WATER POLLUTION CONTROL RESEARCH SERIES • 12060---07/69

Secondary Treatment of Potato Processing Wastes

MENTAL PROTECTION AGENCY • WATER QUALITY OFFICE

WATER POLLUTION CONTROL RESEARCH SERIES

The Water Pollution Control Research Series describes the results and progress in the control and abatement of pollution of our Nation's waters. They provide a central source of information on the research, development, and demonstration activities of the Water Quality Office, Environmental Protection Agency, through inhouse research and grants and contracts with Federal, State, and local agencies, research institutions, and industrial organizations.

Inquiries pertaining to the Water Pollution Control Research Reports should be directed to the Head, Project Reports System, Office of Research and Development, Water Quality Office, Environmental Protection Agency, Washington, D.C. 20242.

SECONDARY TREATMENT OF POTATO PROCESSING WASTES

Prepared by

Kenneth A. Dostal
Pacific Northwest Water Laboratory
200 Southwest 35th Street
Corvallis, Oregon 97330

for the

WATER QUALITY OFFICE

ENVIRONMENTAL PROTECTION AGENCY

Project #12060 _ _ _ 07/69
July 1969

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price 65 cents

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

BOD	5-day, 20°C biochemical oxygen demand, mg/l
BOD_S	Soluble BOD, mg/l
COD	Standard Methods chemical oxygen demand, mg/l
COD_S	Soluble COD, mg/l
COD_M	National Canners Association's modified COD, mg/l
SS	Suspended solids, mg/l
TS	Total solids, mg/l
VSS	Volatile suspended solids, mg/l
TVS	Total volatile solids, mg/l
NH_3-N	Ammonia nitrogen, mg/l as N
TKN	Total Kjeldahl nitrogen, mg/l as N
TPO_4	Total phosphate, mg/l as P
Alk	Total alkalinity, mg/l as $CaCO_3$
TOC	Total organic carbon, mg/l
DOC	Dissolved organic carbon, mg/l
DO	Dissolved oxygen, mg/l
gpm	Gallons per minute

ACKNOWLEDGMENT

The assistance of the Idaho State Health Department, the J. R. Simplot Company, and the consulting firm of Cornell, Howland, Hayes & Merryfield in this study is gratefully acknowledged.

In addition, appreciation is expressed to the Wayne Wiscomb Company and The Eimco Corporation for supplying surface aerators used in this study.

INTRODUCTION

Problem

Annual production of potatoes in the United States has increased from 195 million hundred weight (cwt.) in 1951 to over 300 million cwt. in 1966[1] as shown in Figure 1. The western states of Idaho, Washington, California, and Oregon have accounted for most of this increase, at least during the past 10 years. From 1958 through 1966 these four states had an increased production of 63 million cwt. (from 75 to 138), whereas the total production for the United States increased only 40 million cwt. (from 267 to 307).

These increases in potato production reflected the increased processing of specialty items such as frozen french fries, hash browns, and others. Figure 2 presents the 1955-1965 growth and projects for the next 10 years the quantity of potatoes to be processed into frozen products. This information was a result of a computer analysis by DuPont[2]. From 1955 through 1966 the quantity of frozen potato products increased from 129 million to 1460 million pounds. This analysis predicted that 3926 million pounds would be processed in 1976, an increase of 170 percent, as related to an expected population increase of only 9 percent.

The potato growers and processors in Idaho have participated in this growth. Eleven members of the Potato Processors of Idaho Association had a $23,235,457 payroll and $52,085,335 plant

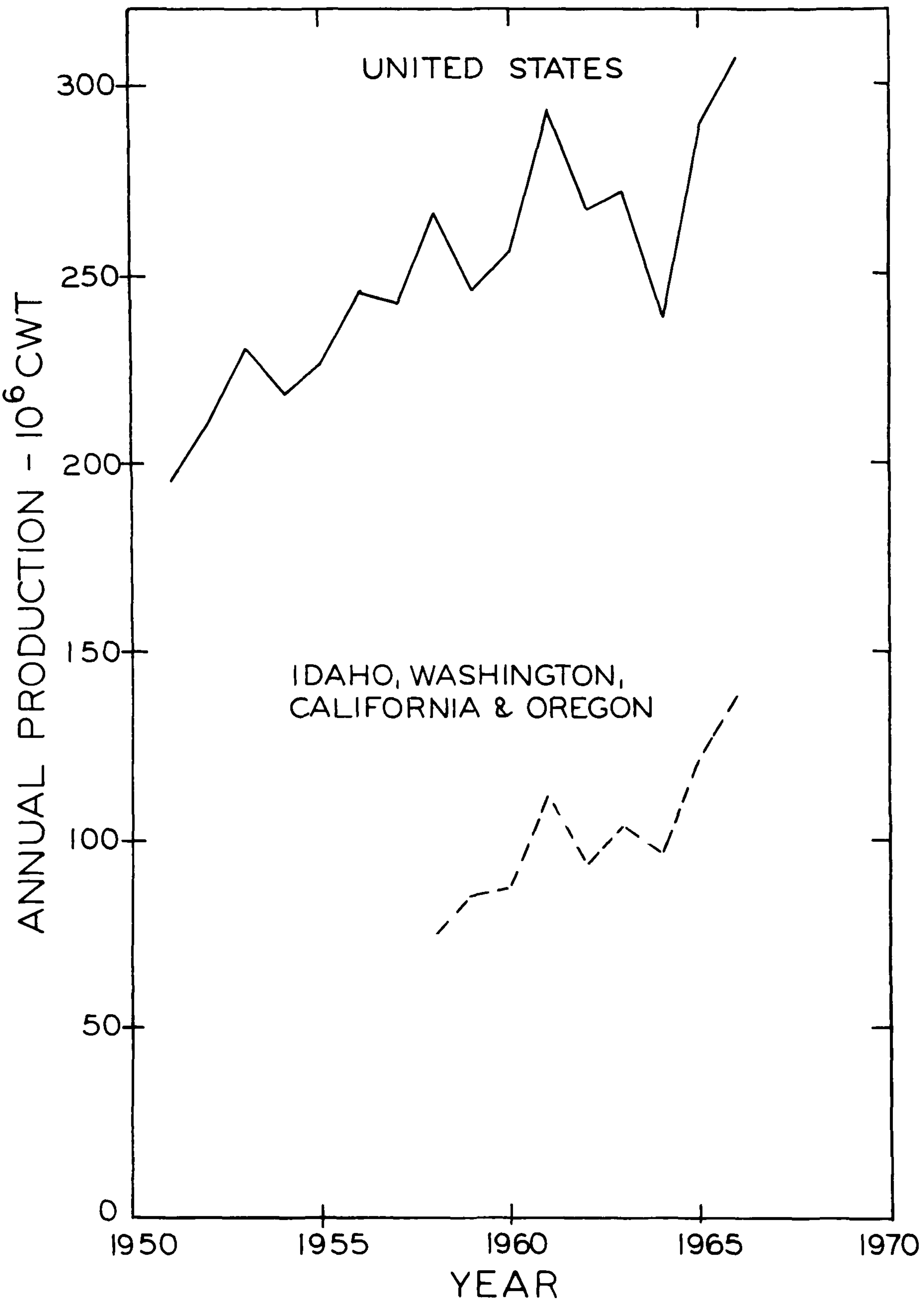

Figure 1.--- TRENDS IN POTATO PRODUCTION

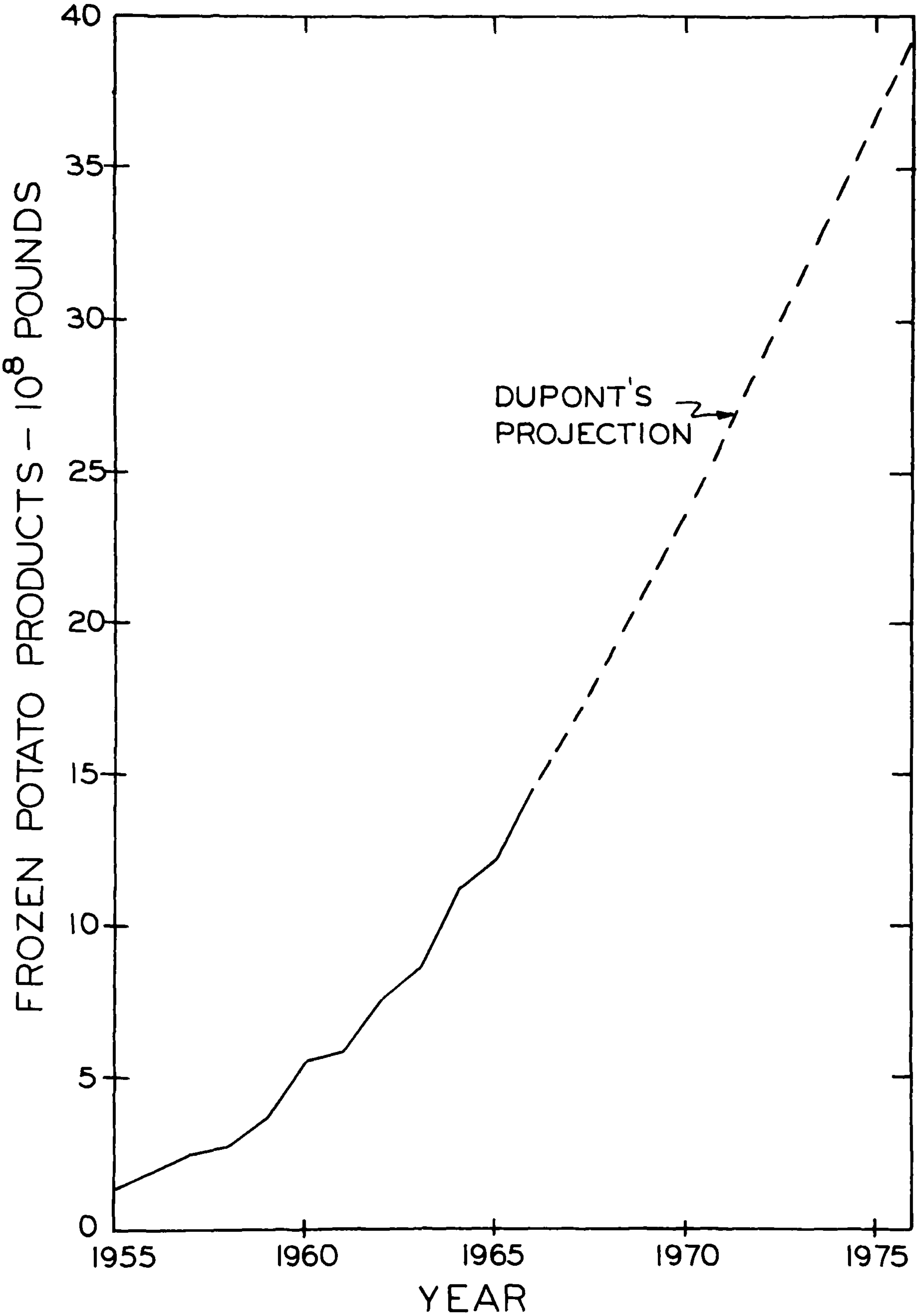

Figure 2.···FROZEN POTATO PRODUCTS PROCESSED

investment during tne 1965-66 processing season[3]. This represents more than a tenfold growth over comparable figures in 1950.

Although the quantity of potatoes produced in Idaho increased only 39 percent in the 10-year period, 1950 to 1960, the amount processed for food products increased almost tenfold as shown in Table 1. In the two-year period, 1958 to 1960, the potatoes processed for food products more than doubled. Since 1960, more than 50 percent of the potatoes produced in Idaho have passed through processing plants. Waste production has, unfortunately, grown accordingly.

Since potato wastes have become one of the State's major water pollution sources, the Idaho State Health Department has been, and is, working closely with the potato processors in the development of effective waste treatment methods. As a result of these cooperative efforts, all major potato processing plants presently (1968) discharging into the Snake River or its tributaries now provide primary treatment of their waste streams. Even with primary treatment, these wastes in combination with others, have resulted in fish kills and other pollutional problems during periods of low flow in receiving streams.

The processing industries have been directed[4] by the Idaho State Health Department to provide secondary treatment of their wastes. The timetable calls for operating waste treatment plants between the dates of July 1969 and July 1973, depending upon plant location on the Snake River and other factors.

Table 1

POTATO PRODUCTION AND PROCESSING IN IDAHO

	Quantity of Potatoes - tons			
Year	Produced	Used in Starch	Used in Food Products	Percent of Crop Processed
1946	1,388,400	153,450	143,800	21.4
1950	1,525,800	240,700	101,250	22.4
1956	1,655,200	163,700	324,250	29.5
1958	2,041,900	344,900	483,500	40.6
1960	2,120,000	77,500	1,005,000	51.1

In 1964, the consulting firm of Cornell, Howland, Hayes & Merryfield (CH_2M) was retained by the Engineering Committee of the Potato Processors of Idaho Association to assist in the design and operation of pilot plant facilities. The pilot plants were used to check the applicability of several secondary waste treatment processes to potato processing wastes. As a result of this work[(5)], design criteria were established for secondary treatment by activated sludge, trickling filter, and conventional stabilization ponds. One of the conclusions from this work was: "Additional study should be given anaerobic ponds and flow-through aeration basins to more closely determine the capabilities of these systems in secondary treatment of potato process water." This, coupled with the fact that both trickling filter and activated sludge treatment plants have high capital and operating costs, prompted the initiation of the study reported herein.

In addition to work reported by CH_2M, Atkins and Sproul[(6)] have reported on laboratory-scale pilot plant studies using both completely mixed activated sludge and contact stabilization to treat potato processing wastes. The completely mixed activated sludge pilot plant reduced the BOD by greater than 90 percent without pH adjustment (lye-peel waste) or addition of inorganic nutrients. Also included in this report were the results of extensive in-plant changes in water use (conservation, recirculation, and by-product recovery). Water use was reduced from 2520 to

2310 gallons per ton of potatoes. The plant effluent BOD was reduced by over 50 percent from 52 to 22 pounds per ton of potatoes and the suspended solids discharged were lowered from 37 to 25 pounds per ton.

At the 18th National Potato Utilization Conference held at Corvallis, Oregon, in July 1968, Mr. Robert P. Graham of the Western Regional Research Laboratory, U. S. Department of Agriculture, Albany, California, reported on a semi-dry method of caustic peeling of potatoes. The work used a 500 pound per hour pilot plant and most of the potential variables were investigated. Should this method prove to be economical, it could reduce the present BOD and SS effluent loads by 50 to 75 percent. Additional work on a larger scale is underway to evaluate the overall economics of this method.

Authority

Federal authorization for this type of cooperative study with both industry and State comes from the Federal Water Pollution Control Act, as amended. Section 5(b) of the Act provides that the Federal Water Pollution Control Administration (FWPCA) may, "upon request of any State water pollution control agency, ... conduct investigations.... concerning any specific problem of water pollution confronting any... industrial plant, with a view of recommending a solution of such problem."

In July 1966, a request to the regional office of the FWPCA was received from the Idaho State Health Department for technical assistance in the development of secondary treatment methods for potato processing wastes. A memorandum of understanding authorizing the study and delineating responsibilities was signed by the three participants: Potato Processors of Idaho, Idaho State Health Department, and FWPCA

Objective

The objective of this study was to bring to conclusion pilot plant studies started in 1965 on feasible methods of secondary treatment of potato processing wastes. Investigation of two methods of secondary treatment was requested:

(1) An anaerobic lagoon followed in series by a surface-aerated aerobic lagoon, and

(2) A surface-aerated aerobic lagoon.

SUMMARY

This report presents the results obtained from three pilot lagoons which were used to treat potato wastes during the period October 1966 through June 1968.

One of the lagoons received primary clarifier effluent and was operated as a surface-aerated, aerobic unit. A second pond also received clarifier effluent but was operated as a completely-mixed, covered anaerobic unit. The effluent from the anaerobic unit was pumped into a third pond which contained a surface aerator. Hydraulic and organic loadings were varied to yield a spectrum of results.

Conclusions drawn from the data collected during this study are:

1. Both systems are economically feasible; the choice would depend upon local costs and conditions.

2. The BOD in these potato wastes could be reduced 90 percent or more by primary clarification plus subsequent treatment in either an aerobic lagoon or anaerobic-aerobic lagoons in series.

3. BOD reduction across the ponds can be adequately described using available mathematical models with necessary constants derived from this study.

4. No chemical additions were necessary for either pH control or inorganic nutrient adjustment.

5. Covering the anaerobic lagoon surface with insulating material will reduce the weather-induced temperature drop and help control odors. Such covering will usually be required for odor control.

6. Secondary clarification for removal of suspended solids should be employed following either an aerobic lagoon or an anaerobic-aerobic lagoon system.

7. Foaming may cause operational difficulties in full-scale aerobic lagoons, but can be controlled by proper design.

DESCRIPTION OF PROCESSING PLANTS

The pilot plant facility of the Processors Association is located at the site of the J. R. Simplot Company's primary waste treatment plant in Burley, Idaho. About 300,000 tons of potatoes per year are processed by three J. R. Simplot Company processing plants in the immediate vicinity.

One of these, the Burley Processing Company, processes about 28 percent of the total. It is a highly automated plant and produces instant mashed potatoes and related specialties. The potatoes are washed, lye-peeled, cut, automatically sorted for flakes or granules, dehydrated, and packed for shipment.

The Heyburn Plant, one of the world's largest in this field, processes about 59 percent of the total, or 180,000 tons of potatoes per year. Products include french fries and potato specialties. Here, too, the potatoes are washed and lye-peeled; then trimmed, blanched, processed, and packed. The remaining 13 percent of the Simplot Company's total potato tonnage at Burley is processed in a starch plant.

During the 1966-67 processing season, these three plants used an average of 4,170 gallons of water per ton of potatoes processed. As shown in Table 2, an average of 90 pounds of BOD and 110 pounds of suspended solids (SS) was added to the waste stream per ton of potatoes processed. Three and one-half pounds

Table 2

WASTE PRODUCTION PER TON OF POTATOES PROCESSED

Parameter	Quantity*
Process water	4200 gal.
BOD	90 lbs.
COD	210 lbs.
SS	110 lbs.
TPO_4	0.6 lb.
Total nitrogen as N	3.5 lbs.

*After screening

of total nitrogen and 0.6 pound of total phosphate were also contributed per ton of potatoes. These figures do not include fat recovered or solids screened out for cattle feed; they were derived from the flows and concentrations measured entering the primary clarifier.

Both the SS and BOD values shown on Table 2 are higher than experienced during previous seasons. Average values for the potato processing industry are about 4200 gallons, 60 pounds of SS, and 50 pounds of BOD per ton processed. As mentioned earlier, these values can all be reduced by about 50 percent through extensive in-plant changes.

PRIMARY WASTE TREATMENT PLANT

Description

Waste streams from the three processing plants are piped to a primary waste treatment plant. They first enter a receiving tank and then are passed through two five-foot diameter, ten-foot long rotary drum screens as shown in Figure 3. All solids retained on the +20 mesh screens are removed and stored in bins.

The screened waste water then enters a 100-foot diameter clarifier which operates with an average overflow rate of about 800 gallons per day per square foot. Most of the settleable solids are removed and the effluent passes through a Parshall flume prior to discharge to the Snake River.

Solids collected in the clarifier are pumped through a centrifuge for thickening. The thickened sludge is also stored in bins and the supernatant is either returned to the clarifier influent or discharged to the river. During the study reported herein the centrifuge was overloaded which reduced its efficiency and resulted in less than optimum operation of the clarifier when the supernatant was added to the influent.

Both the screenings and the sludge from the centrifuge are trucked to a cattle feed-lot operation for use as part of the animals' diet.

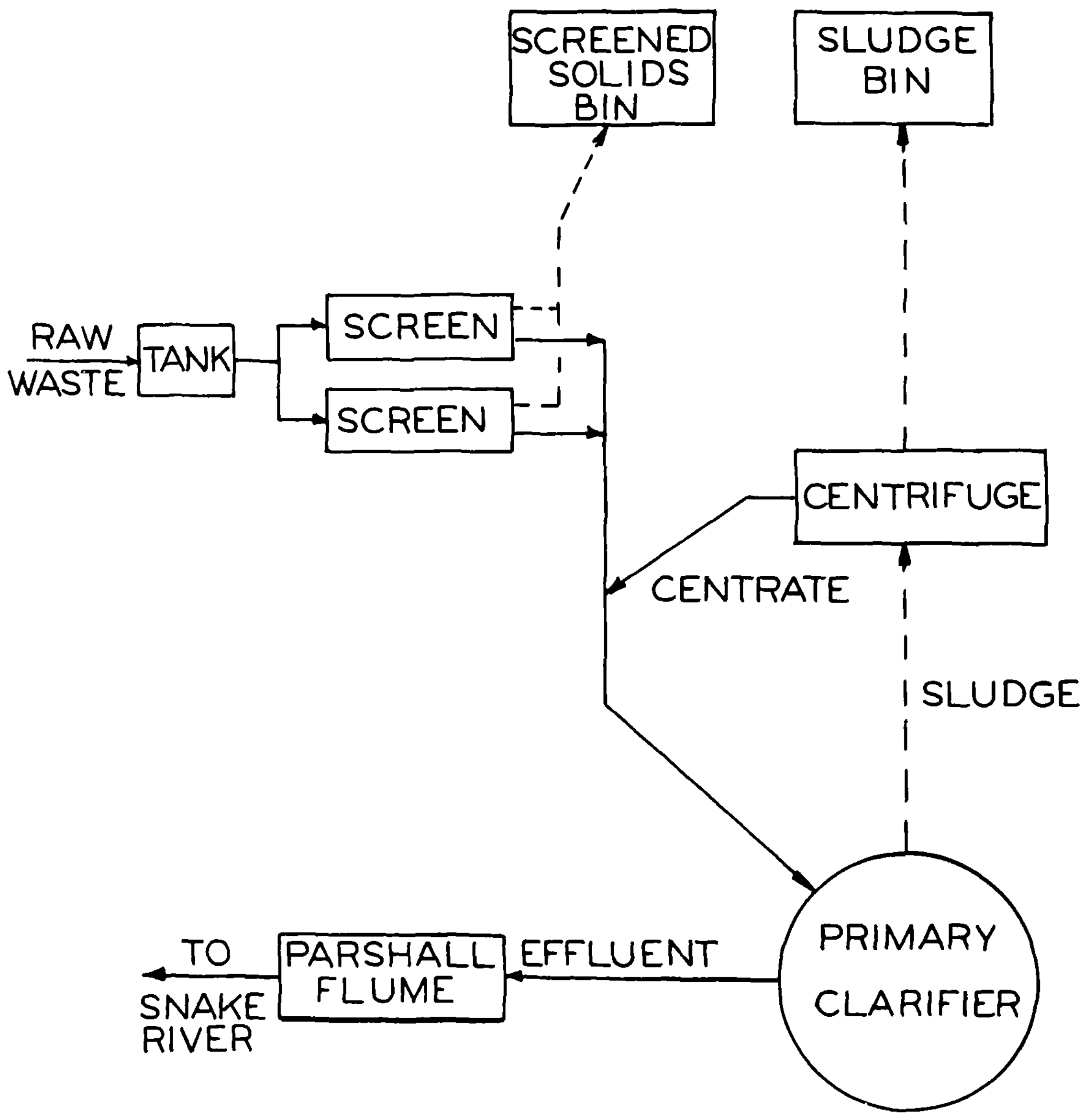

Figure 3.--FLOW DIAGRAM OF PRIMARY TREATMENT PLANT

Efficiency

The efficiency of the primary clarifier at the J. R. Simplot Company's waste treatment plant is indicated by the data shown in Table 3. All data collected on the clarifier influent and the clarifier effluent during both processing seasons are included.

The pH of the clarifier influent ranged from 10.6 to 12.1 with a median of 11.3; for the clarifier effluent it ranged from 7.1 to 11.6 with a median value of 10.4 Temperature of the waste dropped an average of 4°F across the primary clarifier. In the effluent it ranged from 63 to 79°F and averaged 74°F.

BOD removal by the primary clarifier averaged 41 percent. The concentration in the clarifier effluent ranged from 650 to 2570 mg/l and averaged 1600 with a standard deviation of ±24 percent.

Average COD was reduced from 5390 to 2960 mg/l, 45 percent, by the primary clarifier. The clarifier influent contained an average of 2320 mg/l of suspended solids with a range of 280 to 5900 mg/l. Suspended solids in the effluent varied from 80 to 3190 and averaged 620 mg/l for an average reduction of 73 percent.

Both the total Kjeldahl nitrogen and total phosphates were reduced by 21 percent upon passage through the primary clarifier. The effluent contained an average of 84 mg/l of total Kjeldahl nitrogen as N which resulted in a BOD to nitrogen ratio of 19:1. On individual samples this ratio ranged from 7:1 to 33:1. Total

Table 3

OPERATIONAL CHARACTERISTICS OF PRIMARY CLARIFIER

		Clarifier Influent	Clarifier Effluent	Removal %
pH	Range	10.6-12.1	7.1-11.6	
	Median	11.3	10.4	--
Temp.	Range	68-82	63-79	
°F	Median	78	74	--
	Std. Deviation	±3	±3	
BOD	Range	1220-5150	650-2570	
	Mean	2730	1600	41
	Std. Deviation	±790	±390	
COD	Range	3120-9860	1440-6000	
	Mean	5390	2960	45
	Std. Deviation	±1520	±750	
SS	Range	280-5900	80-3190	
	Mean	2320	620	73
	Std. Deviation	±1150	±490	
TKN	Range	73-225	38-175	
	Mean	107	84	21
	Std. Deviation	±28	±25	
TPO_4	Range	7.2-45.1	6.0-37.2	
	Mean	18.0	14.2	21
	Std. Deviation	±6.9	±6.1	

phosphates in the effluent averaged 14.2 mg/l as P. The average of individual BOD:P ratios, which ranged from 48:1 to 285:1, was 130:1.

Effluent from the primary clarifier contained an average of 6.9 mg/l of ammonia nitrogen as N with a range of 3.4 to 16.9 mg/l. An average concentration of 1.8 mg/l was measured for orthophosphates as P with a range of 0.2 to 5.8 mg/l.

PILOT PLANTS

Description

The pilot plant facility of the Potato Processors of Idaho Association was located at the primary waste treatment plant of J. R. Simplot Company in Burley, Idaho. Three earthen ponds sealed with concrete applied as gunite were utilized. Each pond was 40 feet square at the water surface and approximately 10 feet deep. During the 1966-67 processing season each pond had a capacity of 51,000 gallons. Prior to the 1967-68 season overflow weirs were installed in place of the overflow pipes; this reduced the depth and thus the volume of each pond to about 45,000 gallons. The influent to, and the effluent from, the ponds were added and withdrawn, respectively, near the water surface on opposite sides of the ponds.

When the ponds were operated as anaerobic units they were covered with three-inch thick styrofoam blocks to help retard heat loss and control odors.

Two surface aerators were used during most of the study period, a 5 hp floating Wells* aerator and a 10 hp fixed Eimco* aerator.

---

*Mention of specific proprietary equipment is for information purposes only and does not constitute endorsement by the Federal Water Pollution Control Administration and the U. S. Department of the Interior.

Operation

Ponds II and III were started September 19, 1966, as covered anaerobic units while awaiting the arrival of previously ordered surface aerators. They were operated as parallel anaerobic units until the processing and waste treatment plants were shut down for the holidays on December 23, 1966.

Initially both ponds were filled two-thirds with tap water and one-third with primary clarifier effluent. They were seeded initially with activated sludge and later with sludge from another anaerobic lagoon. As suggested in an earlier study[5], the flow-through rates were set and maintained at 1.8 and 8.8 gpm for ponds II and III, respectively. This resulted in theoretical detention times of 20 and 4 days, respectively.

In mid-January 1967, after arrival of the 5 hp surface aerator, pond III was converted from a covered, anaerobic unit to a surface-aerated unit. It was placed in series with anaerobic pond II. At that time a recirculation pump was installed on anaerobic pond II to keep the contents completely mixed. Reasons for this will be discussed later. The two ponds were operated at various hydraulic and organic loadings until the end of processing on May 27, 1967.

During the 1967-68 processing season all three ponds were used. As shown in Figure 4, pond I contained a 10 hp surface aerator and ponds II and III were operated as during the last half of the previous processing season.

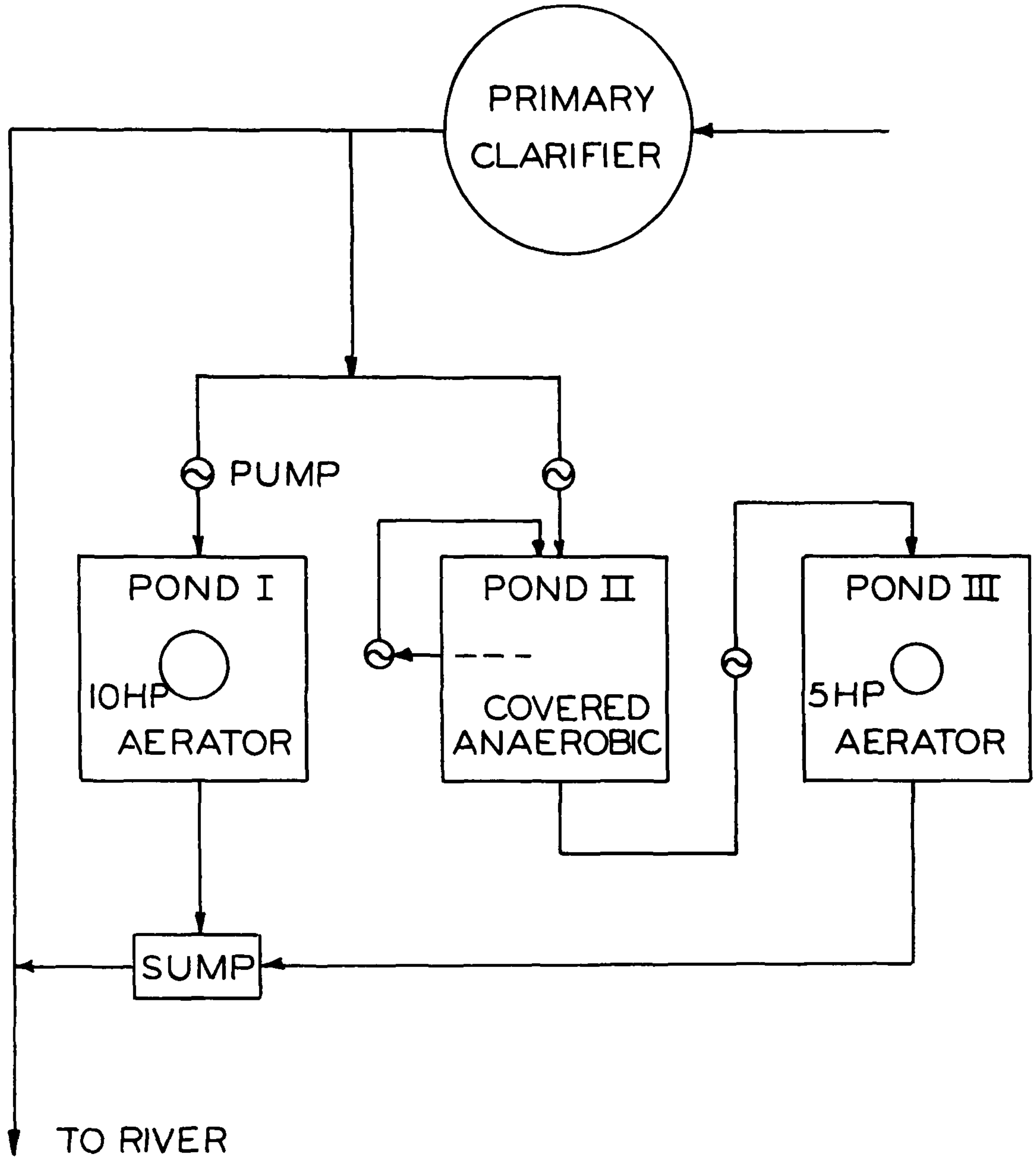

Figure 4.—FLOW DIAGRAM OF PILOT PLANT

Samples were collected from the clarifier influent, clarifier effluent, pond I effluent (when in operation), pond II effluent and pond III effluent. Throughout the study, eight-hourly grab samples of both the clarifier influent and effluent were collected and composited with time. This method was used rather than compositing according to flow, since variations in flow through the clarifier were usually less than ±10 percent of the average based on individual readings.

During the first processing season the effluent samples from ponds II and III were individual grab samples. In the second season of operation, all three pond effluents were sampled hourly for eight hours and composited the same as the clarifier influent and effluent.

Inasmuch as a sanitary engineer was stationed onsite during the first year of operation, most of the analyses were performed onsite. Once per week a set of samples was split three ways with one portion shipped in iced containers to the Idaho State Health Department, one to FWPCA's Pacific Northwest Water Laboratory in Corvallis, Oregon, and one retained for onsite analyses. During the second year of pilot plant operation, most of the analyses were performed by the Laboratory in Corvallis. Onsite determinations were limited to pH, temperature, dissolved oxygen, total alkalinity, and some settleable solids.

Analyses were performed according to Standard Methods[7] with the following exceptions: volatile acids[8], National Canners Association's[9] modified chemical oxygen demand (COD_m), nitrate nitrogen[10], Kjeldahl nitrogen[11], total and ortho-phosphate[12], and total and dissolved organic carbon[13]. In addition to the regular BOD and COD analyses, during the second season most of the samples were centrifuged, with these analyses repeated on the centrates. Other analyses performed on most of the samples included: total solids, total volatile solids, suspended solids, volatile suspended solids, nitrate nitrogen, and ammonia nitrogen.

Table 4 presents the feed rates and theoretical detention times for the main periods of operation of the three ponds. As mentioned earlier, both ponds II and III were operated as incomplete-mix, covered anaerobic units during the September 20 to December 23, 1966, period. From January 2, 1967, on, pond III contained a 5 hp aerator and was operated in series with pond II. Both ponds I and II were fed primary clarifier effluent.

Results

Anaerobic Pond - (unmixed)

A summary of the data collected during the September 20 to December 23, 1966, period when both ponds II and III were operated as covered anaerobic units is presented in Table 5. Pond II was

Table 4

PILOT PLANT FEED RATES

		Pond I		Pond II		Pond II	
No.	Date	Q[a]	t[b]	Q	t	Q	t
1	9/20-12/23/66			1.8	20	8.8	4
2	1/02-01/19/67			1.2	30		
3	2/23-03/20/67			4.0	8.8	4.0	8.8
4	3/29-04/23/67			7.0	5.0	7.0	5.0
5	4/30-05/27/67			15.0	2.4	15.0	2.4
6	9/26-12/19/67	4.0	7.8	8.0	3.9	8.0	3.9
7	1/02-02/29/68	7.5	4.2	15.0	2.1	15.0	2.1
8	3/01-04/02/68	7.5	4.2	10.0	3.1	10.0	3.1
9	4/03-06/15/68	3.0	10.4	6.0	5.2	6.0	5.2

a) Flow through rate - gpm

b) Theoretical detention time - days

Table 5

DATA SUMMARY, 9-20-66 THROUGH 12-23-66

Parameter	Average Concentration[a] Clarifier Effluent	Pond II Effluent	Pond III Effluent	Reduction[b] % Pond II	Pond III
BOD	1490	1160	1240	22	17
COD_s	3130	2160	2500	31	20
COD_m	2380	570	700	76	71
TS	4010	2600	2880	35	28
TVS	2210	1200	1430	46	35
SS	950	360	420	62	56
VSS	860	170	320	80	63
Alk.	870	1010	1010		
Temp. range °F	65-77	60-68	61-69		
pH range	10.3-11.8	6.3-7.0	5.8-7.1		

(a) mg/l unless noted otherwise

(b) Both ponds anaerobic, detention times

pond II - 20 days
pond III - 4 days

fed at a rate of 1.8 gpm which resulted in a theoretical detention period of 20 days and pond III at 8.8 gpm had 4 days. The contents of neither pond were mixed and, judging by the data, short-circuiting occurred in pond II and possibly in pond III. The effluents from both ponds were nearly identical in total alkalinity, pH, and temperature. Had the actual detention time of pond II approached 20 days, the temperature drop should have been more than that observed.

Organic reductions in both ponds were rather low, 22 percent BOD and 31 percent COD for pond II, and 17 and 20 percent, respectively, for pond III. With a BOD loading of 4.7 lbs/day/1000 cu. ft. on pond II, expected reductions would be higher than those observed. A possible reason, other than shortcircuiting, is that it was not operated long enough to properly establish the second stage of anaerobic decomposition-methane formation. The fact that both ponds showed +70 percent reductions in COD_m reveals that changes in molecular structure were taking place. Sedimentation of suspended solids probably accounted for much of the measured reductions in both BOD and COD.

Pond II reduced the suspended solids by 62 percent or 590 mg/l and pond III reduced them by 56 percent or 530 mg/l. The primary clarifier lowered the BOD by 66 mg/l for every 100 mg/l of suspended solids that were removed. If this ratio is assumed for the solids removed by the anaerobic ponds, then the BOD should have been lowered by 390 mg/l across pond II and 350 mg/l across pond III. Measured reductions were 330 and 250 mg/l, respectively.

Anaerobic Pond II - (complete mix)

A summary of the data collected on anaerobic pond II when it was operated as a completely mixed unit is shown in Table 6. The run numbers refer to the listings shown in Table 4. Clarifier overflow was fed to pond II at rates of 1.2 to 15 gpm. These rates resulted in detention times of 30 to 2.1 days as shown in Table 7, which also presents the loadings and average reductions in COD and BOD. Pond loadings varied from 3 to 46 pounds BOD per 1000 cubic feet of volume with a resultant range in BOD reduction of 3 to 50 percent. Reduction in COD ranged from 5 to 47 percent.

Ammonia nitrogen concentration in the effluent averaged 33 mg/l as N and total Kjeldahl nitrogen averaged 80 mg/l. The former had a range of 13 to 88 mg/l and the latter 41 to 119 mg/l. The primary clarifier effluent had an average total Kjeldahl nitrogen concentration of 84 mg/l (Table 3) but this average included the time period when the anaerobic pond operated as an incompletely-mixed unit. This, coupled with the fact that no sludge was found on the bottom during operation or upon termination of the study, indicates that the contents were mixed thoroughly.

Table 6

DATA SUMMARY FOR ANAEROBIC POND II

Run No.	Flow gpm	Temp. °F	COD		SS		VSS		BOD		BOD_S	
			In	Out	In	Out	In	Out	In	Out	In	Out
2	1.2	54	3110	1640	360	470	360	260	1550	780		
3	4	61	3950	2510	530	310	490	280	1460	1180		
4	7	68	3280	2930	400	420	360	360	1770	1600		
5	15	71	3400	2880	610	380	540	300	1690	1520		
6	4	62	2190	1570	460	440	430	350	1470	1240	1180	1060
7	15	63	2210	1770	560	400	500	370	1500	1460	1360	1350
8	10	62	2280	2170	470	400	440	360	1690	1610	1510	1470
9	6	68	2390	2000	350	470	330	460	1610	1410	1440	1410

Table 7

LOADINGS AND REDUCTIONS FOR ANAEROBIC POND II

Run No.	D.T. days	lbs BOD/day/ 1000 cu.ft.	BOD Red. %	COD Red. %
2	30	3.3	50	47
3	8.8	11	19	36
4	5.1	22	10	11
5	2.4	46	10	15
6	7.8	12	16	28
7	2.1	45	3	20
8	3.1	34	5	5
9	5.2	19	12	16

Effluent from the clarifier contained an average of 14.2 mg/l of total phosphates as phosphorus while the effluent from pond II averaged 14.5 mg/l with a range of 7.8 to 20.3 mg/l. Orthophosphate in the effluent ranged from 2.1 to 7.7 mg/l and averaged 4.6 mg/l.

The ratio of BOD to total Kjeldahl nitrogen in the effluent averaged 18 to 1 as compared to 19 to 1 for the effluent from the primary clarifier. It had a range of 8:1 to 28:1. The overall range was slightly reduced from that observed for the clarifier effluent, 7 to 33:1.

In the clarifier effluent the ratio of BOD to total phosphates as P was 130:1 with a range of 48 to 285:1. This was also reduced upon passage through the anaerobic lagoon as it ranged from 67 to 173:1 and averaged 107:1 in the lagoon effluent.

Aerobic Pond I

A summary of some of the data collected for aerobic pond I containing the 10 hp surface aerator is shown in Table 8 along with BOD loadings and both BOD and COD reductions. Three levels of hydraulic loading were fed to the pond: 3, 4, and 7.5 gpm, resulting in theoretical detention times of 10.4, 7.8, and 4.2 days, respectively. Although the average temperatures of the lagoon contents were 44 and 47°F, daily temperatures as low as 32°F were measured.

Table 8

DATA SUMMARY FOR AEROBIC POND I

Run No.	gpm	D.T. days	Temp. °F	COD In	COD Out	SS In	SS Out	VSS In	VSS Out	BOD In	BOD Out	BOD_5 In	BOD_5 Out
6	4	7.8	44	2210	860	490	630	440	560	1410	270	1060	70
7-8	7.5	4.2	44	2160	1480	470	700	420	610	1580	710	1440	340
9	3	10.4	47	2390	1190	310	650	280	620	1700	310	1440	75

Run No.	LOADINGS lbs BOD/acre/day	lbs BOD/day/1000 cu. ft.	lbs BOD/day/lb. MLVSS	COD Red. %	BOD Red. %	BOD_5 Red. %
6	1840	11.3	0.32	61	81	93
7-8	3870	23.7	0.62	31	55	76
9	1660	10.2	0.26	50	82	95

BOD loadings on the pond are shown as lbs/acre/day, lbs/day/1000 cu.ft., and lbs/day/lb MLVSS. In run number 6 the loading was 1840 lbs/acre/day or 11.3 lbs BOD/day/1000 cu.ft. and this resulted in a COD reduction of 61 percent, total BOD reduction of 81 percent, and soluble BOD_S reduction of 93 percent. It should be emphasized that the measured effluent BOD of 270 mg/l contained all the suspended solids (630 mg/l) since the lagoon was completely mixed and no secondary settling facilities were in use. When the load was increased to 3870 lbs BOD/acre/day the reductions fell off: 31 percent for COD, 55 percent for total BOD, and 76 percent for soluble BOD.

The last run, number 9, at 3 gpm produced an effluent with a total BOD of 310 mg/l and a soluble BOD_S of 75 mg/l for reductions of 82 and 95 percent, respectively.

Aerobic Pond III

Table 9 presents a summary of some of the data collected on aerobic pond III which contained the 5 hp surface aerator. Effluent from anaerobic pond II was fed to this pond at varying rates of 4 to 15 gpm during the two processing seasons. These rates resulted in theoretical detention times ranging from 2.1 to 8.8 days. The approximate average temperatures of the lagoon contents ranged from 39 to 56°F as shown in Table 9. Individual daily temperatures ranged from 32 to over 60°F.

With the exception of run number 7, the dissolved oxygen content of the lagoon exceeded 1.5 mg/l. Several readings

Table 9

DATA SUMMARY FOR AEROBIC POND III

Run No.	Q gpm	D.T. days	Temp. °F	COD In	COD Out	SS In	SS Out	VSS In	VSS Out	BOD In	BOD Out	BOD_5 In	BOD_5 Out
3	4	8.8	39	2380	1400	250	730	240	630	1150	180		
4	7	5.1	44	2930	1250	490	820	420	790	1600	270		
5	15	2.4	56	2910	2160	260	860	210	710	1510	640		
6	8	3.9	44	1540	860	410	580	360	510	1150	380	980	80
7	15	2.1	43	1770	1600	400	810	360	650	1460	730	1350	485
8	10	3.1	43	2170	1300	470	890	410	790	1670	550	1470	190
9	6	5.2	50	2150	1100	410	510	340	500	1480	370	1440	110

during run 7 were less than 0.5 mg/l which may have hindered the rate of organic reduction. During that run the average loading on the pond was 260 pounds BOD/day with some loads exceeding 300 pounds.

The average loadings during the seven runs, along with percentage reductions in BOD and COD, are shown in Table 10. In pounds of BOD per acre per day the loading varied from 1500 to 7400 or from 8 to 40 lbs/day/1000 cu.ft. The COD average reduction ranged from 10 to 57 percent and BOD reduction ranged from 50 to 84 percent. During the last four runs, when soluble BOD_S was routinely measured, its reduction averaged 19 percent higher than the reduction in total BOD.

Table 10

LOADINGS AND REDUCTIONS FOR POND III

Run No.	BOD Loadings lbs/acre/day	lbs/day/1000 cu.ft.	lbs/day/lb MLVSS	Reductions-% COD	BOD	BOD_S
3	1500	8	0.21	41	84	
4	3660	20	0.40	57	83	
5	7400	40	0.88	26	58	
6	3000	18	0.58	44	67	92
7	7150	44	0.96	10	50	64
8	5460	33	0.68	40	67	87
9	2900	18	0.57	49	75	92

DISCUSSION

To gain as much information as possible from the data generated during the two processing seasons, several available mathematical relationships were reviewed in an attempt to describe the kinetics of both the anaerobic and the aerobic ponds. In 1942 Monod[14] expressed the relationship existing between bacterial growth rate and the concentrations of a growth limiting nutrient as follows:

$$\frac{dF}{dt} = \frac{k\,M\,s}{K_S + s} \qquad (1)$$

where: $\frac{dF}{dt}$ = rate of waste utilization per unit volume of reactor, mass/volume-time

s = soluble waste concentration in the reactor, mass/volume

M = microorganism concentration, mass/volume

k = maximum rate of waste utilization per unit weight of microorganism at high waste concentration, $time^{-1}$

Ks = half velocity constant equal to the waste concentration when $\frac{dF}{dt}$ is equal to 1/2 of the maximum rate, $\left(\frac{dF}{dt}\right)$ max., mass/volume

According to this equation, at high waste concentrations the waste utilization rate approaches a maximum value which is essentially independent of waste concentration and, at low waste concentration, the rate is proportional to the waste concentration.

This equation, along with appropriate materials balance equations, has been widely used to describe both activated sludge and anaerobic waste treatment kinetics.

Combining equation (1) with the following empirical equation describing the net growth of microorganism as a function of time,

$$\frac{dM}{dt} = a\left(\frac{dF}{dt}\right) - b\,M \qquad (2)$$

where: $\frac{dM}{dt}$ = microorganism net growth rate per unit volume of digester, mass/volume-time

a = growth yield constant

b = microorganism decay constant, time^{-1}

will give the following equation:

$$s = \frac{K_s(1+bt)}{akt-(1+bt)} \qquad (3)$$

where: t = hydraulic detention time, time

It is readily seen that the soluble waste concentration in the reactor is a function of detention time only once the constants a, b, k, and K_s are obtained. For a completely-mixed, aerated lagoon, the soluble waste concentration in the lagoon would be the same as that in the effluent.

Equation (1) can also be rearranged to show the microorganism concentration in the reactor as a function of the waste removed and the detention time as follows:

$$M = \frac{(L-s)(K_s+s)}{k\ s\ t} \qquad (4)$$

where: L = influent waste concentration, mass/volume

The microorganism concentration in the effluent will be the same as in the lagoon for a completely-mixed system.

For aerobic pond I the necessary constants were derived for use in equations (3) and (4). The soluble BOD_S and volatile suspended solids concentrations in the effluent from the pond were calculated using the following values for the constants:

K_S = 110 mg/l

k = 0.64 day^{-1}

a = 0.63

b = 0.06 day^{-1}

The total BOD in the effluent was calculated from:

BOD = s + c M

where: BOD = total effluent BOD, mg/l

s = soluble effluent BOD_S, mg/l

M = effluent VSS

c = BOD equivalent of the effluent VSS

From data collected on both aerobic ponds the value of "c" was found to vary with detention time as shown on Figure 5:

$$c = \frac{1.68 - \log (t)}{2.51} \qquad (5)$$

The following table compares these calculated values with the observed concentrations.

Run No.	VSS Meas.	VSS Cal.	BOD_S Meas.	BOD_S Cal.	BOD Meas.	BOD Cal.
6	560	560	70	95	270	270
7&8	610	640	340	320	710	590
9	620	630	75	70	310	240

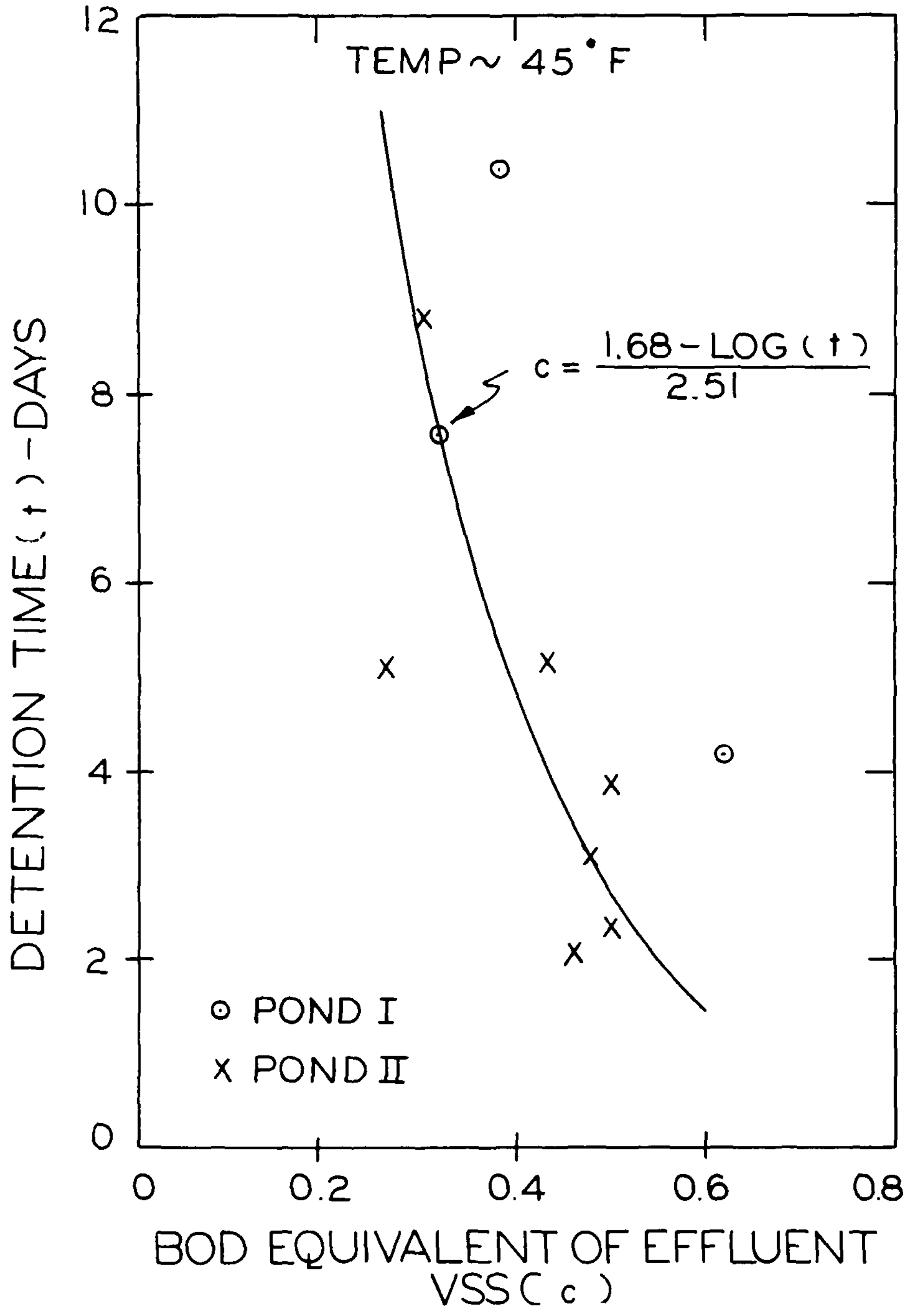

Figure 5.---INFLUENCE OF DETENTION TIME ON BOD OF EFFLUENT VSS

As shown by the comparisons of both the soluble BOD_S and the volatile suspended solids, the equations adequately describe the kinetics. Differences between the calculated and measured values of volatile suspended solids and soluble BOD_S are all within the accuracy limits of the tests. There is a significant difference between the calculated and measured total BOD for the last two sets; 590 versus 710 and 240 versus 310. Some of this difference can be explained by the data points shown on Figure 5. These points were calculated from the observed values as follows:

$$c = \frac{BOD - BOD_S}{VSS} \qquad (6)$$

Since there were only three values for pond I (open circles) they were combined with the data from pond III and a single curve was estimated for all the data. If a separate curve had been drawn for pond I to the right of the existing curve, all three calculated total BOD values would have been within 10 percent of the measured concentrations. Due to the lack of additional data, a single curve was deemed sufficient for both ponds.

At this point it should be pointed out that all of the discussion concerning the values of the constants a, b, k, and K_S, as well as the relationship shown on Figure 5, refers only to a limited temperature range. The average lagoon temperatures for the three runs were 44, 44, and 47°F (Table 8); therefore, it was not possible to determine if the constants as well as the relationship shown for "c" versus "t" were temperature dependent. Temperature would affect the curve on Figure 5 but it is not certain whether it would affect all four of the constants. Over one-half the points for pond III on Figure 6 were also from runs with an average temperature of about 44°F (Table 9), so the same comments hold for the pond III kinetics discussed later.

By using equations (3), (4), (5), and (6) and the values for the constants shown previously, a set of curves was calculated to show the influence of contact time on soluble BOD_S, total BOD, and volatile suspended solids. These curves, shown on Figure 6, would be the expected results when a surface-aerated pond such as pond I was used to treat clarifier effluent containing a BOD of 1600 mg/l. At a hydraulic detention time of four days the soluble BOD_S in the effluent would be about 370 mg/l, VSS would be 620 mg/l, and the total BOD would be 640 mg/l. Increasing the detention time to eight days would reduce the soluble and total BOD to 90 and 290 mg/l, respectively. The VSS would be about the same, 640 mg/l. With a detention time of six days or higher, 90 percent BOD reduction (effluent = 160 mg/l) could be obtained by removal from the effluent of a known amount of VSS. For example, with a detention time of

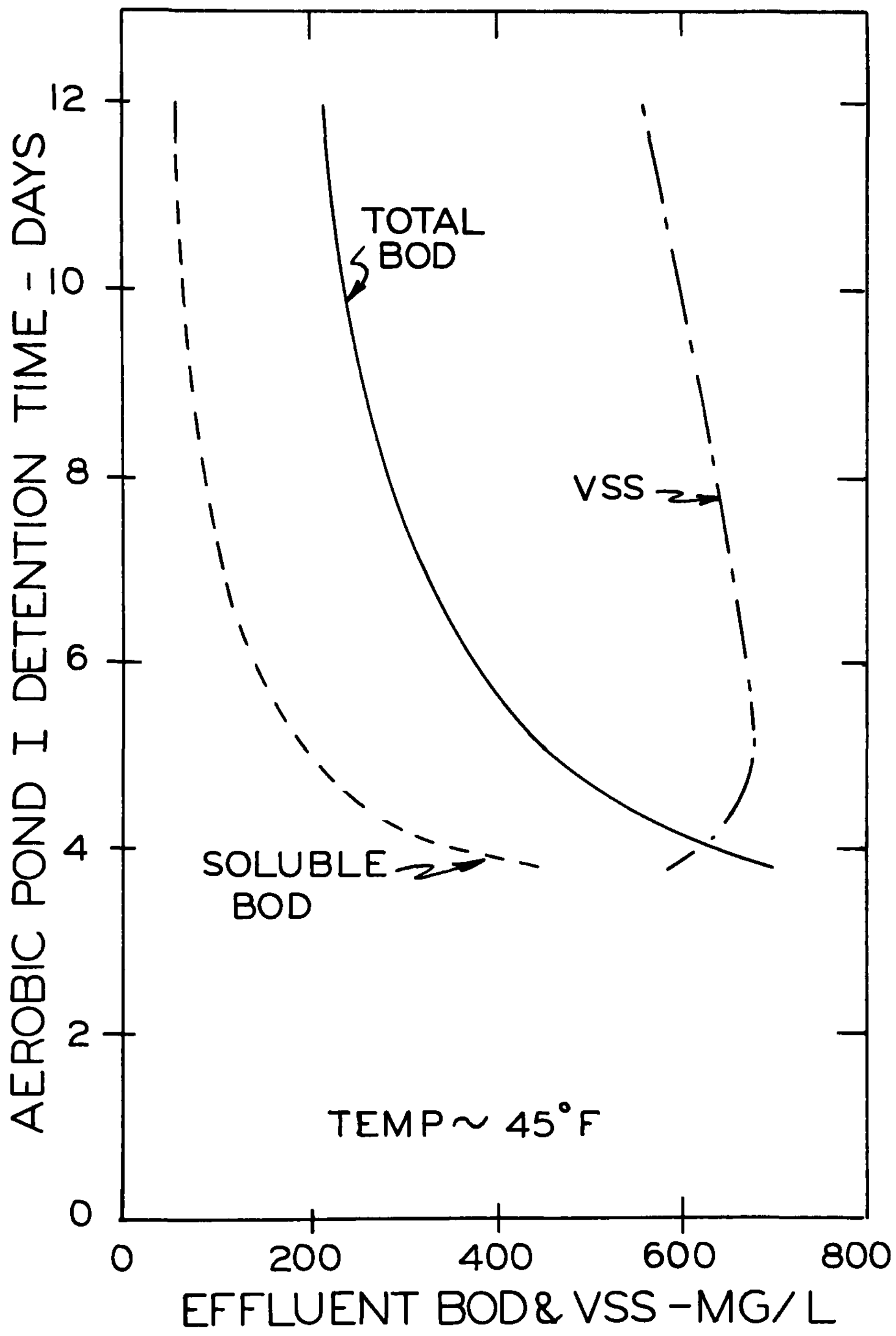

Figure 6.···PREDICTED INFLUENCE OF DETENTION TIME ON EFFLUENT BOD & VSS

eight days, the required VSS reduction would be:

$$R_{vss} = \frac{M-\left(\frac{E-s}{c}\right)}{M} = \frac{640-\left(\frac{160-90}{(0.31)}\right)}{640} = 65\% \qquad (7)$$

where: E = desired total effluent BOD-160 mg/l,

R_{vss} = required VSS reduction

In the completely-mixed, anaerobic pond II, it was assumed that the rate of waste utilization or stabilization was a constant or

$$\frac{dF}{dt} = K \qquad (8)$$

or $F_o - F_{eff} = Kt$

where: F_o = total influent BOD, mg/l

F_{eff} = total effluent BOD, mg/l

t = detention time, days

K = constant, $days^{-1}$

For the various runs the constant K was corrected for temperature by the following:

$$K_T = K_{20}(1.04)^{T-20} \qquad (9)$$

where: T = temperature, °C

combining equations (8) and (9) and using a value of 35 per day for K_{20} gave:

$$F_{eff} = F_o - 35t(1.04)^{T-20} \qquad (10)$$

The table on the following page compares the observed effluent BOD concentrations with those calculated with this equation.

Run No.	Effluent BOD Measured	Calculated	Difference
2	780	780	0
3	1180	1200	20
4	1600	1590	10
5	1520	1600	80
6	1240	1230	10
7	1460	1440	20
8	1610	1600	10
9	1410	1430	20

Agreement between the measured and calculated values is very good considering the accuracy of the BOD test. Only one value in the difference is greater than two percent of the BOD concentration and it is only about five percent, well within the limits of the test.

Figure 7 presents three curves which show the influence of detention time on total effluent BOD at three different operating temperatures with an assumed influent BOD of 1600 mg/l and equation (10). With a 10-day detention time the effluent BOD would be 1360, 1250, and 1170 mg/l at 10, 20, and 25°C, respectively. Percentage reductions would equal 15, 22, and 27 percent, respectively. These reductions would increase to 29, 44, and 53 percent at the three temperatures with a detention time of 20 days.

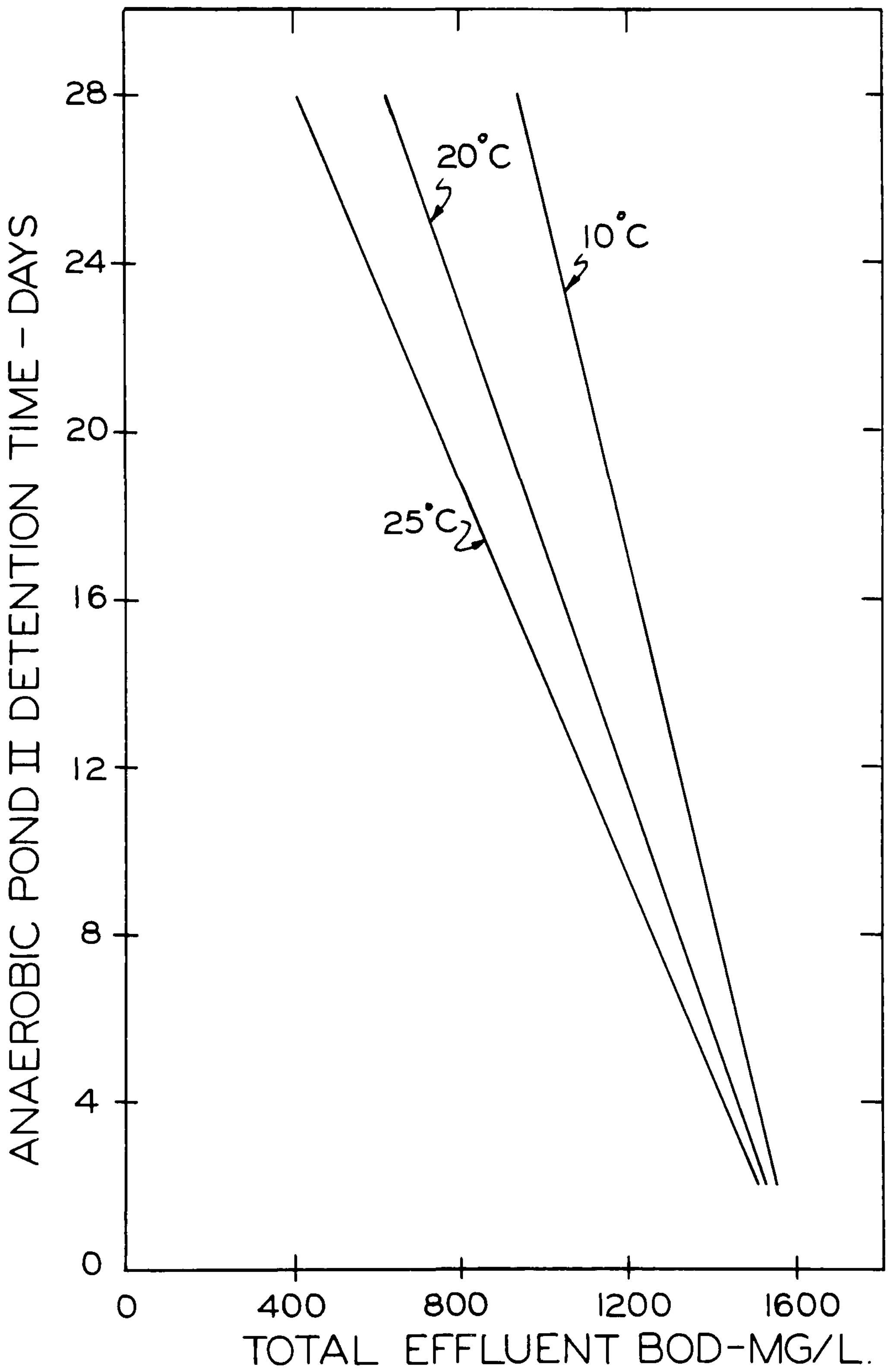

Figure 7. ··· INFLUENCE OF TIME & TEMPERATURE ON CALCULATED EFFLUENT BOD

No attempt was made to formulate the change in suspended solids upon passage through the anaerobic lagoon. It was shown earlier that the volatile suspended solids in the effluent from pond I depended upon time and the amount of BOD removed. Therefore, the solids concentrations in anaerobic pond II effluent were not needed inasmuch as the same kinetic relationships were used for both aerobic ponds I and III.

For aerobic pond III which received the effluent from anaerobic pond II, the constants required in equations (3) and (4) were assigned the following values:

$$K_s = 140 \text{ mg/l}$$

$$k = 1.1 \text{ day}^{-1}$$

$$a = 0.63$$

$$b = 0.06 \text{ day}^{-1}$$

The same values of "a" and "b" were used for pond III as were used for aerobic pond I. As mentioned earlier, the relationship shown for "c" on Figure 5 and by equation (5) was used for both aerobic ponds I and III. The following table compares the observed values of soluble BOD_s, total BOD, and volatile suspended solids with those calculated using the various equations.

As shown in the table, the calculated values of volatile suspended solids are within 10 percent of the measured values except for runs 3, 7, and 9. Agreement on soluble BOD_s in the

Run No.	VSS Meas.	VSS Cal.	BOD_S Meas.	BOD_S Cal.	BOD Meas.	BOD Cal.
3	630	450		47	180	180
4	790	730		82	270	360
5	710	660		310	640	650
6	510	520	80	120	380	360
7	650	550	485	480	730	780
8	790	800	190	170	550	550
9	500	670	110	80	370	340

effluent as well as total BOD is very good inasmuch as only one calculated value is more than 50 mg/l from the observed concentration. Soluble BOD_S was not measured during the first three runs shown in this table.

In view of the fact that no corrections were made for operating temperatures and that several times during various runs the aerator was turned off for repairs, overall agreement of the measured values with those obtained from the kinetic relationships is very good.

Although there was some difference in the value of "K_S" for the two aerobic ponds, 110 for pond I versus 140 for pond III, the primary difference was in the value of "k,", the maximum rate of waste utilization per unit weight of microorganisms at high waste concentrations. For pond I a value 0.64 per day was used as compared to a value of 1.1 for pond III, 56 percent higher. Although the anaerobic pond did not remove many organics as measured by BOD, it very probably altered the molecular structure of many of the more complex organic materials which made them more treatable aerobically. The influence of the different values of "k" and "K_S" on the soluble BOD_S in the effluent is shown on Figure 8. It was assumed both ponds received the same BOD concentrations in the feed so that a direct comparison of effluents could be made. At detention times of six days or less the soluble effluent BOD_S in pond I effluent would be more than double that in the effluent from pond III. A four-day detention time would result in a soluble effluent BOD_S of 370 mg/l for pond I and 110 mg/l for pond III.

The kinetic relationships developed for anaerobic pond II and aerobic pond III can be combined to calculate a series of curves similar to those presented in Figure 6 for pond I. On Figure 9 is shown the influence of contact time in both the anaerobic and aerobic cells on the total BOD in the effluent from the aerobic unit. Also shown is the soluble BOD_S in the aerobic pond effluent but this is independent of the detention time in the anaerobic unit since it does not depend upon the BOD concentration in the aerobic pond influent. An average operating temperature of 63°F (K = 32 per day) was assumed for the anaerobic pond and 45°F for the aerobic pond.

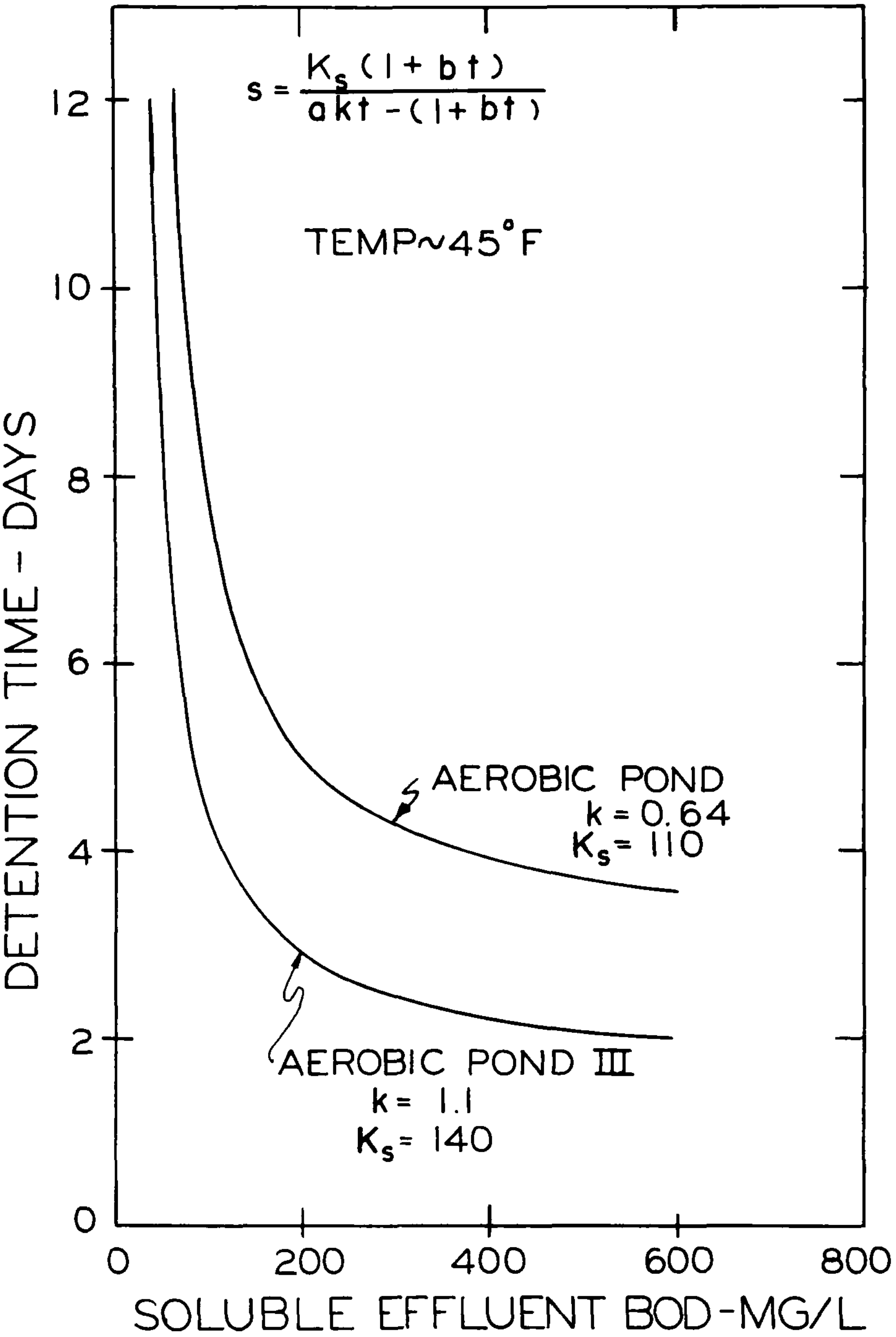

Figure 8.—COMPARISON OF TREATABILITY OF PRIMARY EFFLUENT vs. ANAEROBIC EFFLUENT

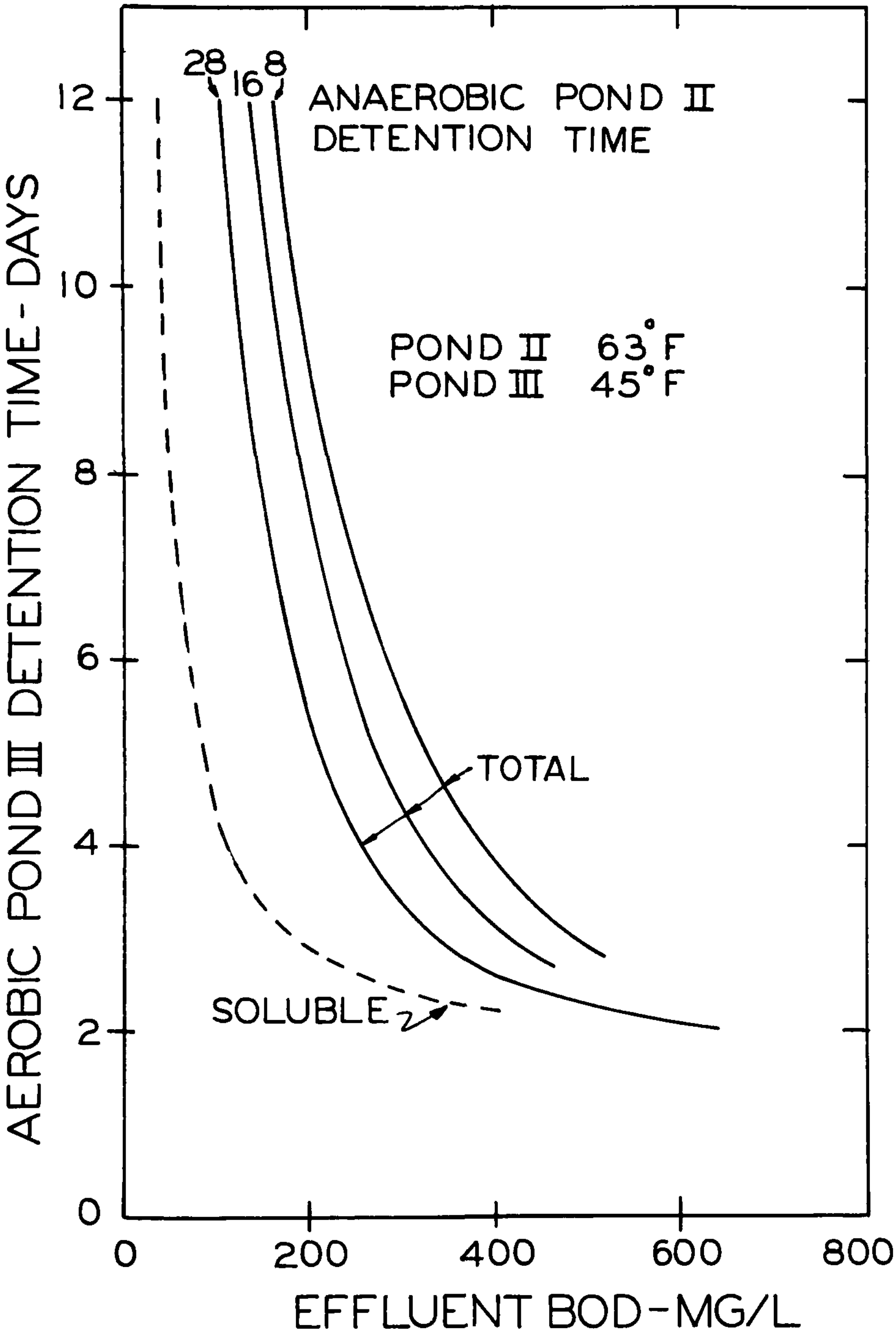

Figure 9.··· INFLUENCE OF DETENTION TIME IN ANAEROBIC POND II & AEROBIC POND III ON SOLUBLE & TOTAL EFFLUENT BOD FROM POND III

For any specific concentration of BOD in the final effluent, a comparison of Figures 6 and 9 shows that when just detention time is considered, aerobic pond I will result in a lower total BOD than the sum of the detention times in ponds II and III. This is only true when secondary clarification is not considered. The soluble BOD_S in the effluent from pond III is markedly lower than it is in the effluent from pond I so, if secondary clarification is employed, a better effluent could be obtained from the anaerobic-aerobic combination than from the straight aerobic unit.

The quantity of volatile suspended solids in the effluent from pond III could differ markedly from pond I, depending mainly upon the detention time in the anaerobic lagoon as shown on Figure 10. With a four-day detention period in the aerobic pond an increase in detention time in the preceding anaerobic pond from 8 to 16 days would result in a reduction in volatile suspended solids in the aerobic pond effluent from 630 to 500 mg/l. The combination of 28 days' detention time in the anaerobic pond and 4 days in the aerobic pond would produce an effluent with an estimated volatile suspended solids concentration of 330 mg/l or nearly one-half the value of that obtained with only 8 days detention time in the anaerobic pond.

Mixing of the anaerobic pond in an anaerobic-aerobic system may not be required in a full-scale installation, depending

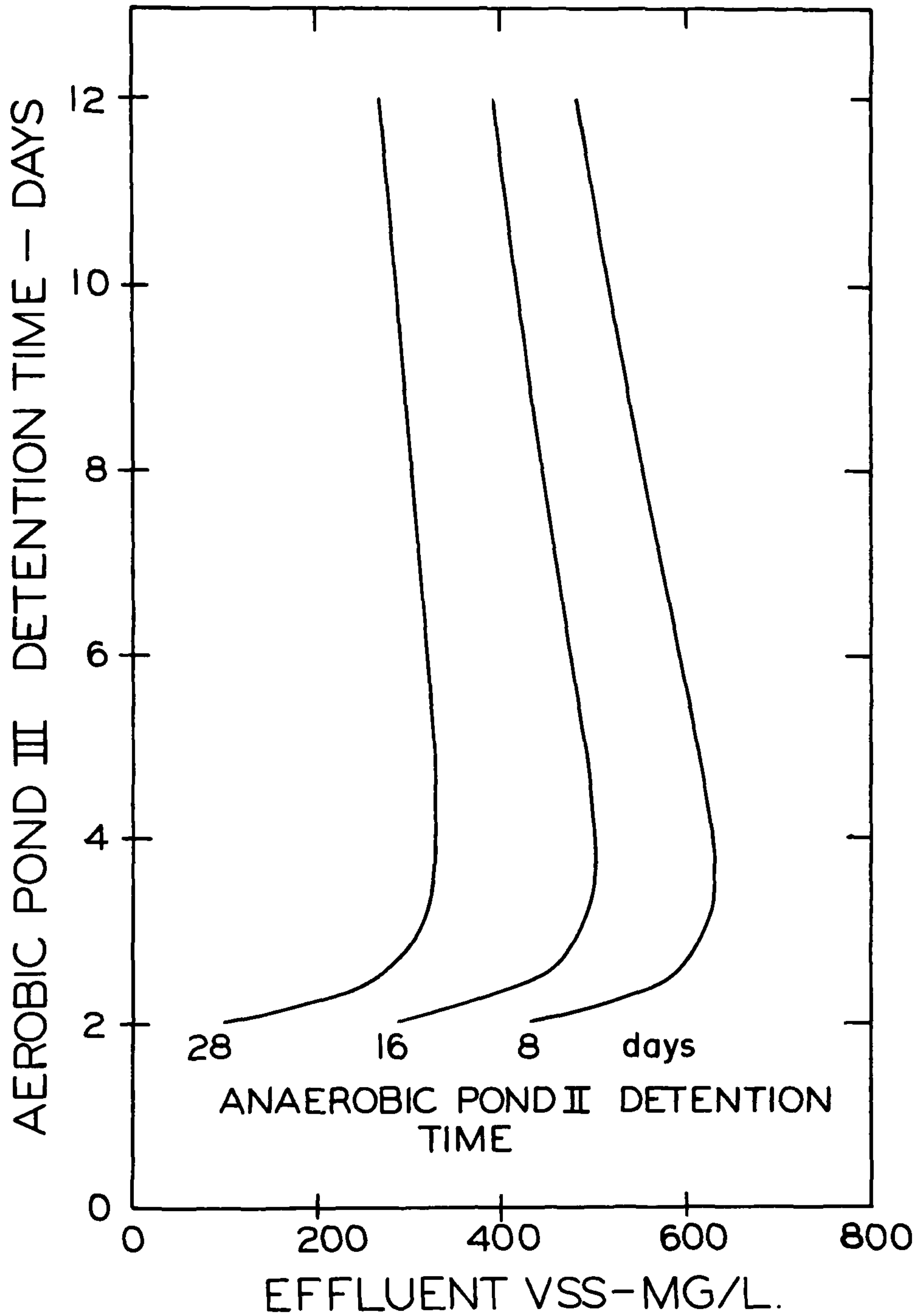

Figure 10.---INFLUENCE OF DETENTION TIME ON POND III EFFLUENT VSS

upon its operational flexibility. An unmixed anaerobic lagoon will remove suspended solids which will accumulate during the cold winter months, unless the lagoon is insulated or its contents heated. Then, as the temperatures increase in the spring, the rate of biological decomposition of the sludge will increase and may result in the effluent from the anaerobic pond containing more BOD than its influent. This was demonstrated during earlier[(5)] pilot plant studies. As a result, the BOD load applied to an aerobic lagoon in series with the anaerobic unit would vary markedly with the climate. This potential increase in load would have to be considered in the design by the use of additional aerators or the use of some two-speed aerators.

Elimination of the mixing in the anaerobic lagoon would be advantageous because it would allow some build-up of solids within the system. This would have the same effect as recycled sludge does in an activated sludge or anaerobic contact process. The loadings on an unmixed anaerobic lagoon in lbs. BOD/day/lb. MLVSS might vary markedly due to this retention of solids within the system. In fact, this could partially explain some of the reported differences in efficiencies in anaerobic systems when they are compared according to loadings in lbs. BOD/day/1000 cu.ft.

Either of the two systems studied will discharge excessive amounts of suspended solids without a secondary solids removal step. Information concerning the ease of solids removal from the effluent of ponds I and III was not obtained due to the lack of manpower and equipment. Data on solids removal from these effluents at various hydraulic and organic loadings would be desirable. Some of this information may be forthcoming from additional studies being conducted during the current (1968-69) processing season.

During the studies reported herein no attempt was made to evaluate "α" or "β", both of which would be needed to design an aerobic system using surface aerators. By definition, "α" is the ratio of oxygen transfer rate in the lagoon contents to the oxygen transfer rate in water, and "β" is the ratio of the oxygen saturation concentration of the lagoon contents to the oxygen saturation concentration of water. Both of these parameters can vary from one day to another at any given plant besides varying between plants due to differences in processing, etc. Evaluation of both "α" and "β" should be made at the plant under consideration prior to design of required horsepower.

Likewise, no attempt was made to formulate the temperature drop across either the anaerobic pond or the aerobic units used in this study. Full-scale lagoons would have an area-to-volume ratio much different from the ratio for the ponds in this study. The horsepower per unit volume in a full-scale aerobic unit would also be different inasmuch as these ponds had excessive horsepower at some of the organic loadings experienced in this study.

This study has demonstrated that the organic material present in potato processing wastes can be reduced by 90 percent or more using either surface-aerated aerobic lagoons or anaerobic plus surface-aerated aerobic lagoons following primary clarification. Mathematical formulations have been presented along with assigned values for the required constants for both of the systems studied. These formulations, accompanied by proper inputs on costs of land, equipment, power, labor, etc., will allow economic comparisons to be made between the two systems reported herein as well as with activated sludge and trickling filter systems.

REFERENCES

1. Agricultural Statistics, 1966. U. S. Department of Agriculture, U. S. Government Printing Office, Washington, D. C., 1966.

2. Anon., "Frozen Potatoes: Computer Projection of Growth The Next Ten Years," Quick Frozen Foods, p. 31, December 1967.

3. "Idaho Image," Idaho State Department of Commerce and Development, Boise, Idaho, July 1967.

4. "Implementation, Enforcement, and Surveillance Plan for the Rules and Regulations for Standards of Water Quality for the Interstate Waters of Idaho," Idaho Department of Health, Boise, Idaho, June 1967.

5. "An Engineering Report on Pilot Plant Studies--Secondary Treatment of Potato Process Water," Cornell, Howland, Hayes & Merryfield, Engineers and Planners, Boise, Idaho, September 1966.

6. Atkins, P. F., Jr. and O. J. Sproul, "Feasibility of Biological Treatment of Potato Processing Wastes." Journal Water Pollution Control Federation, p. 1287, August 1966.

7. Standard Methods for the Examination of Water and Wastewater, 12th Edition, 1965, Boyd Printing Co., Inc. Albany, New York.

8. DiLallo, R. and O. E. Albertson. "Volatile Acids by Direct Titration," Journal Water Pollution Control Federation, p. 356, April 1961.

9. Rose, W. W. and W. A. Mercer. "Chemical Oxygen Demand as a Test of Strength of Cannery Waste Water." National Canners Association Research Laboratories, Berkeley, California, May 16, 1956.

10. Kamphake, L., S. Hannah, and J. Cohen, "Automated Analysis for Nitrate by Hydrazine Reduction." Water Research I, 205, (1967).

11. Anon, Aminco Reprint No. 104. American Instrument Co., Inc., June 1959.

12. Strickland, J. D. H. and T. R. Parsons, "A Manual of Sea Water Analysis." Bulletin No. 125, 2nd Ed., p. 47, Revised Fisheries Research Board of Canada.

13. ASTM D-2579-T, issued 1967. Published by ASTM, 1916 Race Street, Philadelphia, Pennsylvania.

14. Monod, J., Recherches sur la croissance des cultures bacteriennes. Paris: Hermann and Cie, 1942.

APPENDIX

Table A-1 presents averages and standard deviations for various ratios generated from the data collected during the two processing seasons. Thirteen pair of analyses were used to determine the ratio of BOD to COD_m for each of four sampling points. The averages ranged from 0.47 for aerobic pond III effluent to 1.80 for anaerobic pond II effluent and the standard deviation ranged from 21 to 66 percent of the average. As a result of this variability the COD_m test was discontinued after the first processing season.

COD was a better indicator of BOD than COD_m, but even the BOD to COD ratio showed a large variability. In the aerobic pond effluents this ratio was as low as 0.10 but this is common in secondary effluents. Generally, the BOD:COD ratio will decrease with increasing degree of treatment.

The average TOC to BOD ratio was relatively constant from one sampling point to another as the overall average ranged from 0.50 for pond II effluent to 0.67 for pond I effluent. The standard deviation was high for each location as it ranged from 25 to 43 percent of the average.

Soluble BOD_s to soluble COD_s ratios were similar to the BOD to COD ratios.

Table A-1

No.*	Ratio	Clarifier Influent	Clarifier Effluent	Pond I Effluent	Pond II Effluent	Pond III Effluent
13	BOD/COD_m	0.63 ± 0.22**	0.74 ± 0.20	-	1.80 ± 0.38	0.47 ± 0.31
50	BOD/COD	0.53 ± 0.13	0.60 ± 0.14	0.42 ± 0.13	0.67 ± 0.23	0.35 ± 0.16
25	TOC/BOD	0.56 ± 0.22	0.59 ± 0.15	0.67 ± 0.29	0.50 ± 0.18	0.59 ± 0.21
20	BOD_S/COD_S	0.66 ± 0.09	0.77 ± 0.18	0.33 ± 0.14	0.94 ± 0.29	0.34 ± 0.19
55	VSS/SS	0.96 ± 0.04	0.91 ± 0.11	0.87 ± 0.11	0.83 ± 0.17	0.87 ± 0.11
35	TVS/TS	0.73 ± 0.05	0.62 ± 0.04	0.51 ± 0.10	0.52 ± 0.07	0.46 ± 0.07
35	BOD/P		130 ± 46		107 ± 26	
35	BOD/N		19 ± 6		18 ± 5	

*Pairs of analyses in average
**Mean ± 1 standard deviation

Both the VSS:SS and TVS:TS ratios had averages with small standard deviations. For any additional data collection, analyses for just SS and TS (if desired) would suffice.

The BOD:P and BOD:N ratios were discussed in the text of this report.