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Treatment of Packinghouse Wastewater by Intermittent Sand Filtration

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September 1978

TREATMENT OF PACKINGHOUSE WASTEWATER BY INTERMITTENT SAND FILTRATION

by

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DISCLAIMER

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional 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 evaluates a full scale wastewater treatment system consisting of a novel extended aeration unit and intermittent sand filter. This demonstration project is an extension of previous development research to meet future industrial discharge limitations. The treatment system was designed to meet the special needs of small plants. The report will be of interest to those involved with treatment of wastewaters from the meat and poultry processing industries. For further information contact Food and Wood Products Branch, Industrial Pollution Control Division, IERL-Ci.

David G. Stephan
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ABSTRACT

The primary objective of this research project was to evaluate the use of intermittent sand filters as a means of upgrading waste treatment systems for small packinghouses. The project was conducted at the W. E. Reeves Packinghouse in Ada, Oklahoma, and the treatment system consisted of an extended aeration lagoon in series with an intermittent sand filter.

With a hydraulic loading rate of 0.36 mgad and a sand source having an effective diameter of 0.35 mm and a uniformity coefficient of 2.5, a filter run of 109 days was observed. The average BOD_5 and TSS of the filter effluent was 10.4 mg/l and 11.1 mg/l respectively. In relation to the 1983 BAT limitations, the effluent met the maximum day limit for TSS but the 30-day average value for TSS was exceeded (but only within the accuracy of the test). The maximum day and 30-day average limits for BOD_5 were exceeded. The effluent met the limits for fats, oil, and grease and pH. The NH_3-N in the effluent from the treatment system met the BAT limits which were rescinded by the court. The fecal coliform limits were also exceeded.

A secondary objective of the project was to determine the most economical means of meeting the NPDES monitoring requirements. The conclusion was that the small packinghouse managers should use a commercial laboratory when monthly or quarterly analyses are specified.

The report contains information on the cost of construction and operation of the treatment facility. The study revealed an installation cost of \$1.40/gpd capacity and a treatment cost of \$0.29/lb BOD_5 applied. The report also contains the information needed to select, design, and construct an intermittent sand filter.

This report was submitted in fulfillment of Grant No. S-803766-01 by East Central University under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period June 1, 1975, to February 28, 1977, and work was completed as of February 28, 1977.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	-- Analysis of Variance
avg	-- average
BAT	-- Best Available Technology Economically Achievable
BOD_5	-- 5-day biochemical oxygen demand
BPT	-- Best Practical Control Technology Currently Available
Cl^-	-- chloride ion
COD	-- chemical oxygen demand
DO	-- dissolved oxygen
eff. dia.	-- effective diameter
F/M	-- food/microorganism ratio
FOG	-- fats, oil, and grease
ft	-- feet
ft^3	-- cubic feet
gal	-- gallons
gpd	-- gallons per day
hp	-- horsepower
in.	-- inches
JTU	-- Jackson Turbidity Unit
lb/ft^2	-- lbs/square foot
lb/1000 lbs LWK	-- lbs/1000 lbs of liveweight killed
LWK	-- liveweight killed
M-F	-- membrane filter
mgad	-- million gallons per acre per day
mg/l	-- milligrams/liter
MLSS	-- mixed liquor suspended solids
mm	-- millimeter
MPN/100 ml	-- most probable number/100 milliliters
n	-- number
NH_3-N	-- ammonia nitrogen
NO_3^-/NO_2^--N	-- nitrate/nitrite nitrogen
NPDES	-- National Pollutant Discharge Elimination System
Pt-Co	-- platinum-cobalt
SRI	-- sludge retention index
SVI	-- sludge volume index
TKN	-- total Kjeldahl nitrogen
T-N	-- total nitrogen
T-P	-- total phosphorus
TS	-- total solids
TSS	-- total suspended solids
TVSS	-- total volatile suspended solids
unif. coeff.	-- uniformity coefficient

CONVERSION FACTORS[a]

To convert from	to	Multiply by
inch (in)	millimeter (mm)	2.540×10^{1}
foot (ft)	meter (m)	3.048×10^{-1}
foot^2 (ft^2)	meter (m^2)	9.290×10^{-2}
foot^3 (ft^3)	meter^3 (m^3)	2.832×10^{-2}
degree Celsius (°C)	degree Fahrenheit (°F)	$t_{^oF} = 1.8\ t_{^oC}+32$
horsepower (hp)	watt (w)	7.457×10^{2}
pound (lb)	kilogram (kg)	4.536×10^{-1}
pound per day (lb/d)	kilogram/day (kg/d)	4.536×10^{-1}
gallon (gal)	meter^3 (m^3)	3.785×10^{-3}
gallon per day (gpd)	meter^3/day (m^3/d)	3.785×10^{-3}
million gallon per acre per day (mgad)	meter^3/hectare/day (m^3/hec/d)	9.353×10^{3}
cost/gallons per day($/gpd)	cost/meter^3/day ($/m^3/d)	3.785×10^{-3}
cost/pound ($/lb)	cost/kilogram ($/kg)	4.537×10^{-1}
pound per foot^2 (lb/ft^2)	kilogram/meter^2 (kg/m^2)	4.882
pound per 1000 lbs (lb/1000 lbs)	kilogram/1000 kilogram (kg/kkg)	1

[a]Metric Practice Guide. ASTM Designation E-380-74, American Society for Testing and Materials, Philadelphia, Pennsylvania, November, 1974. 34pp.

SECTION 1

INTRODUCTION

The primary objective of this project was to determine the use of intermittent sand filters as a means of upgrading waste treatment systems for small meat packing plants to meet discharge requirements. The meat industry was cited in Public Law 92-500 as an industry requiring standards for wastewater discharges and the National Pollutant Discharge Elimination System (NPDES) permit limitations have been imposed. The industry must meet the maximum limits referred to as the "best practical control technology currently available" (BPT) by July 1, 1977, and the "best available technology economically achievable" (BAT) by July 1, 1983. These BPT and BAT limits for 5-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), and fats, oil, and grease (FOG) and the New Source Limitations for ammonia-nitrogen (NH_3-N) are given in Table 1 (1).

TABLE 1. NATIONAL EFFLUENT GUIDELINES (lbs/1000 lbs LWK)[a]

Parameters	Simple slaughter-houses 30-day avg.	Low packing-houses 30-day avg.	Complex slaughter-houses 30-day avg.	High packing-houses 30-day avg.
1977 limitations (BPT)				
BOD_5	.12	.17	.21	.24
TSS	.20	.24	.25	.31
FOG	.12	.08	.08	.13
New source limitations (include the above plus NH_3-N)				
NH_3-N	.17	.24	.24	.40
1983 limitations (BAT)				
BOD_5	.03	.04	.04	.08
TSS	.05	.06	.07	.10
FOG*	10	10	10	10
NH_3-N*	4	4	4	4

*Values in mg/l.

[a] 1 lb/1000 lbs = 1 kg/1000 kg; conversion factors are presented in the prefatory pages.

The maximum limits for any one day are twice those shown in Table 1 for all parameters except FOG. The FOG maximum limits for any one day are the same as the 30-day average limit. Limitations for pH require that all effluent samples have pH values greater than 6.0 and less than 9.0, and the maximum allowable fecal coliform bacteria limitations are 400 MPN/100 ml. The NPDES system also requires the monitoring of the temperature of wastewater.

In 1975, after initiation of this project, a Federal court rescinded the BAT limits on NH_3-N and the TSS limits for complex slaughterhouses. More recently amendments to Public Law 92-500 have made necessary re-evaluation of all future limits.

Waste treatment investigations began at the W. E. Reeves Packinghouse, Ada, Oklahoma, in 1970. These investigations were conducted as a cooperative effort of the Environmental Protection Agency, W. E. Reeves Packinghouse and East Central University. After the NPDES guidelines more precisely defined the technologies needed by the industry, the scope of the investigations were enlarged to meet these needs. Also, since the use of full-time waste treatment personnel is not practical for small meat packers, minimum operation requirements have been viewed as a basic criteria for suitable treatment systems for small operations. The full-scale processes investigated at the W. E. Reeves facility were aerobic and anaerobic lagoons and extended aeration operated in a batch mode. Pilot-scale studies included overland flow and intermittent sand filtration systems. Earlier publications by Witherow et al. (2, 3, 4, 5) reveal the results of these investigations.

In the past few years, researchers (6, 7, 8) have demonstrated the effectiveness of intermittent sand filters in reducing TSS from domestic wastewaters which had received prior treatment, such as lagoon treatment. Based upon this work and the results of the pilot study conducted at the Reeves facility, a full-scale intermittent sand filter was installed in series with the batch operated extended aeration unit. This treatment system was designed to minimize and automate the mechanical equipment, and to demonstrate a discharge that would meet NPDES limitations within the manpower constraints of small meat packing operations.

A secondary objective of the project was to develop a simple and economically feasible means of meeting the NPDES monitoring requirements for small meat packers. The analytical tests required for the NPDES monitoring reports necessitate trained personnel and laboratory facilities, or the contracting of analytical services by a commercial laboratory. Either of these methods can be expensive and various analytical techniques were examined to see if the monitoring requirement could be simplified and made less expensive, and if laboratory facilities and personnel were feasible for the small meat packer.

The final objective of the project was to provide the small meat packers with the information needed to design, construct, and operate an intermittent sand filter system.

SECTION 2

CONCLUSIONS

During this investigation, packinghouse wastewater treated in an extended aeration unit was discharged to intermittent sand filters in an attempt to upgrade the quality of the wastewater to meet NPDES discharge limits. The effluent from the filter units met all BPT limits, with the exception of fecal coliform bacteria. The effluent also met the new source limitations for NH_3-N. The demonstration revealed that the treatment system used at the W. E. Reeves facility could meet these discharge limits for small packinghouses if a disinfection system was incorporated into the existing treatment plant.

The effluent results were also compared to the BAT limits. Fats, oil, and grease limitations were met and all effluent samples had pH values between 6.0 and 9.0. The effluent met the maximum day limit for TSS. The 30-day average value for TSS was exceeded, but only within the accuracy of the measurement. The effluent also exceeded both the maximum day and 30-day average limits for BOD_5. The NH_3-N in the effluent from the treatment system met the BAT limits which were rescinded by the court. (See Table 11)

A major economic factor in the use of intermittent sand filters is the length of filter run, that is the period of time the filter can be operated before cleaning is required. Factors affecting the length of filter run are the concentration of suspended solids, hydraulic loading rate, and size of filter media. The influent to the filter had an average TSS concentration of 41 mg/l. During this investigation, sand having an effective diameter of 0.2 millimeters (mm) and a uniformity coefficient of 4 was used with hydraulic loading rates of 0.86 million gallons/acre/day (mgad) and 0.55 mgad. These investigations resulted in filter runs of 10 days at the higher hydraulic loading rate of 0.86 mgad and 15 days at a loading rate of 0.55 mgad. When this sand was replaced with sand having an effective diameter of 0.35 mm and a uniformity coefficient of 2.5, the hydraulic loading rate was lowered to 0.36 mgad. The length of filter run in this test was 109 days. This dramatic change from two or three cleanings per month to three cleanings per year made the intermittent sand filter economically feasible for small meat packers.

A number of analytical techniques were evaluated in an attempt to find accurate and inexpensive procedures which would provide the necessary wastewater monitoring data. With one exception, no other analytical tests evaluated were found to be more practical than those given in Standard Methods for the Examination of Water and Wastewater (9) or EPA Methods for Chemical Analysis of Water and Wastes (10). The Hach manometric BOD_5 method was found to be an acceptable substitute for the traditional BOD_5 procedure for monitoring of these wastewaters. An economic evaluation of the necessary laboratory and a trained technician needed to meet the NPDES monitoring requirements indicate that the small meat packer should use a commercial laboratory when monthly or quarterly analyses are specified.

Information on methods and costs of construction and operation of the intermittent sand filter system is provided in this report. This report gives the small packer the information needed to select, design and construct an intermittent sand filter. (See Sections 6, 7, 8 and 9)

SECTION 3

RECOMMENDATIONS

The quality of the effluent from the filters either met or was close to the BAT limits for BOD_5 and TSS; therefore, investigations into methods of improving the removal efficiencies should be conducted. One method which showed promise and should be further examined is chemical treatment in the batch operated aeration unit with coagulants.

The major operational difficulties encountered during this investigation were those related to mechanical failures of the aerator and the automated valves. Difficulty was also encountered with the timers which actuated the aerator and valves. On several occasions, the valve between the extended aeration pond and the filter unit failed to close at the proper time. When the aerator was placed in operation while the valve was still open, the filter would be dosed with mixed liquor and clogging of the filters would occur. More dependable electronic controls should be utilized to prevent such occurrences. Auxiliary aerators and valves are recommended to reduce non-treatment periods to a matter of a few hours.

Ammonia, total Kjeldahl nitrogen (TKN), and nitrate/nitrite nitrogen (NO_3^-/NO_2^--N) readings taken during this investigation indicated that both nitrification and denitrification was occurring. Because the system removed 90% of the total nitrogen, investigations concerning the fate of nitrogen are recommended.

For small meat packers with NPDES permits which require either monthly or quarterly chemical analyses the following are recommended:

1. NPDES report preparation, sample collection, and measurement of pH and temperature should be done by plant personnel.

2. A commerical laboratory should be used to obtain TSS, BOD_5, NH_3-N, FOG, and fecal coliform analyses.

3. An overflow weir should be installed to enable plant personnel to monitor the discharge flow.

4. A daily inspection of the facilities should be conducted by plant personnel.

SECTION 4

EVALUATION OF MONITORING PROCEDURES

The NPDES system requires packing plant managers to monitor wastewater for a number of parameters including flow, TSS, BOD5, NH3-N, FOG, fecal coliform bacteria, pH, and wastewater temperature. For a small plant with a permitted BOD5 discharge of approximately 4 lb/day, these monitoring requirements add significantly to the wastewater treatment costs. The first NPDES permit proposed for the W. E. Reeves Packinghouse required these analyses three times per week. This was estimated to cost $15,000/year which was about 250% of the remaining treatment costs. The permit was modified to monthly analyses which amounted to about 15% of the remaining treatment costs. An objective of this project was to investigate less costly direct and indirect methods of monitoring for compliance with the permits. These methods should require annual expenditures of less than $1000/year and equipment costs of less than $2000.

Those parameters which are of particular concern are BOD_5, TSS, NH_3-N, FOG, and fecal coliform bacteria, since all of these require that the analyses be performed in accordance with EPA approved laboratory procedures. When approved analytical techniques are used it is necessary that scientifically equipped laboratory facilities are available and that the work is done by trained technicians. Each parameter referred to above is discussed in this section.

TOTAL SUSPENDED SOLIDS

The approved TSS test is a gravimetric analysis which requires the use of an analytical balance, a drying oven, a vacuum filtration system, and numerous items of glassware and laboratory apparatus. To reduce the need for this costly equipment and time consuming analyses, an investigation into the feasibility of substituting a spectrophotometric procedure for the gravimetric analysis was conducted. The spectrophotometric concept of monitoring TSS above 30 mg/l has been demonstrated feasible in the works of Kiskowitz (11), Krawczyk (12), and the Hach Chemical Company (13).

Some effluent samples from the sand filter unit were analyzed for TSS by the approved gravimetric procedure and then absorbance readings were made on the same sample using a Bausch and Lomb Spec-20 spectrophotometer with a one-half in. cell. Absorbance measurements were made at various wavelengths but the failure to obtain reproducible readings in these low absorbancy ranges led to the discontinuation of the spectrophotometric work.

The samples with known TSS concentrations were analyzed for turbidity using a Hach 2100 turbidimeter. A comparison of the corresponding TSS and turbidity readings is given in Table 2. The turbidimetric method did not reflect the magnitude of the changes which occurred in the TSS concentrations. The correlation coefficient of the turbidity and the TSS was 0.08. Therefore, the substitution of the turbidimetric procedure for the gravimetric procedure would not be reasonable.

TABLE 2. TURBIDITY VS. TSS

	Turbidity (JTU's)	TSS (mg/l)
Number	39	39
Mean	6.9	11.7
Standard deviation	2.2	8.0
Correlation coefficient (R) = 0.08		

The investigations revealed that the spec-20 spectrophotometer (with a one-half in. cell) or the Hach turbidimeter could not be used for the monitoring of suspended solids in the low concentration ranges characteristic of the filter effluent. This conclusion is not in conflict with the work of other researchers cited earlier since their work involved the TSS monitoring of sewage, not wastewater with TSS concentrations of approximately 10 mg/l.

The gravimetric procedure should be used for the monitoring of the treated meatpacking wastewater since the spectrophotometric methods were not found to be accurate procedures for the monitoring of low range TSS samples.

FIVE-DAY BIOCHEMICAL OXYGEN DEMAND

The EPA approved procedure for performing a BOD_5 test requires that the dissolved oxygen (DO) concentration of the wastewater is determined at the time the test begins and a second DO reading is taken after the wastewater is incubated for 5 days. The DO procedure employed is usually performed by a chemical test such as the azide procedure (10), but a DO meter can be used. The BOD_5 procedure would require a BOD_5 incubator, high quality distilled water, and various items of glassware and apparatus. A number of chemicals are required for the procedure if the azide procedure is used. If the DO meter is used, the chemicals would not be necessary.

A manometric procedure for BOD_5 is available in which a direct reading can be taken from a mercury column (14). A comparison of the results obtained by the standard procedure and the manometric procedure was made. A series of samples of raw wastewater, filter influent, and filter effluent were analyzed by both procedures in triplicate. The results, shown in Table 3, revealed no significant difference at the 5% level ($p < .05$) when the student t-test was used. Therefore, either procedure could be used for monitoring the BOD_5 of the packinghouse wastewater.

TABLE 3. MANOMETRIC BOD_5 VS. STANDARD BOD_5 PROCEDURE

	Raw wastewater		Filter influent		Filter effluent	
	Std.	Manometric	Std.	Manometric	Std.	Manometric
Number	12	12	15	15	15	15
Mean (mg/l)	504	508	45	44	13	12
Minimum (mg/l)	400	415	30	30	4	5
Maximum (mg/l)	627	630	64	60	28	25

The manometric procedure does offer the advantage of providing a simplier technique, however, it requires the use of a special manometric apparatus which costs approximately $250.00. The cost figure of the manometric unit is approximately the same as the cost of glassware and chemicals for the standard procedure. Both procedures require the use of an incubator. Therefore, the manometric procedure offers no savings in equipment costs, but there are savings in labor cost, since the technique requires less time.

Some chemical oxygen demand (COD) techniques were considered as possible substitutes for the BOD_5. (15, 16) These procedures involve the use of laboratory glassware and chemicals and do not require expensive apparatus. When the COD procedures are used, results can be obtained much faster than with the standard BOD_5 procedure. However, since there is no universal correlation between BOD_5 and COD, the only way this substitution could be acceptable would be if a BOD_5/COD correlation study was done for each packing plant. The additional laboratory work would cause the substitution of a COD test for the BOD_5 to be impractical at a small plant where monthly or quarterly analyses are required.

FATS, OIL, AND GREASE

A survey of the literature reveals that all of the acceptable FOG procedures consist of an extraction, distillation, and gravimetric measurement. Any of these procedures would require extraction apparatus, such as a soxhlet extractor, a distillation unit, and an analytical balance, as well as specialized glassware and chemicals. No alternate procedure for those approved methods was investigated.

AMMONIA NITROGEN

Acceptable NH_3-N procedures consist of a distillation followed by a titration. These procedures require apparatus such as Kjeldahl distillation unit, special glassware, and chemicals.

One alternate procedure which was considered for the project was the use of an ammonia specific ion electrode. However, a disadvantage of this technique would be the level of expertise required of the analyst, as the standardization and calibration techniques require sophisticated laboratory skills. Economics is another disadvantage, because the specific ion electrode procedure still may require the distillation apparatus, in addition to the specific ion electrodes (approximately $300) and an expensive instrument capable of providing a millivolt readout. Therefore, the traditional distillation-titration procedure would be the most practical procedure for small packers.

FECAL COLIFORM BACTERIA

A review of the technical literature and an investigation of some manufacturers literature revealed that most of the commercially available simplified methods for fecal coliforms are suitable as screening techniques (17). The membrane filter (M-F) technique is an approved procedure which has gained wide acceptance and is the preferred procedure because the cost is comparable to the simplified methods. This technique requires the use of an incubator, filtering apparatus, glassware, media, and cellulose filters. The most expensive item is the incubator which is also needed if the simplified procedures are used. Therefore the M-F technique was used in the investigation.

pH AND TEMPERATURE

The monitoring of pH should present no problem for packinghouse managers, since this test could be performed easily and economically. Plant employees could be trained to take pH readings with an inexpensive pH meter (approximately $250.00) or with pH hydrion paper. Temperature readings could also be taken by plant personnel and would require no equipment other than a thermometer.

FLOW

The monitoring of flow is a parameter which should be considered in the initial design of the treatment system. The system should be designed to allow for the installation of an overflow weir to monitor the flow. If plant personnel do not have the capability of establishing the flow monitoring program, the services of a consultant or an extension agent can be acquired to install a discharge weir which could be maintained and monitored by plant personnel.

COST

The choices which are available to the plant manager are to establish a monitoring laboratory (assuming that one is not available) and acquiring a trained technician to do the analyses, or acquire the services of a commercial laboratory.

Estimates of monitoring costs were made and are presented in Table 4. These are intended to be used as general guidelines because the cost of establishing and stocking a laboratory, acquiring a technician, etc. may vary from those used by the principal investigator.

TABLE 4. EQUIPMENT COSTS FOR MONITORING REQUIREMENTS

Instrument	Analysis	Cost
Analytical balance	TSS, FOG	\$1000.00
pH meter	pH, NH_3-N	250.00
Drying oven	TSS	250.00
BOD_5 incubator	BOD_5	800.00
Bacteria incubator	Fecal coliform	600.00
Vacuum filter apparatus	TSS	100.00
M-F - filtering apparatus	Fecal coliform	100.00
Soxhet apparatus	FOG	350.00
Distillation rack	NH_3-N	600.00
Distilled water system	-----	550.00
Glassware	-----	1600.00
Miscellaneous apparatus	-----	850.00
Chemicals	-----	1000.00
Total		\$8050.00

The estimates of time for the activities in Table 5 were made with allowance for the preparation of reagents and the establishment of quality control procedures. By amortizing the laboratory cost over five years and using a technician salary of \$5.00/hour, the monthly cost of monitoring would be approximately \$320.00/month. These cost figures did not include a cost for laboratory space, remodeling, or laboratory utilities. Some states which require monitoring reports specify that all analyses must be performed in a certified laboratory. No allowance was made in these cost estimates for such laboratory certification fees.

TABLE 5. LABOR COSTS FOR MONITORING REQUIREMENTS*

Activity	Hours
Sample collection and shipment	2
BOD_5 analysis	4
TSS analysis	2
FOG analysis	4
NH_3-N analysis	3
Fecal coliform analysis	2
Calculation and report preparation	2
Total	19

*Assuming monthly monitoring of BOD_5, TSS, FOG, NH_3-N, and fecal coliform bacteria.

Table 6 presents the cost estimates based on monthly analyses for BOD_5, TSS, fecal coliform bacteria, NH_3-N, and FOG by a commercial laboratory. The cost of monitoring flow, sample collection, pH, temperature, and report preparation was calculated on the basis of 4 hours of plant personnel time at the rate of $5.00/hour. The cost figures for BOD_5, TSS, fecal coliform bacteria, NH_3-N, and FOG are the average costs based on price quotations from five commercial laboratories. These figures vary between laboratories.

TABLE 6. COMMERCIAL LABORATORY COSTS FOR MONITORING REQUIREMENTS

Item	Cost
BOD_5 analysis	$15.00
TSS analysis	5.00
NH_3-N analysis	15.00
FOG analysis	20.00
Fecal coliform bacteria analysis	20.00
Labor of plant personnel	20.00
Total	$95.00

Based on the data in Tables 4, 5, and 6, monitoring costs by plant personnel are estimated to be approximately $320.00/month, compared to a cost of $95.00/month if the analyses were performed by a commercial laboratory. Neither of these cost studies included the cost of daily flow monitoring and inspection of the facilities which would require 15 to 20 manhours per month. Other points that plant managers need to consider would be the necessity of setting floor space aside for a laboratory, even though the laboratory space would be utilized only a small portion of the time. Acquiring a trained technician to be utilized for laboratory analysis on a part-time basis might also be a problem.

SECTION 5

DEVELOPMENT OF TREATMENT FACILITY

DEMONSTRATION SITE

The demonstration site for this study was the W. E. Reeves Packinghouse in Ada, Oklahoma. The plant slaughters 500 to 700 cattle per month and 600 to 800 hogs per month, or about 10,000,000 pounds of liveweight killed (LWK) annually. The W. E. Reeves facility has been used as a demonstration site for a number of other wastewater treatment investigations conducted over the past five years. All of the research activities conducted at the W. E. Reeves Packinghouse were the result of the cooperative efforts of the Environmental Protection Agency, the W. E. Reeves Packinghouse and East Central University.

Previous investigations, which were conducted at the W. E. Reeves facility, were concerned with aerobic and anaerobic lagoon treatment, extended aeration treatment, and overland flow. After the national discharge guidelines were established, the research activities were directed toward the development of feasible treatment systems for small plants which would meet the NPDES effluent guidelines. This meant that practical systems should produce a high quality effluent and should be designed to minimize and automate the mechanical equipment. Systems of this type would be practical for small plants since the need of a full-time waste treatment operator would not be necessary.

Immediately prior to the installation of the intermittent sand filter study, the full-scale treatment process in use at the site consisted of extended aeration operated in a batch mode followed by two aerobic lagoons in series. However, the effluent from this treatment system failed to meet the proposed national discharge limitations. Therefore, there was the need for incorporating some process with the existing treatment facility which would upgrade the quality of the effluent to meet the discharge limitations. The intermittent sand filter was proposed for accomplishing that task.

HISTORY OF SAND FILTRATION

The use of sand filtration for the treatment of water and wastewater is not a recent innovation in the United States. A survey of the literature reveals the existance of sand filtration for the improvement of drinking water supplies in the United States as early as 1828 (18). The population growth in the United States, especially in the eastern cities, created a demand for larger volumes of drinking water, and around the turn of the century a number of slow sand filters were put to use in the United States for the treatment of drinking water supplies.

Just as the population growth in the United States had created a demand for methods of treating larger volumes of drinking water, the need arose for methods of treating the increasing volumes of wastewater produced by the municipalities and intermittent sand filtration was viewed as a wastewater treatment method. An experimental intermittent sand filter unit for the treatment of sewage was built in Lawrence, Massachusetts in 1888 (19). The operation of the intermittent sand filter proved successful. However, a rapid increase in the number of sand filter units for the treatment of sewage was not experienced in the United States until the 1940's. The determining factors for the increased usage of intermittent sand filter units were the availability of natural sand sources meeting the desired specifications and the requirement of large tracts of land.

Following World War II, the rapidly increasing number of subdivisions, mobile home parks, and resort areas in Florida created a need for economical and practical treatment systems which would produce an effluent of suitable quality. This need for simple and economical sewage treatment units for small volumes of wastewater led investigators at the University of Florida to test various designs for intermittent sand filter units (19). Much of the present knowledge concerning intermittent sand filters has come from these early studies at the University of Florida.

The early designs of intermittent sand filters have seen little change over the years that they have been in use. The units usually consist of an underdrain of open-jointed tile or perforated pipe. The underdrain network is covered with approximately 18 inches (in.) of gravel ranging in diameter from 1/8 to 3 in. Filter sand is placed on the gravel at a depth that varies from 24 to 60 in. In the design of an intermittent sand filter, emphasis must be placed on sand specifications. It must be a well-graded sand with the proper effective size and uniformity coefficient. The effective size is usually between 0.15 and 0.35 mm, and the uniformity coefficient is usually less than 3.0. Hydraulic loading rates for sand filters vary depending on the filter media and the amount of suspended solids in the raw wastewater. All of these factors must be considered in order to design a filter unit capable of experienceing a feasible period of operation before clogging of the filter media occurs.

In the past few years, workers have demonstrated the effectiveness of intermittent sand filters in reducing the TSS concentration of domestic waste which has received prior treatment in lagoon systems. Evidence of the effectiveness of intermittent sand filters for the reduction of TSS concentration can be found in the published works of Reynolds (6), Marshall (7), and Walter (8). Other supportive evidence for intermittent sand filters as a means of lowering TSS values can be found in reports by Grantham (20), Furman (21), and Middlebrooks (22).

PILOT-SCALE STUDY

A review of the work by the authors previously cited assisted Witherow and Rowe in the design of a pilot sand filter study. The purpose of the pilot study was to determine if the effluents from the intermittent filter units would meet the BPT and BAT discharge limits. Two pilot scale intermittent sand filter units were used in the study. Each was constructed by welding two 55 gallon (gal) barrels end-to-end. Effluent lines were installed in the bottom of the units and an 18-in. layer of gravel, ranging in diameter from 0.25 to 1.25 in. was placed in the bottom of each unit. The larger particles of gravel were placed in the bottom of the units. The gravel layers were covered with 36 in. of washed sand having an effective diameter of 0.2 mm. During the three month investigation, the filters were operated 5 days/week. They were loaded at approximately 10 a.m. each day with 30 gal (0.5 mgad) of effluent. Cleaning of the filters was not required during the three month study.

Filter No. 1 was loaded with the settled effluent from the extended aeration pond and Filter No. 2 was loaded with effluent from the first aerobic lagoon. Grab samples of effluent from both filters were collected and analyzed for BOD_5, TSS, NH_3-N, TKN, COD, total volatile suspended solids (TVSS), pH, and fecal coliform bacteria. The filter receiving the effluent from the aerobic lagoon usually had higher removal efficiency with respect to TSS values. However, this was due to the higher concentration of TSS in the aerobic lagoon effluent. The difference in the concentrations of pollutants in the discharge from the two filters was not significant. The mean concentrations for the various parameters and the removal efficiencies are given in Table 7. Weekly analyses were made over a 3 month period.

TABLE 7. INTERMITTENT SAND FILTERS-PILOT STUDY
(Mean values)

	Influents (mg/l)		Effluents (mg/l)		Removals (%)	
Items	Filter 1	Filter 2	Filter 1	Filter 2	Filter 1	Filter 2
BOD_5	26.0	28.7	10.4	8.1	60	72
COD	71.2	99.7	40.4	48.1	44	52
TSS	35.5	46.8	23.8	22.2	33	53
TVSS	25.4	32.3	14.4	11.1	44	66
NH_3-N	4.3	2.7	0.3	0.1	93	96
T-N	10.3	6.5	3.3	3.3	68	50
T-P	2.9	4.3	0.8	2.1	73	52

In addition to the TSS analyses, TVSS analyses were determined on the influent and effluent for both filters. An initial washout of fines was expected to increase the TSS concentrations in the effluent, but was not expected to increase the TVSS values, since the fines would be nonvolatile. Since the washout of fines was expected, the 44% and 66% removal of TVSS was considered more representative of the filter performance than the values for TSS.

The filtered effluents from the extended aeration unit and aerobic lagoon met the limitations for BPT limits, but neither met the BAT values. The BOD_5 values from both pilot sand filters exceeded the BAT limits, but only within the accuracy of the measurement. The BAT limits for TSS was greatly exceeded, and an additional reduction would be necessary to meet the BAT limits. The filter effluents are compared to BPT and BAT limits in Table 8.

TABLE 8. PILOT SAND FILTER DISCHARGES VS. EFFLUENT LIMITATIONS (lb/1,000 lbs LWK)

Items	Filter No. 1	Filter No. 2	Low Packinghouse BPT	BAT
BOD_5 mean	.05	.05	.17	.04
BOD_5 max.	.11	.09	.34	.08
TSS mean	.11	.11	.24	.06
TSS max.	.22	.22	.48	.12

During the period of investigation from September to December, the average water temperature dropped from a high of 25°C to a low of 5°C. Little change was observed between the influent and the effluent temperatures. The wastewater from the extended aeration unit consistently showed an increase in DO as a result of the filtration process. However, the DO content of the wastewater from the aerobic lagoon was increased only about 50% of the time. The DO concentrations in the effluent samples from the two filters ranged from 5.0 mg/l to 9.8 mg/l.

FOG measurments of influents to the filters ranged from 5 to 26 mg/l. Analyses on the effluents from the filters revealed that all samples tested contained FOG concentrations of less than 5 mg/l, which is the level of accuracy of the test. The pH values of all effluent samples from both filters met the discharge requirements. The NO_3^-/NO_2^--N value of the influent to the filters was usually increased about 1 mg/l, but a total nitrogen removal was accomplished by both filters.

The analyses for fecal coliform bacteria was made on influent and effluent samples for both filters three times during the investigation. For the six sets of influent-effluent values, five showed a reduction in the fecal coliform count. However, all values collected exceeded the discharge limits of 400 MPN/100 ml. The maximum and minimum counts on the effluent samples from the filters were 14,000 MPN/100 ml and 1,000 MPN/100 ml, respectively.

SECTION 6

DESIGN AND CONSTRUCTION

After a review of the literature and an evaluation of the pilot scale intermittent sand filter study, plans were made for the incorporation of an intermittent sand filter unit into the existing treatment facility at the W. E. Reeves Packinghouse. The existing facility consisted of three full-scale lagoons.

The first lagoon, which received the wastewater from the packinghouse, was operated as an extended aeration unit. The extended aeration unit was a batch treatment process which allows aeration and settling in one basin without the need of a mechanical sludge collection system. The extended aeration pond was in the shape of an inverted, truncated pyramid and had a volume of 18,500 cubic feet (ft^3) at a 9-foot (ft) water depth. Accumulation of one day's flow of wastewater from the plant resulted in a water level increase of 6 to 9 in.

Oxygen for the pond was supplied by a 10 horsepower (hp) Peabody Welles floating aerator with a variable oxygen transfer valve. The aerator was operated from 6 a.m. to midnight and settling of solids was allowed to occur from midnight to 2 a.m. After the two hour settling period, an automatic air activated valve was opened between 2 and 6 a.m. and the supernatent from the pond was allowed to flow through a 6-in. line to the second lagoon. The valve was installed in a manhole for ease of maintenance and both the aerator and valve were controlled by electrical timing devices.

The site chosen for the sand filter unit was such that wastewater from the extended aeration pond or the two aerobic lagoons could be loaded to the filter bed by gravity flow. Figure 1 shows the layout of the treatment facilities at the W. E. Reeves Packinghouse.

The design for the sand filter was based on an average wastewater flow of 18,000 gallons per day (gpd) with a maximum flow of 30,000 gpd. In the early planning state, the intent was to construct one sand filter unit with a surface area of 2,400 square feet (ft^2). However, before construction began, the plans were changed to call for two filter units of unequal size. This change was made so that it would be easier to evaluate several hydraulic loading rates. Also, two filters would give the advantage of having one filter for operation while the other was being cleaned or repaired. The final plans called for the construction of two filter units with sand surface areas of 975 and 1275 ft^2. The design of the filter unit is shown in Figures 2 and 3. The specifications for construction of the intermittent sand filter are given in the appendix.

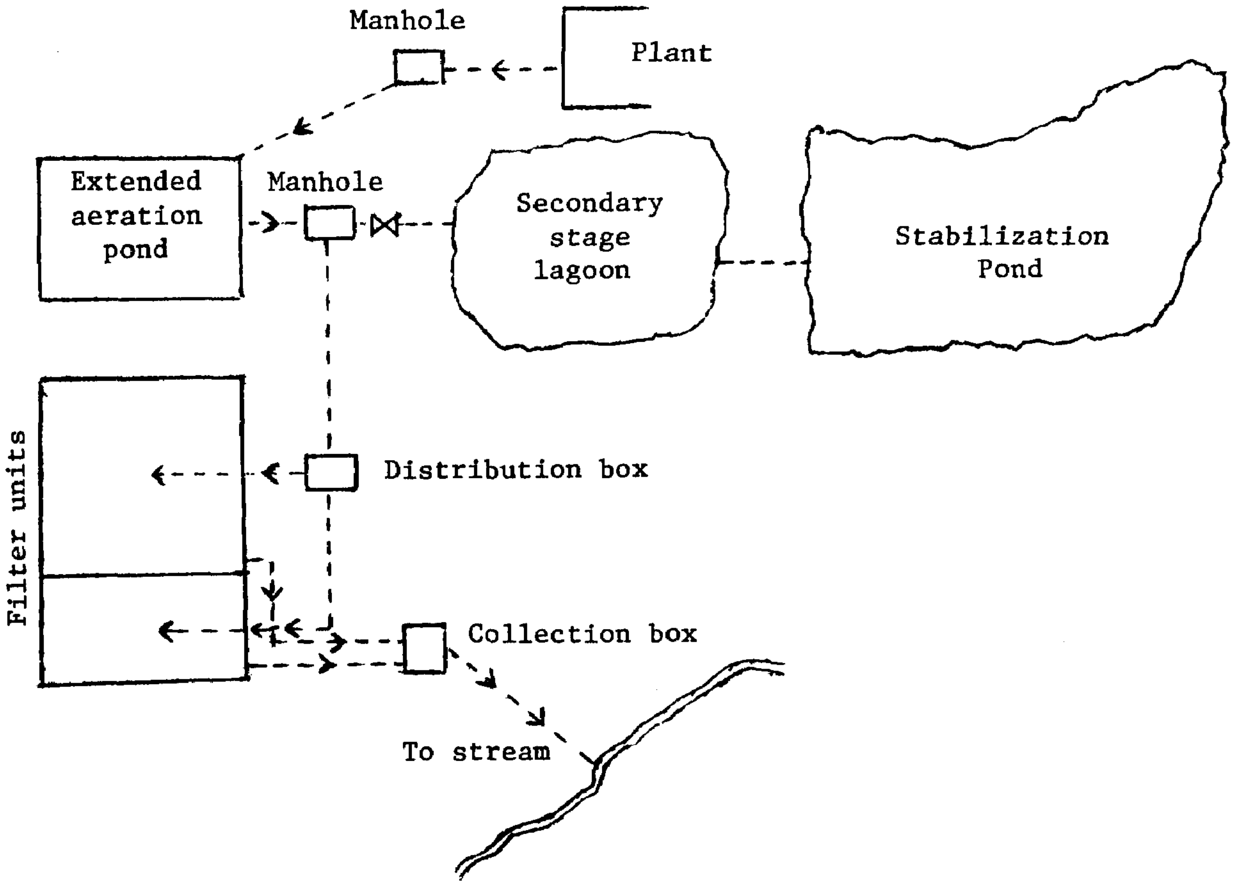

Figure 1. W. E. Reeves treatment facilities.

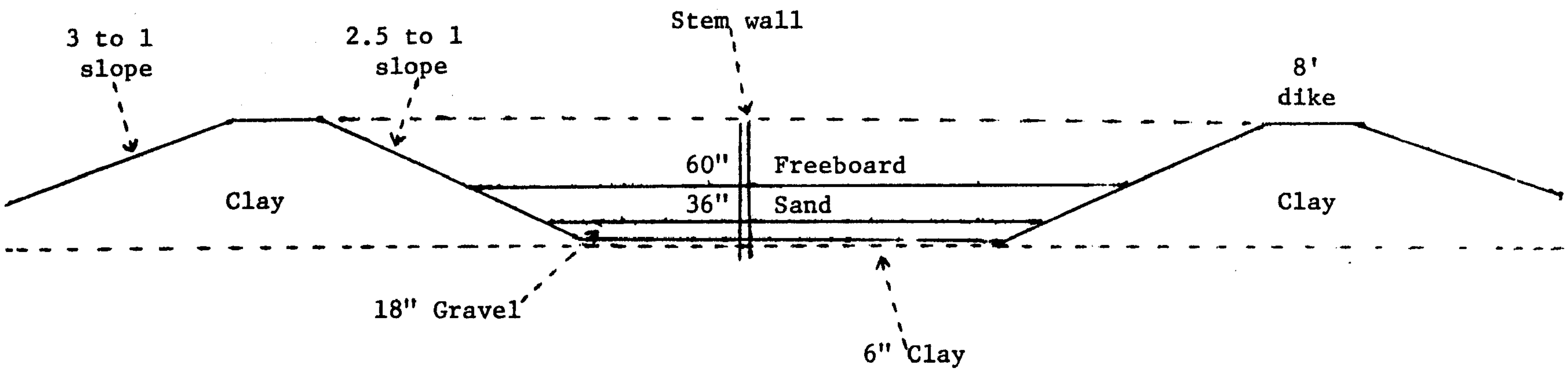

Figure 2. Cross-section of intermittent sand filter.

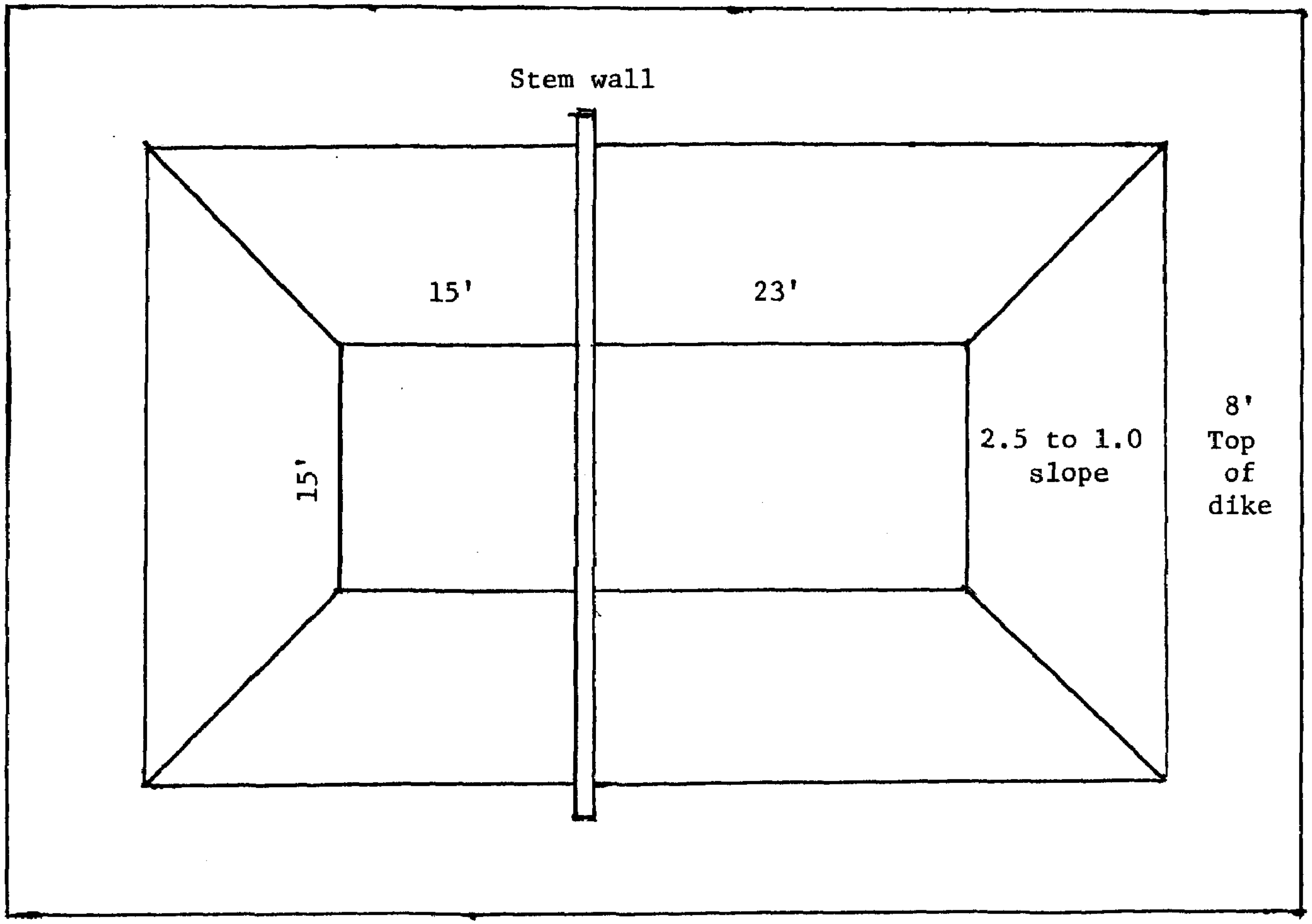

Figure 3. Top view of intermittent sand filter.

The design called for a distribution box between the manhole adjacent to the extended aeration pond and the intermittent sand filters so that the daily wastewater flow could be loaded to either filter or the daily flow could be equally divided and simultaneously loaded on both filters. Based on the average flow of 18,000 gpd, the larger surface area could be used for the evaluation of hydraulic loadings of approximately 0.6 and 0.3 mgad and the smaller surface area could be used for the evaluation of hydraulic loadings of approximately 0.9 and 0.45 mgad.

The W. E. Reeves Packinghouse possessed the necessary equipment and the manpower to complete the construction project and all phases of the construction were completed by the company. Construction of the intermittent sand filter units began in September, 1975, and was completed in early December of that year. One factor that lengthened the construction time was the fact that the site selected was underlain by rock and extensive blasting was required (Figure 4).

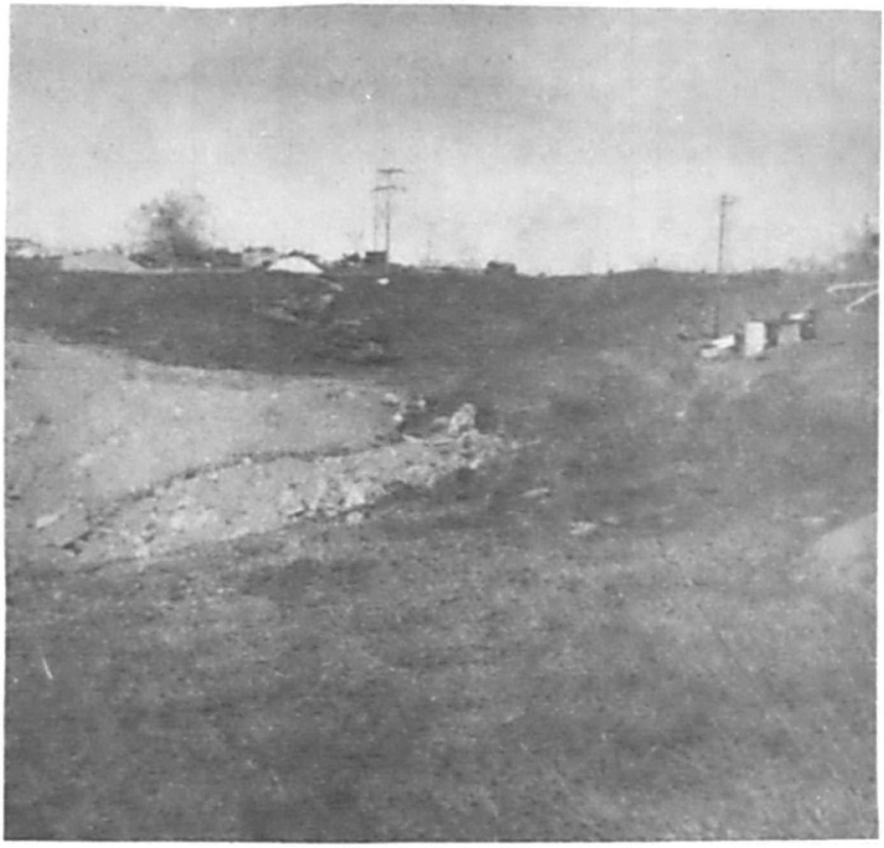

Figure 4. Sand filter construction site.

Plans called for each of the filters to be formed by clay embankments on three sides (Figure 5), and the fourth wall of each was to be formed by a common concrete wall (Figure 6). The purpose of the common concrete wall was

Figure 5. Construction of clay embankments of sand filter.

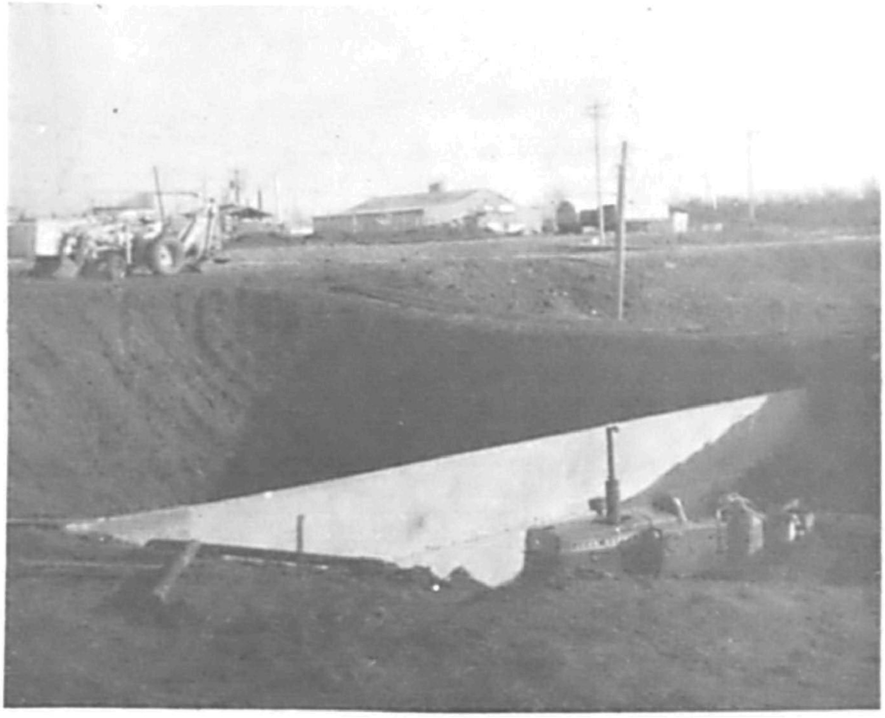

Figure 6. Stem wall of sand filter.

to reduce the land that would have been required if a clay embankment were used to separate the two units. All clay used in the construction had to be hauled to the location from an area approximately one mile from the construction site.

A factor which determined the dimensions of the bottom of the sand filters was the space required for the normal operation of heavy equipment, such as a dozer, during the construction phase of the project. The dimensions of the bottom of the structure were 15 ft by 38 ft. Location of the stem wall was such that the bottom dimensions of the small and large filters would be 15 by 15 and 15 by 23 ft. The dimensions at the sand surface of the small and large filters were 37.5 by 26 and 37.5 by 34, respectively. The bottom of the filter was formed by compacting six inches of clay and the bottom of the filter was sloped toward the effluent outlet to insure proper drainage from the unit.

After the bottom of the filter unit was properly compacted, the clay embankments were formed. The clay embankments were constructed so that the interior of all the dikes were sloped at a ratio of 2.5 horizontal units to 1.0 vertical units from the bottom of the filter to the top of the dike. The specified elevation from the bottom of the filters to the top of all the dikes except one was 9.5 ft. The top of the dike adjacent to the extended aeration pond was 12 ft from the bottom of the filter. This was necessary since the existing dike of the pond was used. The 9.5 ft elevation was selected to allow 1.5 ft of gravel, 3 ft of sand, and 5 ft of freeboard. The 5 ft of freeboard was recommended based upon the maximum depth of wastewater and the maximum expected rainfall allowance. The tops of the embankments were built to a width of 8 ft and these surfaces were leveled. The 8-foot width was selected so that vehicles and machinery could have access to the filter units.

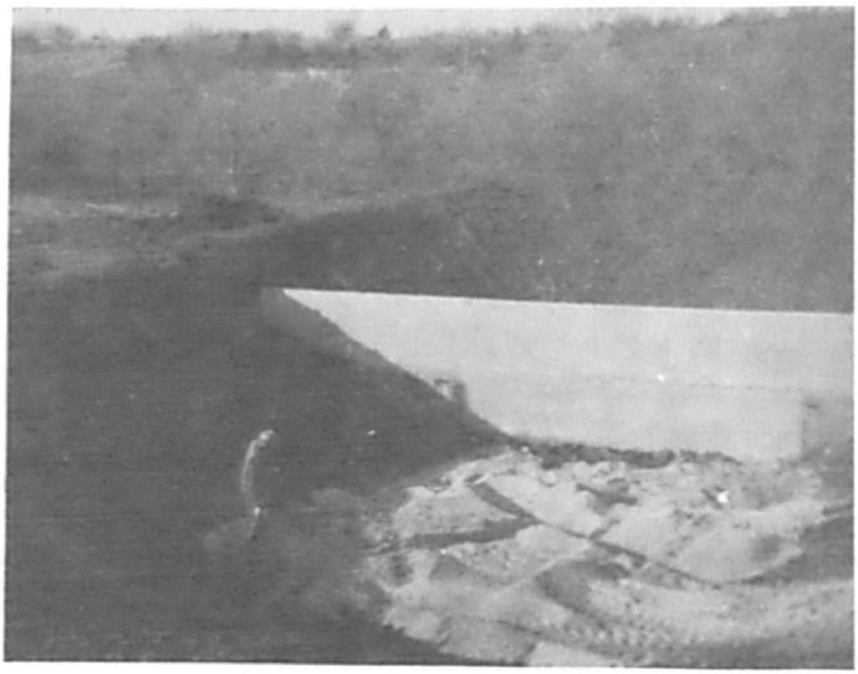

Figure 7. Preparation of bottom of sand filter.

After the bottom and the embankments were formed and compacted, the stem wall was poured. Then the underdrain of each filter unit was installed. The underdrain network of each filter consisted of a series of perforated pipes having 5-in. diameters. These pipes were placed three feet apart, and then each of the horizontal lateral lines was connected to a 6-in. pipe which served as the drain from the filter unit (Figure 8). The two drain lines projected through the wall of the dike and emptied into a sample collection box before discharging the effluent to a stream. The 6-in. steel drainlines were installed as the dike was constructed to prevent seepage and erosion around the pipe. This allowed soil compaction by heavy equipment and prevented later disturbance of the soil by installation of the drain.

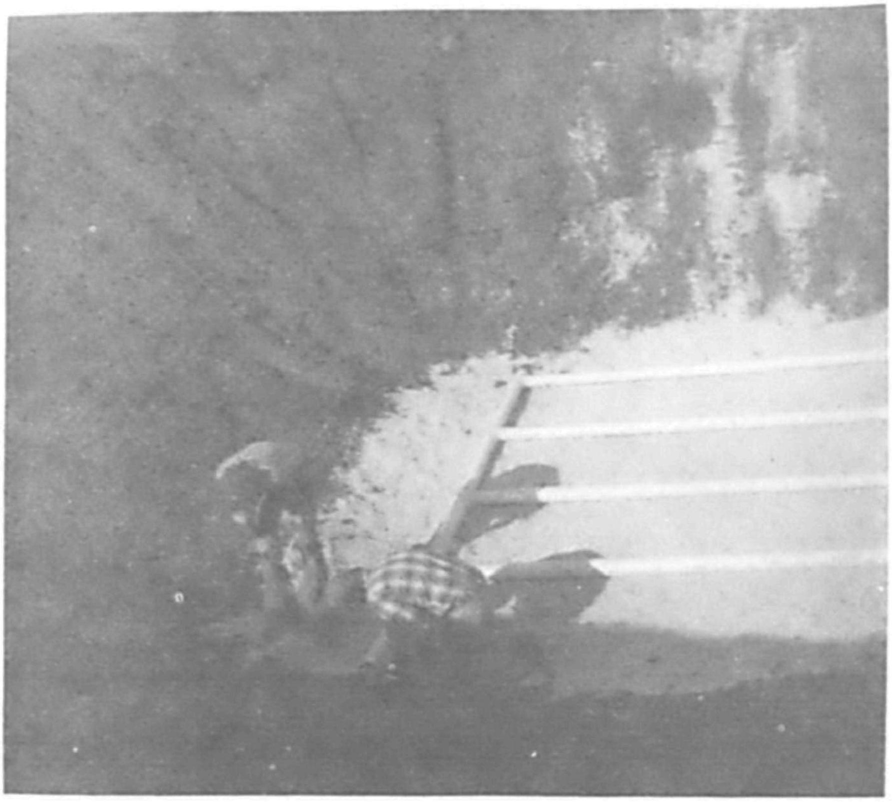

Figure 8. Underdrain system of sand filter.

After the underdrain network was installed, the filter media was added to the system. Eighteen inches of gravel, ranging from a diameter of 0.25 to 1.25 in. were placed in the bottom of each filter unit. Then 36-in. of sand was placed on the gravel. Several local sources of washed sand were examined as the potential filter media. Each sample was screened and the uniformity coefficients and effective diameters were calculated. The sand selected had a uniformity coefficient of 4 and an effective diameter of 0.2 mm. The uniformity coefficient of 4 was greater than the recommended limits, but this sand source was selected because it was readily available and inexpensive. The 36-in. depth of sand was selected so that the filter units could be cleaned several times by removing about three inches of surface sand before the addition of new sand would be necessary.

A manhole existed between the extended aeration pond and the aerobic lagoon, which was used to house the automatic valve and control the flow of wastewater from the extended aeration process (Figure 9). This manhole was used for the connecting line to the sand filter units. A 6-in. diameter line was installed from the manhole to a distribution box for the sand filters. The flow of wastewater into this 6-in. line was regulated by the automatic valve. After the addition of this line, it was possible to direct the flow of

Figure 9. Manhole with automatic valve.

wastewater from the extended aeration process to the lagoon or to the sand filters. These dual secondary treatment systems provided a safeguard in that the wastewater could be diverted to the lagoon in the event that the filters were inoperable.

A concrete distribution box was used to divide the flow to the filters. A 6-in. line connected the control manhole to the distribution box, and was extended from the distribution box down the inside slope, and across the width of each filter bed (Figure 10). The lines to the filters were designed so

Figure 10. Distribution system of sand filter.

that they could be plugged at the distribution box. This system provided a means of loading wastewater onto only one filter, or onto both filters simultaneously. Wastewater was discharged from the distribution box and onto the filter beds through the 6-in. lines by gravity flow. That portion of each distribution line which was in contact with the filter bed was perforated with 1-in. diameter holes. This allowed even distribution to the filter beds (Figure 11).

The underdrain line from each filter unit extended into a concrete sample collection box (Figure 12). The discharge from both filters was then carried underground from the sample collection box to the stream by means of a 6-in. plastic line.

The original plans for the sand filter units specified that the clay embankments would be sprigged with bermuda grass. This was not done upon the completion of the filter units because the project was completed in December. Just prior to the time the evaluation began, a heavy rainfall caused extensive erosion of the embankments and clay was washed onto the sand surface. The top sand layer had to be replaced, and the erosion of the embankments necessitated repairs. Shortly after this incident, bermuda grass sod was placed on the embankments which prevented additional erosion problems during the evaluation period.

Figure 11. Completed sand filter.

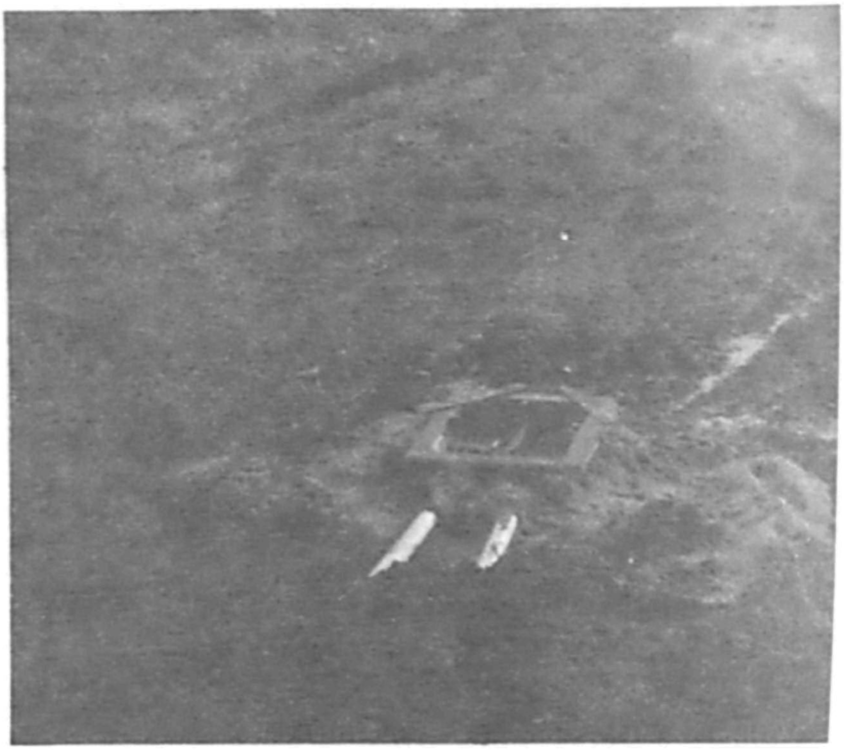

Figure 12. Sample collection box.

SECTION 7

OPERATION

An inspection of the system was done daily, Monday through Friday, between 8 a.m. and 11 a.m. Samples were collected for routine analysis twice each week, with samples for TSS being collected more frequently. The selection of the dates for sample events for each week was made to meet the schedules of the laboratory personnel. Each sample event consisted of:

1. A composite sample of the raw wastewater over the normal operational hours at the packinghouse.

2. A composite sample of effluent from the extended aeration unit between 5 a.m. and 9 a.m. the following morning. (This composite period corresponds to the time the filter is loaded.)

3. A grab sample of filter effluent three hours after loading of the filter.

The composite samples were collected in iced containers and all samples were taken directly to the laboratory and stored at $4^{o}C$ until analyses.

Daily flow measurements were made and _in situ_ measurements were taken for DO and water temperature. Air temperatures and precipitation measurements were obtained from a local weather station. Analyses routinely performed on the samples were those for BOD_5, COD, total solids (TS), TVS, TSS, pH, T-P, TKN, NO_3^-/NO_2^--N, and NH_3-N. Other measurements were total alkalinity, hardness, chloride, fecal coliform bacteria, FOG, iron, color and turbidity. Liveweight killed values were acquired from packinghouse records. All analyses, except some BOD_5 analyses, were performed according to _EPA Methods for Chemical Analysis of Water and Wastes_ (10). After determining the accuracy of the manometric method, this procedure was used for BOD_5 analyses from October 21, 1976 to the end of the project.

Evaluation of the intermittent sand filter units began in March, 1976. During the firt phase of the evaluation, sand with a uniformity coefficient of 4 and an effective diameter of 0.2 mm was used. The average hydraulic loading rates examined during this portion of the study were 0.86 mgad and 0.55 mgad. The length of filter runs were monitored, as well as the quality of the effluent during this evaluation. The filter run is the length of time from the first loading of a filter to the time the filter is plugged (when the wastewater loaded onto a filter remained on the filter surface for more than 24 hours).

When the filters were placed in operation in March, 1976, some mechanical problems were encountered. These resulted due to malfunctions of the newly installed valve and the automatic timers. Problems of this type were minimal after the initial start-up period. During the start-up period the operational scheme of the aerator was changed. Prior to this change the aerator was in operation from 6 a.m. to midnight and settling of solids was allowed to occur from midnight to 2 a.m. and the supernatent was discharged from the pond between 2 a.m. and 6 a.m. In an attempt to decrease the amount of solids discharged in the supernatent, the aerator was operated from 9 a.m. to 11 p.m. and settling of solids was allowed to occur from 11 p.m. to 5 a.m. After the 6-hour settling period, an automatic air activated valve was opened between 5 a.m. and 9 a.m. to allow the supernatent to flow onto the filters.

The first test conducted consisted of loading both filters each day except Sunday by dividing the daily wastewater flow from the extended aeration lagoon. Clogging of the small filter occurred after only 6 days.

After this first test, a series of operating schemes were conducted which consisted of using one filter and loading that filter daily until clogging occurred, using both filters, and loading each filter on alternate days. During these investigations, raking of the sand surface was done to see if it lengthened the filter run. No significant increase was shown. This phase of the project revealed that the critical operating or design criteria for the utilization of the intermittent sand filter units would be that which lengthened the filter runs. Significant reduction in the BOD_5 and TSS concentrations was observed, but none of these trials revealed a filter run which was long enough to be practical (Table 9).

TABLE 9. LENGTH OF FILTER RUNS

Loading rate (MGAD)	Sand (Eff. dia.)	Sand (Unif. coeff.)	Average filter run (Days)	Average filter run (Number of runs)
0.86	0.20 mm	4.0	10	5
0.55	0.20 mm	4.0	15	6
0.36	0.35 mm	2.5	109	1

In September, 1976, after an evaluation of the results of the first phase, further investigation of the sand in the filters was conducted. This investigation revealed that the original screening data was correct, and that the sand did have a uniformity coefficient of 4 and an effective diameter of 0.2 mm. The sand samples were also checked for clay content to see if clogging was due to the erosion of clay from the dikes. The samples were found to have a low clay content but did have a large number of fines. It was decided that clogging was due to the filter media and that the sand should be replaced with another sand source.

In early October, the original sand was replaced with a washed sand having a uniformity coefficient of 2.5 and an effective diameter of 0.35 mm. Since the filter run in the preceding tests had been so short, the decision was made to also decrease the hydraulic loading rates even though the larger sand source was being used. The hydraulic loading rate used in this trial was 0.36 mgad.

Only the large filter was used in this trial, and the filter was loaded daily except Sunday. The study began on October 20, 1976, and the large filter was operated for 109 days (Table 9) until February 23, 1977, at which time the filter was shut down due to clogging. During this interval, the filter was not in operation from November 20, 1976, to November 23, 1976, because the aerator required maintenance. The flow was diverted to the aerobic ponds during this non-treatment period. The filter was not used from January 8, 1977, to January 16, 1977, because the plant was closed due to an unusually severe snow storm.

The investigation conducted with the sand having an effective diameter of 0.35 mm and a uniformity coefficient of 2.5 resulted in a much longer filter run than what had been observed with the original sand source. The reduced hydraulic loading rate could account for some increase in the length of filter run, but the major factor responsible for the increase in the filter run was the new filter media. The number of pounds of suspended solids collected on the sand surface before plugging of the filter occurred was calculated for the various investigations. With the sand having a uniformity coefficient of 4.0 and an effective diameter of 0.20 mm, and with a hydraulic loading rate of 0.86 mgad, plugging of the filter occurred after the accumulation of 0.049 lbs of suspended solids/ft^2 of filter surface. With the same sand and a hydraulic loading rate of 0.55 mgad, 0.047 lbs of suspended solids/ft^2 of filter surface accumulated prior to clogging. The accumulated suspended solids value for the trial using the larger sand (0.35 mm eff. dia.) was 0.225 lbs/ft^2 of surface area.

SECTION 8

RESULTS

FILTER RUN

The investigation revealed that the successful operation of the intermittent sand filters was highly dependent on the filter media. By changing the filter media to a sand having a uniformity coefficient of 2.5 and an effective diameter of 0.35 mm, the length of the filter run was increased by an order of magnitude. The evaluation with the larger sand source also represented a lower hydraulic loading rate (0.36 mgad) than had been used in the earlier test with the sand having a uniformity coefficient of 4. The investigation established that an intermittent sand filter was a practical treatment process for meatpacking wastewaters and that the critical design criteria was the selection of the filter media. Determining the optimum operation of the filter utilizing a high hydraulic loading rate was not possible due to funding limitations.

OVERALL REMOVAL EFFICIENCIES

The wastewater characteristics and removal efficiencies of the system for the entire evaluation period (March, 1976 to January, 1977) are summarized in Table 10. A significant reduction of BOD_5, TSS, NH_3-N, and FOG are experienced by the extended aeration-sand filter system at the W. E. Reeves facility.

TABLE 10. WASTEWATER CHARACTERISTICS AND PERCENT REMOVAL

Parameters	n	Raw waste.	n	Ext. aer. eff.	n	Filter eff.	Percent removal
BOD_5 (mg/l)	46	672.0	51	41.0	57	10.4	98.5
TSS (mg/l)	27	392.0	42	41.0	63	11.1	97.1
FOG (mg/l)	16	138.7	10	29.1	10	5.0	96.4
NH_3-N (mg/l)	16	14.8	14	3.1	14	1.9	87.2

SUSPENDED SOLIDS

The efficiency of removal of TSS is of extreme interest since the BPT and BAT limits proposed for this parameter are those most commonly exceeded by discharges from the meat industry. Also the existing treatment facilities at the W. E. Reeves Packinghouse failed to reduce TSS to these levels. Total suspended solids analyses are presented in Table 11. The mean TSS concentration of 27 samples of untreated wastewater was 293 mg/l. Forty-three composite samples of effluent from the extended aeration unit were analyzed and the mean TSS value was 41 mg/l. This value of 41 mg/l represented the TSS concentration loaded onto the sand filters. The data in Table 11 are grouped by hydraulic loading rates. The hydraulic loading rates investigated, with the sand having a uniformity coefficient of 4, were 0.86 mgad and 0.55 mgad. The sand with a uniformity coefficient of 2.5 was investigated at a rate of 0.36 mgad. The mean TSS concentrations of the effluent resulting from hydraulic loading rates of 0.86 mgad, and 0.55 mgad, and 0.36 mgad were 10.6 mg/l, 11.8 mg/l, and 10.6 mg/l respectively. An examination of the data using the analysis of variance (ANOVA) indicates that there was not a significant difference ($p < .05$) in these values; so the effect of hydraulic loading rate on TSS concentration was considered minor within the range tested. The pilot scale filters reduced TSS from 40 mg/l to 22 mg/l, while the full-scale filters reduced TSS from 41 mg/l to 11 mg/l.

TABLE 11. TOTAL SUSPENDED SOLIDS

	mgad	n	Minimum	Maximum	Mean
TSS (mg/l)	0.36				
Raw wastewater		2	116	198	157.0
Filter influent		8	19	71	35.5
Filter effluent		8	5	17	10.6
TSS (mg/l)	0.55				
Raw wastewater		11	160	694	377.0
Filter influent		19	19	79	44.2
Filter effluent		28	3	45	11.8
TSS (mg/l)	0.86				
Raw wastewater		14	246	861	437.0
Filter influent		16	19	111	40.1
Filter effluent		27	3	32	10.6
TSS (mg/l)	combined				
Raw wastewater		27	116	861	392.0
Filter influent		43	19	111	41.0
Filter effluent		63	3	45	11.1

The BPT 30-day average limit for TSS is 0.24 lb/1000 lbs LWK, and the BAT 30-day average limit is 0.06 lb/1000 lbs LWK. The maximum day limits for both BPT and BAT guidelines are two times the 30-day average values. The test using the sand with a uniformity coefficient of 4 revealed an average value of 0.07 lb/1000 lbs LWK and a maximum of 0.30 lb/1000 lbs LWK. The average and the maximum TSS values for the test with a sand source having a uniformity coefficient of 2.5 were 0.07 and 0.11 lb/1000 lbs LWK, respectively. Upon comparison of the mean and maximum TSS concentrations from the tests and the BPT and BAT guidelines, it is evident that the effluent value met the BPT guidelines. However, the discharges from both sand sizes exceeded the BAT 30-day average by 0.01 lb/1000 lbs LWK, which is within the accuracy of the analyses. The maximum day value corresponding to the sand with the uniformity coefficient of 2.5 met the BAT limits while that with a coefficient of 4.0 did not. A summary of the TSS concentration is shown in Table 12 and a comparison of the quantity discharged to the NPDES limitations is given in Table 13.

FIVE-DAY BIOCHEMICAL OXYGEN DEMAND

A total of 46 samples of the untreated wastewater were analyzed for BOD_5 and the test results revealed a mean BOD_5 value of 672 mg/l. Composite samples of the effluent from the extended aeration unit were also analyzed and the values for 51 analyses had a mean concentration of 41 mg/l. Fifty-seven samples of effluent from the sand filters were analyzed for BOD_5 and were found to have an average value of 10.4 mg/l. This represented a 98.5% BOD_5 removal by the treatment system. The 57 samples of sand filter effluent were representative of the trials with two sand sources and three hydraulic loading rates. The average BOD_5 values were calculated for the trials for each hydraulic loading and each sand source. Based on the ANOVA statistical test, there was not a significant difference in the mean concentrations for these trials. Quantitative information pertaining to BOD_5 values is shown in Table 14.

The average BOD_5 values from the various trials were converted to lb/1000 lbs LWK and compared to the BPT and BAT limits for low packinghouse discharges. This information is revealed in Table 13. The values obtained from these trials indicated that the intermittent sand filter systems produced an effluent which would meet the BPT limits for BOD_5; however, the quality of effluent failed to meet the BAT limits. Pilot scale results indicated the addition of an intermittent sand filter would meet BAT limits. Removal of BOD_5 in the two pilot filters was 60% and 72%. Removal of BOD_5 in the full-scale filter was 75%. The failure to meet the BAT limits was caused by a higher average concentration (41 mg/l) from the extended aeration unit. A previous 12 month evaluation (3) recorded an average effluent from the extended aeration unit of 17.0 mg/l of BOD_5.

TABLE 12. INTERMITTENT SAND FILTER EFFLUENT CHARACTERISTICS

Parameters	n	0.86 MGAD Sand A	n	0.55 MGAD Sand A	n	0.36 MGAD Sand B	n	Combined Data
BOD_5 (mg/l)	21	10.2	26	10.5	10	10.2	57	10.4
TSS (mg/l)	27	10.6	28	11.8	8	10.6	63	11.1
NH_3-N (mg/l)	3	2.4	6	1.9	5	1.6	14	1.9
FOG (mg/l)	1	<5.0	6	<5.0	3	<5.0	10	<5.0
Fecal coliform (MPN/100 ml)	15	2.75×10^4	16	1.39×10^4	6	1.02×10^4	37	1.88×10^4

Sand A - uniformity coefficient of 4; effective diameter of 0.2 mm.
Sand B - uniformity coefficient of 2.5; effective diameter of 0.35 mm.

TABLE 13. COMPARISON OF DISCHARGES AND NPDES LIMITATIONS

Parameter	Low packinghouse limits 30-day avg.	Low packinghouse limits max-day	Sand A results 30-day avg.	Sand A results max-day	Sand B results 30-day avg.	Sand B results max-day
1977 limitations						
BOD_5	.17	.34	.07	.17	.07	.10
TSS	.24	.48	.07	.30	.07	.11
FOG	.08	.16	<.03	<.03	<.03	<.03
New source limitations (include above + NH_3)						
NH_3-N	.24	.48	.01	.03	.01	.02
1983 limitations (BAT)						
BOD_5	.04	.08	.07	.17	.07	.10
TSS	.06	.12	.07	.30	.07	.11
FOG	10 mg/l	20 mg/l	<5 mg/l	<5 mg/l	<5 mg/l	<5 mg/l
NH_3-N	4 mg/l	8 mg/l	2 mg/l	4 mg/l	2 mg/l	3 mg/l

Test Results A - Data collected from filter at loading rate of 0.86 and 0.55 mgad and sand with uniformity coefficient of 4 and effective diameter of 0.2 mm.
Test Results B - Data collected from filter at loading rate of 0.36 mgad and sand with uniformity coefficient of 2.5 and effective diameter of 0.35 mm.

All values in Table 13 are in lbs/1000 lbs LWK except BAT limits for FOG and NH_3-N.

TABLE 14. BIOCHEMICAL OXYGEN DEMAND

	mgad	n	Minimum	Maximum	Mean
BOD_5 (mg/l)	0.36				
Raw wastewater		8	511	902	735.0
Filter influent		9	24	43	32.7
Filter effluent		10	5	15	10.2
BOD_5 (mg/l)	0.55				
Raw wastewater		22	299	1126	700.0
Filter influent		28	19	72	41.7
Filter effluent		26	4	20	10.5
BOD_5 (mg/l)	0.86				
Raw wastewater		16	412	1017	654.0
Filter influent		14	26	90	45.4
Filter effluent		21	4	26	10.2
BOD_5 (mg/l)	combined				
Raw wastewater		46	299	1126	672.0
Filter influent		51	19	90	41.0
Filter effluent		57	4	26	10.3

FATS, OIL AND GREASE

On ten sample dates during the evaluation period, grab samples for fats, oil, and grease analyses were collected in one-liter glass containers. These samples were collected to represent untreated wastewater from the plant, effluent from the extended aeration unit, and sand filter effluent. Mean values for the untreated wastewater and extended aeration pond effluent were found to be 139 and 29 mg/l, respectively. Effluent samples from the sand filter were consistently less than 5 mg/l, the limit of detection of the test. Since the effluent concentrations were low, the number of analyses was reduced in the last part of the study.

The treatment system removed more than 96% of the FOG from the wastewater and the effluent met all BPT and BAT limits with respect to FOG. Since the variation in the concentrations of FOG for the three hydraulic loading rates was not meaningful, the combined FOG results are presented in Table 15. The comparison of the discharge quantity to the NPDES limits is shown in Table 13.

TABLE 15. FATS, OIL, AND GREASE

	n	Minimum	Maximum	Mean
FOG (mg/l)				
Raw wastewater	10	66	231	139
Filter influent	10	11	48	29
Filter effluent	10	5	5	5

FECAL COLIFORM BACTERIA

During the evaluation period, 37 filter effluent samples were analyzed for fecal coliform bacteria. The mean number for these 37 values was 1.88 x 10^4 MPN/100 ml. Analyses for fecal coliform bacteria in the untreated wastewater and the extended aeration pond effluent were not done because both of these sources had been shown in past evaluations to be extremely high (i.e. 1.0 x 10^6 MPN/100 ml) with respect to fecal coliform bacteria. All fecal coliform values for the filter effluents exceeded the established 400 MPN/100 ml limits, except the one value for the date of June 9, 1976, which was 300 MPN/100 ml. Disinfection of the effluent would be necessary to meet the discharge standard.

pH

Routine pH measurements were performed on all samples collected. The untreated wastewater discharged from the packinghouse had an average pH value of 7.4, with minimum and maximum values of 6.0 and 8.4, respectively. The effluent samples from the extended aeration pond had an average pH of 7.6, with the minimum and the maximum of 7.1 and 8.2, respectively. The intermittent sand filter was found to have little effect on the pH, as the average pH value of the sand filter effluent was 7.6, and the minimum and maximum readings were 7.2 and 7.9, respectively. None of the sand filter effluent samples were in violation of NPDES guidelines since none of the readings were below a pH of 6.0 or above 9.0.

AMMONIA NITROGEN

Since the NPDES effluent standards have limits for NH_3-N, routine NH_3-N determinations were done; the results are in Table 16. Sixteen untreated wastewater samples were analyzed and were found to have a mean value of 14.8 mg/l NH_3-N. The mean value of the discharge from the extended aeration unit was 3.1 mg/l NH_3-N which was based on readings from 14 samples. All filter effluent samples were lower than the corresponding influent samples with the exception of one value. On September 16, 1976, an influent reading of 0.5 mg/l NH_3-N was recorded and the corresponding effluent sample had an NH_3-N reading of 0.8 mg/l. The mean filter effluent, based on 14 determinations, was 1.9 mg/l NH_3-N. The total treatment system showed an average removal of 87.2% with respect to NH_3-N. Calculations, using mean values, also showed that the NH_3-N concentrations of the filter influent, was reduced by 61%. The average NH_3-N values of the discharge were converted to lb/1000 lbs LWK and were found to be well below both rescinded BAT limits and the new source limits for NH_3-N. The comparison to NPDES limitations is given in Table 13.

TABLE 16. AMMONIA NITROGEN

	n	Minimum	Maximum	Mean
NH_3-N (mg/l)				
Raw wastewater	16	4.7	23.8	14.8
Filter influent	14	.5	7.1	3.1
Filter effluent	14	.4	4.0	1.9

TOTAL KJELDAHL NITROGEN AND NITRATE/NITRITE NITROGEN

As stated earlier, the treatment system was found to be effective in reducing the NH_3-N. The same effect was shown with respect to TKN (Table 17). The average concentration of TKN in the untreated wastewater was 68.8 mg/l and this was reduced to 11.0 mg/l by treatment in the extended aeration unit. The TKN concentration was further reduced to an average value of 4.5 mg/l by the intermittent sand filter.

TABLE 17. TOTAL KJELDAHL NITROGEN

	n	Minimum	Maximum	Mean
TKN (mg/l)				
Raw wastewater	13	44.1	103.1	68.1
Filter influent	13	6.0	16.4	11.0
Filter effluent	14	2.0	8.7	4.6

Nitrate/nitrite nitrogen analyses were also completed on the wastewater samples (Table 18). A large variation in the NO_3^-/NO_2^--N concentration was found in the untreated wastewater, with a minimum of 0.11 mg/l and a maximum of 4.08 mg/l. The average concentration of NO_3^-/NO_2^--N in untreated wastewater was 1.26 mg/l and the average concentration in the discharge from the extended aeration process was 1.23 mg/l. An examination of the mean values seems to indicate that a slight reduction occurred as a result of treatment in the extended aeration system; however, when 16 sets of NO_3^-/NO_2^--N values for the untreated wastewater and the extended aeration pond effluent were reviewed, a significant increase in NO_3^-/NO_2^--N concentration was apparent in 10 sets of data.

A comparison of the NO_3^-/NO_2^--N concentration for the extended aeration effluent and the corresponding intermittent sand filter effluents revealed that an increase in NO_3^-/NO_2^--N concentrations occurred in all sets of data except one. The mean values for the pond effluent and filter effluent, 1.23 mg/l and 2.19 mg/l, respectively, indicates that nitrification did occur in the sand filter. This NO_3^-/NO_2^--N concentration increase is small in comparison to the TKN decrease, therefore the treatment system accomplished a total nitrogen reduction.

Both NH_3-N and TKN concentrations decreased in the extended aeration unit with only a small percentage of the decrease accounted for by the NO_3^-/NO_2^--N increase. Denitrification occurred, most likely during the 6 hours each day when the aerator was not in operation.

The TKN concentration was decreased as the wastewater passed through the filter unit and the NH_3-N concentration was decreased in all samples except two. The NO_3^-/NO_2^--N concentration of the wastewater was increased in all samples except one. Based on mean values, the increased NO_3^-/NO_2^--N concentration accounted for approximately 30% of the total nitrogen reduction. This indicates that both nitrification and denitrification occurred in the sand filter.

TABLE 18. NITRATE/NITRITE NITROGEN

	n	Minimum	Maximum	Mean
NO_3^-/NO_2^--N (mg/l)				
Raw wastewater	18	0.11	4.08	1.26
Filter influent	16	0.41	2.16	1.23
Filter effluent	16	0.85	4.15	2.19

PHOSPHORUS

Total phosphorus analyses were performed on untreated wastewater and the intermittent sand filter influent and effluent samples (Table 19). The concentration of phosphorus in the untreated wastewater showed a considerable variation, with a minimum of 0.18 mg/l T-P, a maximum of 14.5 mg/l T-P, and a mean concentration of 7.7 mg/l T-P. The mean phosphorus value of both the influent and effluent of the sand filter was 2.4 mg/l T-P, indicating that phosphorus removal was not accomplished by intermittent sand filtration. The 5 mg/l reduction observed in the treatment system was accomplished by the extended aeration process.

TABLE 19. TOTAL PHOSPHORUS

	n	Minimum	Maximum	Mean
T-P (mg/l)				
Raw wastewater	22	.8	14.5	7.7
Filter influent	22	.4	4.5	2.4
Filter effluent	21	.3	4.5	2.4

DISSOLVED OXYGEN

The DO concentration of untreated wastewater showed a large variation due to the variable nature of the waste discharges at the packinghouse (Table 20).

The filter influents were consistently low, but all samples did have a measurable DO concentration. The low values are due to the fact that the aerator was not in operation for several hours prior to and during discharge to the sand filter. The influent to the filter had an average DO value of 0.94 mg/l, a minimum of 0.1 mg/l, and a maximum of 3.0 mg/l. In all sets of analyses, passage of the wastewater through the sand filter increased the DO concentration. The analyses of the effluent samples revealed a mean value of 4.4 mg/l, with a minimum of 1.9 mg/l and a maximum of 7.9 mg/l. The increase in the DO concentration, as a result of sand filtration, occurred in warm weather as well as cold weather.

TABLE 20. DISSOLVED OXYGEN

	n	Minimum	Maximum	Mean
DO (mg/l)				
Raw wastewater	68	0.8	6.6	3.6
Filter influent	68	0.1	3.0	0.9
Filter effluent	68	1.9	7.9	4.4

TOTAL SOLIDS AND TOTAL VOLATILE SOLIDS

The samples of untreated wastewater and the influent and effluent samples of the sand filter were analyzed for total solids (TS) and total volatile solids (TVS). A summary of the data is in Table 21. The effluent from the extended aeration unit was lower in TS than the untreated wastewater. However, there is little change in the TS concentration of the influent and effluent samples of the filter. The average values for the TS of the filter influent and effluent were 1155 mg/l and 1128 mg/l, respectively. A slightly larger variation existed for the filter influent and effluent with respect to TVS. This would be expected, due to the larger amount of organic materials in the form of suspended solids in the influent. The influent had a TVS value of 166 mg/l and the average value for the TVS of the filter effluent was 104 mg/l.

TABLE 21. TOTAL SOLIDS AND TOTAL VOLATILE SOLIDS

	n	Minimum	Maximum	Mean
TS (mg/l)				
Raw wastewater	51	855	2771	1916
Filter influent	50	812	1807	1155
Filter effluent	55	814	1639	1128
TVS (mg/l)				
Raw wastewater	17	329	1545	761
Filter influent	20	95	246	166
Filter effluent	19	65	175	104

CHEMICAL OXYGEN DEMAND

Since future standards may be promulgated on COD values, COD analyses were performed on collected samples during the evaluation. The untreated wastewater had an average COD value of 1553 mg/l and the average COD value of the filter influent was 114 mg/l. Effluent from the filters had a COD of 68 mg/l, which represented a COD removal of 95.6%. The COD data is presented in Table 22.

TABLE 22. CHEMICAL OXYGEN DEMAND

	n	Minimum	Maximum	Mean
COD (mg/l)				
Raw wastewater	45	629	5021	1553
Filter influent	43	66	392	114
Filter effluent	41	26	158	68

CHLORIDE

Water quality standards in some geographical locations require the monitoring of chloride and it is also one parameter used to evaluate the feasibility of land disposal of wastewater. For these reasons, chloride analyses were performed on a total of 22 series of samples representing raw wastewater, filter influent, and filter effluent. These results are presented in Table 23. An examination of the mean values reveals that the effluent from the extended aeration system was higher (82 mg/l) than the mean value of the wastewater. This increase was also found in a previous investigation (3) and is attributed to the sampling schedule. A major salt load is discharged to the treatment system on Saturday when the brine cellar is cleaned. However, samples are not collected on Saturday. The discharge of the chloride is picked up in the effluent samples taken the following week. The sand filtration process resulted in a decrease of 46 mg/l. This is not a significant decrease but could be due to the removal of suspended solids containing chloride, since the sand filter would not remove ionic species such as chloride.

TABLE 23. CHLORIDE

	n	Minimum	Maximum	Mean
Cl^- (mg/l)				
Raw wastewater	22	280	745	459
Filter influent	22	435	635	541
Filter effluent	22	405	650	495

TURBIDITY AND COLOR

Since color and turbidity are sometimes used in evaluating water quality, these parameters were monitored during the investigation. In all instances, the turbidity was reduced by passage of the wastewater through the intermittent sand filter units, thus producing a higher quality effluent. The average of 39 turbidity analyses of the filter influent samples was 20 Jackson Turbidity Units (JTU's) and the wastewater discharged from the sand filters had an average value of 7 JTU's.

The average value of the color readings of 64 filter influent samples was 133 Platinum-Cobalt (Pt-Co) color units and the average value of 59 effluent samples was 53 Pt-Co color units. The color of the raw wastewater was not measured because of the extremely high color range. The intermittent sand filter was found to be beneficial in color removal.

TEMPERATURE AND PRECIPITATION

The air temperatures and precipitation readings were obtained from the local weather station. *In situ* measurements of the temperature of the sand filter effluent were taken. The monthly average values for these parameters are given in Table 24.

TABLE 24. TEMPERATURES AND PRECIPITATION

Month/year	Average air temp. °C	Average effluent temp. °C	Monthly rainfall inches
3/76	17	24	2.96
4/76	21	25	4.04
5/76	21	23	5.21
6/76	28	24	2.72
7/76	28	25	1.43
8/76	33	26	2.55
9/76	28	25	1.22
10/76	17	22	3.99
11/76	11	10	1.17
12/76	7	5	1.73
1/77	5	5	1.40

FLOW AND LIVEWEIGHT KILLED

Flow measurements of the raw wastewater were made on the days that the intermittent sand filters were in operation. These values were taken by a Steven's depth recorder and a 3-in. Parshal flume. Due to recording device error, only 53 reliable flow values are available. The LWK values for the project period were obtained from the packinghouse manager. The flow data and LWK values are summarized in Table 25.

TABLE 25. FLOW RATES AND LIVEWEIGHT KILLED

	n	Minimum	Maximum	Mean
Flow (gallons)	53	15,490	25,120	19,756
LWK (lbs)	81	10,090	57,380	24,617

SECTION 9

EXTENDED AERATION UNIT

The extended aeration unit is an adaptation of the activated sludge process. The unit incorporates the activated sludge process (growth of bacterial floc, mixing and aeration of the floc, separation of the floc, and discharge of the supernatent) into one pond. The pond is in the shape of an inverted, truncated pyramid, and has a volume of 18,500 ft^3 of wastewater at a 9-ft depth. Aeration is accomplished by a 10-hp Peabody Welles floating aerator. The operation of the aerator is controlled by timers. Timers are also used to control an automatic outlet valve to discharge the clear supernatent after the settling of the floc is accomplished.

The extended aeration unit at the Reeves facility has been operated for several years and during a one-year evaluation, the effluent from the process met the BPT limitations, except for the maximum day limits for TSS and the limits for fecal coliform bacteria (3). During the one-year evaluation period the aerator was operated from 6 a.m. until midnight. Settling occurred between midnight and 2 a.m. and discharge of the supernatent was done between 2 a.m. and 6 a.m. The summarized results of this evaluation are shown in Table 26.

TABLE 26. CONCENTRATIONS AND REMOVALS (DURING AERATION STUDY)

Parameter	n	Influent (mg/l)	Effluent (mg/l)	Removal (%)
BOD_5	42	714.8	17.0	98
COD	46	1630.2	121.6	93
TSS	45	535.8	65.4	88
FOG	10	138.6	11.9	91
NH_3-N	44	12.5	1.9	95
NO_3^-/NO_2^--N	44	0.4	2.6	--
TKN	46	79.0	7.8	90
T-P	46	11.0	3.3	71

During this one-year evaluation the extended aeration unit was loaded with lower organic and hydraulic loads than those which are normally used for activated sludge processes. The food to microorganisms ratio (F/M) averaged 0.06 lb BOD_5/lb mixed liquor suspended solids (MLSS). The mean hydraulic detention time was 9.8 days and the average sludge retention index (SRI) was 64 days.

Sludge was wasted 5 times during the 12-month period. The average MLSS was 3350 mg/l and the sludge volume index (SVI) was 217.

Prior to the time the evaluation of the sand filter began, the aerator in the extended aeration system had been out of operation and the wastewater in the pond had become anaerobic. The aerator was operated for several weeks before the sand filter evaluation began. After one week of the evaluation, sludge was wasted from the extended aeration pond because the MLSS value was found to be 7600 mg/l. Sludge was wasted from the pond again on April 9, 1976 because the MLSS value was 5210 mg/l. After that removal of sludge, the MLSS value of the mixed liquor in the pond was 1915 mg/l. Sludge was not wasted again during the evaluation period until September 21, 1976. The concentrations and removal efficiencies of the extended aeration system for various parameters during the period of time the sand filter was evaluated are given in Table 27.

TABLE 27. CONCENTRATIONS AND REMOVALS (DURING FILTER STUDY)

Parameter	n	Influent (mg/l)	n	Effluent (mg/l)	Removal (%)
BOD_5	46	672.0	51	41	94
COD	45	1553.0	43	114	93
TSS	27	392.0	42	41	90
FOG	16	138.7	10	29.1	79
NH_3-N	16	14.8	14	3.1	79
NO_3^-/NO_2^--N	18	1.26	16	1.23	2
TKN	13	68.1	13	11.0	84
T-P	22	7.7	22	2.4	69

During the period of time the sand filter evaluation study was done, the aerator in the pond was operated from 9 a.m. to 11 p.m. The aerator was off from 11 p.m. until 5 a.m. in order to allow a longer settling time than the one used during the previous evaluation of the extended aeration pond. The supernatent was discharged from the pond and onto the filters between 5 a.m. and 9 a.m.

The F/M ratio during this evaluation was .045 lb BOD_5/lb MLSS and the mean hydraulic detention time was 7.5 days. The SRI for this evaluation was 38 days. The average MLSS value was 2750 mg/l and the average SVI was 120.

The BOD_5 removal efficiencies accomplished by the extended aeration unit during the first year evaluation and the sand filter evaluation period are 98% and 94% respectively. However, during the one-year evaluation prior to the incorporation of the sand filter, the average BOD_5 of the effluent from the pond was 17 mg/l as compared to 41 mg/l for the effluent loaded onto the sand filter.

During the one-year evaluation of the extended aeration unit, the unit showed a removal efficiency with respect to TSS of 88%. The average TSS of the discharged waste was 65.4 mg/l. An examination of the data for the extended aeration unit during the time the sand filter was evaluated reveals that the extended aeration unit removed 90% of the TSS and that the average TSS of the wastewater loaded onto the sand filter was 41 mg/l. The use of the average values is misleading, because during the one-year evaluation the TSS value of 65.4 mg/l occurred as a result of the exceedingly high TSS values during the first few months of operation of the extended aeration unit. After the first two months of operation, the TSS values dropped to approximately 20 mg/l which is considerably lower than the corresponding 41 mg/l values observed during the evaluation of the sand filter.

The wastewater discharged from the extended aeration unit to the sand filter was higher with respect to BOD_5 and TSS than the effluent from the unit during an earlier investigation. This deterioration in the quality of the influent could account for the fact that the effluent from the sand filter did not meet BAT limits for BOD_5 and TSS as expected.

COAGULATION-FLOCCULATION STUDY

After considerable data had been acquired on influent and effluent samples of the sand filter, calculations were made to see if the effluent would meet NPDES guidelines. The calculations revealed that the effluent might not meet all BAT guidelines for TSS and BOD_5.

Based on these observations, consideration was given to methods which might improve the efficiency of the treatment system (23, 24). One method considered as a possible means of improving the quality of the effluent was a batch chemical treatment of the wastewater in the aerated lagoon. This process would be simple, as chemicals could be added directly to the extended aeration pond and mixing would be accomplished by the aeration unit. If low cost chemicals were found to be effective, this process would also be economically feasible. Favorable results with alum and lime have been demonstrated by Rea (25) in a single cell activated sludge system.

The first investigation conducted in reference to the feasibility of batch chemical treatment consisted of taking samples from the extended aeration pond and subjecting these to chemical addition. These samples were treated with various concentrations of alum and lime. Turbidity measurements were taken at various time intervals and these results were compared to turbidity readings taken on settled samples from the pond which had not been subjected to chemical treatment. Turbidity measurements were used as an index to the effectiveness of the chemicals since it is much faster and easier to perform than the TSS readings. The results of one test using alum addition equivalent to 0.8 lb/1000 gal and lime equivalent to 1.0 lb/1000 gal are shown in Figure 13.

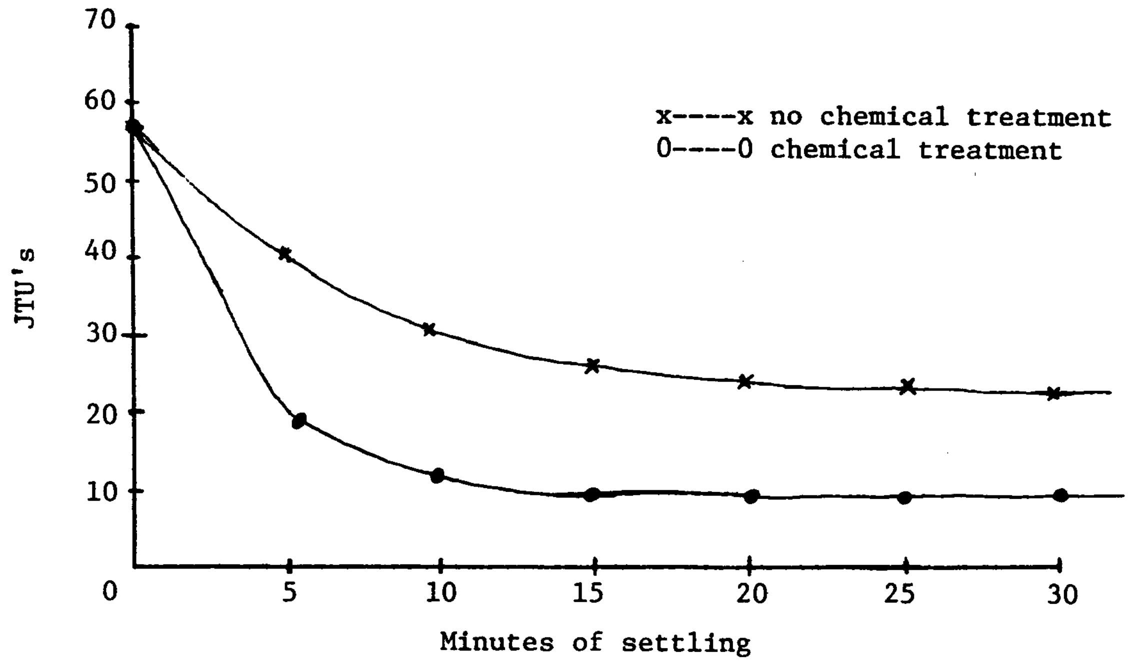

Figure 13. Chemical treatment effectiveness.

In a second investigation, effluent samples from the extended aeration pond were subjected to chemical treatment with alum at the rate equivalent to 0.8 lb/1000 gal and lime at the rate of 1.0 lb/1000 gal prior to filtration through the pilot scale sand columns. These results were compared to filtered wastewater samples which had not been subjected to chemical treatment. These results are shown in Table 28.

TABLE 28. ALUM TREATMENT STUDY

	Without chemicals		With chemicals	
Parameter	Avg.	n	Avg.	n
TSS (mg/l)	11.9	18	10.5	18
Turbidity (JTU's)	8.0	18	6.2	18

Laboratory jar tests using alum and ferric chloride were conducted on mixed liquor from the aerated pond. The samples were separated into three portions. One portion was allowed to settle without chemical treatment. A second portion was treated with alum and lime and the third portion was treated with ferric chloride and lime. The test was repeated three times using various concentrations of alum or ferric chloride. The concentration of lime was 1 lb/1000 gal in all tests. All samples were subjected to mixing for 5 minutes. After a settling time of 30 minutes, TSS analyses were performed on the settled portions of the mixtures. These results are shown in Table 29.

TABLE 29. CHEMICAL TREATMENT-SEDIMENTATION STUDY

	Chemical dosage lb/1000 gal	n	Avg. TSS (mg/l)
Mixed liquor			
Trial 1	-----	3	49
Trial 2	-----	3	46
Trial 3	-----	3	46
Combined	-----	9	47
Mixed liquor with alum			
Trial 1	0.4	3	37
Trial 2	0.8	3	30
Trial 3	1.6	3	35
Combined	-----	9	34
Mixed liquor with ferric chloride			
Trial 1	0.4	3	42
Trial 2	0.8	3	37
Trial 3	1.6	3	32
Combined	-----	9	37

Since quantitative studies were not completed, definite conclusions cannot be made, but the brief studies did reveal that batch chemical treatment might be economically and technically feasible. Polyelectrolytes were not used in the brief studies but the use of polyelectrolytes should be investigated as a possible method of improving the quality of the effluent from the extended aeration system. A supplemental request for $18,867 to demonstrate the utilization of batch chemical addition to the system at the W. E. Reeves Packinghouse was denied.

SECTION 10

COSTS

One of the objectives of the project was to develop a treatment system which would be economical to construct, operate, and maintain.

An earlier publication by Witherow (2) revealed that the cost of the three lagoons and appurtenances was $20,000. From this figure, the cost of the first pond and appurtenances, which was used in conjunction with the sand filters, was calculated to be $6,700. Equipment included for this system was the floating aerator, control panel, automated valve, air compressor, pneumatic and electrical supplies. The cost figure for these items was $6,000. This figure also included the cost of installation. The cost of construction of the intermittent sand filter system was $13,300. Of this figure, $1,800 was the cost of the sand. The capital cost of the system evaluated in this study included the cost of the pond, equipment, and sand filter unit. The total capital cost was $26,000.

Other expenditures would be incurred for operation and maintenance labor, equipment repair, power, monitoring, and reporting. The annual equipment repair cost based on experience during the study was set at 8% of capital cost, or $480/year. The electrical power cost was based on monthly billings for the treatment facility. That cost figure was $1100/year.

The operation and maintenance labor cost was based on 8 to 10 man-hours/week. This would include routine maintenance and repairs, daily inspection, and weekly sample collection. The cost figure for this activity was $2600/year.

Sand replacement cost was calculated to be $600/year. This figure would allow for a replacement of 1 foot of sand per year at a cost of $6.75/cubic yard.

The monitoring costs were based on the assumption that the plant employees would collect monthly samples and ship the samples to a commercial laboratory for analysis of those parameters listed on the NPDES permits. Plant personnel would then be responsible for completing and forwarding the NPDES report forms. The estimated cost of this activity was $980/year.

The annual cost of the extended aeration system followed by intermittent sand filtration was derived by amortizing the structures at a rate of 7% over 20 years, and amortizing the equipment at 7% over 10 years. This results in a total annual cost of $8,500. These figures are summarized in Table 30.

TABLE 30. TREATMENT COSTS FOR FULL-SCALE SYSTEM

Capital costs	
Extended aeration pond	\$ 6,700
Sand filter	13,300
Installed equipment	6,000
Capital cost	\$26,000
Annual costs	
Amortized structure (7% - 20 yrs.)	1,890
Amortized equipment (7% - 10 yrs.)	850
Equipment repair (8%)	480
Operating and maintenance labor	2,600
Electrical power	1,100
Monitoring and reporting	980
Sand replacement	600
Total annual costs	\$ 8,500
Installation cost:	\$1.40/gpd capacity
Treatment cost:	\$0.29/lb BOD_5 applied

These cost figures did not include the cost of incorporating a disinfection system into the existing facility or the cost of land acquisition.

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APPENDIX

SPECIFICATIONS FOR CONSTRUCTION OF AN INTERMITTENT SAND FILTER SYSTEM

The specifications described herein are for the construction of an intermittent sand filter system for East Central Oklahoma State University. This system will be located adjacent to the Reeves Packinghouse, which is located 1-1/2 miles west of Ada, Oklahoma. Access to the job site is by paved county road. This system contains one unit separated by a 6-inch concrete wall to form two intermittent sand filters.

The system appurtenances consist of a manhole, a diversion box, inlet and outlet devises for each filter unit, base and pipe, sewer, flow measuring devises, automatic sampling devises and weirs and valves.

SITE INVESTIGATION AND REPRESENTATION

The Contractor acknowledges that he has satisfied himself as to the nature and location of the work, the general and local conditions, particularly those bearing upon availability of transportation, disposal, handling and storage of materials, availability of labor, water, electric power, roads, and uncertainties of weather, river stages, or similar physical conditions at the site, the conformation and conditions of the ground, the character of equipment and facilities needed preliminary to and during the prosecution of the work and all other matters which can in any way affect the work.

The Contractor further acknowledges that he has satisfied himself as to the character, quality, and quantity of surface and sub-surface materials to be encountered from inspecting the site, all exploratory work done by the Owner, as well as from information presented by the Drawings and Specifications made a part of the Contract. Any failure by the Contractor to acquaint himself with all the available information will not relieve him from responsibility for estimating properly the difficulty or cost of successfully performing the work.

The Contractor warrants that as a result of his examination and investigation of all the aforesaid data that he can perform the work in a good and workmanlike manner and to the satisfaction of the Owner.

The Contractor will be responsible for all clearing and grubbing, excavation preparation of land to be filled, filling land, spreading, compaction and control of the fill, all necessary work to complete the grading of the cut and fill areas to conform to accepted plans. Contractor will be responsible for the furnishing of all materials, equipment, tools, labor, and superintendence and other services necessary to construct an intermittent sand filter system according to plans and specifications.

AUTHORITY OF THE ENGINEER

The Engineer will be the individual selected by the Owner. The Engineer shall have the authority to reject all work and materials and to stop the work whenever such rejection and/or stoppage may be necessary to insure execution of the work in accordance with the intent of the plans and specifications.

DUTIES AND RESPONSIBILITIES OF THE ENGINEER

The Engineer shall make periodic visits to the site of the project to observe the progress and quality of the work and to determine, in general, if the work is proceeding in accordance with the plans and specifications. He shall not be required to make comprehensive or continuous inspections to check quality or quantity of the work, and he shall not be responsible for construction means, methods, techniques, sequences, or procedures, or for safety precautions and programs in connection with the work. Visits and observations made by the Engineer shall not relieve the Contractor of his obligation to conduct comprehensive inspections of the work and to furnish materials and perform acceptable work, and to provide adequate safety precautions.

The Engineer will establish the center lines of principal structures, roads, pipelines, and facilities, set slope stakes when required, and set bench marks convenient for the Contractor's use as necessary to establish the basic layout. All labor and stakes will be provided by the Owner. It will be the Contractor's responsibility to lay out the work from the lines set by the Engineer.

One or more inspectors may be assigned to observe the work and to act in matters of construction under this Contract. It is understood that such inspectors shall have the power to issue instructions and make decisions within the limitations of the authority of the Engineer. Such inspection shall not relieve the Contractor of his obligations to conduct comprehensive inspections of the work and to furnish materials and perform acceptable work, and to provide adequate safety precautions, in conformance with the intent of the Contract.

REJECTED MATERIAL

Any material condemned or rejected by the Engineer or his authorized inspector because of nonconformity with the Contract Documents shall be removed at once from the vicinity of the work by the Contractor at his own expense, and the same shall not be used on the work.

ROCKS

When fill material includes rocks, no large rocks shall be allowed to nest and all voids must be carefully filled with earth, properly compacted.

No large rocks will be permitted closer than twelve inches (12") below the finish grade except on the inside slope of the dikes.

MOISTURE CONTENT

The fill material shall be compacted at the optimum moisture content of 20 to 25 percent specified for the soil being used.

COMPACTION OF FILL LAYERS

Compaction shall be by sheepsfoot rollers, multiple-wheel pneumatic-tired rollers or other types of suitable compaction equipment. Compaction equipment shall be of such design that it will be accomplished while the fill material is at the specified moisture content. Compaction of each layer shall be continuous over its entire area and the compaction equipment shall make sufficient trips to insure that the required density has been obtained.

DENSITY TEST

Ninety-five to ninety-eight percent proctor density is required. Field density test shall be made by the Inspector of the compaction of each two foot (2') lift of fill. Where sheepsfoot rollers are used the soil may be disturbed to a depth of several inches. Density tests shall be taken in the compaction material below the disturbed surface. When these tests indicate that the density of any layer of fill or portion thereof is below the required density, the particular layer of portion shall be reworked until the required density has been obtained. Sufficient density tests shall be taken in each layer to show uniform compaction of the layer.

Operate compacting equipment so that full width of the fill is covered. A coverage shall be considered as one continuous trip from end-to-end and shall overlap previous coverage by not less than 3 inches. For pipelines laid in the fill, construct fill surface to at least an elevation 2 feet above the top of proposed pipeline prior to starting trench excavation for installation of pipelines. Sprinkle fill material with water as necessary to produce satisfactory compaction. If material is too wet for proper compaction, aerate by blading and discing as required. Upon competion, grade surface to proper elevations and cross sections. Dress side slopes as indicated.

FINISH ELEVATION

The fill operation shall be continued in six inch (6") compacted layers, as specified above, until the fill has been brought to the finished elevations shown on the engineering plans.

PREPARATIONS FOR PLACING BACKFILL

Do not backfill around concrete structures until the concrete has obtained a compressive strength equal to 2/3 of the specified compressive strength. Remove all form materials and trash from the excavation before placing any backfill. Obtain the Engineer's approval of concrete work and conditions prior to backfilling.

Do not operate any heavy earth-moving equipment within 5 feet of walls of concrete structures for the purposes of depositing or compacting backfill material unless approved by the Engineer. Compact backfill adjacent to concrete walls with pneumatic tampers or other approved equipment that will not damage the structure.

SUPERVISION

Supervision by the Contractor and certification by the Inspector shall be continuous during the fill and compaction operations and construction of the appurtenances necessary to construct this waste treatment system.

DISPOSAL OF EXCESS EXCAVATION

All excess excavation, not required or suitable for backfill or filling, shall be disposed of in the waste area designated by the Owner. The waste area shall be uniformly graded to conform to existing contours, left with a neat appearance, and be free-draining.

PLACING TOPSOIL

After grading hereinbefore specified is completed and approved by Engineer, spread topsoil over entire graded area, excluding the graveled surfaced area inside dike slopes and bottoms of filter and sprig Bermuda grass.

SETTLEMENT

Any settlement noted in backfill, fill, or in structures built over the backfill or fill within the one-year guarantee period will be considered to be caused by improper compaction methods and shall be corrected at no additional cost to the Owner. Any structures damaged by excessive settlement shall be restored to their original condition by the Contractor, also, at no additional cost to the Owner.

CLAY PIPE

Clay pipe where called for in plans and specifications shall be standard strength clay sewer pipe and conform to ASTM Designation C 13-50t. When pipe is being placed the lower 90 degree arc of the barrel of the pipe will be in firm contact with undisturbed earth. Small excavations will be made for the bells. These should be no larger than necessary to clear the bell. Where clay pipe is to be laid on rock where the surface is unsmooth and irregular a four inch (4") layer of sand, crushed rock or small aggregate will be placed under pipe for complete support. Clay pipe will be laid also with correct alignment and slope. Joints must be watertight to hold infiltration to a minimum. Trenches should be kept water-free during jointing and for a sufficient period thereafter to allow the jointing material to become fully set and completely resistant to water penetration.

TRENCH EXCAVATION AND BACKFILL

Excavation and backfill shall be performed as required for the installation of piping and appurtenances in conformance with these Specifications and the Plans.

TRENCH EXCAVATION

Obstructions to the construction of the trench, such as tree roots, stumps, abandoned structures, and debris of all types, shall be removed by the Contractor at his own expense without additional compensation from the Owner.

TRENCH WIDTH

Minimum width of unsheeted trenches in which pipe is to be laid shall be 18 inches, except by permission of the Engineer. Sheeting requirements shall be independent of trench widths.

GRADE

Carry the bottom of the trench to the lines and grades shown or as established by the Engineer with proper allowance for pipe thickness and for base or special bedding when required. Correct any part of the trench excavated below the grade at no additional cost to the Owner, by placing the sand over the full width of trench in thoroughly compacted layers not exceeding 6 inches to the established grade.

TRENCH STABILIZATION

If, in the opinion of the Engineer, the material in the bottom of the trench is unsuitable for supporting the pipe, the Contractor shall excavate below the flow line as directed by the Engineer and backfill to the required grade with sand.

EXCESS EXCAVATED MATERIAL

All excess excavated materials from the trench backfill operations shall be used for plant site fill.

BASE FOR PIPE

Sand base shall be placed to the thickness shown for each pipe. The base shall be placed for the full width of the trench with the top of the base at bottom of the pipe. The gravel base shall be placed and raked to grade ahead of the pipe laying operation.

PIPES THROUGH EMBANKMENTS

Where pipes pass through embankments, no granular pipe base or pipe zone material shall be used. Instead, the pipe shall be laid on the trench invert.

EXCAVATE FOR BELLS

Steel pipe joints shall be welded. Backfill with selected trench side material as approved by the Engineer.

MATERIALS

GRAVEL

Gravel for the filter units must be a minimum of 1/4 inch and a maximum of 1 1/2 inch in diameter. Gravel must meet the approval of the project Engineer.

SOIL EMBANKMENT

The embankments of the filter unit must be of bank run granular fill material. The fill material must meet the approval of the project Engineer.

SAND

Concrete run washed sand with an effective size of 0.170 mm. The sand must meet the approval of the project Engineer.

CONCRETE AND GROUT

Conform to applicable portions of Section Concrete. Standard premixed mortar conforming to ASTM C 387 may be used at the Contractor's option.

Polymeric Water Gel may be used to join the Keylock precast manhole sections.

FORMS

Exterior exposed surfaces shall be plywood; others shall be matched boards, plywood, or other approved material. Form all vertical surfaces. Trench walls, large rock, or earth will not be approved form material.

PRECAST SECTIONS

Precast manhole sections conforming to ASTM Standards, with circular reinforcement, may be used. Diameter shall be as shown in the plans.

CONCRETE BASE

Remove water from excavation. Construct concrete base so that first section of precast manhole has uniform bearing throughout full circumference.

Deposit sufficient grout on base to assure watertight seal between base and manhole wall or place the precast section of manhole in concrete base before concrete has set, if preferred. The section shall be properly located and plumbed.

If material in bottom of excavation is unsuitable for supporting manhole excavate below the line shown as directed by Engineer, and backfill to required grade with 3-inch minus, clean, pit-run material.

INSTALLATION

FLOW MEASURING AND SAMPLING DEVISES

The Contractor shall install flow measuring and sampling devises furnished by the Owner. A Parshal flume of the type produced by Thompson Pipe and Steel Company with a three-inch throat width, stilling well, and Stevens recorders shall be installed prior to the diversion box as shown in the plans. A Stevens type recorder will be installed in the final outlet devise as specified by the Engineer. The Contractor shall provide facilities to enable installation of automatic samples, Model PPD2 by Nappe Corporation or equivalent at the diversion box, and effluent lines from the filter units.

FILTER PARTITION

The Contractor shall furnish the necessary material and install a watertight barrier between the two filter components. The barrier shall be made of 6 inch concrete.

MATERIALS AND APPLIANCES

Unless otherwise stipulated, the Contractor shall provide and pay for all materials, labor, water, tools, equipment, light, power, transportation, and other facilities necessary for the execution and completion of the work.

ACCESS FOR INSPECTION

The Contractor shall furnish, without extra charge, the necessary test pieces and samples, including facilities and labor for obtaining the same, as requested by the Engineer. When required, the Contractor shall furnish certificates of tests of materials and equipment made at the point of manufacture by a recognized testing laboratory.

The Engineer and his representatives shall at all times have access to the work wherever it is in preparation or progress, and the Contractor shall provide facilities for such access and for inspection, including maintenance of temporary and permanent access.

If the Specifications, the Engineer's instructions, laws, ordinances, or any public authority require any work to be specially tested or approved, the Contractor shall give timely notice of its readiness for inspection. Inspections to be conducted by the Engineer will be promptly made, and where practicable, at the source of supply. If any work should be covered up without approval or consent of the Engineer, it shall, if required by the Engineer, be uncovered for examination at the Contractor's expense.

Re-examination of questioned work may be ordered by the Engineer; and, if so ordered, the work shall be uncovered by the Contractor. If such work be found in accordance with the Contract Documents, the Owner will pay the cost of re-examination and replacement. If such work be found not in accordance with the Contract Documents, the Contractor shall correct the defective work at no additional cost to the Owner.

SAFETY PRECAUTIONS

The Contractor shall take all necessary precautions for the safety of employees on the work and shall comply with all applicable provisions of Federal and State safety laws and building codes to prevent accidents or injury to persons on, about, or adjacent to the premises where the work is being performed. The Contractor shall, without further order, provide and maintain at all times during the progress or temporary suspension of the work, suitable barricades, fences, signs, signal lights, and flagmen as are necessary or required to insure the safety of the public and those engaged in the work. The operations of the Contractor, for the protection of persons, and the guarding against hazards from machinery and equipment, shall meet the requirements of the applicable State laws and the current safety regulations.

DIVERSION AND CARE OF WATER

The Contractor shall construct the necessary ditches, provide the necessary pumps, and take such precautions as are required to protect the work. Divert or pump the streamflow and drain the construction area so the work may be carried on in a satisfactory manner. Drain or otherwise dewater all excavation areas as required to permit satisfactory operation at all times.

ACCESS ROAD

The Contractor shall maintain the access road between the county road and the work site during construction and leave the road suitable for continued use by autos.

USE OF COMPLETED PORTIONS

The Owner shall have the right to take possession of and use any completed or partially completed portions of the work, notwithstanding the time for completing the entire work or such portions may not have expired, but such taking possession and use shall not be deemed an acceptance of any work not completed in accordance with this document.

CLEANING UP

The Contractor shall, at all times, at his own expense, keep property on which work is in progress and the adjacent property free from accumulations of waste material or rubbish caused by employees or by the work. Upon completion of the construction, the Contractor shall, at his own expense, remove all temporary structures and equipment, rubbish, and waste materials resulting from his operations.

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

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16. ABSTRACT

A full scale wastewater treatment system consisting of a novel extended aeration unit and intermittent sand filter was demonstrated. The treatment system was designed to meet the special needs of small plants and to meet future industrial discharge limitations.

With a hydraulic loading rate of 0.36 mgad and a sand source having an effective diameter of 0.35 mm and a uniformity coefficient of 2.5, a filter run of 109 days was observed. The average BOD_5 and TSS of the filter effluent was 10.4 mg/l and 11.1 mg/l, respectively. The cost of construction and operation of the treatment facility is presented. The study revealed an installation cost of $1.40/gpd capacity and a treatment cost of $0.29/lb BOD_5 applied. Information needed to select, design, and construct an intermittent sand filter is also presented.

The project evaluated the most economical means of meeting the NPDES monitoring requirements. The conclusion was that the small packinghouse managers should use a commercial laboratory when monthly or quarterly analyses are specified.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Food Processing, Industrial Wastes, Aeration, Sand Filtration, Waste water	Meat Packing Industry, Slaughterhouses, Poultry Processing Industry, Extended Aeration, Wastewater Treatment	68 D

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