	60.4	63800	43840	19960	68.7
10/1/74		yes	>10	7.18	78320	48520	29800	61.9	67120	45800	21320	68.2
10/3	1	yes	>10	7.09	76160	49280		64.7	64920	46840		72.1
10/3	2	yes	>10	7.18	94120	58320		62	82000	55800		67.8
10/3	3	yes	>10	7.16	81120	52760		65	69560	49680		71.4
10/8	3	yes	>10	7.08	69600	44240		63.6	59360	41800		70.6
10/8	4	yes	>10	7.06	76480	49600		64.9	64840			
10/8	5	yes	>10	7.18	75640	44800		59.2	63720	41840		65.7
10/16		yes	>10	7.20	87440	54080	33360		74560	50920	23640	68.3
10/17	1	yes	>10	7.06	103840	64440	39400		90840	61640	29200	67.9
10/17	2	yes	>10	7.04	81240	48480	32760		69040	45960	23080	66.6

TABLE 50A. PRIMARY SLUDGE ANALYSES

Date	COD mg/l	Oil & grease mg/l	Total Kjeldahl nitrogen mg/l	Ammonia mg/l	Calcium mg/l	Total chromium mg/l
12/21/73	--	46440	4700	430	7306	1187
7/11/74	125290	19120	5250	--	--	1128
7/26/74	105272	17200	5050	580	--	1153
8/6/74	126200	21000	7000	1090	--	2144
8/9/74	141360	20000	4450	1070	--	2198
8/16/74	11930	33000	4700	800	--	2531
9/16/74	94600	10000	5500	950	5790	1906
9/18/74	90454	14000	5600	720	5371	1635
9/20/74	110400		6100	680	6333	1954
10/1/74	100700	16600	5500	950	7188	1954
10/3/74	105600	16000	5450	920	5890	
10/16/74	81072	20000	6550	86	6525	1104

*Extent of WAS. filtered is an estimation of cycles/week as contribution to total: 5--minor, 10--significant.

TABLE 51. MEAN SLUDGE ANALYSES--JULY TO OCTOBER, 1974

Parameter	Concentration, mg/l	Percent volatile
Total solids	104,800	64.4
Suspended solids	86,400	70.4
COD	109,100	
Oil and Grease	21,200	
Total Kjeldahl nitrogen	5,500	
Calcium	6,350	
Chromium	1,685	
pH, standard units	6.5-9.1	

sludge into the resistance meter, tighten the cover, and supply the nitrogen gas at the requisite pressure. The filtrate would be collected in a graduate cylinder or burette and the filtrate volume recorded in 1 minute intervals after a 2 minute initial filtration period. Additional information was recorded for the sludge such as pH, temperature, and total solids.

A plot of the filtrate volume data, wherein t/V versus V was prepared where t equals elapsed time in seconds and V equals volume of filtrate collected. The graph of t/V versus V results in a linear plot from which the slope " b " was determined.

The specific resistance, R, of the sludge was calculated by the following formula:

$$R = \frac{K \times b}{C}$$

where R = specific resistance

b = slope of plot t/V versus V

C = solids of the sludge, $\frac{\text{wt sludge dry solids}}{\text{wt of sample} - \text{wt sludge dry solids}}$

K = constant, function of temperature (viscosity)

A value of 3 or less indicates the sludge is properly conditioned for dewatering on the filter press with the lowest values representing the more readily dewatering characteristics.

The specific resistance determination permitted the evaluation of the effects of various concentrations of conditioning agents and various operating pressures.

To obtain information pertaining to the effect of pressure on the filtration of the sludge, the specific resistance measuring device was readily adapted to this function, wherein the specific resistance values could be determined at various operating pressures. Table 52 presents a summary of measurements made at normal terminating operating pressure of 225 psi and for lower pressure values for a given sludge sample.

The results indicate that reducing the terminating operating pressure as measured by the specific resistance test did not yield higher or lower specific resistance values in a consistent manner.

An empirical relationship between pressure and specific resistance follows:

$$R_2 = R_1 P_1{}^s$$

where: R = specific resistance;

P = pressure;

s = coefficient of compressibility.

The value s can be determined as the slope of a plot of log specific resistance versus log pressure. An s value of 1.0 would indicate a compressible cake, with the increase in specific resistance being directly proportional to the filtering pressure. As the value of s approaches zero, the specific resistance values would be more independent of pressure or considered to be of a non-compressible nature. On two dates, 7/16/74 and 7/25/74, the specific resistance measurements were made in the range of pressures from 150 to 225 psi and 100 to 225 psi respectively (Table 52). In the first instance the specific resistance values increase with pressure indicating the compressible nature of the cake, whereas in the second instance, there is an increase in specific resistance with pressure for 100 psi and 150 psi values, however, in the pressure range from 150 to 225 psi, no increase in specific resistance is noted.

TABLE 52. EFFECT OF PRESSURE ON SPECIFIC RESISTANCE

Date	Cycle no.	*Conditioning kg/kg		Sludge character			Specific resistance at different pressures			
		FeCl3	Lime	pH	Temp °C	Solids %	Psi/R=	Psi/R=	Psi/R=	Psi/R=
11/27/73	2	0.0395	0.128	12.2	29	12.1	175/1.5	225/1.97		
1/28/73	2	0.0468	0.144	12.0	25	10.0	175/1.163	225/1.047		
11/29/73	2	0.0468	0.117	12.0	26	10.0	175/1.45	225/1.15		
	4	0.0374		11.8	21	12.5	175/1.82	225/1.95		
12/4/73	3	0.0297	0.0659	11.8	23	16.1	135/1.57	225/1.21		
	5	0.0365		11.9	25	13.1	135/2.06	225/1.56		
12/5/73	2	0.0390	0.111	12.2	30	12.8	135/2.06	225/1.59		
12/7/73	2	0.0562	0.114	12.2	26	8.5	135/1.10	225/.85		
12/11/73	2	0.0395	0.0641	12.0	26	12.1	100/1.10	225/.74		
	5	0.0405	0.0909	11.95	27	11.8	100/1.59	200/1.36		
12/12/73	2	0.0405	0.147	12.12	19	11.8	100/.79	225/.83		
	3	0.0389		12.12	23	12.3	100/1.65	225/1.25		
12/28/73	2	0.0590	0.114		24	8.1	175/1.77	225/1.49		
	3	0.0520			24	9.2	175/1.87	225/1.87		
12/27/73	1	0.0569			23	8.4	175/1.77	225/1.48		
1/2/74	2	0.0473			23	10.1	100/.59	225/1.65		
	1	0.0525	0.0754		22	9.1	100/1.53	225/2.02		
1/16/74	1	0.0577		12.1	14	8.1	100/.82	225/.30		
1/22/74	2			12.1	21	9.1	150/.78	225/.69		
7/16/74			0.0949	11.5	26	11.6	150/1.86	180/2.72	200/3.12	225/2.76
7/25/74	3	0.0410	0.114	11.6	29	11.4	100/.84	140/1.82	180/1.52	225/1.64
9/4/74	1	0.0499		12.4	26	12.5	100/1.17	150/1.90	225/1.18	
	2	0.0491		12.2	26	12.7	120/1.12	200/.99	225/.72	

*Expressed as weight of chemical as $FeCl_3$ or $Ca(OH)_2$ per unit weight of dry sludge solids.

The specific resistance test is performed at a constant pressure throughout the test period whereas the pressure under full-scale filter operating conditions increase from the precoat pressure to the terminating pressure of 225 psi, thus the cake so formed is subject to the range of operating pressures rather than a constant pressure during the filter cycle. Generally, for a given target filter cake moisture content, the higher the terminating operating pressure the shorter the filter time and hence greater production. This relationship is evident from the equation developed by Jones (5).

$$T = \frac{0.321\ R\eta d^2(C_i - C_f)^2}{PC_i\ (100-C_i)}$$

where T = filter time, hours

R = specific resistant of the sludge in 10^7 cm per gram

η = viscosity of filtrate, in centipoise

d = distance between cloths (chamber thickness), in inches

C_i = initial sludge moisture content, in percent

C_f = final sludge moisture content, in percent

P = filtration pressure, in lb per sq in

In that filter time is inversely proportional to pressure, the benefit of higher terminating operating pressures are evident. However, if specific resistance increases with pressure in direct proportion, (i.e., for s value of 1.0), the benefit of increased pressures would be nullified as expressed in this equation. The filter time can be minimized by decreasing the moisture content of the feed sludge, the filtrate viscosity (higher temperature) and specific resistance. The latter is affected principally by sludge conditioning measures. The desired moisture content of the cake C_f depends upon ability to form cakes which will be readily released from the press and the ultimate disposal of the cake, whether or not incineration is to be employed or the cake placed in a landfill.

Specific Resistance Measurements of Special Sludge Mixtures

The dewatering properties of several different sludges were evaluated by the use of the specific resistance test. It was desired to determine the influence of primary tank scum, principally grease, in combination with primary sludge underflow on the dewatering properties of the combination. Also, additional specific resistance information was desired for the dewatering of the waste biological sludge separately

The scum sludge was conditioned with ferric chloride and lime and added to conditioned primary sludge in various volume proportions in accordance with Table 53.

TABLE 53. EFFECT OF SCUM ON SPECIFIC RESISTANCE

Sample no.	Relative volume of sludge mixtures, mls: Contact tank	Scum sludge	Equivalent scum sludge per cycle %	Solids %	pH	Specific resistance R
1	100	100	50	15.9	11.08	0.84
2	100	100	33	14.7	10.58	1.31
3	200	50	20	13.5	12.64	0.50
4	200	20	10	11.4	12.6	1.12
5	200	10	5	13.1	11.4	0.77

The resulting specific resistance measurements indicate that the mixture of scum sludge and primary sludge with appropriate conditioning could be dewatered, i.e., R less than 3. The effect of continued dewatering of a sludge with a high grease content on a full-scale filter was not evaluated. The possible blinding of the filter cloth or weeping of the oil bearing substances requires evaluation for extended periods.

The dewatering of waste activated sludge is usually more difficult than for primary sludges. A combination of biological solids from an aerobic digester and mixed liquors from high and low solids biological treatment units were conditioned with ferric chloride and lime in the proportions shown in Table 54. The resulting specific resistance measurements of the conditioned biological solids are shown. The results indicate that a properly conditioned biological sludge can be dewatered separately.

In the third test, waste activated sludge from a low solids biological system was flocculated with 300 mg/l ferric chloride, settled and thickened before the resulting sludge was chemically conditioned. The resulting specific resistance values are reported in Table 55.

The value of specific resistance near 3 and below indicate that the solids so conditioned would be filterable. In that the biological sludge solids were flocculated with ferric chloride, apparently the ferric chloride requirement for sludge conditioning is lower than in the foregoing test.

TABLE 54. SPECIFIC RESISTANCE OF CONDITIONED BIOLOGICAL SOLIDS

Sample no.	Chemical dosage, kg/kg: Ferric chloride as $FeCl_3$	Chemical dosage, kg/kg: Lime as $Ca(OH)_2$	Sludge solids %	pH	Specific resistance
1	None	None	3.4	7.8	14.0
2	0.047	0.12	12.1	12.8	1.14
3	0.081	0.25	8.6	12.6	1.76
4	0.082	0.18	12.3	12.3	1.49

TABLE 55. SPECIFIC RESISTANCE OF CHEMICALLY COAGULATED BIOLOGICAL SOLIDS

Sample no.	Chemical dosage, kg/kg: Ferric chloride as $FeCl_3$	Chemical dosage, kg/kg: Lime as $Ca(OH)_2$	Sludge solids %	pH	Temp °C	Specific resistance
1	None	None	6	8.6	15	38
2	None	0.24	6	12.6	15	3.2
3	0.091	0.23	6.3	13.1	16	.74
4	0.100	0.25	5.7	13.1	16	.66
5	0.070	0.31	4.6	13.6	16	2.38

Effect of Sludge Aging on Specific Resistance

The purpose of this evaluation was to determine if conditioned sludge loses filterability, as measured by specific resistance, as the contact time increases.

Six samples of primary sludge, 11.4% total solids including raw and waste activated sludge solids, were conditioned by ferric chloride and lime at 12.2 pounds of $Ca(OH)_2$ and 4.2 pounds of $FeCl_3$ per 100 pounds of sludge solids and placed on a magnetic stirrer for agitation for a specified time. The results are shown in Table 56.

TABLE 56. SPECIFIC RESISTANCE OF CHEMICALLY CONDITIONED STORED SLUDGE

Test no.	Length of mixing after chemical addition (hours)	Sludge soils of conditioned sample (%)	pH	Temp °C	Specific resistance
1	Immediately	11.7	12.2	17	5.4
2	1 hr.	12.7	12.2	19.5	6.2
3	2 hr.	11.4	12.6	21	5.0
4	4 hr.	12.3	11.7	22	5.2
5	8 hr.	12.2	11.7	24	10.3
6	24 hr.	12.7	10.6	23	9.8

None of the samples so conditioned had specific resistance values of 3 or less. Some deterioration in dewatering properties occurred for the 8 and 24 hour elapsed time intervals. Usually the conditioned sludge remains in the contact tank less than 4 hours which apparently would not adversely affect the dewatering properties of the sludge.

SLUDGE CONDITIONING

Routinely ferric chloride and lime were used as the sludge conditioning chemicals throughout the course of the experimental work. Other materials were used on a limited basis as conditioning agents such as, scraps and shavings, and buffing dust, both separate and in combination with the chemical conditioners.

Ferric Chloride

Ferric chloride was received as an acidic solution having an average $FeCl_3$ content of 39.2% with an average dry weight of 4.63 pounds per gallon. The material was stored in two-8000 gallon reservoirs located inside the sludge dewatering building.

Normally, $FeCl_3$ used in conjunction with lime would form the alkaline flocculant precipitate of $Fe(OH)_3$ to facilitate dewatering of the solids. The flocculant material likely serves to gather highly dispersed fine solids which contribute to the poor dewatering properties of the solids present. For the tannery sludge dewatered in this instance, the ferric chloride also served to combine with the sulfide present forming ferric sulfide, an insoluble precipitate without benefit as a conditioning substance. However, the ferric sulfide so formed served to minimize secondary odors which would result from the presence of free sulfide for the cake disposal practices employed.

The extensive use of sulfide for hair pulping operations has been identified and presented in previous sections of this report. Although the soluble sulfide fraction would not be removed by primary sedimentation practices, a significant portion of sulfide is associated with the insoluble fraction of the hair pulp. Additional sulfide generation can occur in the thickening zones of the primary clarification units wherein higher oxidized forms of sulfur are biologically reduced resulting in additional sulfide generation. Although the sulfide contents of the primary sludge were not measured, operating personnel estimated that the $FeCl_3$ dosages required for sludge dewatering were increased by 10 to 30% as a result of the presence of sulfide.

Lime

Slaked lime, a material extensively used in the tannery beamhouse operations, was obtained from the industry's lime slaker for use as a sludge conditioning agent. The lime slurry was periodically sampled and analyzed for total and fixed solids and unit weight in kg/l (lb/gal). The results of the periodic analyses of the lime slurry indicated the following mean values:

Total solids	193,000 ppm
Total fixed solids	161,000 ppm
Density	1.10 kg/liter (9.21 lb/gal)

Buffing Dust

The use of buffing dust as a sludge conditioning agent was tried on a limited basis. The properties of the buffing dust are presented in a subsequent section on filter precoat materials. Although the specific resistance results indicated that buffing dust may have some potential as a conditioning agent, the filter cycles of operation employing buffing dust indicated a lighter wetter cake. (Results, August 2, 1974). Also, the available buffing dust indigenous to this industry would be insufficient for use both as a precoat and conditioning agent.

Combinations of Conditioning Materials

Several experimental trials were made for a combination of chemical conditioning agents, with and without buffing dust and/or shavings, in conjunction with primary sludge and specific resistance measurements were made of the sludge so conditioned. The results for several experimental trials are shown in Tables 57, 58, 59, and 60.

TABLE 57. TRIAL #1--FEBRUARY 6, 1974

Test no.	Conditioning materials: Ferric chloride kg/kg	Lime kg/kg	Buffing dust kg/kg	pH	Sludge solids %	Temp °C	Specific resistance
1	0.070	0.147	None	13.1	12.3	23	0.64
2	0.032	0.123	0.096	13.1	14.7	23	1.01
3	0.031	0.117	0.183	13.1	15.4	23	1.31
4	0.035	0.133	None	13.2	13.6	23	1.20
5	None	0.104	0.326	13.2	17.3	22	13.2

Results of Trial #1 indicate that buffing dust in combination with lime and ferric chloride conditioners did not appear to improve the dewatering properties of the sludge as measured by specific resistance. Test No. 5 did demonstrate the need for ferric chloride as one of the conditioning agents.

TABLE 58. TRIAL #2--JULY 22, 1974

Test no.	Conditioning materials: Ferric chloride kg/kg	Lime kg/kg	Buffing dust kg/kg	Shavings kg/kg	pH	Sludge solids %	Temp °C	Specific resistance
1	0.050	0.134	None	None	10.6	10.8		3.9
2	0.035	0.132	None	None	11.0	10.9		7.3
3	0.029	0.110	0.029	None	11.0	13.1		2.5
4	0.032	0.178	None	0.046	11.5	8.1		1.6
5	None	0.172	None	0.045	11.9	8.4		15.9
6	None	0.119	0.031	None	11.5	12.1		29.1
7	None	0.128	None	None	10.5	11.3		17.0
8	None	None	None	None	7.6	12.8		290

Results of Trial #2 (Table 58) indicate that both buffing dust and shavings used singly improved the dewatering properties of the sludge as measured by specific resistance. Ferric chloride as a conditioning agent is again demonstrated as needed to facilitate the dewatering of the sludge. The need for lime was not evaluated in a similar fashion.

TABLE 59. TRIAL #3--AUGUST 21, 1974

Test no.	Conditioning materials: Ferric chloride kg/kg	Lime kg/kg	Buffing dust kg/kg	Shavings kg/kg	pH	Sludge solids %	Specific resistance
1	0.049	0.130	none	none	11	11.1	2.47
2	0.032	0.119	none	none	12.7	12.1	2.19
3	0.032	0.119	0.034	none	12.8	12.1	2.91
4	0.032	0.118	none	0.034	12.6	12.2	3.96

Results of Trial #3 (Table 59) indicate that neither the addition of shavings or buffing dust improved the dewatering properties of the sludge.

TABLE 60. TRIAL #4--SEPTEMBER 11, 1974

Test no.	Conditioning materials: Ferric Chloride kg/kg	Lime kg/kg	Buffing dust kg/kg	pH	Sludge solids %	Specific resistance
1	0.028	0.160	none	9.9	13.5	2.93
2	none	0.278	none	11.5	10.4	17.0
3	0.056	none	0.182	6.8	10.3	8.5

The results of Trial #4 (Table 60) are inconclusive but there is an indication that the combination of ferric chloride and lime is more desirable than lime alone on the combinations of ferric chloride and buffing dust.

Polymer Conditioning

The possible use of polymers as a conditioning agent was considered but not evaluated. The use of polymers to replace all or part of the lime requirements would have the advantage of dewatering less solids, because of the solids produced as a result of lime addition. The polymers would likely be unaffected by the sulfides present as well. The major disadvantage would be related to the apparent loss of effectiveness of polymers at high pH values, with a pH 9 to 9.5

representing the upper limit. The pH of the primary sludge in the absence of waste secondary sludge may exceed this value. The use of lime appears to be beneficial both to overcome the sticky properties of sludge having a high grease content and to reduce the $FeCl_3$ conditioning requirement, thus extensive testing would be necessary to optimize the use of polymers which was not within the scope of the work reported herein.

FILTER PRECOAT MATERIALS

Several materials are used in conjunction with the precoat of pressure filters. Incinerator ash is most frequently used when the sludge cake is incinerated or when other sources of ash are readily available. If ash is not available, the use of diatomaceous earth is frequently recommended.

As part of the objectives of this study, waste materials indigenous to the industry were to be used for both precoating and conditioning of the sludge. One material that showed considerable promise in the sludge dewatering pilot studies was the use of "buffing dust", a waste product normally disposed of as a solid waste.

The dry buffing dust was transferred from the storage bin by an augur to the precoat tank, the amount of weight was controlled by the operating time and speed of the augur. Thus a predetermined amount of precoat materials were transferred to the precoat tank for wetting and subsequent batch use during the precoat operation.

The solids analysis of the buffing dust for the test period were as follows (Table 61).

TABLE 61. SOLIDS AND VOLATILE CONTENT OF BUFFING DUST

Date	Percent solids	Percent volatile on dry weight basis
7/10/74	86.1	83.6
7/19	90.0	82.7
7/29	93.4	75.6
8/21	88.7	77.9
8/28	90.4	83.4
9/6	89.8	67.8
9/10	89.5	80.2
9/16	95.2	63.1

(continued)

TABLE 61. (CONTINUED)

Date	Percent solids	Percent volatile on dry weight basis
9/26	93.3	63.9
10/1	91.4	77.0
10/16	92.4	69.5
10/21	93.7	76.1
	Mean = 91.2	Mean = 75.1
	s = 2.56	s = 7.33

The sampling results indicate a mean percent solids of 91.2 and with a percent volatile content of 75.1 on a dry weight basis.

The buffing dust applied to the filter press per cycle during the course of the study ranged from 136 to 244 kg (28 to 50 lb) for the filter surface. The filter had a total surface area of 178 m^2 (1913 ft^2). Depending on the number of dewatering cycles required, the pressure filtration process utilized 50 to 90% of the buffing dust generated by the tanning process, the remainder of which was disposed of as refuse.

The use of buffing dust as a precoat affected the filtration operation in several ways. The buffing dust tended to blind the filter cloth material resulting in higher headloss through the filter medium. This was evidenced by the sequential increase in precoat pressures required for subsequent filter cycles after media cleaning. Normally, the filter medium was cleaned at the end of each operating week. The precoat pressures for various operating periods are shown in Figure 79. It is apparent that the precoat pressure increased with each cycle of operation after cleaning of the filter cloth when buffing dust is used as a precoat material. Diatomaceous earth precoat material, for the limited operating period October 2-8, 1974, did not have as pronounced increase in precoat pressure with subsequent filter cycles. After filter cloth cleaning the precoat pressures for the first filter cycle may vary from 45 to 55 psi which is primarily related to the relative cleanliness of the drainage grooves in the filter plate. This effect is evident in Figure 79 also.

Although diatomaceous earth as a precoat material would have demonstrated advantages, the use of buffing dust, a solid waste material,

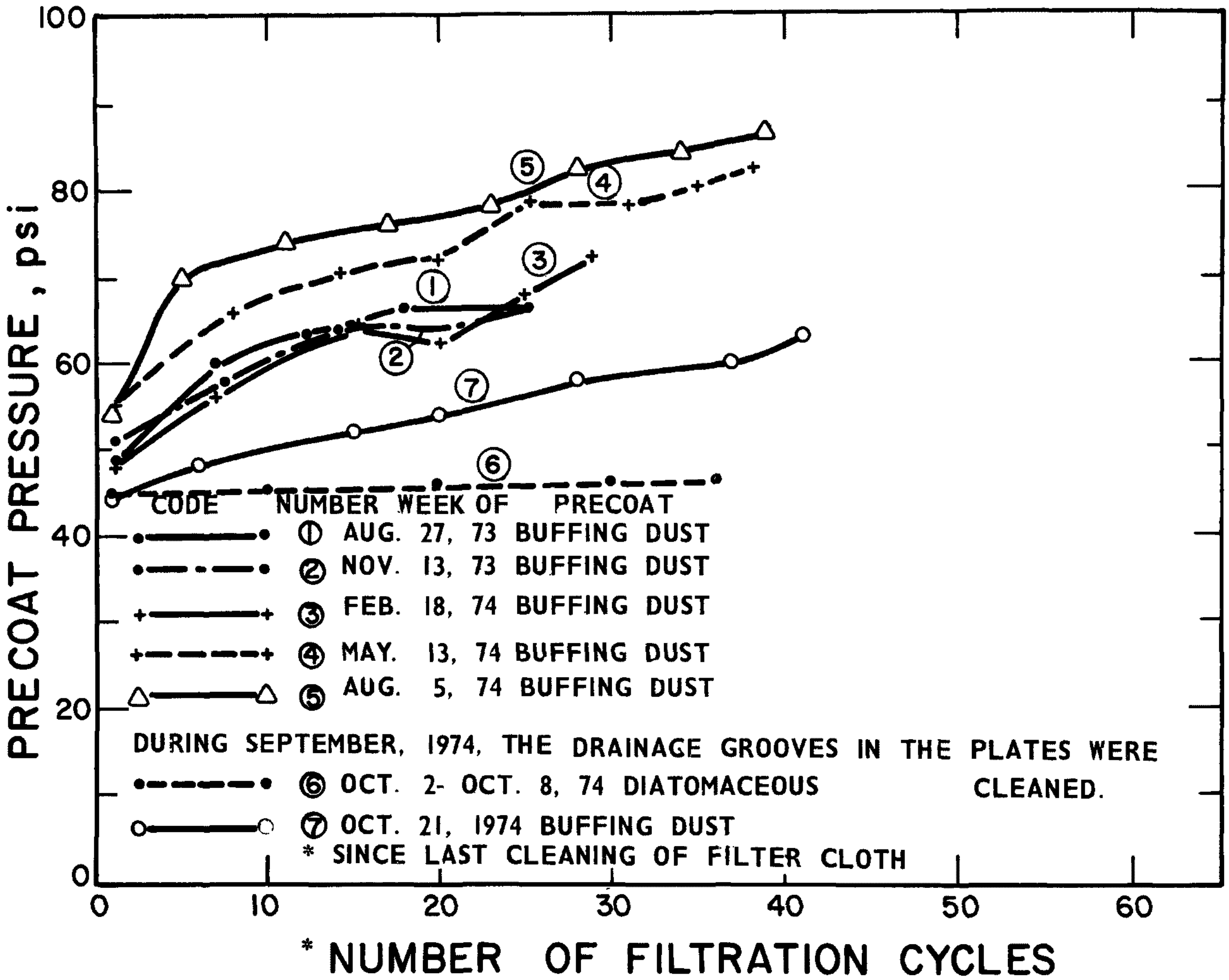

Figure 79. Precoat pressures related to number of filtration cycles and precoat material.

can be successfully employed with appropriate maintenance procedures.

FILTER PRESS PERFORMANCE

Over a period of 7 months, detailed information was collected on the operating conditions and performance of the filter press. Data was collected on sludge characteristics, cake solids, dosage of chemical conditioning agents, cycle times, filtration rates with respect to time, terminating filter pressures, temperature and specific resistance measurements of the conditioned sludge. The information obtained was used to evaluate the influence of the various factors on the dewatering properties of the sludge in the full scale press. The performance of the filter press and dewatering properties of the sludge can be determined from the length of the filter run or 'filter time' or from the average filtration rate over the length of the filter run. The shortest filter time and the highest mean filtration rate to produce a filter cake of desired moisture content represents the highest performance for the filter press but would not necessarily represent optimum or minimum costs associated with the application. Generally, chemical conditioning costs will be higher for operating conditions which will minimize the filter time and maximize the filtration rate. This study was not directed to minimizing costs, but rather to determine those factors and the relative significance of the factor in improving filter performance.

In addition to the use of filter time and mean filtration rate as filter performance variables, the first order rate constant was determined for each of the filtrate volume versus time curves. Table 62 presents the filter data that included filtrate volume with respect to time for filter runs throughout the 7 months period. Figures 80 and 81 show the relationships for filtration rate and cumulative filtrate volume with respect to elapsed time from the start of the filtration cycle for two runs on different dates. In addition, the filter time in minutes as well as the average or mean filtration rate is indicated on each plot. It is apparent that these two parameters only define or are related to the terminal condition of the filtrate volume-time curve.

In this study an additional parameter was used to characterize the filtrate volume-time curve. By the use of statistical curve fitting procedures, both first order and second order relationships were determined for each of the runs presented in Table 62. The rate constants determined by this procedure resulted in the minimum sums of squares fit for each set of filtrate volume-time data. The sums of squares were compared for the first order and second order model for each set of data and in all but one instance the first order model resulted in the minimum sums of squares fit and therefore was used as the third

TABLE 62. FILTRATE VOLUME-TIME AND PERFORMANCE RELATIONSHIPS

Date	Run no.	Temp °C	Cumulative filtrate volume, gallons / Elapsed filter time, minutes														Filter time min.	Mean filtr. rate gpm	1st order K min^{-1}
3/7/74	2	20	319	711	959	1153	1308	1430	1524	1599	1671	1734	1787	1834	1917		69.6	27.5	0.035
			7	12	17	22	27	32	37	42	47	52	57	62	72				
3/7	6	21	207	434	648	833	986	1114	1219	1385	1454	1520	1574	1659			74.8	22.2	0.020
			8	13	18	23	28	33	38	48	53	58	63	73					
3/12	1	20	308	542	660	1055	1315	1500	1625	1724	1803	1824					75.8	24.1	0.032
			7	10	12	22	32	42	52	62	72	75							
3/12	4	18	336	729	1012	1238	1406	1531	1636	1732	1812	1880	1940	1994	2079		74.3	28.0	0.031
			8	13	18	23	28	33	38	43	48	53	58	64	74				
3/22	1	19	328	868	1157	1363	1514	1625	1716	1796	1863	1915	1956				56.3	34.7	0.042
			7	12	17	22	27	32	37	42	47	52	57						
3/26	3	16	160	242	542	575	715	822	918	1002	1078	1142	1191				65.0	22.0	0.017
			8	10	18	19	24	29	34	39	44	49	54						
3/28	9	(20)	21	136	448	669	818	920	1005	1074	1129	1172					50.2	23.3	0.016
			7	9	14	19	24	29	34	39	44	49							
4/4	6	21	443	727	1036	1244	1408	1508	1582	1641	1686						45.9	36.7	0.049
			7	10	15	20	25	30	35	40	45								
4/16	3	21	318	387	552	750	892	992	1064	1121	1169						42.7	27.4	0.046
			6	7	12	17	22	27	32	37	43								
4/16	7	20	180	378	826	1125	1318	1460	1562	1638	1696	1744					49.0	37.9	0.047
			4	6	11	16	21	26	31	36	41	46							
4/30	2	17	198	665	960	1132	1266	1383	1480	1563	1630	1687	1735	1768			61.0	29.0	0.038
			6	11	16	21	26	31	36	41	46	51	56	60					
5/9	3	27	168	360	602	772	927	1050	1160	1260	1354	1432	1484				54.7	27.1	0.026
			6	9	13	17	22	27	32	37	42	47	52						
5/14	6	22	160	480	830	1078	1246	1381	1498	1598	1686	1763	1828	1938			66.0	29.4	0.036
			4	8	13	18	23	28	33	38	43	48	53	63					
5/14	8	17	167	558	832	1028	1179	1301	1406	1496	1573	1635	1687				56.2	30.0	0.030
			6	11	16	21	26	31	36	41	46	51	56						
5/29	3	25	144	626	984	1184	1332	1466	1509								39.6	38.1	0.061
			3	8	13	18	23	33	38										
5/29	8	25	50	278	771	1062	1269	1424	1537	1621	1684	1734					45.4	38.2	0.037
			4	6	11	16	21	26	31	36	41	44							
6/4	5	25	64	342	893	1194	1406	1557	1670	1706	1820	1867					47.1	39.6	0.036
			5	7	12	17	22	27	32	37	42	47							
6/13	7	23	23	104	565	865	1093	1275	1421	1538	1632	1712	1782	1840	1890	1908	64.1	29.8	0.024
			6	7	12	17	22	27	32	37	42	42	52	57	62	64			

(continued)

TABLE 62. (CONTINUED)

Date	Run no.	Temp °C	Cumulative filtrate volume, gallons / Elapsed filter time, minutes																	Filter time min.	Mean filtr. rate gpm	1st order K min^{-1}
6/18	3	23	213	583	852	1061	1226	1361	1474	1566	1639	1699	1743							55.2	31.6	0.030
			6	11	16	21	26	31	36	41	46	51	55									
7/11	4		88	320	533	711	860	980	1086	1176	1248	1308	1368	1427	1483	1535	1586			75.6	21.0	0.024
			4	9	14	19	24	29	34	39	44	49	54	59	64	69	74					
7/18	6	27	95	351	599	796	954	1089	1214	1300	1439	1539	1631	1716	1866	1981	1990			82.0	24.3	0.019
			4	9	14	19	24	29	34	39	44	49	54	59	69	79	80					
7/22	2	24	172	526	771	944	1086	1210	1322	1424	1522	1614	1698	1773	1846	1911	1964	2017		81.4	24.8	0.025
			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80				
7/22	3	24	32	173	476	672	822	948	1072	1184	1286	1382	1472	1552	1626	1696	1761	1846	1908	85.2	22.3	0.017
			5	7	12	17	22	27	32	37	42	47	52	57	62	69	72	77	82			
8/1	2	27	230	382	702	940	1130	1298	1424	1549	1662	1764	1857	1939	2107	2192				81.2	27.0	0.018
			8	10	15	20	25	35	40	45	50	55	60	65	75	85						
8/8	8	27	308	708	998	1206	1388	1553	1683	1798	1906	1996	2078	2153	2220	2272				70.7	32.0	0.026
			7	12	17	22	27	32	37	42	47	52	57	62	67	71						
8/8	9	28	83	422	651	887	1030	1256	1468	1673	1808	1844								75.1	24.6	0.016
			7	12	17	24	29	40	50	62	72	75										
8/15	4	26	164	508	871	1136	1388	1613	1766	1896	2016	2125	2223	2308	2448	2640				82.7	31.4	0.027
			4	8	13	18	23	28	33	38	43	48	53	58	68	84						
8/20	2	28	484	630	883	1078	1242	1375	1468	1540	1665									53.5	31.4	0.028
			11	13	18	23	28	33	38	43	53											
8/20	4	27	240	628	948	1190	1370	1510	1625	1785	1829									53.2	33.9	0.033
			6	11	16	21	26	31	36	46	54											
9/5	4	25	440	875	1140	1330	1480	1602	1702	1780	1845									46.6	39.2	0.037
			8	13	18	23	28	33	38	43	47											
9/5	6	22	324	702	916	1105	1246	1354	1436	1506										40.6	36.7	0.042
			6	11	16	21	26	31	36	41												
9/10	5	27	101	478	767	994	1175	1326	1456	1568	1666	1752	1827	1893	1965					67.0	29.3	0.022
			6	11	16	21	26	31	36	41	46	51	56	61	67							
9/10	7	27	304	862	1192	1438	1640	1793	1913	2010	2090	2162	2225	2279	2308					62.4	37.2	0.047
			4	9	14	19	24	29	34	39	44	49	54	59	62							

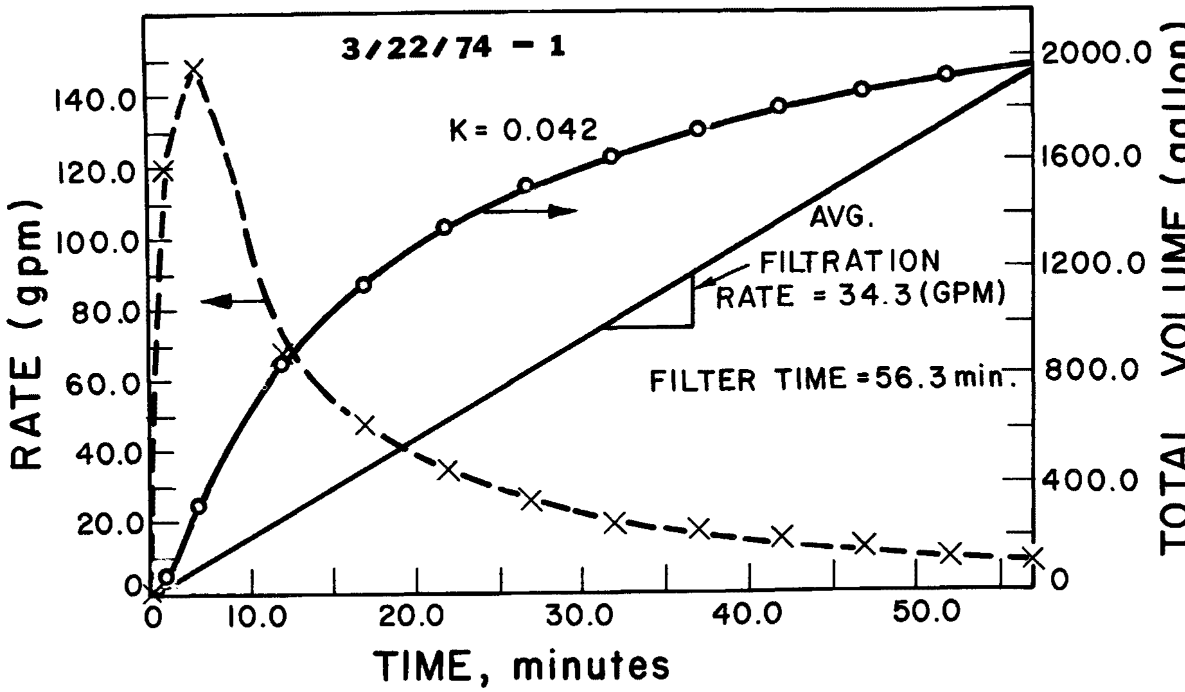

Figure 80. Sludge dewatering filtrate rate and volumes, 3/22/74, Run 1.

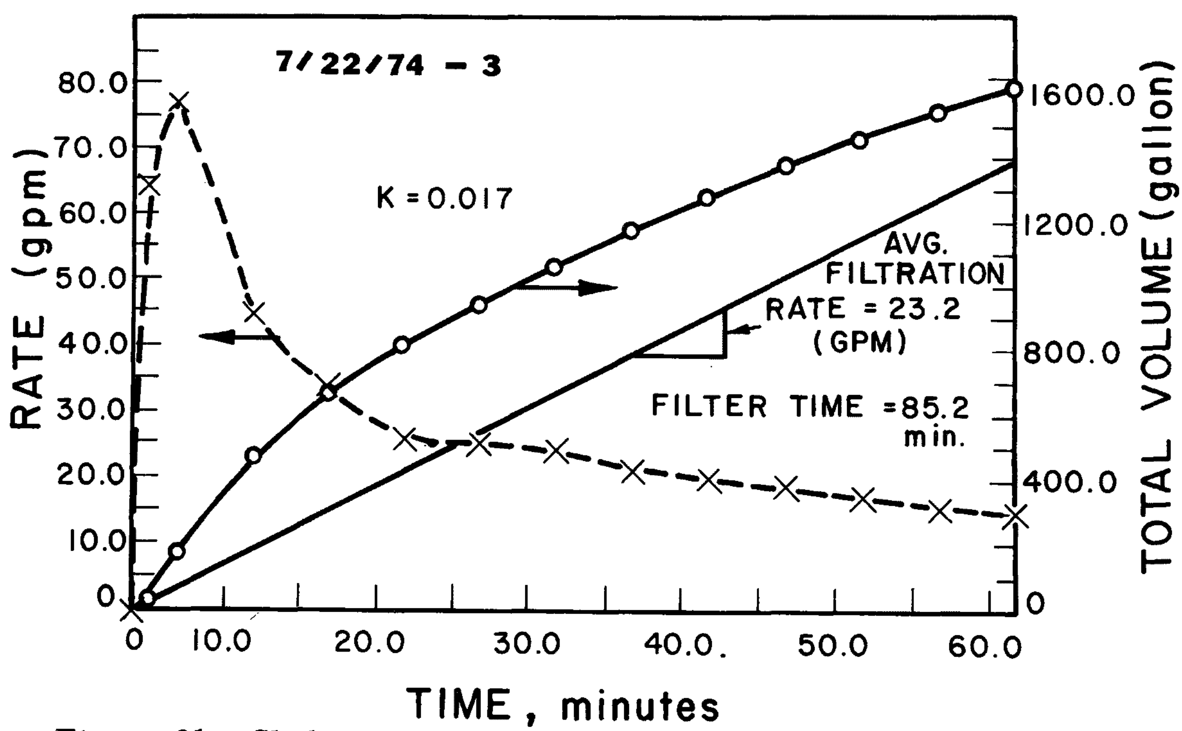

Figure 81. Sludge dewatering filtrate rate and volumes, 7/22/74, Run 3.

parameter, K, to describe the filtrate volume-time relationships as presented in Table 62 and in Figures 80 and 81. As would be expected higher values of K are associated with shorter filter runs and higher filtration rates.

In order to evaluate various factors on the filter performance as measured by the three variables described, multiple linear regression analyses were performed on various combinations of dependent and independent variables. A summary of the variables used in the multiple regression analyses and presented in Table 63 showing the range of values used for a given variable over the test period. The independent variables were not varied randomly over the range of values experienced but rather, the values presented represent actual operating and performance conditions for filter runs where the filtrate volume-time relationships were available.

In the first series of multiple linear regression analyses performed the dependent variable, one of the three filter performance measures, was correlated with the independent variables of sludge feed concentration in percent, dewatered cake solids concentration in percent, ferric chloride added as a percent of dry solids weight, lime added as a percent of dry solids weight, filter cake dry weight and specific resistance. The results of these analyses are presented in Table 64 wherein the partial regression coefficient, partial correlation coefficient, and significance level is indicated for each independent variable as well as the multiple correlation coefficient and coefficient of determination for the multiple linear regression. A positive partial regression coefficient for an independent variable indicates an increase in the independent variable results in an increase in the dependent variable and likewise a negative partial regression coefficient for an independent variable indicates a decrease in the dependent variable. For the three filter performance dependent variables, low values for filter time and high values for filtration rate and first order K are the desired objectives. The partial correlation coefficients for the independent variables indicate the correlation between the dependent factor and each independent variable eliminating any tendency for the other independent variables to obscure the relation. A partial correlation value of +1 or -1 would indicate perfect correlation between the independent and dependent variables whereas a value of 0 indicates the complete lack of correlation between the two variables. The significance level is indicated for each independent variable with two levels of confidence selected at 95%, significant, corresponding to a significance level of 0.05, and 99% highly significant, corresponding to a significance level of 0.01, to denote that the regression parameter differs significantly from zero. The multiple correlation coefficient shows the relative strength of the linear relationship between the dependent variable and all the independent variables in the regression

TABLE 63. MULTIPLE LINEAR REGRESSION ANALYSIS DEPENDENT AND INDEPENDENT VARIABLES

Date	Run no.	Sludge feed solids concentration %	Dewatered cake solids conc. %	Ferric chloride * added to dry weight %	Lime hydrated added to dry weight %	Filter cake yield dry weight pounds	Specific resistance 10^7cm/g	Viscosity of filtrate centipoise	$\frac{(C_i - C_f)^2}{C_i(100-C_i)}$	Terminal pressure psi	$\left(\frac{\text{Sludge}}{\text{density}}\right)^2$ $(lb/ft^3)^2$	Filter time min.	Mean filtration rate gpm	1st order K $min.^{-1}$	Weight ratio lime/ ferric chloride
3/7/74	2	12.5	45.4	3.88	11.8	3042	0.46	1.0050	0.9896	224	1049.8	69.6	27.5	0.035	3.04
3/7	6	12.7	45.8	4.51	11.8	2685	0.62	0.9810	0.9882	222	1024.0	74.8	22.2	0.020	2.62
3/12	1	12.3	46.2	4.58	18.7	3014	0.84	1.0050	1.0654	223	1049.8	75.8	24.1	0.032	4.08
3/12	4	11.4	50.0	3.67	10.5	3127	0.80	1.0559	1.4751	220	1108.9	74.3	28.0	0.031	2.86
3/22	1	11.4	48.9	5.90	13.1	3198	1.41	1.0299	1.3923	224	1169.6	56.3	34.7	0.042	2.22
3/26	3	12.8	41.3	4.66	12.8	2793	1.50	1.1111	0.7277	222	998.6	65.0	22.0	0.017	2.75
3/28	9	15.3	43.9	5.53	12.5	2934	1.10	1.0050	0.6158	223	1232.0	50.2	23.2	0.016	2.26
4/4	6	12.7	44.9	5.22	16.3	2968	0.64	0.9810	0.9352	227	894.0	45.9	36.7	0.049	3.12
4/16	3	8.7	48.0	4.83	12.5	3229	2.18	0.9810	1.944	225	1225.0	42.7	27.4	0.046	2.59
4/16	7	19.1	43.1	5.65	15.1	2838	0.75	1.0050	0.3728	225	1024.0	49.0	37.9	0.047	2.67
4/30	2	16.2	46.7	5.18	17.2	3062	0.65	1.0828	0.6852	225	1197.2	61.0	29.0	0.038	3.32
5/9	3	17.2	50.2	5.77	14.6	3371	1.38	0.8545	0.7647	226	1398.8	54.7	27.1	0.026	2.53
5/14	6	14.1	47.1	4.40	12.4	3313	1.53	0.9579	0.8991	227	1391.3	66.0	29.4	0.036	2.82
5/14	8	14.2	46.0	4.54	11.8	3105	1.59	1.0828	0.8300	225	1149.2	56.2	30.0	0.030	2.60
5/29	3	10.1	43.6	4.35	10.7	2968	0.75	0.8937	1.2360	227	846.8	39.6	38.1	0.061	2.46
5/29	8	14.6	47.7	3.77	8.20	3256	0.84	0.8937	0.8787	227	1267.4	45.4	38.2	0.037	2.18
6/4	5	12.6	47.5	3.95	9.76	3185	0.76	0.8937	1.1060	226	1169.6	47.1	39.6	0.036	2.47
6/13	7	16.5	49.7	4.55	12.1	3302	0.79	0.9358	0.8000	228	1156.0	64.1	29.8	0.024	2.66
6/18	3	10.9	46.5	4.14	12.1	3128	1.03	0.9358	1.3050	226	985.9	55.2	31.6	0.030	2.92
7/11	4	14.1	45.7	5.06	19.3	2930	2.25					75.6	21.0	0.024	
7/18	6	11.2	45.5	4.45	14.8	2918	2.56	0.8545	1.1829	220	1062.8	82.0	24.3	0.019	3.33
7/22	2	12.4	44.2	3.99	9.40	3096	2.82	0.9142	0.9339	223	1069.3	81.4	24.8	0.025	2.35
7/22	3	11.7	42.7	3.98	8.49	2994	2.46	0.9142	0.9302	224	894.0	85.2	22.3	0.017	2.13
8/1	2	11.4	45.8	5.36	15.1	3071	2.59	0.8545	1.1716	220	1062.8	81.2	27.0	0.018	2.82
8/8	8	12.7	45.3	4.46	10.5	3048	2.15	0.8545	0.9586	220	992.3	70.7	32.0	0.026	2.35
8/8	9	9.7	42.4	3.98	10.5	2891	2.01	0.8360	1.2208	220	818.0	75.1	24.6	0.016	2.64
8/15	4	11.8	48.2	5.18	13.2	3254	0.89	0.8737	1.2731	214	1190.3	82.7	31.4	0.027	2.55
8/20	2	13.4	46.0	5.62	18.5	3022	0.75	0.8360	0.9158	224	1190.3	53.5	31.4	0.028	3.29
8/20	4	13.6	46.9	4.28	7.39	3155	0.95	0.8545	0.9437	220	1232.0	53.2	33.9	0.033	1.73
9/5	4	12.1	45.5	6.64	13.7	2785	1.20	0.8937	1.0489	223	1122.2	46.6	39.2	0.037	2.06
9/5	6	12.5	36.5	8.18	16.0	2291	1.10	0.9579	0.5266	227	702.3	40.6	36.7	0.042	1.96
9/10	5	12.2	46.8	6.35	18.5	2917	1.20	0.8545	1.1176	220	1204.1	67.0	29.3	0.022	2.91
9/10	7	11.9	47.6	6.35	11.5	3056	0.81	0.8545	1.2157	220	1149.2	62.4	37.2	0.047	1.81

TABLE 64. MULTIPLE LINEAR REGRESSION ANALYSIS OF PRESSURE FILTER PERFORMANCE RELATED TO SLUDGE FEED, CAKE SOLIDS AND CHEMICAL DOSAGE

Dependent variable	Number of observations	Independent variables: Constant	Feed solids concentration %	Dewatered cake solids concentration %	Ferric chloride added %	Hydrated lime added %	Filter cake dry weight pounds	Specific resistance 10^7 cm/g	Multiple correlation coefficient	Coefficient of determination
Filter time, min	33								0.6633	0.4399
Partial regression coefficient		48.51	0.187	2.841	-7.249*	1.000	-0.0366	11.03**		
Partial correlation coefficient		0.209	0.035	0.336	-0.456	0.233	-0.311	0.535		
Significance level		0.2848	0.8602	0.0800	0.0148	0.2320	0.1073	0.0034		
Average filtration rate, gpm	33								0.7087	0.5022
Partial regression coefficient		36.40*	-0.0238	-0.9517	2.982*	-0.7397*	0.0129	-4.863**		
Partial correlation coefficient		0.380	-0.011	-0.292	0.474	-0.413	0.282	-0.580		
Significance level		0.0463	0.9543	0.1313	0.0109	0.0291	0.1416	0.0012		
1st order K, min^{-1}	33								0.6101	0.3722
Partial regression coefficient		0.0285	-0.00147	-0.00191	0.00453	-0.00024	0.000034	-0.00974**		
Partial correlation coefficient		0.147	-0.308	-0.272	0.353	-0.069	0.336	-0.550		
Significance level		0.4559	0.1106	0.1611	0.0654	0.7275	0.0800	0.0024		

Statistical significance: * 95% confidence level, significant
** 99% confidence level, highly significant

equation with values between 0 and 1. The coefficient of determination which is the square of the multiple correlation coefficient represents the fraction of total variation of the dependent variable explained by all the independent variables in the regression equation.

In comparing the multiple correlation coefficients and coefficient of determination for the multiple linear regression analysis presented in Table 64, it is evident that the variation of the dependent variable, average filtration rate, was better explained by the independent variable, 50%, than for filter time or first order K values with corresponding values of 44 and 37%. A review of each of the independent variables indicates that specific resistance is highly significantly correlated with the dependent variables indicating that an increase in specific resistance will increase filter run time and decrease filtration rate and first order K values. This finding supports the value of utilizing specific resistance measurements for the purpose of evaluating conditioning agents and other operating conditions for expected filter performance. The other independent variable affecting the filter performance showing significance is the ferric chloride added as a percent of sludge dry solids wherein an increase in ferric chloride for the range tested indicates a decrease in filter time and an increase in filtration rate with an increase in ferric chloride dosage whereas lime additions showed a significant decrease in filtration rate with an increase in lime added whereas the filter performance parameters of filter time and K showed no significant effect. The independent variables feed sludge solids concentration and dewatered cake solids concentration showed that an increase in these independent variables resulted in an increase in filter time and a decrease in filtration rate and K but not significantly so. The filter cake dry weight independent variables was negatively correlated to filter time and correlated positively with mean filter rate and first order K but not significantly so.

A second series of multiple linear regression analyses were performed between the three dependent filter performance variables and the same independent variables with the exception that the weight ratio of lime to ferric chloride was used rather than the two independent variables of ferric chloride and lime as in the previous analysis. The results are presented in Table 65.

The combination of the ferric chloride and lime variables as a single ratio resulted in a decrease in the multiple correlation coefficients and corresponding coefficients of determination but the relative values are in the same order as the results presented in Table 64. As in the first series of results, the specific resistance values are highly significantly correlated to the three filter performance values.

TABLE 65. MULTIPLE LINEAR REGRESSION ANALYSIS OF PRESSURE FILTER PERFORMANCE RELATED TO SLUDGE FEED, CAKE SOLIDS AND CHEMICAL DOSAGE RATIO

Dependent variable	Number of observations	Independent variables: Constant	Feed solids concentration %	Dewatered cake solids conc. %	Ratio lime/ ferric chloride	Filter cake solids weight pounds	Specific resistance 10^7 cm/g	Multiple correlation coefficient	Coefficient of determination
Filter time, min.	33							0.6157	0.3791
Partial regression coefficient		-15.76	-0.2290	1.974	8.247	-0.0153	11.0347**		
Partial correlation coefficient		-0.076	-0.042	0.241	0.350	-0.149	0.518		
Significance level		0.6959	0.8268	0.2075	0.0630	0.4392	0.004		
Average filtration rate, gpm	33							0.6722	0.4519
Partial regression coefficient		49.24**	-0.1586	-0.3387	-4.927**	0.00589	-4.676**		
Partial correlation coefficient		0.523	-0.076	-0.109	-0.499	0.149	-0.553		
Significance level		0.0036	0.6957	0.5719	0.0059	0.4413	0.0019		
1st order K, min^{-1}	33							0.5449	0.2969
Partial regression coefficient		0.0708*	-0.00109	-0.00121	-0.0032	0.0000169	-0.00958**		
Partial correlation coefficient		0.372	-0.231	-0.176	-0.168	0.193	-0.525		
Significance level		0.0469	0.2289	0.3601	0.3844	0.3170	0.0034		

Statistical significance: * 95% confidence level, significant
** 99% confidence level, highly significant

Also, the independent variable lime to ferric chloride ratio was highly significantly correlated to average filtration rate with high values of the ratio resulting in a decrease in filtration rate. The significant level for this ratio is 0.063 for filter time which also demonstrates the relative importance of reducing this ratio. This result reinforces in general the value of increasing ferric chloride dosage to improve filter performance and the negative effect of high lime dosages.

Another set of multiple linear regression analyses were performed using the various terms of the Jones equation and sludge density as the independent variables with each of the three filter performance measures. The dependent variable in the Jones equation is filter time and should represent the best correlation with the independent variables. A review of the results presented in Table 66 shows this to be the case wherein the largest multiple correlation coefficient 0.72 and coefficient of determination of 52% for filter time as the dependent variable as compared to coefficients of determination of 45 and 41% for the dependent variables of first order K and average filtration rate respectively. Again the specific resistance independent variable is significantly correlated for filter time and highly significantly correlated with average filtration rate and first order K dependent variables. Filtrate viscosity is significantly correlated with average filtration rate but not so with the other two filter performance variables wherein an increase in viscosity would result in a decrease in filtration rate. The independent variable term related to initial moisture content in the feed sludge, Ci, and final moisture content in the cake, Cf, shows that a decrease in C_i should result in a substantial decrease in filter time for a given cake moisture content C_f in that this term is directly proportional to filter time in the Jones equation. The results of the multiple linear regression analysis show that there is no significant relationship between this term and filter time or average filtration rate. A significant correlation is indicated between the moisture term and the first order K value which indicates that a higher moisture content in the feed solids would result in higher first order K rates. The signs of this term are the opposite to what one would expect for all three filter performance factors. The terminal pressure independent variable is highly significantly correlated with filter time and first order K dependent variables wherein an increase in terminal pressure results in lower filter times and higher first order K values as one would expect over the narrow range of terminal pressures encountered. The significance level for terminal pressure as related to average filtration rate is 0.0515 just under 95% confidence level which represents a sizable level of significance for this filter performance parameter as well. The independent variable of the square of the sludge cake density is not correlated with any of the three filter performance factors.

TABLE 66. MULTIPLE LINEAR REGRESSION ANALYSIS OF PRESSURE FILTER PERFORMANCE RELATED TO JONES EQUATION

Dependent variable	Number of observations	Independent variables: Constant	Specific resistance 10^7 cm/g	Filtrate viscosity centipoise	$\frac{(C_i - C_f)^2}{C_i(100-C_i)}$	Terminal pressure psi	$\left(\text{Sludge density}\right)^2$ $(lb/ft^3)^2$	Multiple correlation coefficient	Coefficient of determination
Filter time, min.	32							0.7182	0.5158
Partial regression coefficient		635.32**	7.573*	21.98	-4.193	-2.677**	-0.00168		
Partial correlation coefficient		0.643	0.442	0.169	-0.121	-0.621	-0.027		
Significance level		0.0002	0.0187	0.3894	0.5404	0.0004	0.8927		
Average filtration rate, gpm	32							0.6383	0.4074
Partial regression coefficient		-71.474	-4.217**	-28.077*	1.696	0.6079	-0.00345		
Partial correlation coefficient		-0.206	-0.520	-0.438	0.109	0.372	-0.121		
Significance level		0.2934	0.0045	0.0196	0.5815	0.0515	0.5397		
1st order K, min^{-1}	32							0.6709	0.4501
Partial regression coefficient		-0.3224*	-0.00741**	-0.00604	0.0138*	0.00164**	-0.00001		
Partial correlation coefficient		-0.444	-0.488	-0.055	0.422	0.491	-0.181		
Significance level		0.0179	0.0084	0.7822	0.0254	0.0080	0.3557		

Statistical significance: * 95% confidence level, significant
**99% conficence level, highly significant

The results of these multiple linear regression analyses indicate the following:

1) The specific resistance values represent the most consistent single factor significantly correlated to full scale filter performance and should be used as the measure for evaluating chemical conditioning and operating characteristics.

2) Increases in ferric chloride dose for sludge conditioning has a pronounced effect on the improvement of filter performance in the range of concentrations encountered.

3) Increases in lime dose for sludge conditioning in the range encountered resulted in a detriment to the filter performance.

4) The feed sludge solids concentration or the final dewatered sludge cake solids did not prove to be significantly correlated with the filter performance measures.

5) All three filter performance variables, i.e., filtration time, average filtration rate and first order K values, were near equally useful as measures of filter performance for the independent variables studied. Filter time was better suited as the dependent variable for the Jones equation and average filtration time for the independent variables related to sludge feed, cake solids, and chemical conditioning dosages.

The dewatering process can be optimized by conducting statistical studies employing evolutionary operation procedures wherein sludge conditioning chemicals and dosage levels could be evaluated along with certain physical operating parameters. In that the specific resistance measurements have a highly significant correlation with the filter performance measures utilized, initial studies should be conducted on a laboratory scale, optimized and expanded to the full scale performance. Economic factors should be considered in the final optimization.

SECTION XIV

DEWATERED SLUDGE CAKE DISPOSAL

The ultimate disposal of dewatered sludge cake at this tannery was accomplished by landfilling. Because landfilling the sludge cake singly or in combination with municipal refuse could represent practice industrywide, eight solid waste cells or bins were constructed which would permit the monitoring of certain physical and chemical characteristics of the material so placed. The controlled variables for the eight test bins were (1) the composition of the solids waste placed, i.e., dewatered sludge cake only, municipal refuse only and combinations thereof; and (2) the presence or absence of earth cover. The response variables included the measurements of internal temperatures at various locations within the solid waste material placed, the settlement or consolidation of the solid waste, the composition changes of the solid waste regarding volatile solids and moisture content, and the characterization of the leachate collected from each bin regarding volume and chemical analyses such as BOD_5, COD, residue, pH, chromium, calcium, chloride, sulfide, oil and grease, and alkalinity.

The placement of the refuse, cake, and refuse-cake combinations for each experimental bin were conducted according to schedule and amounts shown in Table 67. The municipal refuse was obtained from the City of Red Wing, Burnside area. At the time of the study the garbage generated in this area was part of the municipal refuse collected therefrom. The bins that were constructed in the late summer of 1973 containing municipal refuse, likely had a higher content of yard vegetation than those constructed in the spring of 1974. The weight of refuse placed in each bin was obtained, but, the composition of the refuse was not determined.

The dewatered sludge cake was obtained from the pressure filtration system and the weight of the filter cake placed was determined either by truck weighings (August - September, 1973) or by weighing individual cakes from the filter press (March - April, 1974). Random samples were collected from the cakes for determination of percent solids, percent volatile, and chromium content. Throughout the study, buffing dust was used as a precoat material and ferric chloride and

TABLE 67. LANDFILL TEST BIN CONTENTS AT TIME OF PLACEMENT

				Dewatered sludge cake						Municipal refuse		
Bin no.	Date of placement	Composition by weight	Earth cover 10-15cm(4-6")	Total weight kg(lb)	Percent of total weight	Percent dry solids	Volume of water gal	Total chromium kg(lb)	Density lbs/ft^3	Total weight kg(lb)	Percent of total weight	Density lbs/ft^3
1	9/14/73	100% refuse	yes	--	100	--	--	--	--	4780(10540)	100	14.8
2	9/7/73	20% cake 80% refuse	yes	1311(2890)	20.2	54.2	159	--	--	5175(11410)	79.8	20.2
3	8/16/73	100% cake	no	12200(26890)	100	47.0	1709	--	45.6	--	--	--
4	8/24/73	100% cake	yes	12580(27740)	100	48.0	1731	--	44.4	--	--	--
5	8/30/73	50% cake 50% refuse	yes	4470(9860)	54	48.3	596	--	--	3806(8390)	46	27
6	4/17/74	50% cake 50% refuse	no	3000(6615)	46.4	48.4	409	7.17(15.8)	--	3461(7630)	53.6	18.7
7	4/10/74	100% cake	yes	11640(25673)	100	44.7	1704	29.8(65.6)	52	--	--	--
8	3/22/74	100% cake	no	11960(26363)	100	48.4	1631	30.1(66.4)	44.5	--	--	--

lime were the conditioning chemicals.

After placement of the bin contents, the solid wastes were compacted. In those instances where cover was desired, 10-15 cm (4-6 in) of earth were applied, compacted and sloped for surface runoff to the front of the bin. The depth of the placement of the solid waste material was about 5 feet to the rear of the bin to 4 feet at the front. Each bin was 3.05 by 4.57 m (10 by 15 ft) in plan with a concrete floor and trench underdrain. Timber sides lined with plastic for waste containment were employed, and the leachate was collected at a sample point to the front of the bin in an individual collection well (see Figures 82 and 83).

SETTLEMENT

Measurements of the settlement of the bin contents provides information useful for the design of landfills. Each test bin was provided with three settlement plates placed 15 cm(6 in) below the top surface to record the drop in elevation as a result of consolidation or settlement of the material placed. The plates were metal, 30.5 cm(1 ft) square with a 46 cm (18 in) length of 2.54 cm (1 in) pipe attached to the center so as to extend above the surface of the landfill to facilitate measurements. The three plates for each bin were placed with one plate forward and center of the bin with the remaining two placed on the right and left areas at the rear of the bin.

All changes in elevation were observed with the aid of surveying instruments wherein bench marks were established external to the site as well as at the exposed corners of the concrete base for each test bin. Measurements were made after the completion of the placement of the bin contents and then, at first, thereafter at one week intervals. After changes in elevation become less pronounced, the changes in elevation of the settlement plates were recorded in two week, one month and two month intervals. The last measurements were made in November, 1974, some 14 months after placement of solid waste in bins 1 through 5 and 7 months after the placement of solid waste in bins 6 through 8.

The results of the settlement measurement are presented in Table 68 wherein the average cumulative settlement that occurred over the test period as well as during the first two months was reported. The average settlement in meters represents the average of the results for the three settlement plates in each bin. The greatest settlement occurred in test bins containing 100% dewatered sludge cake placed without earth cover (bins 3 and 8). A comparison of bins 3 and 4 shows the settlement in meters to be greater for 100% dewatered sludge cake uncovered (bin 3) than for 100% cake covered (bin 4).

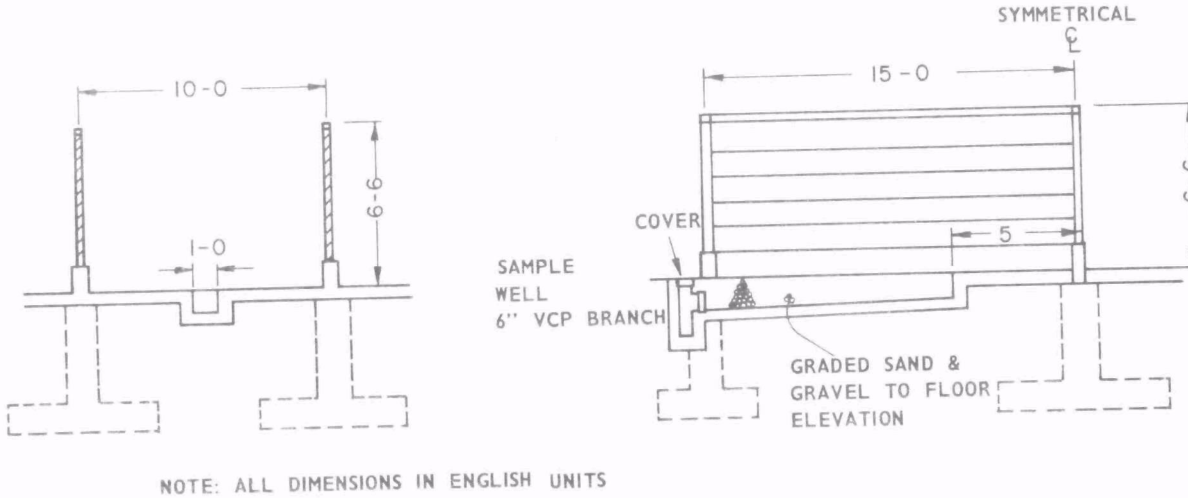

Figure 82. Landfill test bins.

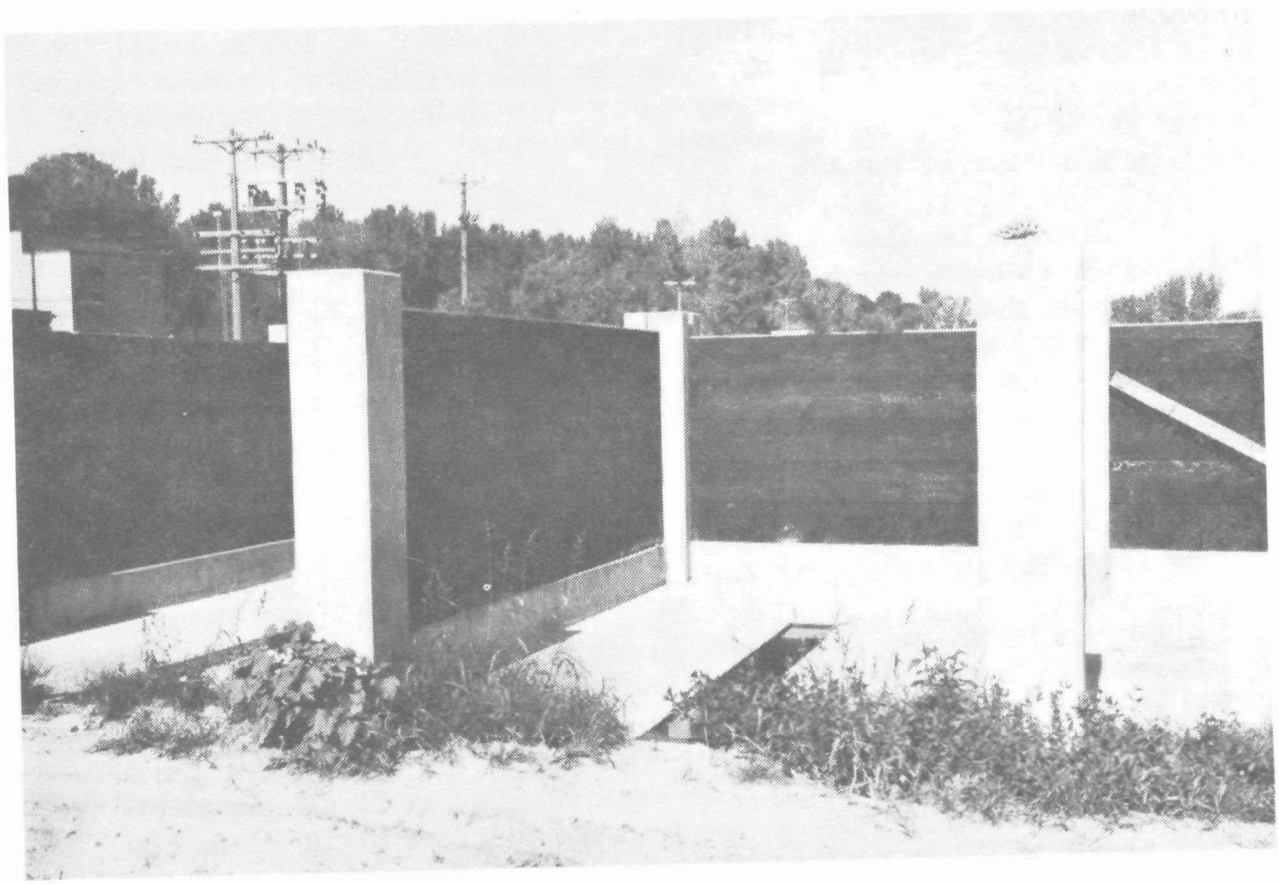

Figure 83. End view of landfill test bins.

TABLE 68. SETTLEMENT MEASUREMENTS OF SOLID WASTES

Bin no.*	Bin contents percent by weight	Cumulative settlement: Average m	Cumulative settlement: Range m	Cumulative settlement: As percent of original height	Initial settlement (first 60 days): Settlement m	Initial settlement (first 60 days): Percent of total settlement	Initial settlement (first 60 days): Settling rate initial m per m/height/mo
1	100% municipal refuse covered	0.314	0.241-0.421	20.3	0.131	42.1	0.04
2	80% municipal refuse 20% sludge cake uncovered	0.354	0.302-0.399	23.0	0.122	34.2	0.04
3	100% sludge cake uncovered	0.411	0.329-0.466	34.4	0.274	66.7	0.11
4	100% sludge cake covered	0.323	0.247-0.445	23.6	0.250	77.4	0.09
5	50% municipal refuse 50% sludge cake uncovered	0.280	0.235-0.311	19.0	0.107	38.0	0.04
6	50% municipal refuse 50% sludge cake covered	0.344	0.287-0.369	22.2	0.280	81.1	0.09
7	100% sludge cake covered	0.283	0.215-0.320	21.6	0.210	74.2	0.08
8	100% sludge cake uncovered	0.555	0.543-0.576	43.8	0.418	75.0	0.16

* Bins 1 through 5 were constructed in August - September, 1973 (14 months of data). Bins 6 through 8 were constructed in March - April, 1974 (7 months of data).

The settling rate in meters per meter of initial height per month for the first 60 days shows the rates for covered and uncovered to be nearly the same (bins 4 and 3 respectively). However, for the sludge cake placed in April, 1974, for covered and uncovered, bins 7 and 8 respectively, the cumulative settlement in meters for the uncovered sludge cake and the rate of settlement for the first 60 days was two times that for the covered cake. The settlement 60 days after the date of placement for bins 3 and 8 represented 67.7 and 75% respectively of the total settlement during the test period.

The results for cumulative settlement in meters and feet over the test period for each of the bins areshown in Figure 84. Although sanitary landfill practices required the placement of earth cover for municipal refuse for purposes of public health, it is apparent that the benefits of landfill consolidation or settlement is better realized with the testbins when no cover is provided as evidenced for the 50:50 combinations and 100% dewatered sludge cake materials. The settlement of the material can be related to a combination of the following factors.

1) Physical compaction of the material resulting in a lower void volume to total volume ratio (porosity).

2) Loss of water as a result of evaporation.

3) Volatilization or degradation of organic matter by biological matter.

4) Loss of material as part of the leachate.

It was apparent from other measurements of moisture content, volatile solids content and temperature development within the solid waste material that loss of water and volatilization or degradation of organic matter was a significant factor for the settlement of the uncovered bins 3, 6 and 8. The uncovered test bins would tend to promote aerobic biological activity similar to compost and the attendant rapid rise of internal temperatures discussed in the following section seem to support this.

INTERNAL TEMPERATURE

The temperatures within the solid waste material for each bin was monitored by the use thermocouples and a readout potentiometer. The thermocouples were placed in a centrally located area near the back of the solid waste bins. Initially the thermocouples were placed at several locations with reference to the supporting concrete floor and the

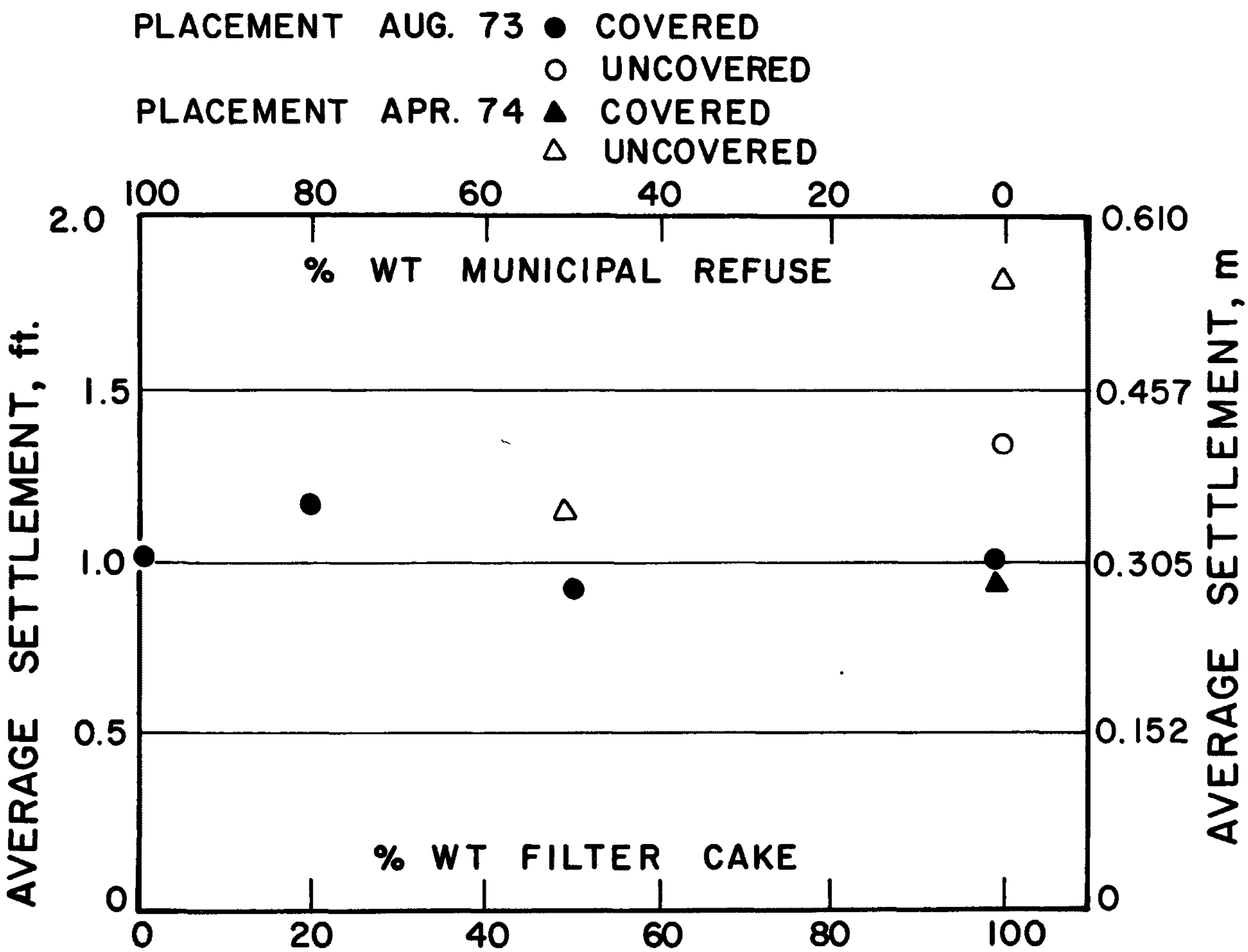

Figure 84. Landfill settlement (November 1974).

material surface. As a result of settlement over the test period the position of the thermocouples changed with respect to the supporting floor. The locations of the thermocouples and the resulting temperatures for the dates indicated and corresponding elapsed time from placement are presented in Tables 69 and 70. In addition the average air temperature and the rainfall in centimeters for the corresponding months are indicated.

Results:

Bin no. 1 (100% municipal refuse, covered)--Internal temperatures within a short period of time rose to between 60 and 70°C for a period of about 3 months well above the monthly ambient air temperature 17 to -7°C. The internal temperatures dropped markedly during the winter months of January, February, March and half of April with the lowest value of 4°C attained by the end of February thereafter, the temperature levels rose again to a range of 40 to 60°C during the warm weather months followed by decreasing temperatures during the fall.

Bin no. 2 (80% municipal refuse, 20% sludge cake, covered)--The internal temperature buildup was not as great for bin no. 2 as for bin no. 1, however, the temperatures remained more uniform over the test period generally between the temperatures of 40 to 60°C. The minimum temperatures were experienced during the first half of the month of April.

Bin no. 3 (100% dewatered sludge cake, uncovered)--Although the increase in internal temperatures did not occur as rapidly as in bin no. 1, within 6 weeks after placement the temperatures were in excess of 70°C. The decrease in temperatures during the winter months was similar to that of bin no. 1, however, a temperature increase from a level of low teens at the end of March to a level of 77°C occurred during the month of April with monthly average ambient air temperatures during the month of April of only 9.4°C. For the remainder of the test period the internal temperatures were in the 40 to 60°C for the most part. The high temperatures experienced early after placement for bin no. 3 and the reoccurrence of high temperatures in the spring appears to be related to the cyclic effect in moisture content wherein the initial moisture was evaporated during the early phases. After the winter months with the spring thaw and incident rainfall the moisture content increased to a level which permitted accelerated biological activity as evidenced by the rapid rise in temperature during the month of April.

TABLE 69. TEMPERATURE VARIATIONS IN BIN CONTENTS WITH RESPECT TO ELAPSED TIME AFTER PLACEMENT

Date	Bin no. 1 100% municipal covered		Bin no. 2 20% sludge cake 80% municipal covered		Bin no. 3 100% sludge cake uncovered		Bin no. 4 100% sludge cake covered			Bin no. 5 50% sludge cake 50% municipal covered		Monthly mean Temp °C	Rainfall cm/mo	Date	Rainfall cm
	Elapsed Time Days	Probe Temp °C	Elapsed Time Days	Probe Temp °C	Elapsed Time Days	Probe Temp °C	Elapsed Time Days	Probe 1 Temp °C	Probe 2 Temp °C	Elapsed Time Days	Probe Temp °C				
8/16/73					date of placement							22.8	7.82*		
8/24							date of placement					22.8	7.82		
8/28					12	30	4	32	30			22.8	7.82		
8/30										date of placement		22.8	7.82		
9/6					21	38	13	56	46	7	72	16.7	6.45	9/1-3	0.56
9/7			date of placement									16.7	6.45		
9/13			6	48	28	46	20	64	58	14	57	16.7	6.45	9/8	0.46
9/14	date of placement											16.7	6.45	9/15-21	0.91
9/18	4	66	11	46	33	48	25	66	59	19	60	16.7	6.45		
9/22	8	68	15	49	37		29	69	68	23	70	16.7	6.45	9/24-28	4.52
9/27	13	72	20	55	42	70	34	67	56	28	71	16.7	6.45		
10/1	17	70	24	53	46	70	38	56	49	32	68	13.3	4.80		
10/4	20	70	27	51	49	71	41	53	47	35	65	13.3	4.80	10/3	0.53
10/9	25	72	32	48	54	73	46	55	45	40	70	13.3	4.80	10/6	1.07
10/10	26	69	33	44	55	70	47	54	44	41	68	13.3	4.80	10/8-11	2.44
10/11	27	69	34	45	56	71	48	53	44	42	68	13.3	4.80		
10/18	34	66	41	50	63	72	55	50	42	49	63	13.3	4.80		
10/23	39	64	46	46	68	65	60	49	41	54	65	13.3	4.80		
10/24	40	64	47	45	69	62	61	49	40	55	66	13.3	4.80	10/24	0.05
10/26	42	66	49	45	71	68	63	50	40	57	60	13.3	4.80	10/26	0.69
10/30	46	62	53	57	75	69	67	52	42	61	60	13.3	4.80	10/30	0.02
11/1	48	62	55	56	77	65	69	50	40	63	60	2.2	5.82	11/6	0.05
11/21	68	38	75	60	97	37	89	57	40	83	64	2.2	5.82	11/14	0.74
11/23	70	59	77	56	99	71	91	52	38	85	66	2.2	5.82	11/20-22	4.11
11/30	77	58	84	59	106	64	98	36	32	92	58	2.2	5.82	11/25 11/28	0.30 0.41
12/7	84	62	91	60	113	62	105	44	40	99	58	-7.2	2.79	12/5	0.86
12/13	90	60	97	60	119	58	111	58	46	105	60	-7.2	2.79	12/9	0.08
12/21	98	49	105	48	127	42	119	43	32	113	41	-7.2	2.79	12/14	0.23
12/28	105	42	112	38	134	38	126	44	33	120	44	-7.2	2.79	12/18	0.08

(continued)

TABLE 69. (CONTINUED)

Date	Bin no. 1 100% municipal covered		Bin no. 2 20% sludge cake 80% municipal covered		Bin no. 3 100% sludge cake uncovered		Bin no. 4 100% sludge cake covered			Bin no. 5 50% sludge cake 50% municipal covered		Monthly mean Temp °C	Rainfall cm/mo	Date	Rainfall cm
	Elapsed Time Days	Probe Temp °C	Elapsed Time Days	Probe Temp °C	Elapsed Time Days	Probe Temp °C	Elapsed Time Days	Probe 1 Temp °C	Probe 2 Temp °C	Elapsed Time Days	Probe Temp °C				
1/1/74	112	47	119	42	141	42	133	40	29	127	48	-10	0.33	12/25-28 1/8	1.55 0.06
1/14	122	38	129	44	151	45	143	34	26	137	48	-10	0.33		
1/18	126	30	133	40	155	36	147	26	22	141	46	-10	0.33	1/20	0.25
1/24	132	28	139	44	161	25	153	26	24	147	48	-10	0.33		
1/28	136	30	143	46	165	21	157	32	23	151	52	-10	0.33	1/30	0.01
2/7	146	28	153	45	175	11	167	30	26	161	44	-7.8	2.95	2/1-4	1.68
2/11	150	22	157	45	179	12	171	31	25	165	41	-7.8	2.95	2/9	0.30
2/14	153	18	160	48	182	7	174	34	24	168	42	-7.8	2.95	2/13-14	0.30
2/18	157	14	164	43	186	6	178	31	26	172	37	-7.8	2.95		
2/22	161	10	168	46	190	10	182	36	19	176	44	-7.8	2.95	2/20-21	0.71
2/25	164	4	171	48	193	6	185	37	38	179	38	-7.8	2.95		
2/28	167	7	174	46	196	4	188	48	29	182	38	-7.8	2.95		
3/4	171	8	178	40	200	2	192	34	26	186	32	-0.6	3.89		
3/7	174	10	181	40	203	6	195	34	26	189	35	-0.6	3.89		
3/12	179	12	186	40	208	9	200	35	27	194	38	-0.6	3.89	3/14-15	0.51
3/15	182	12	189	39	211	9	203	37	38	197	42	-0.6	3.89	3/18	0.05
3/18	185	13	192	39	214	10	206	38	34	200	40	-0.6	3.89	3/22	0.10
3/22	189	16	196	41	218	12	210	38	30	204	39	-0.6	3.89	3/25	0.38
3/28	195	12	202	36	224	13	216	40	30	210	33	-0.6	3.89	3/27-30	2.84
4/1	199	11	206	38	228	28	220	48	30	214	31	9.4	2.95	4/1-4	0.79
4/4	202	13	209	34	231	24	223	38	29	217	28	9.4	2.95		
4/8	206	14	213	30	235	36	227	37	28	221	33	9.4	2.95		
4/12	210	19	217	17	239	49	231	32	25	225	39	9.4	2.95	4/11-13	1.85
4/15	213	36	220	39	242	62	234	32	25	228	20	9.4	2.95		
4/19	217	50	224	36	246	76	238	32	23	232	48	9.4	2.95		
4/22	220	62	227	42	249	72	241	35	24	235	58	9.4	2.95	4/21-22	0.23
4/26	224	63	231	45	253	77	245	36	31	239	56	9.4	2.95	4/27-28	0.09
4/29	227	64	234	46	256	77	248	36	24	242	57	9.4	2.95		

(continued)

TABLE 69. (CONTINUED)

Date	Bin no. 1 100% municipal covered Elapsed Time Days	Bin no. 1 Probe Temp °C	Bin no. 2 20% sludge cake 80% municipal covered Elapsed Time Days	Bin no. 2 Probe Temp °C	Bin no. 3 100% sludge cake uncovered Elapsed Time Days	Bin no. 3 Probe Temp °C	Bin no. 4 100% sludge cake covered Elapsed Time Days	Bin no. 4 Probe 1 Temp °C	Bin no. 4 Probe 2 Temp °C	Bin no. 5 50% sludge cake 50% municipal covered Elapsed Time Days	Bin no. 5 Probe Temp °C	Monthly mean Temp °C	Rainfall cm/mo	Date	Rainfall cm
5/2	230	62	237	43	259	50	251	37	23	245	58	13.3	9.40	5/2	0.30
5/6	234	56	241	48	263	56	255	41	28	249	55	13.3	9.40		
5/9	237	48	244	44	266	46	258	36	25	252	49	13.3	9.40		
5/13	241	42	248	44	270	43	262	34	26	256	48	13.3	9.40	5/7-18	6.71
5/17	245	38	252	44	274	47	266	30	24	260	44	13.3	9.40		
5/21	249	39	256	42	278	44	270	30	24	264	42	13.3	9.40	5/21	0.84
5/23	251	44	258	43	280	48	272	30	24	266	44	13.3	9.40		
5/28	256	40	263	38	285	42	277	28	22	271	40	13.3	9.40	5/29-30	1.55
5/31	259	45	266	44	288	48	280	30	24	274	45	13.3	9.40		
6/3	262	44	269	43	291	46	283	32	26	277	48	20	13.31	6/3-13	7.70
6/7	266	44	273	46	295	42	287	33	25	281	47	20	13.31		
6/10	269	44	276	48	298	42	290	33	26	284	47	20	13.31		
6/14	273	42	280	42	302	42	294	30	26	288	44	20	13.31		
6/17	276	42	283	41	305	48	297	31	26	291	43	20	13.31	6/18-20	5.61
6/21	280	44	287	38	309	48	301	28	24	295	43	20	13.31		
6/24	283	40	290	38	312	53	304	27	22	298	44	20	13.31		
6/28	287	45	294	44	316	56	308	31	26	302	48	20	13.31		
7/1	290	48	297	44	319	53	311	32	25	305	50	24.4	5.36	7/1-3	0.58
7/3	292	48	299	44	321	52	313	33	25	307	51	24.4	5.36		
7/8	297	49	304	44	326	52	318	32	25	312	50	24.4	5.36		
7/11	300	48	307	44	329	53	321	31	25	315	49	24.4	5.36	7/10-12	0.76
7/17	306	51	313	50	335	54	327	47	29	321	54	24.4	5.36		
7/19	308	48	315	48	337	52	329	38	30	323	54	24.4	5.36	7/18	0.08
7/22	311	50	318	50	340	52	332	38	30	326	56	24.4	5.36		
7/25	314	55	321	54	343	53	335	39	30	329	57	24.4	5.36	7/23-24	3.94
7/29	318	52	325	56	347	56	339	40	32	333	60	24.4	5.36		

(continued)

TABLE 69. (CONTINUED)

Date	Bin no. 1 100% municipal covered Elapsed Time Days	Bin no. 1 Probe Temp °C	Bin no. 2 20% sludge cake 80% municipal covered Elapsed Time Days	Bin no. 2 Probe Temp °C	Bin no. 3 100% sludge cake uncovered Elapsed Time Days	Bin no. 3 Probe Temp °C	Bin no. 4 100% sludge cake covered Elapsed Time Days	Bin no. 4 Probe 1 Temp °C	Bin no. 4 Probe 2 Temp °C	Bin no. 5 50% sludge cake 50% municipal covered Elapsed Time Days	Bin no. 5 Probe Temp °C	Monthly mean Temp °C	Rainfall cm/mo	Date	Rainfall cm
8/2	322	49	329	52	351	44	343	38	29	337	55	20	6.86	8/1-3	4.14
8/5	325	46	332	52	354	45	346	38	30	340	53	20	6.86		
8/9	330	48	337	55	358	54	350	38	32	345	55	20	6.86	8/9-10	0.38
8/12	333	44	340	51	361	46	353	36	29	348	52	20	6.86		
8/16	337	48	344	51	365	46	357	34	28	352	53	20	6.86		
8/19	340	48	347	51	368	50	360	34	26	355	56	20	6.86	8/20-21	1.32
8/24	345	54	352	58	373	52	365	42	32	360	63	20	6.86		
8/26	347	51	354	55	375	55	367	46	35	362	64	20	6.86		
8/29	350	48	357	53	378	50	370	41	30	365	60	20	6,86	8/30-9/2	1.14
9/3	355	45	362	58	383	59	375	47	38	370	66	14.4	2.51		
9/6	358	42	365	56	386	48	378	38	28	373	58	14.4	2.51		
9/9	361	36	368	48	389	44	381	36	30	376	52	14.4	2.51	9/9-12	2.39
9/13	365	49	372	63	393	61	385	45	36	380	66	14.4	2.51		
9/16	368	37	375	53	396	56	388	38	32	383	58	14.4	2.51		
9/25	377	32	384	44	405	46	397	32	28	392	44	14.4	2.51		
10/4	386	27	393	43	414	40	406	30	26	401	40	11.1	3.43	10/6	0.36
10/11	393	24	400	44	421	36	413	30	22	408	37	11.1	3.43	10/10	0.56
10/17	399	31	406	72	427	44	419	36	27	414	58	11.1	3.43	10/13	0.25
10/21	403	41	410	79	431	66	423	48	37	418	64	11.1	3.43	10/27-31	2.24
11/1	414	17	421	54	442	50	434	28	18	429	37	1.1		11/10	0.99
12/2	445	19	452	58	473	54	465	61	45	460	26	-3.3			

*Rainfall for 8/15/73-8/31/73.

Probe locations: Bin no. 1: 38 cm(15") above bottom, 91 cm(36") below top of landfill.
Bin no. 2: 15 cm(6") above bottom, 109 cm(43") below top of landfill.
Bin no. 3: 10 cm(4") above bottom, 74 cm(29") below top of landfill.
Bin no. 4(1): 48 cm(19") above bottom, 84 cm(33") below top of landfill.
(2): 5 cm(2") above bottom, 127 cm(50") below top of landfill.
Bin no. 5: 51 cm(20") above bottom, 79 cm(31") below top of landfill.

TABLE 70. TEMPERATURE VARIATIONS IN BIN CONTENTS WITH RESPECT TO ELAPSED TIME AFTER PLACEMENT

	Bin no. 6 50% watered sludge cake 50% municipal refuse uncovered			Bin no. 7 100% dewatered sludge cake covered			Bin no. 8 100% dewatered sludge cake uncovered				
Date	Elapsed time days	Temp°C Probe 1*	Temp°C Probe 2*	Elapsed time days	Temp°C Probe 1*	Temp°C Probe 2*	Elapsed time days	Temp°C Probe 1*	Temp°C Probe 2*	Monthly mean temp°C	Rainfall cm/mo
3/22/74							date/placement			-0.6	3.89
3/28							6	13	8	-0.6	3.89
4/1							10	13	9	9.5	2.95
4/4							13	21	11	9.5	2.95
4/8							17	55	23	9.5	2.95
4/10				date/placement						9.5	2.95
4/12				2	27	16	21	70	40	9.5	2.95
4/15				5	34	18	24	72	63	9.5	2.95
4/17	date/placement						26	83	67	9.5	2.95
4/18							27	82	62	9.5	2.95
4/19	2	24	24	9	40	22	28	81	60	9.5	2.95
4/22	5	38	49	12	38	24	31	80	67	9.5	2.95
4/23							32	80	62	9.5	2.95
4/24	7	36	48				33	78	61	9.5	2.95
4/25							34	77	59	9.5	2.95
4/26	9	32	54	16	34	25	35	80	60	9.5	2.95
4/29	12	44	55	19	30	24	38	78	60	9.5	2.95
5/2	15	38	60	22	29	26	41	72	57	13.3	9.40
5/6	19	25	53	26	32	30	45	70	60	13.3	9.40
5/9	22	26	48	29	31	30	48	66	52	13.3	9.40

(continued)

TABLE 70. (CONTINUED)

Date	Bin no. 6 50% watered sludge cake 50% municipal refuse uncovered			Bin no. 7 100% dewatered sludge cake covered			Bin no. 8 100% dewatered sludge cake uncovered			Monthly mean temp° C	Rainfall cm/mo
	Elapsed time days	Temp°C Probe 1*	Temp°C Probe 2*	Elapsed time days	Temp°C Probe 1*	Temp°C Probe 2*	Elapsed time days	Temp°C Probe 1*	Temp°C Probe 2*		
5/13	26	33	49	33	31	33	52	64	49	13.3	9.40
5/17	30	46	52	37	36	32	56	65	48	13.3	9.40
5/21	34	48	52	41	36	32	60	64	48	13.3	9.40
5/23	36	42	46	43	35	31	62	64	48	13.3	9.40
5/28	41	43	42	48	37	29	67	49	40	13.3	9.40
5/31	44	36	48	51	40	30	70	52	45	13.3	9.40
6/3	47	30	48	54	40	32	73	52	43	20	13.31
6/7	51	39	48	58	40	32	77	58	44	20	13.31
6/10	54	26	48	61	41	32	80	54	42	20	13.31
6/14	58		51	65	38	32	84	60	44	20	13.31
6/17	61	22	50	68	38	32	87	48	43	20	13.31
6/21	65	36	51	72	39	31	91	54	44	20	13.31
6/24	68	37	54	75	38	30	94	63	46	20	13.31
6/28	72	38	56	79	40	31	98	61	48	20	13.31
7/1	75	40	57	82	38	30	101	56	48	24.4	5.36
7/3	77	48	52	84	38	31	103	53	49	24.4	5.36
7/8	82	42	53	89	38	32	108	55	50	24.4	5.36
7/11	85	48	51	92	38	30	111	54	49	24.4	5.36
7/17	91	40	54	98	44	34	117	53	48	24.4	5.36
7/19	93	40	52	100	41	32	119	52	47	24.4	5.36
7/22	96	36	54	103	44	35	122	52	49	24.4	5.36
7/25	99	42	56	106	48	37	125	50	49	24.4	5.36

(continued)

TABLE 70. (CONTINUED)

	Bin no. 6 50% watered sludge cake 50% municipal refuse uncovered			Bin no. 7 100% dewatered sludge cake covered			Bin no. 8 100% dewatered sludge cake uncovered				
	Elapsed time days	Temp°C		Elapsed time days	Temp°C		Elapsed time days	Temp°C			
Date		Probe 1*	Probe 2*		Probe 1*	Probe 2*		Probe 1*	Probe 2*	Monthly mean temp°C	Rainfall cm/mo
7/29	103	32	56	110	45	36	129	51	58	24.4	5.36
8/2	107	38	53	114	41	37	133	51	53	20	6.86
8/5	110	33	49	117	38	36	136	38	52	20	6.86
8/9	114	47	60	121	38	40	140	56	60	20	6.86
8/12	117	41	55	124	36	32	143	62	59	20	6.86
8/16	121	42	58	128	37	36	147	60	56	20	6.86
8/19	124	39	57	131	35	34	150	58	56	20	6.86
8/24	129	34	58	136	40	40	155	70	60	20	6.86
8/26	131	30	56	138	41	38	157	62	61	20	6.86
8/29	134	29	52	141	36	36	160	56	60	20	6.86
9/3	139	16	54	146	38	40	165	59	66	14.4	2.51
9/6	142	25	55	149	36	40	168	58	65	14.4	2.51
9/9	145	23	46	152	33	36	171	50	55	14.4	2.51
9/13	149	28	60	156	43	44	175	66	68	14.4	2.51
9/16	152	18	51	159	34	30	178	58	51	14.4	2.51
9/25	161	22	43	168	39	34	187	49	51	14.4	2.51
10/4	170	16	38	177	30	30	196	47	40	11.1	3.43
10/11	177	18	38	184	26	30	203	53	49	11.1	3.43
10/17	183	10	55	190	37	45	209	76	77	11.1	3.43
10/21	187	1	60	194	46	54	213	84	86	11.1	3.43
11/1	198	20	48	205	24	32	224	76	65	1.1	
12/2	229	4	30	236	48	50	255	40	60	1.1	

(continued)

TABLE 70. (CONTINUED)

* Probe locations:

Bin no. 6 (1) 97 cm (38 in) above bottom 36 cm (14 in) below top of landfill
(2) 28 cm (11 in) above bottom 104 cm (41 in) below top of landfill
Bin no. 7 (1) 46 cm (18 in) above bottom 71 cm (28 in) below top of landfill
(2) 20 cm (8 in) above bottom 97 cm (38 in) below top of landfill
Bin no. 8 (1) 64 cm (25 in) above bottom 46 cm (18 in) below top of landfill
(2) 33 cm (13 in) above bottom 76 cm (30 in) below top of landfill

Bin no. 4 (100% dewatered sludge cake, covered)--A temperature rise peaked within 30 days after placement with a high in the upper 60's and a rapid decrease in temperature to the 40 to 50°C level. During the winter months, like bin no. 2, the temperatures remained in the 20 to 40°C range and for the most part remained at about 30°C for the following late spring and summer. No attendant secondary rise in temperature was experienced in late April such as with bin no. 3 for the same material uncovered.

Bin no. 5 (50% municipal refuse, 50% sludge cake, covered)--The internal temperature results for this bin were similar to the patterns experienced for bins 1 and 3. An early rapid rise in temperature in excess of 70°C, the decrease during winter and attendant rise in April during the spring thaw and a somewhat steady temperature pattern between 40 and 60°C for the remainder of the study.

Bin no. 6 (50% municipal refuse, 50% sludge cake, uncovered)--The results appear in Table 70 for the 7 months test period from April-March through November of 1974. The temperature rise to 50 to 60°C within several weeks after placement remained essentially unchanged for the duration of the study for the deep probe (2). The shallow probe (1) showed greater variations with a drop in temperature occurring in early fall.

Bin no. 7 (100% dewatered sludge cake, covered)--The internal temperatures represented by Probe 2 showed a gradual rise in temperature to about 40°C with temperature generally in the 30 to 40°C range throughout the study unlike the rapid temperature rise displayed for the same material covered represented by bin no. 4.

Bin no. 8 (100% dewatered sludge cake, uncovered)--Within aperiod of 30 days after placement a sharp rise in temperature to values in the high 70's with a decrease to temperature in the 50 to 60°C range within 60 days after placement for most of the remainder of the test. A brief secondary rise in temperature to the high 70's level was experienced in October without apparent explanation.

The results of the internal temperature measurements demonstrate the benefit of placing the dewatered cake uncovered in a landfill as evidenced by the higher internal temperatures for uncovered bins 3 and 8 versus covered cake bins 4 and 7. The higher temperatures result in greater moisture loss, consolidation and compost bacterial activity or organic volatilization. The results of the refuse-cake mixtures are not as conclusive with regard to the benefits of covered or uncovered placement conditions when one compares the results of bin 5 covered with bin 6 uncovered for 50% refuse-50% cake. However, the bins were placed into service over two different time intervals. The 100% refuse covered bin no. 1 had internal temperature development patterns similar to the 100% dewatered cake uncovered in bin no. 3.

ANALYSIS OF DEWATERED SLUDGE CAKE BINS

The analyses of the solid wastes in the bins were performed only for the bins containing the dewatered sludge cake. The heterogeneity of the bins containing municipal refuse or mixtures of refuse and cake would likely result in large variations in the results obtained making interpretation difficult. The dewatered sludge cake was most uniform which greatly facilitated the interpretation of the results obtained.

The bin contents were sampled with the aid of a posthole digger wherein samples were collected from the four corners and center of the bin at 0.152, 0.305, 0.457, 0.610, 0.762 and 0.914 meters (0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 feet) below the surface for bins 3 and 4 representing uncovered and covered cake, respectively. The results of the sampling for percent total solids and percent moisture are summarized in Table 71.

TABLE 71. BIN SOLIDS ANALYSES FOR DEWATERED SLUDGE CAKE

Sampling depth meters(feet)	Bin no. 3 uncovered (placed 8/16/73; sampled 12/28/73)		Bin no. 4 covered (placed 8/24/73; sampled 12/18/73)	
	Percent total solids	Percent moisture	Percent total solids	Percent moisture
Surface	43.5	56.5	---	---
Subsurface	37.5	62.5	31.7	69.3
0.152 (0.5)	41.3	58.7	---	---
0.305 (1.0)	60.0	40.0	50.1	49.9
0.457 (1.5)	90.3	9.7	51.2	48.8
0.610 (2.0)	89.0	11.0	52.2	47.8
0.762 (2.5)	86.8	13.2	40.4	59.6
0.914 (3.0)	82.8	17.2	41.4	58.6

It is readily apparent that bin no. 3 with the uncovered dewatered sludge cake had a much lower moisture content than for the covered cake approximately 4 months after placement. The high temperature development in the uncovered bin no. 3 is likely a contributing factor to the evaporation or loss of moisture as well as the opportunity for the moisture to be discharged to the atmosphere.

A more detailed analyses was performed for bins 7 and 8 containing dewatered sludge cake representing covered and uncovered placement respectively. Analyses for volatile and fixed solids as well as for moisture content were made to determine the extent to which volatile solids are reduced and determine changes in the density of the bin contents. The bins received dewatered sludge cake on April 10 and March 22, 1974, respectively for bins 7 and 8, each receiving four cycles from the filter press. For each cycle 9-12 samples of cake were analyzed for percent solids and percent volatile solids. The average results indicated that bin no. 7 had a percent total solids 44.7 and a percent volatile solids of 57.5 whereas bin no. 8 had 48.4 percent total solids and 56.8 percent volatile solids.

The results of the analyses for the various sampling times after material placement are presented in Table 72. Several findings are worthy of note with reference to changes in percent dry solids, percent volatile solids and percent reduction of volatile solids. The first indicates the changes in moisture content with respect to time and the remaining two parameters indicated the extent to which volatile or organic solids are decomposed or converted to gaseous end products. With appropriate accountability for organic losses in the leachate the advantages or disadvantages of covering sludge cake can be assessed. The results are as follows:

Bin no. 7 (cake covered)--The dry solids increased 5.4% in 3 1/2 months reflecting a moisture loss with some moisture gain by the end of the test period for a net increase in dry solids of 3.6%. The percent volatile solids content decreased from 57.5% to 46.8% representing a 10.7% decrease. The reduction in volatile solids for the test period was 35.2%.

Bin no. 8 (cake, uncovered)--The percent dry solids increased from 48.4% to 71.6% or a difference of 23.2% in a 3 month period following placement. As previously stated, the internal temperatures of the solid waste exceeded 70°C during this initial period. The percent volatile solids content decreased from 56.8% to 37.1% representing a difference of 19.7%. The percent reduction of volatile solids was 55.2% for the test period.

It is evident that the uncovered cake bin no. 8 represented the

TABLE 72. SUMMARY OF ANALYSIS OF BIN CONTENTS FOR DEWATERED CAKE SLUDGE --COVERED VERSUS UNCOVERED

Parameter	Bin no. 7 100% Dewatered sludge cake covered				Bin no. 8 100% Dewatered sludge cake uncovered					
Date:	4/12/74	7/29/74	9/30/74	11/4/74	3/25/74	5/20/74	7/2/74	7/29/74	9/30/74	11/4/74
Total cake weight, kg	11645	7844	10254	8554	11971	7380	5947	5533	5285	6813
Dry solids, %	44.7	49.9	46.8	48.3	48.4	63.8	71.6	70.0	73.4	58.3
Dry weight, kg	5220	3914	4795	4134	5788	4707	4258	3872	3879	3970
Fixed, %	42.5	56.3	45.9	53.2	43.2	53.0	58.6	64.5	64.4	62.9
Fixed weight, kg	2215	2204	2200	2199	2500	2497	2496	2496	2496	2496
Volatile, %	57.5	43.7	54.1	46.8	56.8	47.0	41.4	35.5	35.6	37.1
Volatile weight, kg	2985	1710	2595	1935	3288	2210	1762	1376	1383	1474
Volatile reduction, %		42.7	13.1	35.2		32.8	46.4	58.2	57.9	55.2
Bin cake volume, m^3	14.0	11.2	11.1	11.2	16.8	10.8	9.66	9.18	9.06	9.06
Density:										
Total, kg/m^3	832	700	924	764	713	683	616	603	583	752
Dry, kg/m^3	371	349	432	369	344	436	441	422	428	438
Cake water content:										
kg	6445	3929	5459	4421	6170	2673	1689	1661	1406	2843
m^3	6.44	3.93	5.46	4.42	6.17	2.67	1.69	1.66	1.41	2.84
Filter press cake Volume, m^3	10.7	--	--	--	10.5	--	--	--	--	--

more desirable placement procedure. Regarding loss of volatile solids by leachate presented in the following part, only 7.7 kg as compared to 49.9 kg were lost from bin no. 8 as compared to bin no. 7 which further supports the uncovered placement procedure. The relatively small loss of volatile material by the leachate indicates the biological conversion of organic matter to gaseous end products. The high temperature development in the uncovered bin no. 8 indicates that a greater opportunity for aerobic, compost-like conditions to prevail for at least part of the time whereas the covered bin no. 7 temperature development indicates that likely more anaerobic conditions prevail.

LEACHATE QUALITY AND QUANTITY

The liquid which percolates through the solid waste material is of particular interest in indicating the activity within the cell and the potential for affecting subsurface groundwater quality.

A major factor that influences leachate production is the incident rainfall assuming the landfill is above the groundwater table. Factors such as earth cover, soil type, and sloped surface to facilitate drainage would bear on the amount of leachate generated. Also the development of high internal temperatures with the opportunity for liquid evaporation or the presence of absorptive materials which retain the moisture until field capacity is reached would also effect the quantity of leachate generated. The inherent errors in measurement or undetected leakage also may affect the results.

A rain gage was installed adjacent to the test bins to determine the incident rainfall over the test period. During the 14 month test period for bins 1 through 5, the accumulative rainfall was 78.66 cm (30.97 in) which is 13% lower than for average rainfall conditions. During the 7 month period for bins 6 through 8, the precipitation was 47.70 cm (18.78 in), some 20% below the average rainfall.

The leachate collected from the bin sampling well at the front of the bin was monitored for volume throughout the test periods. The results for the total volume of precipitation on a given test bin presented in Table 73 was based on rainfall and the horizontal surface area of the bin over the test period. The rainfall data in centimeters throughout the test periods are presented in Tables 69 and 70. The total volume of leachate and leachate volume as a percent of total rainfall are presented in Table 73. A graphical plot of the results are presented in Figure 85.

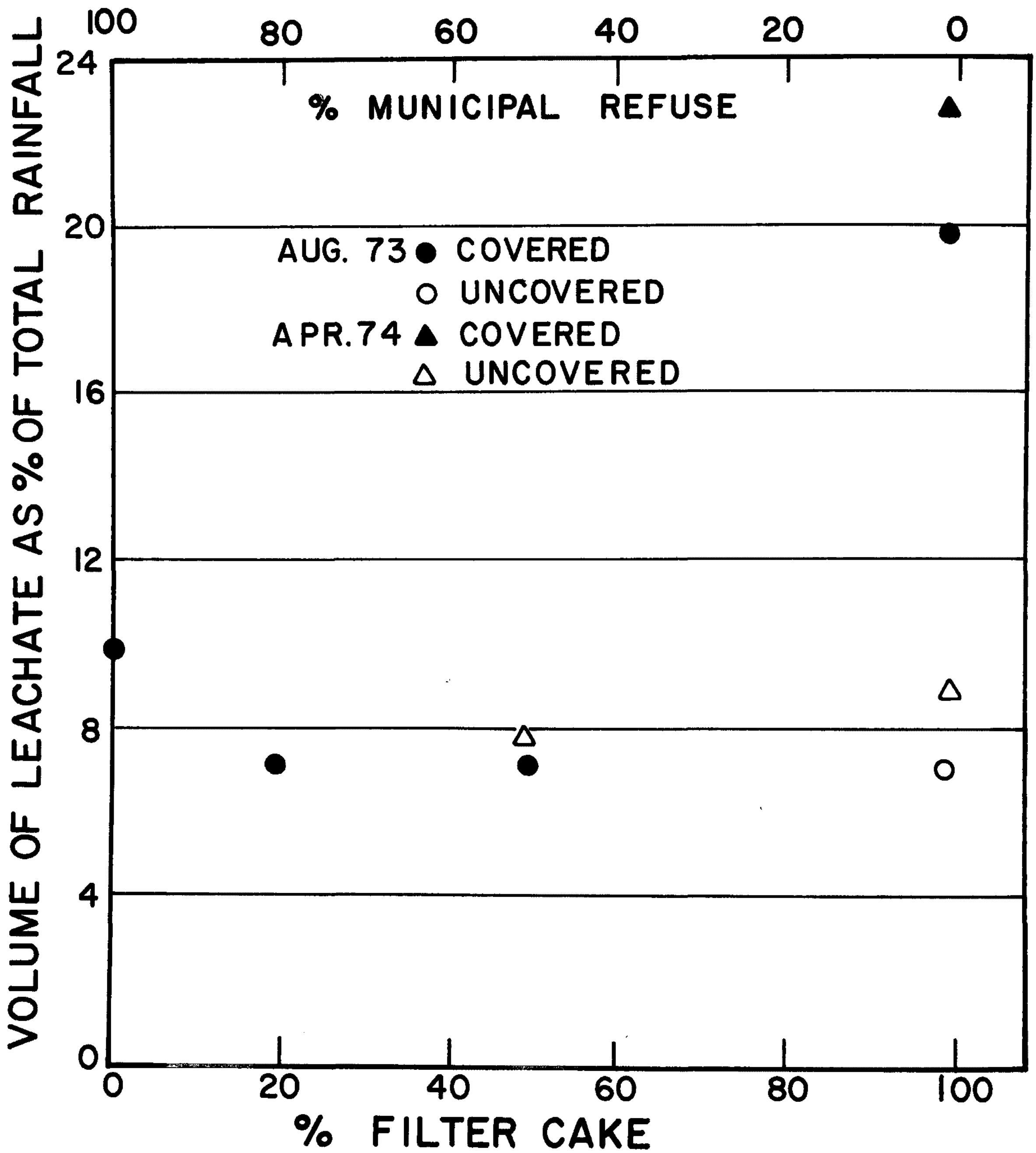

Figure 85. Landfill leachate production.

TABLE 73. LEACHATE VOLUME AS PERCENT OF TOTAL RAINFALL

Bin number	Total volume of leachate liters	Total volume of rainfall liters*	Leachate as a percent of total rainfall	Period of record
1	920.0	9220	10.0	9/14/73-11/6/74
2	670.1	9280	7.2	9/7/73-11/6/74
3	721.3	10383	6.9	8/16/73-11/6/74
4	1842.3	9354	19.7	8/24/73-11/6/74
5	677.3	9354	7.2	8/30/73-11/6/74
6	417.7	5438	7.7	4/17/74-11/6/74
7	1280.3	5683	22.5	4/10/74-11/6/74
8	538.0	6224	8.6	3/22/74-11/6/74

* Total volume of rainfall based on rain gage measurements on site for the horizontal surface area of the landfill bin.

It is apparent that the covered test bins containing 100% dewatered sludge cake produced a significantly greater amount of leachate than all other bins. Although the uncovered 100% dewatered sludge material would readily permit incident rainfall to penetrate the landfill, the amount of leachate is less than for covered cake. The high temperature development within the uncovered bins must represent the benefit of attendant high evaporation rates. The covered bins containing municipal refuse had leachate volumes of 7 to 10% of the incident rainfall, in the same range as for uncovered dewatered sludge cake. High internal temperatures in these bins were not as marked as in the bins with uncovered cake.

The results of the chemical analyses of the leachates are presented as concentrations (mg/l) in Table 74 and as total mass amounts in kg and kg/1000 of material placed in Table 75. The analyses for COD and solid residues were performed routinely whereas analyses for other parameters were performed less frequently but as often as time would permit.

It is apparent from reviewing these results that the highest concentrations and mass amounts for the parameters measured of the leachate are for bins 4 and 7, 100% covered, dewatered sludge cake. Bins 3 and 8, uncovered dewatered sludge cake, yielded as a group the second greatest amount of pollutants with the remaining bins containing municipal refuse or combined solid wastes with lower but less definitive results. Bins 5 and 6 contained 50% refuse and 50% sludge cake under covered and uncovered conditions respectively indicate, that with the exception of the parameters COD and sulfide the covered bin no. 5 had the highest amount of pollutants in the leachate. Direct comparison of the results of these two test bins should be qualified because of the differing elapsed times over which these results were obtained with the longer period for bin no. 5.

The combination of 80% municipal refuse, 20% sludge cake for bin no. 2 compared to 100% municipal refuse for bin no. 1, both covered, yield leachate results which are similar except for higher values of chromium and chloride for bin no. 2 as one might expect.

A more detailed analysis was made with reference to solid material and leachate for total solids, volatile solids and total chromium for bins 6, 7 and 8 to determine the percentage of chromium placed found in the resulting leachate. The results are presented in Table 76 where it is evident in comparing bins 7 and 8 that the covered bin no. 7 resulted in the highest percentage of total solids, volatile solids and total chromium in the leachate. It is likely that more nearly anaerobic conditions prevail in the covered bin no. 7 whereas the opportunity for ventilation in the uncovered bins would be greater. Under anaerobic or reducing conditions the formation of organic acids would tend to enhance the solubility and hence migration of chrome to the leachate.

TABLE 74. AVERAGE CONCENTRATIONS OF LEACHATE SAMPLES *

	Concentrations, mg/l							
Parameter Bin no.	1	2	3	4	5	6	7	8
BOD_5	83	86	719	3018	79	59	27700	8120
COD	843	993	4380	11200	952	1750	65100	15000
Total solids	2700	6130	15000	18700	6900	3460	51400	22100
T. volatile solids	742	1220	6780	12500	1710	939	39200	14300
T. suspended solids	205	140	457	717	575	276	1090	446
Volatile susp. solids	75	99	231	476	88	124	523	207
Oil and grease	68	71	62	107	69	47	85	44
Calcium	148	330	1010	271	602	326	1440	762
Chloride	392	1610	2930	6180	1300	791	4550	4000
Sulfide	0.04	0.08	0.73	135	0.02	--	160	5.5
Total chromium	0.17	1.68	4.76	8.74	4.78	0.22	9.81	0.95

$$* \text{ Average concentration} = \frac{\text{Total weight of matter (milligrams)}}{\text{Total volume of leachate (liters)}}$$

for the period from placement to November, 1974.
Bin no. 1-5 placement: August - September, 1973.
Bin no. 6-8 placement: March - April, 1974.

TABLE 75. SUMMARY OF LEACHATE CHEMICAL ANALYSES--TOTAL AND UNIT MASS BASIS

Parameter	Bin no. 1 100% municipal refuse covered		Bin no. 2 80% municipal refuse 20% sludge cake covered		Bin no. 3 100% sludge cake uncovered		Bin no. 4 100% sludge cake covered	
	kg*	kg/1000 kg+	kg	kg/1000 kg	kg	kg/1000 kg	kg	kg/1000 kg
BOD_5	0.765	0.016	0.058	0.009	0.519	0.043	5.56	0.041
COD	0.776	0.162	0.665	0.102	3.16	0.259	20.6	1.63
Total solids	2.49	0.520	4.11	0.633	10.8	0.884	34.5	2.74
Total volatile solids	0.683	0.143	0.816	0.126	4.89	0.401	23.1	1.84
Suspended solids	0.189	0.039	0.094	0.014	0.330	0.027	1.32	0.105
Volatile susp. solids	0.064	0.013	0.067	0.010	0.166	0.013	0.877	0.070
Total chromium	0.000154	0.00003	0.00113	0.00017	0.00343	0.00028	0.0161	0.0013
Oil and grease	0.0625	0.013	0.048	0.007	0.045	0.004	0.198	0.016
Calcium	0.136	0.028	0.221	0.034	0.729	0.060	0.499	0.040
Chloride	0.360	0.075	1.081	0.167	2.116	0.173	11.38	0.903
Sulfide	0.000035	0.000007	0.000056	0.0000086	0.000529	0.000043	0.250	0.020

(Continued)

* kg represents total mass of stated parameter over test period in kilograms.

+ kg/1000 kg represents unit mass of stated parameter based on total mass of stated parameter divided by total mass of material placed without regard to parameter.

TABLE 75. (CONTINUED)

Parameter	Bin no. 5, covered 50% municipal refuse 50% sludge cake		Bin no. 6, uncovered 50% municipal refuse 50% sludge cake		Bin no. 7 100% sludge cake covered		Bin no. 8 100% sludge cake uncovered	
	kg	kg/1000 kg	kg	kg/1000 kg	kg	kg/1000 kg	kg	kg/1000 kg
BOD_5	0.053	0.006	0.025	0.004	35.4	3.04	4.37	0.365
COD	0.645	0.078	0.732	0.113	83.3	7.15	8.07	0.674
Total solids	4.67	0.564	1.45	0.224	65.9	5.65	11.88	0.992
Total volatile solids	1.16	0.140	0.392	0.061	50.1	4.30	7.67	0.641
Suspended solids	0.389	0.047	0.115	0.018	1.40	0.120	0.240	0.020
Volatile susp. solids	0.060	0.007	0.052	0.008	0.670	0.057	0.112	0.009
Total chromium	0.00324	0.00039	0.000092	0.000014	0.013	0.001	0.00051	0.000043
Oil and grease	0.047	0.006	0.0196	0.0030	0.109	0.009	0.023	0.002
Calcium	0.408	0.049	0.136	0.021	1.845	0.159	0.410	0.034
Chloride	0.880	0.106	0.330	0.051	5.76	0.494	2.148	0.179
Sulfide	0.0000118	0.0000014	0.115	0.018	0.205	0.017	0.00294	0.00025

TABLE 76. SOLID WASTE CHROMIUM BALANCES FOR PERIOD APRIL-NOVEMBER, 1974.

	Bin no. 6 Municipal refuse 53.6% Dewatered cake 46.4% Uncovered Placed 4/17/74		Bin no. 7 Dewatered cake 100% Covered Placed 4/10/74	Bin no. 8 Dewatered cake 100% Uncovered Placed 3/22/74
	Total	Sludge cake only	Total	Total
Solid material:				
Total weight placed, kg	6461	3000	11645	11958
Total solids, %		48.4	44.7	48.4
Total weight dry solids, kg		1452	5205	5788
Volatile solids, %		66.0	57.5	56.8
Volatile Solids weight, kg		958	2998	3288
Total weight chromium, kg	7.18*	7.18	29.8	30.2
Percent of total weight placed, %	0.11	0.24	0.26	0.25
Dry solids, %		0.49	0.57	0.52
Leachate:				
Total solids, kg	1.45		65.9	11.9
Total dry solids, %			1.27	0.21
Volatile solids, kg	0.39		50.1	7.67
Volatile solids, %			1.67	0.23
Total chromium, kg		0.000092*	0.013	0.00051
Percent of chromium placed, %		0.0013*	0.044	0.0017

*Assumes no chromium in refuse placed.

SECTION XV

FINANCIAL CONSIDERATIONS

CAPITAL COSTS

The capital costs for the treatment facilities are summarized in Table 77. The contracts were let for the treatment plant, associated equipment, and engineering costs in the spring of 1970 for the amount of $950,000. The contracts for sludge handling structures, equipment and engineering costs were let in the springs of 1972 and 1971 in the amount of $575,000. The total capital cost of the treatment and sludge handling facilities was $1,525,000 and if amortized at 6% over a 20-year period the annual cost related thereto amounts to $132,956 per annum.

TABLE 77. CAPITAL COSTS

Treatment Plant (Bid Spring 1970)		
Construction		$700,000
Euipment		
Primary and Final Clarifiers	$35000	
Aerators	42500	
Mazorator	6900	
Pumps	29800	
Chlorine Feed	3200	
Metering	6600	
Mechanical Rakes	2000	
CO_2 System	13000	
Primary Sludge Pump	3000	
Subtotal		142,000
Engineering		108,000
Sludge Dewatering		
Construction (Bid Spring 1972)		230,000
Equipment (Bid Spring 1971)		325,000
Engineering		20,000
Total Capital Costs		$1,525,000
Annual Captial Cost Amortized 6% 20 year		$132,956

POWER COSTS

Both electrical and natural gas was consumed in the operation of the wastewater treatment facilities. The electrical energy was used to operate all pumps, mechanical equipment, aerators, mixers and miscellaneous control equipment whereas the gas was used in space heaters for the purpose of heating treatment plant buildings. As a result of the joint effort between the industry and the City of Red Wing, the utility rates reflected schedules consistent with municipal services. During the operating period from starting through the middle of March, 1974, the electrical unit costs were 1.38 to 1.45¢/KWH, thereafter for the remainder of the project the unit costs were 1.62-1.64¢/KWH. The natural gas costs ranged from 11 to 13¢/cu. ft.

The total energy requirements were different for winter than for summer periods of operation. During winter operation only two of the four lagoons were operated which reduced the electrical energy requirements for aerators, however, natural gas was consumed during the winter for building heating.

Table 78 summarizes the unit costs and the monthly costs of $2300 and $3200 for winter operations and spring-summer-fall operations respectively during the 1973-1974 operating period.

TABLE 78. POWER CONSUMPTION AND COSTS

Unit Power Costs		
Electric	1.38-1.45¢/KWH	1972, 1973, 1974(3 mos)
Natural Gas	1.62-1.64¢/KWH	4/1974-
	11-13¢/cu. ft.	
Monthly Average Power Consumption and Cost		
Winter (3 mos, 1973-1974)		
Electric	120,000 KWH	
Gas	4,000 cu. ft.	
Cost	$2300/month	
Spring Summer Fall (9 mos, 1974)		
Electric	190,000 KWH	
Cost	$3200/month	

CHEMICAL COSTS

Table 79 lists the chemicals used in treatment of the wastewater during the project period. Although facilities were provided in part for CO_2 addition to the raw wastewater near the end of the project period, CO_2 was not employed to facilitate separation of solids in the primary settling units. The ferric chloride and lime was used primarily in conjunction with sludge dewatering. Ferric chloride was also used on occasion as an additive to the raw wastewater for purposes of controlling sulfide losses to the atmosphere. The defoamers were used to control foaming in the aerated ponds with weekly costs ranging from $100 to $500. Phosphoric acid was used a nutrient supplement for certain of the operating modes wherein dosages of 7-10 mg/l of P were employed for a weekly cost of $225 to $325. Chlorine obtained in 150 pound cylinders was applied to the treated effluent from 75 to 100 pounds per day for a weekly cost of $100 to $125.

The annual costs associated with chemical use are summarized in Table 80.

TABLE 79. CHEMICAL COSTS 1974

Chemical	Unit Cost	Remarks
Ferric Chloride (40% solution)	8.3¢/dry lb delivered	freight 4.3¢/dry lb
Lime (Dry)	1.1¢/dry lb	slaked by tannery
Defoamers	18-38¢/liquid lb	several types used
Phosphoric Acid	92¢/lb phosphorus	
Chlorine	12-20¢/lb	150 lb cylinders
Carbon Dioxide	4.5¢/lb	not used during study

OPERATION AND MAINTENANCE COSTS

The operation and maintenance costs summarized in Table 80 reflect power, labor and chemical costs for the year 1974. Although the numbers of project personnel was increased to 18 persons during the peak of data gathering activity, the costs for salaries shown in Table 80 represent costs for 8 and 11 persons for winter and spring-summer-fall periods respectively. The additional personnel are required during the spring-summer-fall period for operation of the sludge handling facilities over extended periods to remove the excess sludge accumulation in the aerated pond systems. The total annual operating and maintenance cost of $257,829 includes $192,915 for personnel and $64,914 for equipment repair and replacements, supplies and disposal of sludge cake.

TABLE 80. OPERATION AND MAINTENANCE COSTS 1974.

Item		
Salaries	$20226 *	$75240 +
Power	6930	28116
Chemicals	13794	48609
Subtotal	$40950	$151965
Total		$192915
Equipment Repair and Maintenance, Supplies and Sludge Disposal		$64914
Total Annual Cost		$257829

* 8 persons.
+ 11 persons for additional sludge dewatering.

SUMMARY OF COSTS OF TREATMENT

The amortized capital cost at 6% over 20 years from Table 77 and the annual costs for operation and maintenance from Table 80 give a total annual cost of $390,785, as shown in Table 81.

The unit costs based on BOD and COD applied or 1000 gallons of wastewater are presented in Table 81, at $0.263 per kg BOD ($0.119 per pound BOD), $0.0965 per kg COD ($0.0438 per pound COD), or $0.434 per m^3 ($1.645 per 1000 gallons of flow). These costs are not additive, but merely reflect the total annual costs divided by the total annual weight or volume of wastewater characteristic. Assignment or allocation of costs by unit operation relative to the wastewater characteristic is not presented.

TABLE 81. SUMMARY OF TREATMENT COSTS.

Item	
Amortized Capital Cost	\$132,956
Operation and Maintenance Cost	\$257,829
Total Annual Cost	\$390,785

Estimated Cost of Treatment

1,485,500 kg (3,275,000 lbs) BOD/year
\$0.263 per kg (\$0.119 per lb) BOD applied

4,050,600 kg (8,930,000 lbs) COD/year
\$0.0965 per kg (\$0.0438 per lb) COD applied

899.320 m^3 (237,600,000 gals) wastewater/year
\$0.434 per m^3 (\$1.645 per 1000 gals of wastewater flow)

SECTION XVI

REFERENCES

1. Polkowski, L. B. and Boyle, W. C. An Investigation on the Biological Treatment of Wastes from the S. B. Foot Tanning Company Alone and in Combination with Red Wing, Minnesota Municipal Wastewaters. November, 1966.

2. Polkowski, L. B., Boyle, W. C. and Rohlich, G. A. Investigation on the Treatment and Disposal of Wastes from the S. B. Foot Tanning Company at Red Wing, Minnesota. November, 1965.

3. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Leather Tanning and Finishing Point Source Category. U.S. Environmental Protection Agency. 440/1-74-016-a. March, 1974.

4. Eckenfelder, W. W. Industrial Water Pollution Control. McGraw-Hill, Inc. 149-160. 1966.

5. Jones, B. R. S. "Vacuum Sludge Filtration II Prediction of Filter Performance." Sewage and Industrial Wastes. 29(9):1103-1115. 1956.

6. Eckenfelder, W. W. and Ford, D. L. Water Pollution Control-Experimental Procedures for Process Design. Pemberton Press, Jenkins Publishing Company, Austin, Texas. 1970.

SECTION XVII

APPENDICES

APPENDIX A: ANALYTICAL PROCEDURES

Sampling

The sampling of wastewaters within the plant were performed by hand or by the use of specially designed automatic flow compositing samplers located at the primary sedimentation tank effluent lines, the lagoon sedimentation tank effluent lines and the final effluent line from the chlorine contact chamber. Details on hand sampling and compositing of samples are outlined under the appropriate study phase within this report. The design and operational details of the automatic samplers are presented in the following subsection.

Continuous monitoring systems were installed to measure pH, temperature and dissolved oxygen at selected points within the plant. Leeds and Northrup pH probes and thermocouples and Weston Stack D.O. probes were employed. The signals were picked up by Leeds and Northrup monitors and transmitted to multipoint recorders located within the buildings. The monitors were located in insulated wooden boxes equipped with 60 watt lightbulbs to maintain temperature in the winter. Lines from the probes to the monitor and from the monitors to the recorders were buried. Two recorder systems were employed. System 1 picked up pH and temperature signals from the raw wastewater and the primary effluent. System 2 detected pH, temperature and D.O. from the lagoons as well as pH and temperature of the final effluent from the chlorine contact chamber. Details of these monitoring systems and operational difficulties with them appear in a following subsection entitled 'Monitoring System'.

Automatic Sampling System--

The automatic samplers were designed with the assistance of Mr. Donald Nelson (Ph.D. candidate, Electrical Engineering, University of Wisconsin) by Polkowski, Boyle, and Associates. The sample consisted of a sequence of solenoid valves and timers which were actuated by a signal from the magnetic flow meter. On a signal from the flow meter, a solenoid valve was opened in the sampling line and the line was completely flushed to waste for approximately 20 seconds. Upon closing a short pause was induced to allow for dampening of resulting transient water pressures and then a timer controlled solenoid valve was opened to allow the sample to flow at a prescribed time to the sampling vessel. After the sampling, the valve closed to complete the sampling sequence. The timer control could be set from 0 to 3 seconds in 0.05 second intervals depending upon the quantity of sample desired. In the sampling program conducted at this plant a 0.25 second opening time was employed producing 50 to 80 ml of wastewater per sampling interval. The sample was collected in a 3.78 liter container placed in an insulated chest. Ice was packed around the container to keep the sample cool over the 24 hour storage period. (Most sampling was done over a 24 hour interval.)

Flow was monitored by a Fisher-Porter magnetic flowmeter located in the 36 cm diameter raw wastewater line from the raw wastewater pumps to the primary sedimentation tanks. The signal from the flowmeter was transmitted to a recorder to indicate rate of flow. A flow integrator was also provided to indicate total quantity of flow. A signal to the automatic samplers was obtained by employing a Bliss Eagle predetermining counter which was set to store a series of signals from the flow integrator. Thus a signal was sent to the predetermining counter for every 1000 gallons of raw wastewater and when 10 such signals were received (10,000 gallons) a signal was transmitted to the automatic samplers. Over a typical process day approximately 1,000,000 gallons would flow producing 100 signals to the samplers and yielding approximately 5 to 8 liters of waste sample.

Normally, samplers were actuated at about 7 a.m. on a selected sampling day. By experience it was found that the 3.78 liter containers were filled by 4 or 5 p.m. The sample collected at that time was then transferred to a 7.57 liter container and refrigerated. The remainder of the sample was then collected and the two aliquots were mixed and analyzed the following morning.

The automatic samplers were located at four points within the plant. Primary effluent was collected from the effluent line from the sedimentation tank to the outfall chamber. The sampler was located in the primary clarifier building. Lagoon effluents were collected from the inlet chamber to the final clarifiers. Final clarifier effluent samples were collected in the clarifier effluent lines to the chlorine contact chamber. Final effluent samples were collected from the effluent end of the chlorine chambers ahead of the overflow weir. These last three sampler systems were located within the final clarifier building.

There were no operational difficulties recorded for the automatic samplers once they were properly adjusted. Some maintenance problems were experienced with the flowmeter system. Initially, no clean-out or bypass had been provided around the magnetic flowmeter to allow for cleaning. A buildup of lime and grease covered the sensors within the throat producing erroneous results. Once provisions were made for adequate cleaning of the meter, no other difficulties were encountered. Because of the highly corrosive atmosphere within the pump buildings, it was determined that the electronic components of all sensors including the automatic samplers be sealed against the ambient environment. Sealing proved to be effective as no failures in electronic systems due to corrosion were recorded.

Monitoring System--

The monitoring system was designed by Leeds and Northrup in accordance with specifications presribed by Polkowski, Boyle and Associates. Leeds and Northrup monitors and multipoint recorders were employed with appropriate probes to provide continuous monitoring of selected sites.

System 1, which measured pH and temperature from the raw and primary effluent systems, employed a six point recorder located within the raw waste pumping station. Temperature and pH probes were placed in the raw wastewater line and the primary effluent line from one sedimentation tank. Analyses were made at 30 second intervals. Considerable difficulty was encountered in maintaining the pH probes in the raw waste stream. Even the placement of a baffle around the probe did not prevent rapid fouling with hair, grease and lime scale. Therefore, raw waste pH was continuously monitored only on days when 24 hour raw waste surveys were conducted. During these times sufficient manpower was available to keep the probes clean and properly calibrated. The monitoring of pH in the primary effluent was not as difficult to maintain. The probes were calibrated two or three times per week and held their calibration satisfactorily. Occasional removal of scale from the probe was practiced by soaking them in 15% of HCl. The temperature probes at both points performed satisfactorily and were cleaned periodically to remove extraneous scale, hair and grease.

System 2 monitored pH, D.O. and temperature within selected lagoons and pH and temperature of the final effluent at the chlorine contact chamber. A twelve point recorder was employed using a 30 second sampling interval. The probes for the lagoons were installed on a special hoist arrangement on the outlet structure. They were placed below the water surface and could be easily raised and swung into position for calibration and cleaning by the operator. Two probe systems were available and could be moved from one lagoon to another. Wiring was available at all four lagoons, but only two systems could be monitored at one time. The pH probes performed satisfactorily in the lagoons and final effluent. Calibrations were checked two or three times per week and occasional cleaning with dilute HCl was used to remove scale. The temperature probes were satisfactory. Considerable maintenance was required for the D.O. probes. They did not hold calibration as well as anticipated due primarily to the wastewater characteristics--grease and solids scale. The probes were provided with mixers to maintain adequate velocity across the probe but this action did not prevent deposition on the membrane surface.

Analyses

The analyses performed during this study were conducted in accordance with Standard Methods for the Examination of Water and Wastewater, 13th edition, except as noted. Details of the conduct of these analyses follow.

Chemical Methods--

Alkalinity-- Alkalinity was initially determined employing bromcresol green-methyl red indicator for end point detection. In July, 1973, the potentiometric titration procedure was employed using a pH meter. Dissolved alkalinity was estimated by filtering a sample through Whatman 42 filter paper and after January, 1974, by filtering through Whatman GF/C glass fiber paper.

Calcium-- Calcium was determined by the EDTA titrimetric method. In order to eliminate interference by organic matter, all samples were fired in a muffle furnace at 550°C for 50 minutes, redissolved and titrated. Dissolved calcium was obtained by filtering samples through Whatman GF/C glass fiber paper.

Chloride-- Chlorides were measured by the Argentometric method. Organic interferences were eliminated by firing samples in a muffle furnace at 550°C for 50 minutes, redissolving and titrating. Beginning in March, 1973, Quantab Chloride Titrators (Ames Co., Division of Miles Laboratory, Inc., Elkhart, Indiana) were employed. Automatic titration was accomplished through capillary action in the Quantab strip. Comparisons with the Argentometric method indicated values within 100 mg/l over the range of 2,000-3,000 mg/l chloride.

Chlorine-- Chlorine was determined by the DPD ferrous titrimetric method. In the absence of iodide, free available chlorine reacts instantly with the N, N,-diethyl-p-phenylenediamine (DPD) indicator to produce a red color. Subsequent addition of a small amount of iodide ion acts catalytically to cause monochloramine to produce color. Further addition of iodide in excess evokes a rapid response from dichloramine. Manganese interference was removed in the procedure. The endpoint was clearly visible for the final effluent.

Chrome-- The analysis for chrome followed the procedure of the Permanganate-Azide method outlined in Standard Methods with modifications. Initial studies using this procedure indicated poor recoveries of chrome added to wastewater samples. It was determined that wet ashing was superior to dry ashing which often left black particulates. Permanganate was used primarily because alternative mthods required removal of too many interferences. The oxidation step was carried out in 0.5 N H_2SO_4 using sodium azide to eliminate excess permanganate. Careful pH control was essential during color development. Constant pH was maintained on all samples and standards by use of 0.2 N H_2SO_4. Finally it was found that dissolving S-diphenyl carbazide (DPZ) reagent in ethyl acetate produced a more stable reagent giving improved performance and shelf life over the use of ethyl or isopropyl alcohol.

Color-- Color was determined by the Spectrophotometric Method outlined in Standard Methods. Samples were filtered through a calcined filter aid and light transmittance was measured.

Dissolved Oxygen-- Dissolved oxygen was measured with a Yellow Springs Instrument Company dissolved oxygen probe and meter, calibrated by the azide modification of the Winkler procedure.

Fats, Oils and Grease (FOG)-- FOG was measured using the Soxhlet Extraction Method employing hexane as the solvent.

Nitrogen-- NH_3N-Ammonia was measured by the use of an Orion model 95-10 specific ion electrode employing procedures outlined in Standard Methods, Methods for Chemical Analysis of Water and Wastes (U.S. EPA, 1971), and R.F.Thomas and R.L.Booth, ("Selective Electrode Measurement of Ammonia in Water and Wastes", Environmental Science and Technology, 1, 6, 1973).

Kjeldahl-N--The micro Kjeldahl method was employed to determine total organic nitrogen. Ammonia collected was analyzed by use of the Orion Model 95-10 specific ion electrode.

Nitrate-N--The aluminum reduction of nitrate to ammonia was employed to determine nitrates. In brief the procedure was as follows: 100 ml of sample was placed in a round-bottom flask equipped with magnetic stirring bar. One ml concentrated HCl and approximately 0.5 g of NaF was added and stirred vigorously. To this mixture 0.1 finely divided aluminum powder was added. After the evolution of hydrogen (5 to 7 minutes), 1 ml of 10 M NaOH was added and the contents were poured into a beaker for analysis of ammonia with the Orion Model 95-10 specific ion electrode. A control sample was also run to give backgound ammonia levels. A recovery study in the wastewater indicated that from 85-90% of the nitrate could be recovered by this method.

Phosphorus--

Orthophosphate-P--Phosphates which responded to the stannous chloride color development employing benzene-isobutanal solvent extraction, without preliminary hydrolysis or oxidative digestion were considered orthophosphates. Filtered orthophosphates were obtained by filtration through prewashed GF/C filter paper (pore size--0.5 microns).

Condensed Phosphate-P--The phosphates obtained as the difference between orthophosphates as measured above and the phosphate found after mild acid hydrolysis and stannous chloride color development employing benzene-isobutanol solvent extraction. Dissolved portions were determined as above.

Total Phosphate-P--Because of technical difficulties in the laboratory perchloric acid digestion and sulfuric acid-nitric acid digestion methods were not employed to determine total phosphates. A procedure employed extensively by the State of Wisconsin Water Quality Evaluation Section was carefully tested and found to be very satisfactory for this study. Recoveries of added phosphates to selected wastewater streams in the plant ranged from 90-112%. The procedure is briefly described below.

Five ml of a 15% solution of magnesium nitrate [$Mg(NO_3)_2 \cdot 6H_2O$] was added to 25 ml of sample. The sample was evaporated to dryness at 103°C and then fired over a Bunsen burner for between 5 and 15 minutes until only white ash remained. The ash was completely dissolved using strong acid solution and heat. After dissolution, stannous chloride color development, employing benzene-isobutanol solvent extraction was used to determine the phosphorus content. Dissolved portions were determined as above.

Residue--Suspended solids analyses were performed using Whatman No. 40 filter paper from October, 1971, to February, 1973. In March, 1973, Whatman GF/C glass fiber filters were employed.

Sulfide--The Methylene Blue Photometric Method was employed for sulfide analysis. Zinc acetate and sodium carbonate were employed as preservatives for sulfide samples. For the very thick wastewaters coming from the hair pulping operation, it was necessary to first dilute the same with oxygen free water before preservation since incomplete precipitation of zinc sulfide occurred in the undiluted sample.

Biological Methods--

Total Bacteria-- Total bacteria were enumerated on Plate Count agar after incubation at 20°C for 72 to 120 hours. The colonies were slow growing at this temperature so longer incubation times than prescribed in Standard Methods used.

Total Coliforms-- Total coliforms were determined by the membrane filter method using Gelman GN 6 white membrane filters. The filters were incubated on M-Endo medium for 24 hours at 35°C.

Fecal Coliforms-- Fecal coliforms were determined by the membrane filter procedure employing Gelman GN 6 white membrane filters. The filters were incubated M-FC medium for 24 hours at 44.5°C.

Sludge Accumulation Measurements

Since the aerator power in the lagoons was not sufficient to maintain all suspended solids in a suspended state, it was desireable to routinely determine sludge accumulation within the lagoons so that estimates could be made on sludge generation. Sludge accumulations were monitored by the use of a 20.3 cm (2.31 in) pie pan attached to a 1.83 m (6 ft) 0.635 cm (0.25 in) diameter steel rod. The rod, graduated in feet, weighed 1.05 kg (2.31 lb). The pan was lowered in the lagoon until it met resistance. The water depth was measured and the sludge depth was obtained by difference. This procedure was satisfactory for the heavy inorganic sludges encountered in this study but would likely be inadequate for a lighter biological sludge. It is reasonable to assume that the lighter material in these lagoons would remain in suspension since mixing by the aerators did provide substantial horizontal velocities.

The lagoons were divided into sectors by describing sampling lines across the width, intersecting each aerator and bisecting the distance between adjacent aerators. Thus 21 width lines were established. Along each width line, seven equidistant points were sampled producing a total of 147 sampling points. The bottom of the lagoons occupied approximately 1672 m^2 (18,000 ft^2), therefore, each sample point represented about 11 m^2 (120 ft^2).

Based on the survey, a cross section of each width station was prepared. Total sludge volumes were estimated between width stations by averaging procedures.

Samples of sludge were also collected during the survey and analyzed for percent solids, percent volatile solids, COD, TKN, and Ca. These analyses were employed to estimate changes in accumulated masses of organic and inorganic matter within each lagoon.

Analytical Procedures Employed for the Wastewater Effluent Reuse, Section XII

The following methods were employed to determine the results presented in Tables 46, Leather Analysis, and 47, Physical Leather Properties, in Section XII on Wastewater Effluent Reuse of this report. The standard procedures employed are identified by determination accordingly below.

Moisture	FED STD - 311 Method 6221
(Fat) Chloroform soluble materials	FED STD - 311 Method 6341
(H.S.) Hide Substance	ASTM D2868 - 70T
Ash	ASTM D2617 - 69
Organic	by difference
(CR_2O_3) Chromic Oxide in Leather	ASTM D2807 - 69T
pH of Leather	ASTM D2810 - 69T
(Satra Grain Crack) Distension and strength of grain by ball burst test	SLTC S.L.P. 9
(Mullen) Grain Crack	ASTM D2210 - 64 (1970)
Tensile strength of leather	ASTM D2209 - 64 (1970)
Elongation of leather	ASTM D2211 - 64 (1970)

Test Methods Used

Federal Test Method Standard - 311 (FED STD - 311)

The American Society of Testing and Materials (ASTM)

Society of Leather Trades' Chemists (SLTC)

APPENDIX B: OXYGEN UPTAKE AND OXYGEN TRANSFER STUDIES

Oxygen transfer studies were performed in selected lagoons during the research study. Figure 86 depicts the sampling points used to conduct this study. Samples were collected two feet below the water surface at each sampling point. Oxygen uptake rates were then measured for each sample collected. Analyses were also made *in situ* for dissolved oxygen, mixed liquor solids temperature and sulfides.

Alpha tests were performed on mixtures of samples collected taken in each one-third of the lagoon. The diffused aeration technique described by Eckenfelder and Ford (6) was employed for alpha estimations. A typical graphical calculation of alpha is shown in Figures 87 and 88.

A typical analysis for oxygen uptake rates appears in Table 82. Average uptake rates were then used to estimate total oxygen consumption within the lagoon system. Oxygen uptakes per unit of BOD_5 removed were estimated based upon BOD_5 data for the lagoon studied during the sampling period.

Oxygen transfer rates were estimated by averaging oxygen uptake rates, alpha values and total sulfide oxidized during the test period. Beta values were estimated by both measurement in the laboratory and by calculation using a total dissolved solids correction on the depression of the oxygen saturation value.

An example of the calculation employed to determine oxygen transfer rates under standard conditions is given in Table 83. Values were expressed on a nameplate horsepower basis and included sulfide oxidation where applicable.

TABLE 82. OXYGEN UPTAKE MEASUREMENTS

November 29, 1972 -- Lagoon #2

Length Station	Width Station	D.O. mg/l	Temp. °C	Oxygen Uptake mg/l/hr	TSS mg/l	VSS mg/l
0 + 14	0 + 56	2.6	12	10.1	1260	547
0 + 50	0 + 35	2.8	12	10.6	1170	503
0 + 63	0 + 56	3.8	12	8.73	1190	397
1 + 13	0 + 35	3.3	12.5	8.64	1100	413
1 + 63	0 + 56	3.8	12	9.8	1020	427
2 + 13	0 + 35	2.5	13	11.8	1100	453
2 + 63	0 + 56	2.4	12	10.1	1000	420
Effluent		2.2	13.5	9.4	940	347

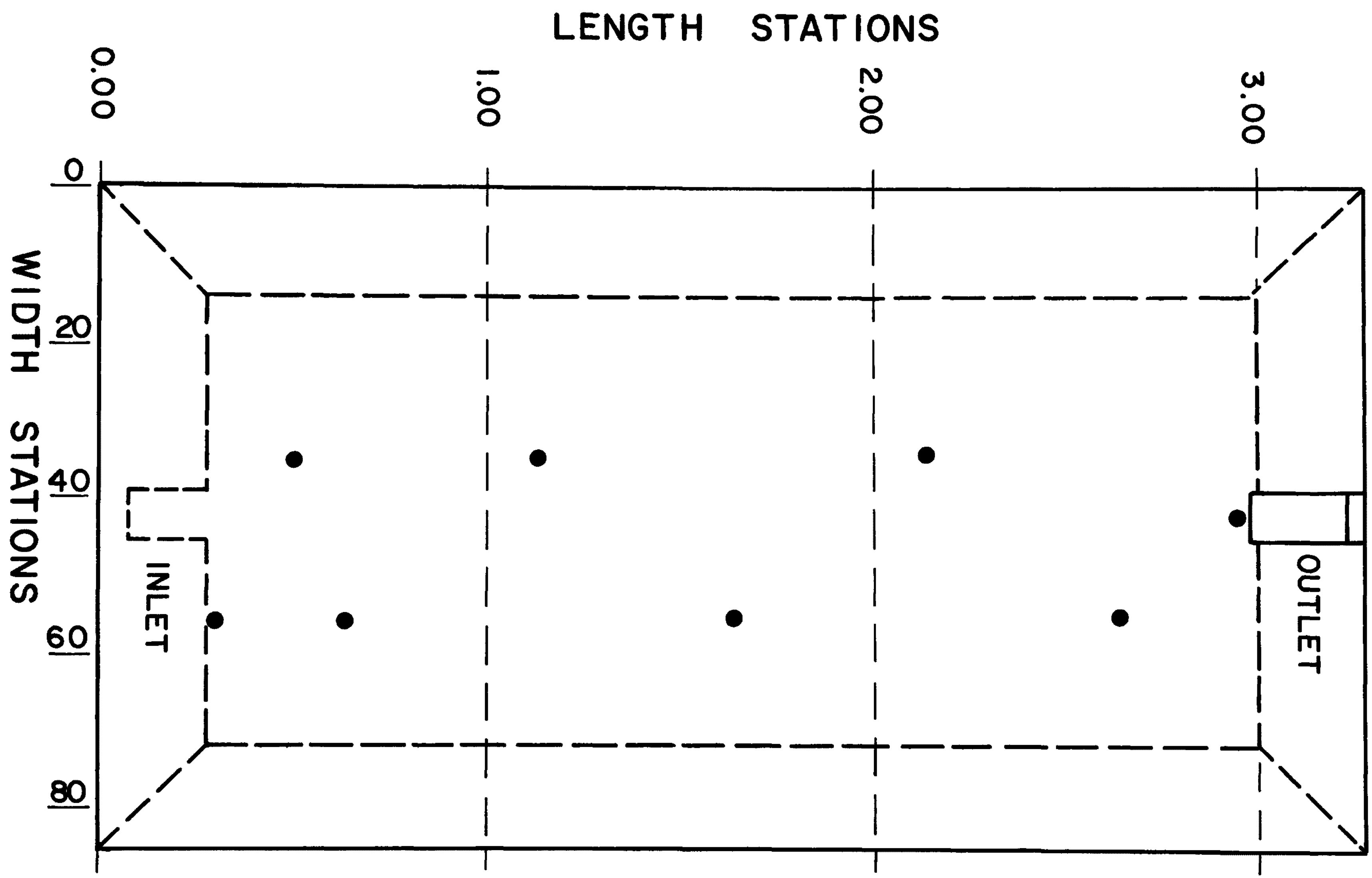

Figure 86. Oxygen transfer lagoon sampling point locations.

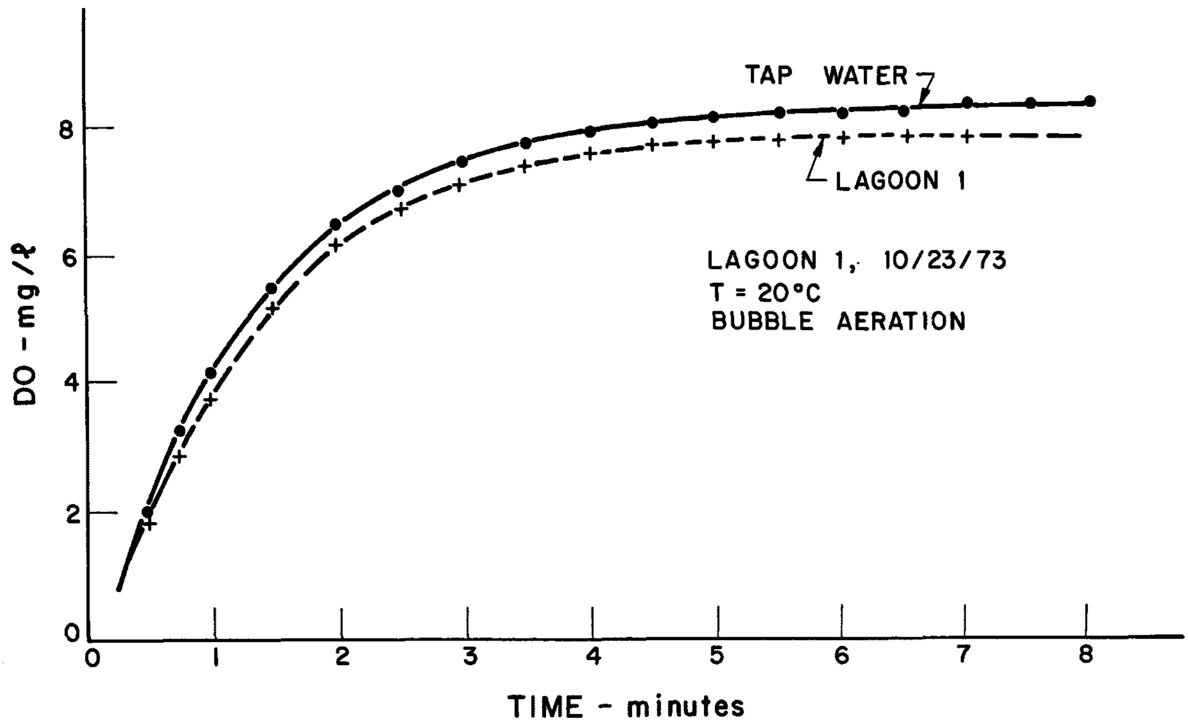

Figure 87. Oxygen transfer studies--alpha determination.

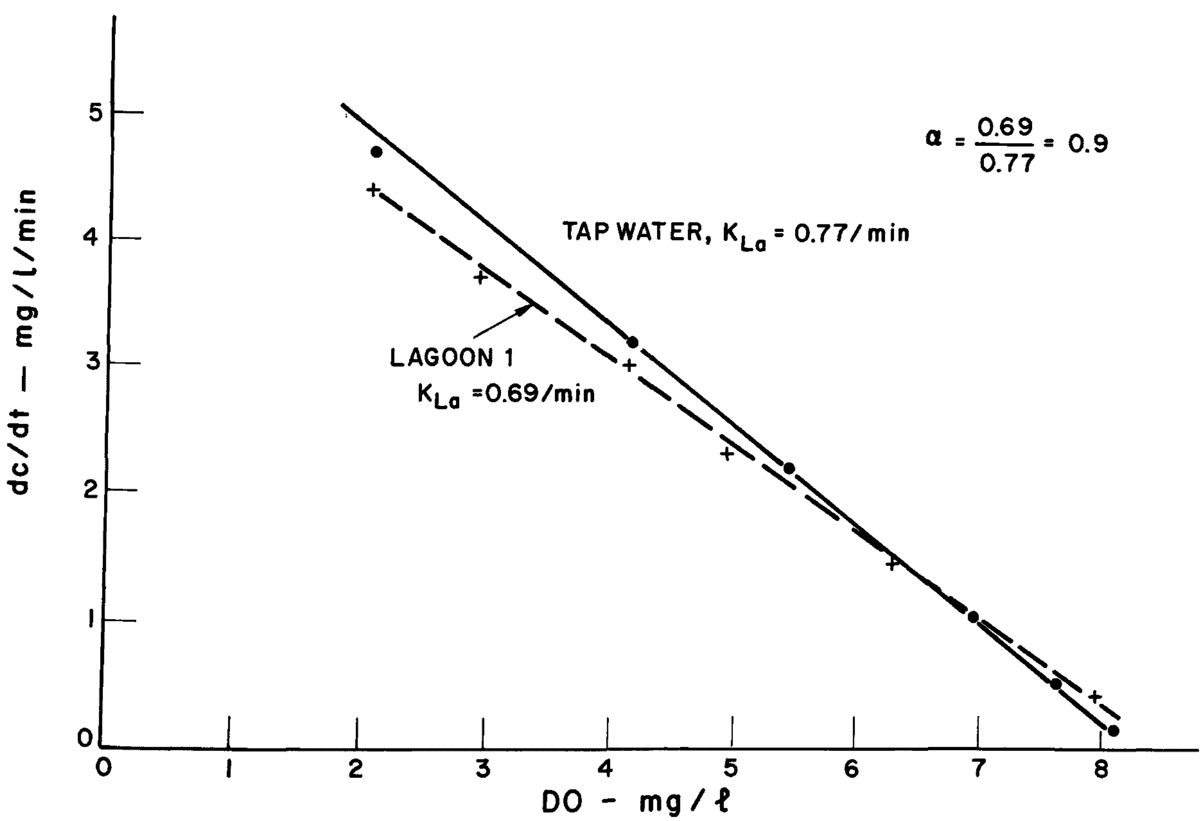

Figure 88. Slope plot for determination of KLa.

TABLE 83. OXYGEN TRANSFER EFFICIENCIES. SAMPLE CALCULATION.

Test Condition 2; 10/23/73; Lagoon 1

Average oxygen uptake rate = 2.3 mg/l/hr
Volume = 0.971 mg
Aerator HP = 11 x 5 = 55
Sulfide oxidized = 50 lb/d

Lb O_2/hr = 2.3 x 8.34 x 0.971 = 18.63 lb/hr
O_2 Equivalent of sulfide = 2 x 50 = 100/d = 4.17 lb/hr
22.80 lb/hr

$$N = \frac{22.8 \text{ lb/hr}}{55} = 0.41$$

T = 14°C
C_L = 8.5 mg/l
C_{sw} = 9.33 mg/l (β = 0.90)
α = 0.91

$$N_o = \frac{N}{\alpha} \quad \frac{C_s}{C_{sw} - C_L} \quad 1.02^{20-T}$$

$$= \frac{0.41}{0.91} \times \frac{9.17}{9.33-8.5} \quad 1.02^{20-14}$$

N_o = 5.60 lb/HP hr (nameplate basis)

APPENDIX C: COMMENTS ON TREATMENT PLANT OPERATIONS

Wastewater Pumping Station

The 61 cm influent pipe to the pumping station required annual cleaning which was accomplished during the summer vacation period. The material deposited in the pipe was principally grit and a fire hose water stream was used to remove these materials. Additional cleaning was found to be necessary at times as evidenced by the reduction of hydraulic capacity in this 61 cm influent line.

Raw wastewater screens--In the design of the treatment plant, a Mazorator, for grinding or cutting the larger pieces of flesh and scraps to an acceptable smaller size, was supplied on the primary influent channel. The problems experienced with the Mazorator suggested a misapplication of the unit.

Pieces of flesh and scraps, especially after tanning, are extremely tough and resistant to cutting and the unit was unable to cope with the task. In the first eight months of operation, the Mazorator was down 38% of the time. By October, 1972, 13 months after start-up, the Mazorator was permanently removed.

During the period when operating difficulties were experienced with the Mazorator, a mechanical rake was provided on the secondary channel. The rake was designed by the plant engineer and was similar to the rake used in the old pumping station. When the Mazorator was removed, another rake and bar screen were installed on the primary channel. The rakes so provided were not trouble free and would break down on numerous occasions. However, the standby unit was available, the cost to repair was minimal and the rake was usually back in service within a day. The rake and bar screen units did perform adequately but not as effectively as the Mazorator potentially offered. Problems with scraps continued to be experienced elsewhere such as with the grinding of primary settling tank sludge and binding of the raw wastewater pumps.

Deposits in the wet well--It was necessary to clean the wet well three to four times a year as a result of the solids deposited on the bottom, in the corners and the formation of a grease layer at the surface. The deposits caused air locking of the raw waste pumps and the grease layer formed on the surface, became unsightly, odorous, and caused pumping problems.

The wet well was cleaned by dislodging the deposits with a fire hose stream and the resulting mixture was pumped with the raw wastewater pumps to the primary settling tanks.

Deposits in the raw wastewater pumps--The scrap material which passed through the bar screens caused a maintenance problem with the raw wastewater pumps. The scrap material would become bound in the pump impellers and substantially decrease its output. During poorest operating periods, a pump would need cleaning by removing the obstruction from the housing three to four times a day, but was normally done once a day per variable speed pump.

The plugging problem was common to the two variable speed pumps but not to the constant high speed standby pump and that the binding of scrap material in the pump impeller occurred at low speeds. To minimize the problem, adjustments were made in the pump controls to increase low discharge from 1.04 m^3/min to 1.89 m^3/min (275 gpm to 500 gpm) with a maximum of 6.06 m^3/min (1600 gpm).

Magnetic flowmeter maintenance--The raw wastewater passing through the flowmeter caused a scale deposit to form and eventually coated the meter electrodes. When this occurred, the unit failed and required an extended period of factory servicing in early 1973.

Thereafter, routine removal of the meter for electrode cleaning was needed every four to six months to insure continued performance. The meter was selected for design flow rates of 0 to 18930 m^3/day (0 to 5.0 MGD), whereas the average daily flow during the study was less than 3785 m^3/D (1 MGD). The accuracy of the unit for the low end of the range is subject to greater errors for the flow determinations than would have been experienced at higher flow rates.

Primary Clarifiers and Pumping Station #1

Primary clarifiers--The mechanical equipment provided with the primary tanks operated relatively maintenance free during the demonstration project. As part of a preventive maintenance program, each primary tank was drained and the equipment inspected for wear at four to six month intervals. A series of steps were used to clean and inspect a primary clarifier.

A portable gas operated pump was used to pump the liquid remaining in the tank. Residual sludge in the tank was pumped to the other settling tank or back to the wet well and the center feed well was pumped to remove accumulated material.

When empty, the sludge collector mechanisms were inspected, the walls and floors scraped to remove scale and the sludge withdrawal pipe to the sludge pumping station was cleaned with a Roto Rooter after which the tank was put back in service.

Routinely during each operational week, the three raw waste pumps were operated simultaneously to put a high flow rate through the center feed well to dislodge accumulated sediments. This procedure was used to reduce headlosses and facilitated the equal distribution of flow to each clarifier. The flow division to the two primary tanks should have been 50/50 for similar influent piping and equal effluent weir levels; however, as can be observed in the dewatering studies, the division of flow appeared not to be equal. This cleaning procedure and the resetting of the weirs (March, 1974) were employed to provide more effective sedimentation operation.

Primary sludge pumps--The primary sludge pumps operated under a heavy load and for the most part performed well. The positive displacement pumps broke down when the hydraulic headlossess were high and the sludge concentration was too high. The breakdown usually involved shear pin breakage and within minutes the pump was back on line. A reliable pressure gage by Ronningen Petter (0-80 psi) was installed on the discharge side of the pumps and through the use of water on the suction side of the pump and by observation of the pressure gage, the operator was able to pump the primary sludge as thick as possible to the desired location with a minimum of breakdown.

The normal recommended maintenance on the pumps was followed and all sludge piping was dismantled and cleaned quarterly to prevent build up from affecting the pump performance.

Primary clarifier scum handling--In the original design and construction of the treatment plant, separate lines were provided for conveying primary sludge and primary scum to the dewatering process. When the sludge dewatering building was designed, the entrance point of the materials into the building was changed and these lines had to be relocated. It was decided for this relocation to combine the two lines into one common 15.2 cm (6 in) pipe. The connection of the scum piping to the sludge piping was made in pumping station #1. Although this change seemed economically attractive, the reaction between the scum and the sludge in the underground line produced an adverse effect of solidifying and blocking of the pipe.

To overcome this problem, the decision was made to keep the sludge and scum systems separate. The lack of a separate scum line to the dewatering building is unfortunate in that dewatering studies on a sludge scum mixture indicated compatability.

The concentrated scum was removed from their storage tanks by a portable gas pump used to fill private haulers trucks for subsequent disposal off-site. Normally, the work necessitated two operators, the truck drivers and took four to five hours to complete at monthly intervals. The frequency of disposal was increased when the rendering operation began in March, 1974.

Sludge piping maintenance--As indicated above, the maintenance of the sludge piping, especially for the underground section was critical. It was necessary to contract with a private company to clean the sludge line three to four times a year. The method used was either by a high speed cutting blade or a high velocity water spray to remove the deposited material.

In addition to this procedure, daily preventive maintenance was performed. During the last filtration cycle for each day, the operator would shorten the sludge contact tank make up time to flush the sludge line with a fire hose back into the clarifiers to remove the sludge. The underground sludge line was drained back into the pumping station to remove any loose sediment and the line would be left dry for the next operating day.

Various chemicals were tried to remove the pipe scale but were unsuccessful for the most part.

Aerated Lagoons

Removal of accumulated sludge--The major maintenance required in the lagoon area was the removal of accumulated sludge. As indicated previously, the specifications concerning the provision for adequate velocities in the lagoon were not met by the original equipment provided. The original Sigma Pac aerators were replaced by more numerous, lower horsepower high speed aerators. Though this replacement was an improvement, settling of solids was not completely eliminated. This section describes the procedure utilized to physically clean a lagoon of settled sludge.

The best results were obtained by pumping the sludge back to the primary tanks for subsequent dewatering of the sludge using the filter press. One primary tank was taken off-line to receive the sludge for this purpose.

The lagoon to be cleaned was taken out of service and the aerators were removed. The liquid contents of the lagoon was then pumped into an adjacent lagoon by a portable gasoline pumping unit of 2.27 m^3/min (600 gpm) maximum capacity.

Upon completion of the dewatering operation, the sludge was pumped daily to the primary clarifier. The amount of sludge pumped was normally equal to the volume of sludge dewatered the previous day to minimize carryover of the concentrated liquor to the other operating lagoons. Where the settled sludge was too thick to pump from the lagoon, primary effluent was introduced to thin the sludge, or the operators physically mixed the sludge at the suction point. In many instances a front end loader was used to mix the entire lagoon contents to give a pumpable mixture and the front end loader was used daily to move the sludge to the suction point.

Through this procedure provided an excellent method to handle the settled sludge, the rate of removal was limited by the capacity of the filter press to dewater this sludge in addition to sludge resulting from primary settling of the raw wastewater and waste activated sludge. To increase production of the sludge dewatering system, three shifts (24 hour) of operation was employed and diatomaceous earth (DE) was used as a filter precoat. The DE precoat material eliminated the filter cloth washing required when buffing dust is employed.

The distribution chamber preceding the aerated lagoons was cleaned yearly of accumulated sludge. The amount of sludge was minimal, and was normally pumped into a lagoon.

Foam-- The control of foam in the aerated lagoons was a continual problem throughout the project.

When uncontrolled, the level of foam reached was significant wherein foam would accumulate and be carried out of the aerated lagoons to deposit the trapped solids on the grounds adjacent to the lagoons, forming nuisance conditions for the operators.

Some observations regarding the occurrence of foam formation follow.

(a) As the percent of the total primary effluent flow directed to the lagoon increased, foaming tendencies increased.

(b) Foam tended to form beginning in the late afternoon and through the night which may coincide with the discharge of the hair pulp to the plant from noon to 7:00 p.m. and the reduction of foam film evaporation in absence of sunlight.

(c) The accumulation of foam was more significant on weekends rather than weekdays.

(d) As mixed liquor solids increased, the ability to control foam without the benefit of defoamers increased.

(e) Foaming problems appeared to be more intensified when ambient air temperatures ranged from -1.1 to 10^oC (30^o to 50^oF).

(f) As the efficiency of the biological system increased the ability to control foam without the benefit of defoamers increased.

(g) Extensive foaming and the associated deposition of solids around the lagoon resulted in lowering the lagoon's mixed liquor suspended solids concentrations.

To control foam, various defoamers were employed during the project. All were liquids, oil based, and contained surface active agents. Initially, pail quantities of defoamers were thrown into the lagoon each night or when the foam was excessive. This procedure was not entirely satisfactory, and arrangements were made to feed defoamers on a continual basis. Defoamer feed pumps, Brunner chemical solution pump, Model 22SP, were purchased and installed to introduce the defoamer either at the distribution chamber as influent to the lagoons or in the basement of pumping station #2 in the return sludge. The pumping rate was adjustable and a time clock controlled the operation.

Through operator control, feed rates were adjusted to levels that would contain the foam in the aerated lagoons. By continued evaluation of various defoaming products, significant progress was made in controlling foam at reasonable costs.

Winter operation--The proper operation of the biological system was hampered by winter cold weather. The effects of cold weather were related to reduced biological activity and the failure of mechanical floating aerators to operate continuously. The problem of aerator shutdown was anticipated to occur but the extent to which this occurred was not predictable.

Both types of aerators provided experienced cold weather problems and the circumstances of occurrence were similar. Under cold temperatures, and ice build-up would begin beneath the vertical mounted motor and expand, thereby increasing the submergence of the unit, thus causing the unit to work harder with associated high amperage draw. As a result, the electrical heaters installed in the control box would shut the unit down. The length of time required to cause shut-down was dependent on the severity of the cold, with lower temperatures, the shutdown would occur sooner. As a general guideline, for the Sigma Pacs to operate without failing, air temperatures of above -12.2°C (10°F) were required. To lengthen the operating time at lower temperatures, half of Sigma Pacs blades were removed to reduce the weight. For the high speed aerators, an air temperature of -17.8°C(0°F) seemed to insure continuous operation with moderate attention.

Once the aerators shut off, different procedures were required to restart the units. With both types, first it was necessary for the operator to row out and physically remove the ice. With the Sigma Pac aerators, the operators checked to see if the blades turned freely. With the high speed units, the water in the narrow throat construction would freeze if too long a period had elapsed and the aerator had to be brought into the tannery to thaw. With both units, if the blades or propeller turned freely the unit was restarted as soon as possible. The high speed aerators were more reliable but it is important to restart the aerators as soon after shutdown as possible. Operation of the floating aerators will be a continual winter problem. Measures to conserve heat to prevent shutdown should be employed.

Transfer of aerators--In operating the aerated lagoons, it was necessary to transfer the mechanical aerators within the lagoon or from one lagoon to another. The procedures necessary to accomplish this action were: Sigma Pacs--The 750 kg m/sec (10 HP) units were not easily adapted to transferring. The motor, gear reducer and blades were mounted to a circular unit that was 2.44 m (8 ft) in diameter, 1.22 m (4 ft) high, and had 0.305 m (1 ft) thick walls. The ballast had three separate compartments for water which had to be removed before transferring the unit. A crane was used to transfer the 544 kg (1200 lb) aerator to its new lagoon and the ballast had to be refilled. The Sigma Pac aerators were secured by three stainless steel wires to anchoring posts at the lagoon edge.

High speed--The 375 kg m/sec (5 HP) units were lighter and more easily movable because there were no water ballasts on the units. The scoop of a front end loader was sufficient to adequately move the aerator. These units were secured by four guylines, two of which were tied to other units.

Scum formation--At various times, it was visually evident that a scum layer was formed on the surface of the aerated lagoons. Cold weather seemed to intensify the problem and the scum blanket would be found in areas where surface velocities were low. In the design of the treatment plant, scum dewatering pads were provided at each end of the aerated lagoons. These pads were inadequate since the scum was not confined to areas near the pad.

Aside from being unsightly, there is some question as to whether the scum blanket would impair mixing by impeding surface movement, as well as reduce oxygen transfer. To minimize the scum blanket formation a grease dissolving chemical was used which appeared to alleviate the problem.

Grease balls--Wooden slotted gratings were installed across the effluent structure to keep debris and vegetation, blown into the lagoons, from entering the effluent piping (Figure 7). The gratings became a catch basin for trapping grease balls formed by the rotating action of the aerators and required almost a daily cleaning of the gratings. The grease dissolving chemical helped to curtail the grease ball production.

Miscellaneous comments-- Pipe scaling was not observed to be a problem in operating the treatment plant. The primary effluent had Langlier Saturation Index (SI) values greater +2.0, while the lagoon effluent had SI values less than +.50. Calcium carbonate precipitation occurred within the aerated lagoon representing a significant portion of the sludge accumulations. Analysis of the sludge deposits showed calcium carbonate to be 40 to 50% of the total solids on a dry weight basis.

During the first months of plant operation, it was apparent that regular attention was needed for floating aerators. Relocation, greasing, ice removal were among the routine maintenance activities required. A boat was used extensively by the operators to perform their work.

When the change was made from the Sigma Pac to the high speed aerators, additional electrical controls were needed with the increase from 12 to 48 aerators. Rather than locate the controls in pumping station #2, as originally provided, panel boxes for the additional aerators were located at the lagoons. The panel housing the electric controls were wooden, insulated and heated, and provided an economical and convenient solution.

The major electrical problem experienced with the aerators was motor burn-out. Drain holes on the aerator housing became plugged with solids and water penetrated into the motor with the result that the motor needed rewinding. Field modification of drilling the drain holes larger reduced the motor burn-out problem.

Final Clarifiers, Pumping Station #2

Final clarifiers--The final clarifiers did not require as close attention as the primary clarifiers. The pumping out of the clarifier for cleaning and inspection was performed on an annual basis.

One problem experienced with the final clarifiers was during periods of extremely cold weather wherein the temperature of the waste water was lowered to near freezing. Without the aid of scum scrapers to create movement, the surface of the final clarifier would form surface ice with a narrow opening at the weirs for effluent release. To prevent structural damage to the clarifier the operators cleared an opening around the center feed well and around the effluent weir. The ice would remain until the wastewater temperature increased.

A second maintenance activity was the removal of grease and scum from the clarifier inlet structure. This material would be contained in the inlet and the operator would periodically scrap the scum out for disposal.

Return and waste sludge pumps--The centrifugal pumps operated well but two major maintenance activities were necessary. One problem involved the pumping of too thick a final sludge. To either clean the discharge piping of the thick sludge or to thin the sludge when pumping, the effluent reuse pump was used. Final effluent water was used for this purpose and the connection between the water reuse pump and the sludge piping was made by using a fire hose. Normally the sludge piping was flushed for a period of one to two hours only. The chlorine system was shut off during these brief periods to insure that the return sludge was not being adversely affected.

The second problem involved cleaning of the centrifugal sludge pumps when they would become plugged by extraneous matter, such as weeds, sticks, or scraps. The pumps would plug and lose efficiency when low pumping rates, less than 0.19 m^3/min (50 gpm), were employed. The operator had to dismantle the pump and clean out the impeller, at times as often as two to three times a day. This operating nuisance contributed to the employment of high pumping rates by the operators and resulted in high recirculation rates for some biological systems.

Chlorine Contact Tank and Chlorination System

Chlorine contact tank--With the actual flow less than half the design flow, the chlorine contact tank was underloaded. Horizontal velocities were very low, 0.46 m/min (1.5 ft/min) and no mechanical mixing was provided. During process upsets and deteriorated final clarifier effluent quality, settled sludge accumulated in the contact tank.

Periodically, it was necessary to clean the contact tank to restore the detention time and to eliminate the chlorine demanding sludge. This cleaning was done in the spring and the portable gas pump was used.

Each spring the flow was backed up in the lagoons by closing the discharge valves and the contents of the contact tank were pumped by a portable gasoline pump into a partially filled final clarifier for subsequent discharge to the wet well.

As indicated in the treatment plant flowsheet description, wooden planks were added to the effluent end of the contact tank to serve as a scum baffle to prevent discharge of this material to Hay Creek. Therefore, it was necessary for the operators to remove the floating scum from the contact tank for disposal as needed and varied from daily to weekly.

Chlorination system--At the time the treatment plant was designed, Minnesota required chlorination from May 1 to November 1 only. During the fall as temperatures cooled, the ability to maintain chlorine feed rates was hampered by the cold temperature experienced in the chlorine room. A small space heater was used to keep the 68 kg (150 lb) cylinders warm to maintain the desired feed rate.

During the initial year of operation, the weighing mechanism for the chlorine corroded and had to be replaced. Thereafter, closer attention was paid to maintaining the system. Due to a higher than expected chlorine demand, the chlorine feeding capacity was changed from 0 to 45 kg (100 lb) per 24 hours to a rate of 0 to 90.7 kg (200 lb) per 24 hours.

Sludge Dewatering

Sludge grinder--A sludge grinder was provided in the Passavant dewatering system to cut or grind large peices of material in the primary sludge. As was the case with the Mazorator, the extraneous matter found in tannery wastes, i.e., leather scraps, fleshings, etc., proved to be too difficult for the sludge grinder. Unable to cut the material, the sludge grinder plate and chamber would plug causing increased discharge pressure on the primary sludge pumps. Before the pressure reached a point of causing the positive displacement pump to fail, the operators would shut off the make-up system and clean the sludge grinder. Pressure gages on either side of the grinder indicated when plugging was occurring.

During periods when winter hides were processed or when problems were experienced with the mechanical rakes, the maintenance problem was more severe. Whether cutting or blocking, the sludge grinder unit served the purpose of excluding large extraneous material from entering the sludge dewatering process.

Sludge piping--As indicated in foregoing sections of this operations summary, special operational procedures were performed each night to maintain the piping between pumping station #1 and the sludge dewatering building in operating order. Within the sludge dewatering building, the piping between the sludge grinder and the contact tank needed an extensive cleaning every two weeks. A Roto Rooter was used to clean this piping.

The piping between the contact tank and the filter press, a continuous welded section, remained clean. It was feared that a blockage in this section would be a major problem; however, the problem never developed. Valves on the ferric chloride lines did require some maintenance. Tanks such as the large surge tank, filtrate tank, precoat tank and bin required a periodic cleaning to remove accumulated deposits.

Filter cloth--In the original discussion with the Pasavant personnel, the indicated life span for the 90 filter cloths was 4000 cycles (2 years). It was determined that the porous underline media had slipped slightly and was forming a cutting edge against the outer nylon cloth. This cut was prevalent around the four metal bosses and center feed hole. Using Passavant's recommendation, the underdrain media was resupported. Studies during the project last six months showed the filtering cloths failure rate to decrease substantially.

When a tear or rip occurred in the nylon cloths, efforts were made to patch the cloth rather than replace it. Spare cloths were used to supply patching material, and patches were glued on. Weekly the patches would loosen and new rips were found with the net result that three to five hours were required each week on patching or replacing the outer nylon cloths.

Odor Control

One problem that needed continual attention during the 3 1/2 years of treatment plant operation was odor control. Various chemicals and procedures were employed to affect odor control.

Sludge disposal basins--The treatment plant operated for 21 months before the pressure filtration solids handling method was available. In the interim, primary sludge was pumped to diked low areas. The sludge solids were allowed to consolidate and the supernatant was pumped into an aerated lagoon. The sludgeholding basin generated odors and control was required.

The basic odor control procedure employed consisted of spraying a lime slurry--orthodichlorobenzene (odorfresh) mixture onto the sludge bed surface. The purpose was to raise the pH to discourage anaerobic activity and secondly the chemical bactericide was intended to reduce the number of odor causing organisms.

The depth of supernatant liquid over the sludge was maintained at a minimum to keep the sludge as dry as possible, thereby reducing anaerobic activity.

During the winter of 1973-74, with the dewatering system operational, the two sludge beds were covered with 15.2 cm (6 in) of dirt.

Dewatered cakes-- The odor from the disposed dewatered sludge cakes was not considered significant. As was indicated in the section on the solid waste study, covering the cakes did much to curtail decomposition and drying. While the cakes were exposed to the atmosphere, they were sprayed with an orthodichlorobenzene solution.

Aerated lagoons--At one time it was felt that the sludge deposits formed on the lagoon's bottom contributed to the odor. While the lagoon was in active use, little odor control was applied so as not to interfere with the aerobic biological system. When the lagoon was removed from service and emptied for cleaning, lime and odor-fresh was used to control the odor.

Primary sedimentation tanks--With the prevailing alkaline pH in the raw wastewater, odor problems were not as severe as expected. It was assumed that the sulfide reduction was accomplished in part by oxidation in the lagoon.

During the summer of 1975, some discoloration was experienced to the painted surface of homes approximately 0.8 km from the treatment plant. This was similar to occurrences experienced in 1971, the summer before the new plant was placed in operation. The discoloration was attributed to hydrogen sulfide. Though in 1971, Hay Creek as well as sludge lagoons may have been the source of H_2S emission, studies in the summer of 1974 traced the H_2S emission to the aerated lagoons.

Under conditions of high mixed liquor solids, nutrient phosphorus additions and operating conditions representing higher than normal organic loadings resulted in biological respiration requirements which exceeded the capability of the aeration system resulting in reduced oxidation of the sulfide. This combined with the phenomena of discharging a primary effluent of high pH, wherein the H_2S remains in solution, into the aerated lagoons of operating pH values of near 8 resulted in release of H_2S to the atmosphere.

To control the sulfide, ferric chloride was added to either the raw waste or primary effluent. The ferric combined with the sulfide to form a precipitate thus eliminated the problem. The amount of $FeCl_3$ added was balanced chemically to the sulfide levels. It appears that to a great extent the odors generated at other areas were due to lower, but not recognizable, H_2S levels. Some odor generation connected with the sludge dewatering operation may be attributed to the release of NH_3 resulting from increasing the pH of the conditioned sludge to values near 11.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-78-013	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Biological Treatment, Effluent Reuse, and Sludge Handling for the Side Leather Tanning Industry		5. REPORT DATE February 1978 (issuing date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) L. B. Polkowski, W. C. Boyle, and B. F. Christensen*		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS *S. B. Foot Tanning Co. Red Wing, Minnesota 55066		10. PROGRAM ELEMENT NO. 1BB610 11. CONTRACT/GRANT NO. 12120 DSG
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory--Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

L. B. Polkowski and W. C. Boyle are with Polkowski, Boyle & Associates, Madison, Wisconsin 53705

16. ABSTRACT

An evaluation of the treatability of unsegregated, unequalized, and unneutralized wastewaters from a side-leather tanning industry utilizing the hair pulping process by primary and secondary biological and gravity separation in clarifier-thickeners, whereas the secondary treatment method employed aerated ponds and final clarifiers with the capability of recycling biological solids. The system was operated over a wide range of detention times, with and without solids recycle, and nutrient (phosphorus) addition, and during seasonal variation representing mean monhtly air temperature variations from -14°C to 30°C. The removal efficiencies were related to loading relationships as well as temperature variations. The secondary treatment effluent was reused in the beamhouse operations under test conditions to evaluate the effects of water conservation practice on leather qualities as well as to determine the buildup of conservative substances in the wastewater effluent such as chloride.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Industrial wastes Waste treatment Sludge disposal	Leather tannery Waste characterization Temperature effects Water reuse	43 50 B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 248
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

☆ U. S. GOVERNMENT PRINTING OFFICE: 1978 — 757-140/1320