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Title: THE CHARACTER AND BIOLOGICAL TREATABILITY OF LOG POND WATER

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A study was conducted to determine the chemical nature and the biological treatability of log pond water. Various analyses including total solids, volatile solids, suspended solids, dissolved oxygen, pH, COD, BOD_5, BOD_{20}, total Kjeldahl nitrogen, nitrate nitrogen, phosphate, and PBI were performed on water samples from each of the four ponds studied. Each pond proved to be homogeneous with respect to these analyses. Factors such as log storage time and overflow rate were found to affect the chemical nature of the log ponds.

All the ponds had very low five-day biochemical oxygen demand (BOD_5) values in comparison to their respective chemical oxygen demand (COD) values, indicating high concentrations of non-biodegradable substances. The log ponds contained sufficient nitrogen and phosphorus to support biological activity.

Two bench scale extended aeration units were used for the biological treatability study. The log pond water was fed to the units which contained an acclimated sludge and this mixture was aerated.

The aeration units performed quite well and produced similar results. Generally, the longer the detention time, the higher the COD, BOD_5 and PBI removals. However, these removals tended to level off at the five-day detention period so a further increase in detention time would not have increased the removals substantially. The following removals were obtained with a five-day detention time: total COD = 63%, soluble COD = 52%, BOD_5 = 93%, PBI = 64%.

The mixed liquor suspended solids (MLSS) level ranged from 380 mg/l at a five-day contact period to 1060 mg/l at a one-day contact time. The oxygen uptake of the MLSS was only 3.1 mg O_2 per hour gram MLSS.

The unitless oxygen transfer parameter, α, was found to be 1.1 for log pond water demonstrating that the rate of oxygen transfer into log pond water was greater than into distilled water.

The results of this study clearly indicate that log pond water can be effectively treated using aerobic biological processes.

The Character and Biological Treatability of Log Pond Waters

by

Jack Wayne Hoffbuhr

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INTRODUCTION

General

Down through the ages, man has relied upon wood as one of his principal natural resources. Even in today's complex industrial society, wood is the world's most widely used raw material. Although the primary use of wood is still as a construction material, technological advances in wood chemistry and related fields have given birth to a whole new realm of forest products. The manufacture of pulp and paper, packaging materials, cellulosic fiber, plastics, drugs and other wood chemicals constitute vast industries and consume huge quantities of wood.

Wood Products Industry in the Pacific Northwest

The magnificent forests of the Pacific Northwest supply a very large percentage of the timber used in the United States. These forests contain 42 percent of all the softwood sawtimber and 35 percent of the total sawtimber in the Nation. Furthermore, during 1963 this region produced 41 percent of all the softwood lumber manufactured in the United States, and in 1962 produced 16 percent of the Nation's wood pulp (21). Obviously, the timber resources of the Pacific Northwest are a major factor in the economy of the region.

The wood pulping plants and sawmills operating in the Pacific Northwest find it necessary to store a large percentage of the logs they cut in order to maintain production during periods of the year when logging is impossible or impractical. Timber disasters, such as insect epidemics and forest fires, require logging the damaged trees rapidly in order to save the lumber. These salvage operations bring in logs faster than they can be processed; therefore, large scale storage is necessitated.

The most widely used storage method is simply floating the logs in a pond, lake, estuary or river. Not only is the handling of the logs greatly facilitated in this manner, but degrading factors such as end splitting, surface cracking, fungal attack and insect damage are inhibited due to the high moisture content which can be maintained in the logs. On the other hand, dry storage (cold decking) does not offer any of the above advantages. Sprinkling the cold decks can provide the same protection as floating storage, although the equipment required and the resulting runoff have thus far made this procedure more expensive and unwieldy.

The forest products industries have alleviated their storage dilemma by floating the logs, but perhaps have caused an even more serious problem, water pollution. Any threat to water quality in the Pacific Northwest is critical since the water resources form such an integral part of the region. Not only are these resources an immense source of enjoyment to the people living in the area, but they also are a vital economic factor. Sports fishing, water-based recreation and sight-seeing compose the foundation of a thriving tourist business. In addition, commercial fishing ranks as an important industry in the region. Obviously, a high standard of water quality is essential.

The pollution potential of logs rafted in lakes and rivers is readily apparent. Not so apparent, but very much a serious pollution threat, are the numerous log ponds which dot the Pacific Northwest. A great number of these ponds are operated on an overflow basis with the overflow being discharged to the nearest watercourse. The fact that there are approximately 12, 000 acres of log ponds in Oregon alone, stresses the extent of the problem (18). Before any corrective measures can be undertaken, however, an understanding of the many factors involved is imperative. Hopefully, this thesis will provide a portion of that understanding.

STATEMENT OF THE PROBLEM

The first objective of this study was to obtain data concerning the physical and chemical makeup of typical log ponds. Four ponds were chosen for the study. The water from these ponds was sampled and analyzed extensively in order to obtain an idea as to the homogeneity and character of each pond and how the ponds compared.

The second objective was to determine whether or not the log pond water could be degraded biologically. Two bench scale plastic treatment units were used in which the pond water was placed in contact with activated sludge and aerated. In order to make the study meaningful the log pond water was subjected to biological treatment at four different detention periods ranging from one to five days. Several analyses were performed during each detention period to determine to what degree the pond water was being assimilated by the activated sludge.

REVIEW OF LITERATURE

The Chemical Nature of Log Pond Water

Wood Chemistry

The composition of log pond water can be estimated by understanding a few basic principles of wood chemistry.

Wood is customarily differentiated into the major cell wall components and the extraneous components. The major cell wall components consist of cellulose, hemicelluloses and lignin. Cellulose makes up 40 to 50% of wood by weight. The hemicelluloses are polysaccharides which are closely related chemically to cellulose. Lignin forms the boundary between adjacent cells and acts as a cementing material which bonds the cells together (9. p. 9-18). With the exception of a small part of the lignin these components are insoluble in organic solvents and in water (24).

The extraneous components are soluble in many solvents, including water, and are frequently termed extractives for that reason. The character of the extractives depends upon the species of wood but generally include tannins, resins, essential oils, fats, terpenes, flavanoids, quinones, carbohydrates, glycosides, and alkaloids (24).

Douglas fir and ponderosa pine are the two predominant timber species in the Pacific Northwest; therefore, their extractives are of particular interest. Considerable research has been conducted on the extractives from the bark of the above two species. Since the vast majority of ponded logs still have their bark intact, the bark extractives could well be the major components of the pond water.

Kurth and Hubbard (13, 16) have reported that the principal water soluble extractive of Douglas fir and ponderosa pine bark is tannin. They found the tannin content of Douglas fir bark to vary from 7.5 to 18% (based on oven-dry bark weight) and that of ponderosa pine bark from 5.6 to 11.4%. Although the above percentages are based on hot-water extractions, Kurth (15) has found that the tannin content of bark taken from ponded logs is considerably lower, indicating that tannin is also soluble in cold-water.

In addition, Kurth, Hubbard and Humphrey (17) have found ponderosa pine bark to have a water soluble reducing sugar content of 3 to 6% (based on oven-dry weight of bark) while Douglas fir bark contained only one-tenth of this amount.

Log Pond Studies

McHugh, Miller and Olsen (18. p. 187) surveyed over 80 log ponds in Oregon in an attempt to find a chemical means to measure the degree of pollution of a pond. This is the only extensive study of log pond water found by this investigator to date. Generally, they found the log ponds to have high chemical oxygen demand (200 ppm[1] to 700 ppm) and total solids (200 ppm to 800 ppm) values. Average concentrations of 0.48 ppm for phosphates, 0.56 ppm for nitrates, and 5 ppm for soluble carbohydrates were reported. Very low concentrations of nitrites, sulfates, and dissolved oxygen were found for most all the ponds. The researchers also concluded that ponds containing logs without bark (peelers) were just as polluted as those containing an equivalent volume of bark-covered logs per unit volume of water.

Ellwood and Ecklund, (8) during a study of bacterial attack on pond stored logs, reported the following values for a log pond storing ponderosa pine: suspended solids = 38 ppm, dissolved oxygen = 0 ppm, pH = 6. 8. The authors attributed the strong, sour smell of log ponds to the production of organic acids as a result of carbohydrate breakdown by microorganisms present in the ponds.

Henriksen and Samdal (12) agitated bark with distilled water and measured the chemical oxygen demand (COD) at different intervals. After 65 hours they found that a total of 43, 200 mg. COD/kg bark had been extracted.

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[1] ppm = parts per million

Biological Treatment of Log Pond Water

This investigator found no reference to any method for the treatment of log pond water in the literature. However, many references describe numerous biological treatment methods being used by the pulp and paper industries on their wastes. The composition of pulping wastes and log pond water are probably similar in many respects. Of course, the pulping wastes are much stronger in terms of COD, total solids, etc. due to the nature of the pulping process.

The most popular method of biological treatment seems to be extended aeration using stabilization basins and mechanical aerators. Gellman (11) reported on seven such installations treating a total flow of 50 million gallons per day (MGD). These basins were providing as much as 90% biochemical oxygen demand (BOD) removal.

White (22) described a 76-acre aerated basin in Riegelwood, North Carolina. The basin receives a waste flow of 35 MGD and a BOD loading of 80, 000 lb./day. The installation of fourteen 60 horsepower (hp.) float-mounted, mechanical aerators have made possible BOD removals as high as 85%. Biological solids production is in the range of 0. 15 to 0. 2 lb. solids/lb. BOD removed.

An aerated basin in British Columbia, which provides over 70% BOD removal for 13 MGD of kraft mill effluent, was reported by Bailey (3). The 23-acre basin receives 15,000 lb. BOD/day and provides a seven-day detention time. Four 60 hp. and five 15 hp. aerators provide the required mixing and aeration.

Middlebrooks _et al._ (19) described a unique approach to the log storage waste treatment problem which is being used at pulp and paper mills in the South. Waste is pumped from the stabilization basin and sprayed over the stacked logs. The run-off is then collected in a canal and discharged. The stacked logs act as a huge trickling filter. The waste being sprayed has a BOD (five day) of 150 to 250 ppm and is applied at a rate of 2500 gal./min. BOD removals from 50 to 80% have been obtained.

LABORATORY INVESTIGATION

Methods and Materials

General

Log ponds at the following sites were selected for this investigation:

1. Pond A, Corvallis, Oregon
2. Pond B, Independence, Oregon
3. Pond C, Prineville, Oregon
4. Pond D, Prineville, Oregon

These ponds were selected since they exhibited different physical characteristics (i.e., surface area, type of logs stored, etc.) which are summarized in Table 1. Figure 1 depicts a typical log pond, whereas Figure 2 illustrates the murky, unpleasing appearance of log pond water.

Sampling Techniques

Several points were sampled within each pond to determine if the pond water was homogeneous with respect to chemical characteristics. Figure 3 is a sketch of Pond B showing the sampling points. Similar sketches for the remaining ponds are included in the Appendix.

Table 1. Physical Characteristics of Log Ponds Studied

Pond	Surface area, acres	Average depth, ft.	Age of pond, years	Type of logs stored	Length of storage	Water source	Remarks
A	26	8	11	Douglas fir	1-3 yrs.	stream	Non-overflowing except during high runoff periods. Sanitary wastes dumped into pond.
B	20	6-8	14	Douglas fir	80% of logs about one week	wells	Non-overflowing except during high runoff periods. Sanitary and glue wastes from plywood plant dumped into pond.
C	2.5	12	19	85% Ponderosa pine 15% Douglas fir	two weeks	stream	Overflowing at about 400 gallons per minute.
D	3	4-5	39	Over 90% Ponderosa pine	one week	springs: irrigation ditch	Overflowing at about 16 gallons per minute.

Figure 1. Typical log pond

Figure 2. Log pond water

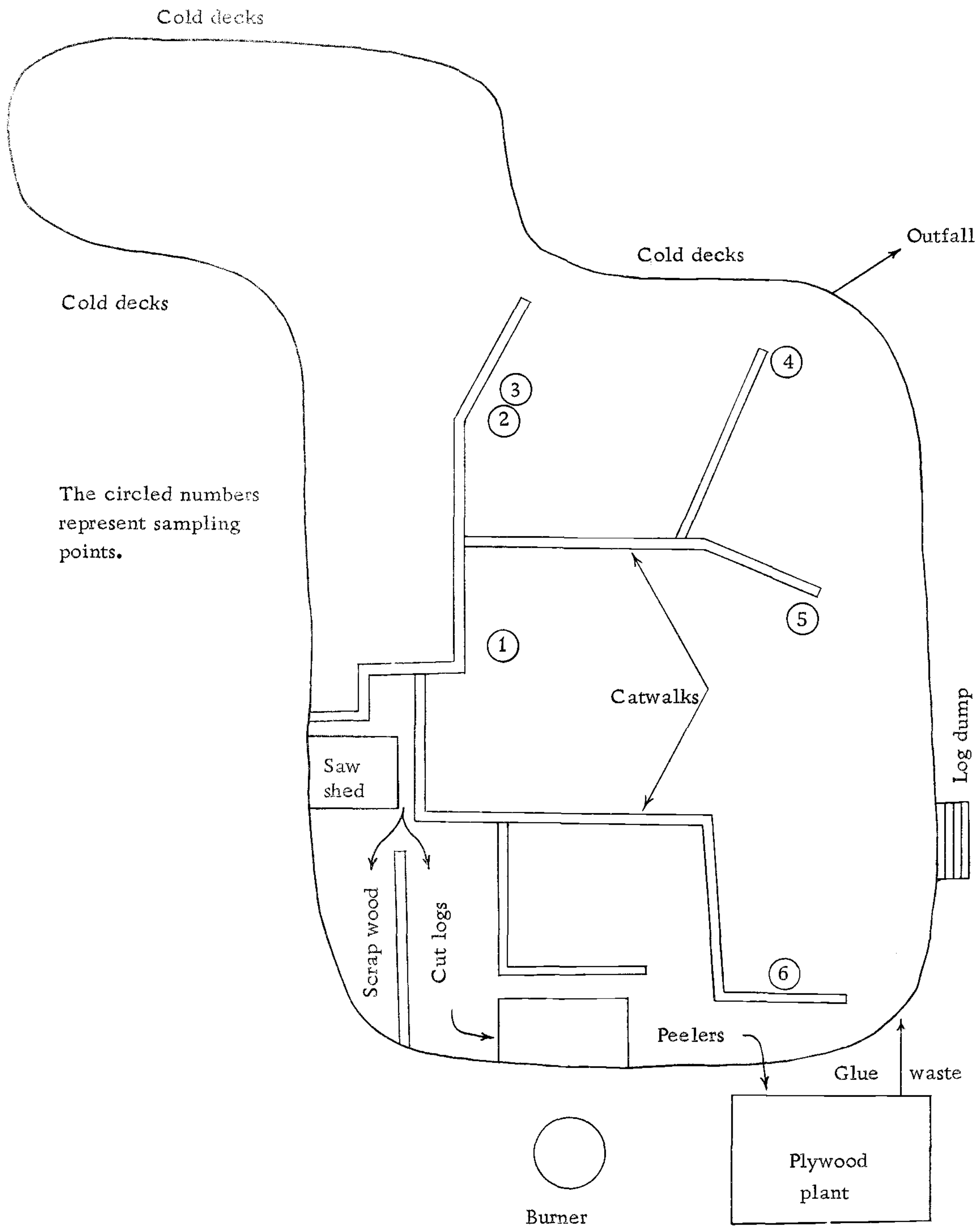


Figure 3. Pond B

All of the samples for the initial chemical analyses were taken at least one foot below the surface of the pond (except for the bottom samples) and with a sampler similar to the type described in Standard Methods (2, p. 405). The large volumes of sample needed for the treatability study were taken at the surface, but floating matter such as bark and insects were removed.

Sample Storage

Since the samples could usually be collected, returned to the laboratory and analyzed within six hours, no storage problems were encountered. The portion of the pond water not being used for analysis was stored at approximately 4°C in a refrigerator.

The two ponds near Prineville were too far away for the above procedure to be used. Therefore, some of the pond water was frozen by placing the sample bottles in a styrofoam container with dry ice. Additional samples were merely chilled by packing them with ordinary ice. Because freezing arrests most biological activity, the frozen samples were used for the biochemical and chemical oxygen demand tests. However, the freezing and subsequent thawing process will measurably affect the suspended and volatile suspended solids values (1); therefore, the chilled samples were used for these determinations.

The log pond water for the treatability study was stored at $4^{o}C$ both before and during use.

Acclimation Procedure

Three liters of settled sludge, taken from an activated sludge unit at the Oregon State University Advanced Waste Treatment Laboratory, were placed in an aeration tank. Six liters of substrate were added and the mixture was aerated. The air passed through an oil trap before entering the tank.

After 12 hours, the air was shut off and the sludge was allowed to settle. The supernatant was siphoned off until the three liter level was reached. Then six more liters of feed were added, and aeration was started again. This procedure was followed every 12 hours.

For the first two days the substrate was fresh domestic sewage (overflow from the primary clarifier) taken from the Corvallis Sewage Treatment Plant. However, on the third day the feed solution was composed of 10% log pond water (i.e., 5.4 liters of sewage plus 0.6 liters of log pond water). Thereafter, the amount of log pond water in the substrate was increased by 10% per day until all six liters of feed were pond water. Raw log pond water was added for three additional days. During this time chemical oxygen demand (COD) removals were determined. Since the COD removals (approximately 30%) were found to remain constant for each 12-hour aeration period, the sludge was assumed to be acclimated.

During the period when no sewage was being mixed with the log pond water, nitrogen (N) and phosphorus (P) were added according to a ratio of 5-day BOD: N: P of 60: 3: 1 (6. p. 178).

The log pond water used for acclimation was obtained from Pond A.

Biological Treatability Study Procedure

The apparatus used for the biological treatability investigation is sketched in Figure 4. The two aeration units were constructed of clear plastic and of such design as to provide a rotary liquid circulation due to the air flow and the baffle plate. Each unit had a volume of 8.5 liters to the overflow. Figure 5 presents a more detailed view of one of the units.

The baffle plate maintained quiescent conditions in the settling basin. The inclined portion of the settling basin allowed the settled solids to be reintroduced into the contact (aeration) basin. The air flow and the height of the baffle plate could be adjusted to permit any level of mixing desired. In order to reduce evaporation the tanks were covered, and the air stream was saturated with water. The air was filtered through cotton before entering the saturation device. Figure 6 shows the two units in operation.

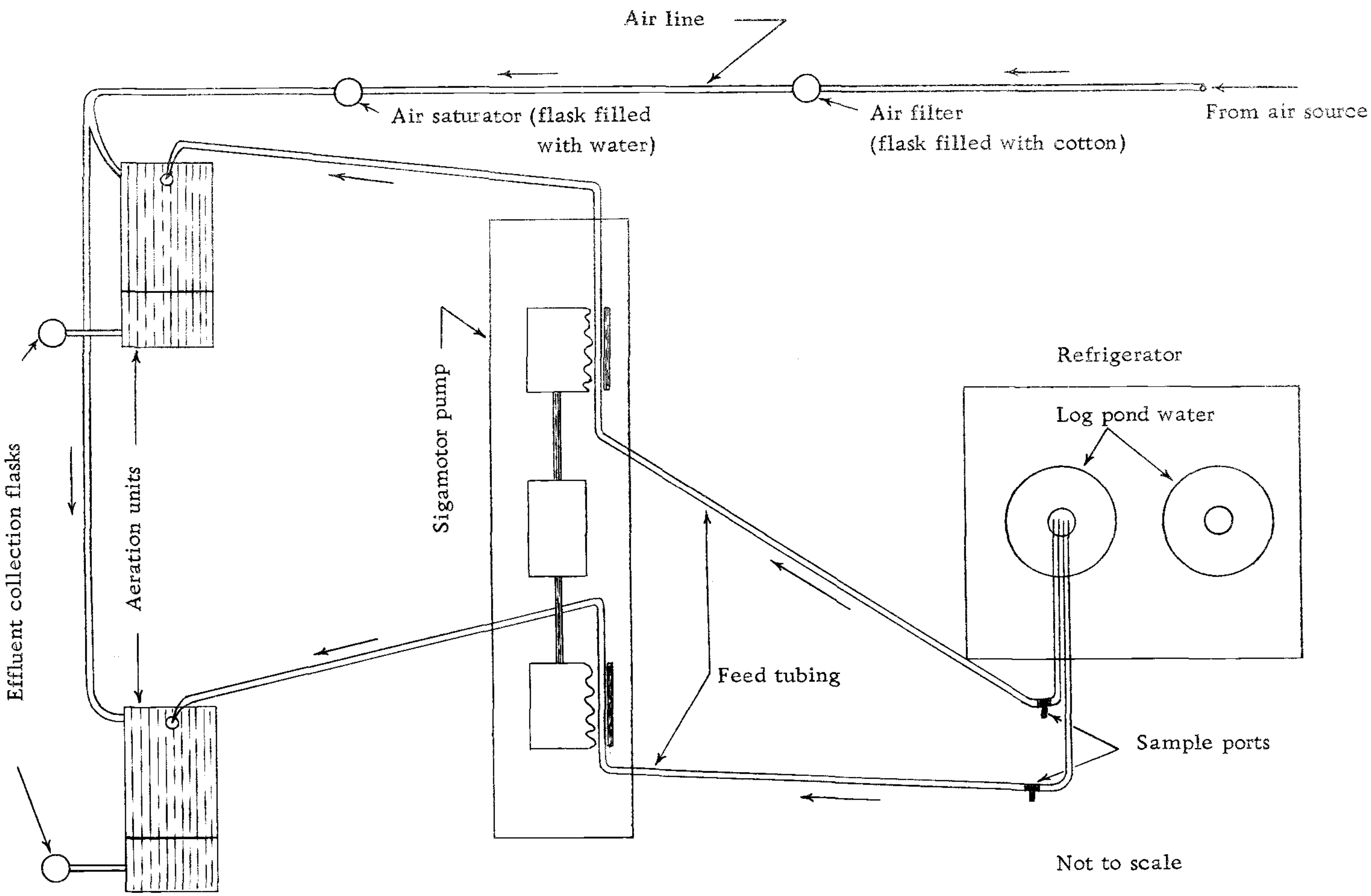
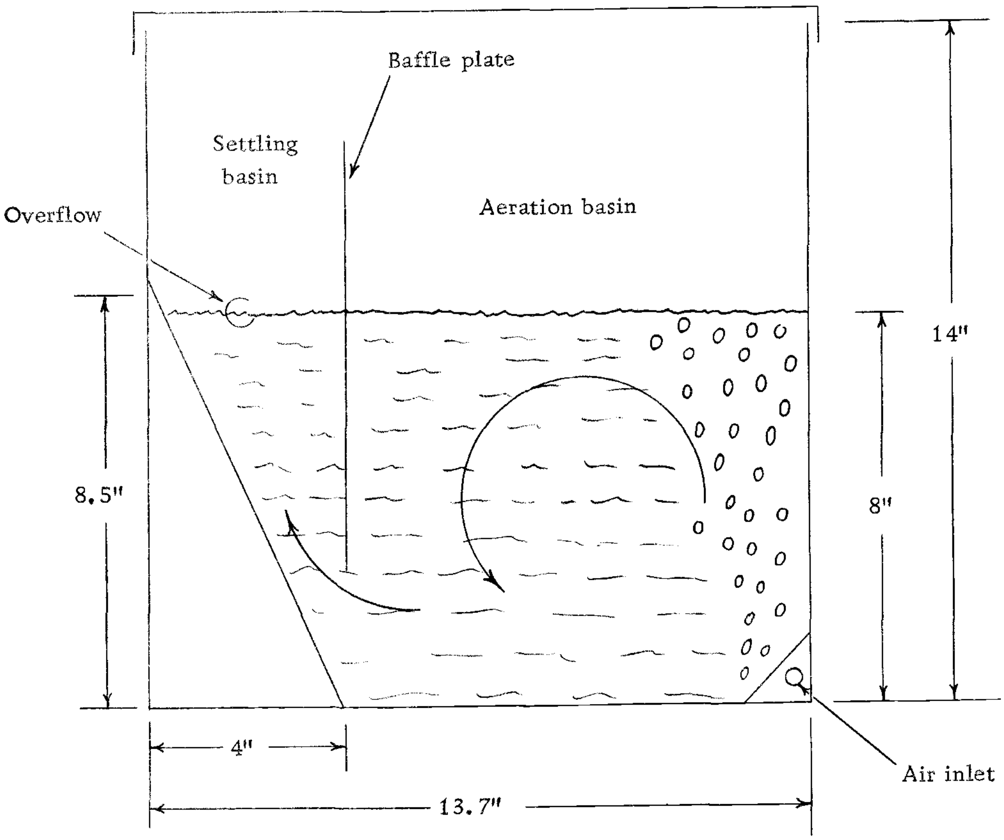


Figure 4. Diagram of experimental apparatus used for biological treatability study.



liquid volume to overflow = 8.5 liters
width of tank = 6 inches
Scale: 1:40

Figure 5. Aeration unit used for biological treatability study

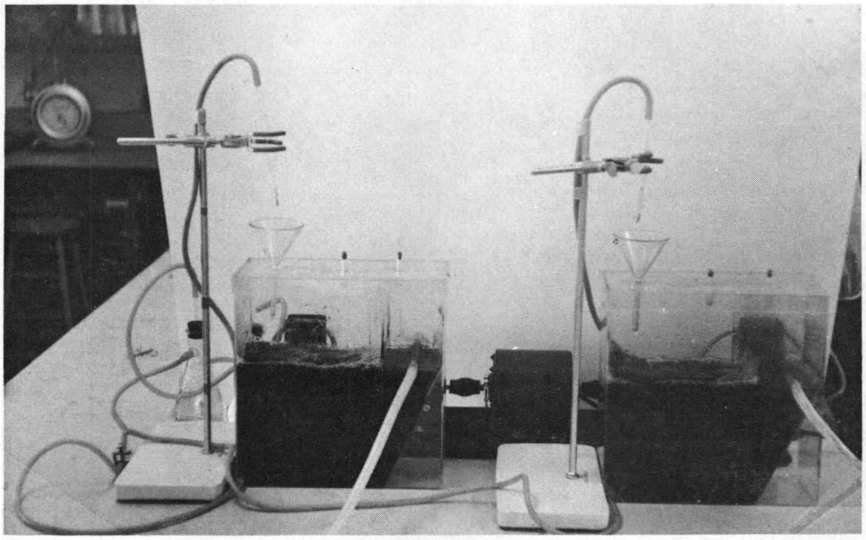


Figure 6. Aeration Units in Operation

The inside of each tank was sprayed with CHR Rulon Spray[2] (a fluorocarbon, anti-stick agent) to prevent the biological solids from clinging to the sides, inclined plates and baffle plates. As a result, the solids moved readily down the inclined plates and into the aeration basins which was essential for successful operation of the units.

A Model T-8 Sigmamotor Pump[3] was used to supply the required continuous flow rates for the detention periods selected. Table 2 lists the detention times used in the study and the corresponding flow rates.

[2] Manufactured by Connecticut Hard Rubber Company, New Haven, Connecticut

[3] Manufactured by Sigmamotor Company, Middleport, New York

Table 2. Aeration Unit Flow Rates

Detention time, days	Feed rate, ml/min.
1	6.0
2	3.0
3	2.0
5	1.2

The flow rates were checked frequently during the study to insure constant detention periods. The pump proved to be quite dependable so few adjustments were required. In addition, the peristaltic action provided by the pump prevented clogging of the tubing connecting the substrate supply to the tanks.

The substrate supply (i.e., the log pond water) was stored in a 15-liter carboy which was kept in a refrigerator at about 4°C. All the connecting tubing was opaque to help prevent biological growth from occurring within the tubes. After each detention period was completed the tubes were flushed thoroughly with water.

At the start of the investigation one liter of the acclimated sludge was added to each treatment unit. Log pond water was then added until the units were filled to the overflow level. Aeration was started and the feeding rate was set for a five-day detention period.

No sampling was done for five days to allow the systems to reach equilibrium. At the end of this time a complete set of samples was taken and analyzed each of three successive days. The detention time was then changed to three days and five more days were allowed before sampling. This same procedure was followed each time the detention period was changed. During each of the three sampling days for each detention time, samples were taken of the following:

1. the influent (the raw log pond water)
2. the mixed liquor from the aeration basin
3. the effluent from the settling basin

The first five-day detention period was run using water from Pond A. However, log pond water with a higher COD and BOD was desired to make the treatability study more meaningful. Therefore, water from Pond B was used for the remainder of the investigation. The five-day detention period was also repeated using water from Pond B.

Until chemical analyses showed that log pond water contained sufficient nitrogen and phosphorus to maintain biological growth, these two elements were added as discussed previously in the acclimation procedure.

Laboratory Tests

1. Chemical Oxygen Demand (COD)

A rapid or short term COD test, developed by J. S. Jeris (14) was used exclusively since the test was both fast and reproducible. However, correlations between the rapid test and the Standard Methods long-term COD test (2. p. 510-514) were obtained for water from each log pond. The values obtained with the rapid test were found to range between 96 and 100% of the long-term values; therefore, no correction factor was applied.

COD tests were performed on the raw log pond water and the effluent from the treatment units. Soluble COD values were obtained by filtering the samples through Millipore Filters[4] (Type Hawg) before testing.

2. Biochemical Oxygen Demand (BOD)

The standard five-day BOD (BOD_5) and 20-day BOD (BOD_{20}) were run as outlined in Standard Methods (2. p. 415-421) with two exceptions. First, a YSI Model 54 Oxygen Meter[5] was used to determine the dissolved oxygen present in the BOD bottles after

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[4] Manufactured by Millipore Corporation, Bedford, Mass.

[5] Manufactured by Yellowsprings Instrument Company Yellowsprings, Ohio

incubation. The meter was carefully calibrated using the Azide Modification of Iodometric Method (2. p. 406-410) with tap water.

Secondly, acclimated sludge from the treatment units was used as seed instead of fresh sewage. This was done in order to assure meaningful BOD values, since the organisms found in fresh sewage would not be accustomed to the log pond water. Therefore, higher BOD values would result than if an unacclimated seed were used.

The BOD_5 tests were run on both the influent and effluent of the units, while the BOD_{20} tests were only conducted on the influent.

3. Total Solids and Total Volatile Solids

These tests were performed as described in Standard Methods (2. p. 423) on samples from both the influent and effluent.

4. Total Suspended Solids

Suspended solids determinations were made using glass fiber filters according to the method outlined by B. M. Wyckoff (25). This procedure has proven to be much more convenient and reproducible than the Gooch Crucible Method in Standard Methods (2. p. 424). The glass fiber filters used were 4.25 cm. Whatman Glass Paper, grade GF/C.[6]

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[6] Manufactured by W. & R. Balston, Ltd. of England

The suspended solids tests were run on samples from the influent, mixed liquor, and effluent of the units.

5. Nitrogen

Nitrate and total Kjeldahl (ammonia and organic nitrogen) analyses were made on water from each log pond. Nitrite determinations were not run since previous researchers (18. p. 48) found this form of nitrogen to be generally absent in log ponds they investigated.

The total Kjeldahl tests were run as outlined in Standard Methods (2. p. 404). The standard Brucine Method (2. p. 393) was used for the nitrate determinations since this procedure is not as susceptible to interferences as some of the others listed. The colorimetric equipment used was a Beckman DU-2 Spectrophotometer.[7]

6. Total Phosphate

The standard total phosphate analysis (2. p. 236) was run on samples from each log pond. The stannous chloride method (2. p. 234) was used to determine the orthophosphate in each sample after the polyphosphates had been converted to the ortho

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[7] Manufactured by Beckman Instruments Incorporated, Fullerton, California

form by boiling with acid. Furthermore, an extraction step (2, p. 234) was employed in order to increase the sensitivity of the test and to reduce interferences. Once again the Beckman DU-2 was used for the colorimetric analyses.

7. Pearl-Benson Index (PBI)

The concentrations of lignins, tannins and other phenolic compounds present in log pond water, before and after treatment, were evaluated with the standardized Pearl-Benson method (4). The standard spent sulfite liquid solids called for by this procedure were obtained from the Crown Zellerback Corporation in Lebanon, Oregon. The log pond water samples were filtered through Whatman GF/C filters[6] before analysis. The Beckman DU-2 Spectrophotometer was used for the colorimetric determinations.

8. Oxygen Transfer Coefficients

Figure 7 illustrates the apparatus used in determining the overall oxygen transfer coefficient K_{La}. This term will be more fully discussed in the Results section of this thesis.

The basic components of the setup included a 1/20 hp. Dayton Motor[8] (1800 rpm.), a 15 liter aeration vessel (see Figure 8)

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[8]Manufactured by Dayton Electric Mfg. Company, Dayton, Ohio

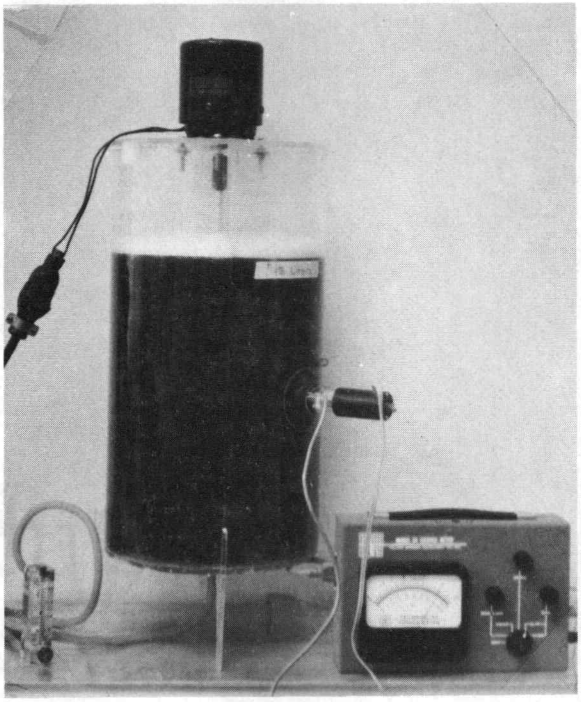

Figure 7. Apparatus used in determing oxygen transfer coefficients.

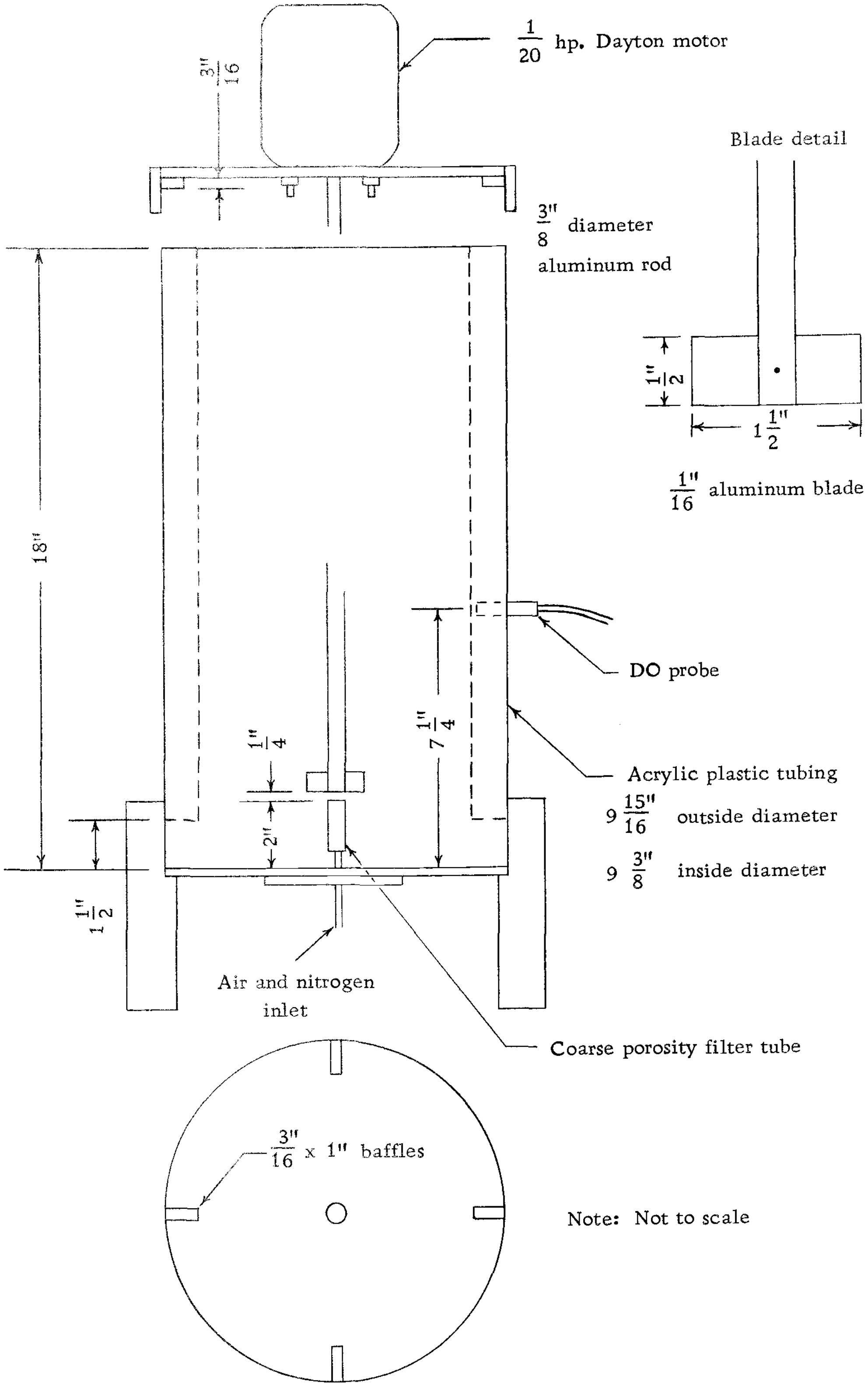

Figure 8. Aeration tank used in determining oxygen transfer coefficients.

the YSI oxygen meter and a rotameter[9] which regulated the air flow. The procedure used was as follows:

1. 15 liters of distilled water (the standard) or log pond water was placed in the vessel.
2. The liquid was sparged with nitrogen until the dissolved oxygen (DO) level approached zero.
3. The air flow was then turned on and adjusted to one standard cubic foot per hour (scfh).
4. Dissolved oxygen readings were taken every 30 seconds until the DO level neared the saturation value.
5. The air flow was shut off and DO readings were observed every minute for ten minutes to determine if biological activity was utilizing any of the DO.
6. The above steps were then repeated using an air flow rate of two scfh.

The distilled water and the log pond water were allowed to equilibrate to room temperature before testing so that temperature would not influence the results. The DO saturation concentrations of the log pond water were assumed to be equal to the saturation concentrations of the distilled water at room temperature. The

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[9] Manufactured by F. W. Dwyer Mfg. Company, Michigan City, Indiana

values were taken from Standard Methods (2. p. 409).

9. Oxygen Uptake

The oxygen uptake rate of the biological sludge was determined by taking a 300 ml. sample of the mixed liquor and placing it in a clean BOD bottle. The bottle was then placed on a magnetic stirring device in order to keep the liquor well mixed. The probe of the YSI Oxygen Meter was placed in the bottle and readings taken at regular intervals until the DO level dropped to about one ppm.

Suspended solids values were obtained before each test while soluble COD analyses were run before and after each test.

10. pH

All pH values were obtained using a Beckman[7] Model 76 pH meter.

RESULTS AND DISCUSSION

Composition of Log Pond Water

General

Table 3 summarizes the results of the tests performed on water from each of the four ponds. Generally, the ponds proved to be quite homogeneous with respect to the various characteristics investigated. For this reason some of the more time consuming tests (BOD, PBI, etc.) were not run for all the sampling points.

Furthermore, the length of storage time and overflow rate seem to influence a log pond's chemical nature significantly. Ponds B and D, which have short log storage times and low overflow rates, exhibit higher values for most all the characteristics studied than the other two ponds. This is particularly evident in terms of the COD, total solids, and PBI values.

As logs are added to a pond, leaching of the water soluble materials begins immediately. The actual rate of leaching depends upon the nature of the substance and the water temperature. As time goes on the water soluble substances are depleted until finally no further leaching can take place. Obviously, the shorter the log storage period, the greater the amount of substances available to be leached.

Table 3. Chemical Characteristics of Log Ponds Studied

POND A

Point	TS, mg/1[a]	% VS	SS, mg/1	DO, mg/1	Temp, °C	pH	COD, mg/1	BOD_{20}, mg/1	BOD_5, mg/1	$\frac{BOD_5}{COD}$	k, day^{-1}	N,[b] mg/1	NO_3-N,[c] mg/1	PO_4, mg/1	PBI, mg/1
1	254	59	43	0.1	22	6.9	116	48	29	0.25	0.08	2.4	0.6	0.5	175
2	253	53	38	0.1	22		116								
3	230	49	27	0.4	22		104								
4	238	53	14	0.2	22		116								
4-B	301	46	21				100								
5	260	56	35	0.2	22		116								

[a] mg/1 = milligrams per liter = ppm

[b] N = total Kjeldahl nitrogen (ammonia plus organic nitrogen)

[c] NO_3-N = nitrate nitrogen

4-B = bottom sample taken at point 4.

Table 3. (continued)

POND B

Point	TS, mg/1	% VS	SS, mg/1	DO, mg/1	Temp, °C	pH	COD, mg/1	BOD_{20}, mg/1	BOD_5, mg/1	$\frac{BOD_5}{COD}$	k, day^{-1}	N, mg/1	NO_3-N, mg/1	PO_4, mg/1	PBI, mg/1
1	747	55	180	0.3	21.5	7.1	496	167	54	0.11	0.03	10.4	1.5	1.2	545
2	724	63	162	0.2	21.5	7.1	484								
3-B	776	60	266	0.0	21		504								
4	720	61	234	0.2	22		488								
5	723	57	248	0.3	22		488								
6	755	56	256	0.1	22		504								

3-B = bottom sample taken at point 3.

Table 3. (continued)

POND C

Point	TS, mg/1	% VS	SS, mg/1	DO, mg/1	Temp, °C	pH	COD, mg/1	BOD_{20}, mg/1	BOD_5, mg/1	$\frac{BOD_5}{COD}$	k, day^{-1}	N, mg/1	NO_3-N, mg/1	PO_4, mg/1	PBI, mg/1
1	352	30	d	1. 5	23		20								
2	356	31	d	1. 7	23	7. 5	24	10	6	0. 25	0. 08	1	0. 1	0. 1	35
3	360	32	d	2. 0	23		26								
4	352	30	4				22								

[d] Frozen samples-suspended solids tests not run.

POND D

1	550	40	d	0. 4	21		312								
2-B	580	50	d	0. 2	20. 5		316								
3	530	44	d	0. 5	21		310								
4	606	46	122	0. 7	21. 5	7. 4	353	116	68	0. 19	0. 08	4. 9	0. 7	2. 0	338

2-B = bottom sample taken at point 2.

A pond with a log storage time of a week, therefore, will build up far greater concentrations of tannins, wood sugars, etc. than a pond which stores logs for a year. Accordingly, the values of COD, PBI, PO_4 and other characteristics will also be higher for a pond with a short log storage period.

The overflow (discharge) rate is also significant in determining the nature of a log pond. A high overflow rate (Pond C) results in the addition of more fresh water to the pond. Therefore, the concentrations of the leached substances are not allowed to build up as they are in a pond with a low discharge rate.

COD

As shown by Ponds B and D, the COD of a log pond can be quite high (504 and 353 mg/l, respectively) indicating that much of the material leached from the logs was organic. Pond B exhibited higher COD values than the other ponds because it had a very short log detention period (two weeks) and no overflow. In addition, glue waste is dumped into Pond B and the pond stores many more logs per acre than the others.

BOD

The BOD_{20} values for each pond were much lower than the COD values. For example, Pond B had a COD of 496 mg/l and a corresponding BOD_{20} value of only 167 mg/l. Ideally, these two values should have been quite close; however, the discrepancy can be easily explained by considering what each test measures. The COD test measures most all organic compounds which can be oxidized to carbon dioxide and water by strong chemical oxidizing agents. This test measures the total quantity of oxygen required for the chemical oxidation to take place, regardless of the biological assimilability of the particular substance.

The BOD determination, on the other hand, is a measure of the oxygen required to biologically oxidize (mainly by bacterial action) an organic material. Since most wastes contain organic compounds that cannot be stabilized totally through biological action, the COD values are higher than the BOD values.

The fact that the COD values for the ponds were 3 to 4 times greater than the corresponding BOD_{20} values clearly indicates that a large amount of the extracted organic compounds were non-biodegradable. Consequently, the BOD_5 to COD ratios, which ranged from 0.11 to 0.25, were also quite small for all four ponds. A more degradable waste would have exhibited a BOD_5 to COD ratio of 0.4 to 0.6.

Another important parameter of any waste is the BOD reaction rate constant denoted as k. Values for k are found by solving the general BOD equation (20. p. 396) when the BOD_5 and BOD_{20} values are known. The higher the k value the faster the BOD is being exerted. Very simple substrates such as glucose are degraded rapidly thus the k rates are high (0.20 to 0.30 day^{-1}). More complex materials result in lower k rates. The k rates for the four ponds ranged from 0.03 to 0.08 day^{-1} which further indicates the complexity of the organic compounds present in the water.

Although Ponds B and D had similar BOD_5 values (54 and 68 mg/l, respectively), the k rate for Pond B was only 0.03 day^{-1} whereas the k rate for Pond D was 0.08 day^{-1}. One possible reason for the difference is that Pond D stores ponderosa pine while Pond B stores Douglas fir. As mentioned in the Literature Review, ponderosa pine bark contains ten times more reducing sugars than does Douglas fir bark. Since these sugars could be degraded rapidly by bacteria, the higher k rate would result.

Solids

Ponds B and D had the highest values for the three types of solids determined. Within any particular pond the values were highest in those areas which had the greatest density of logs.

Total solids values for the four ponds ranged from 230 mg/l to 776 mg/l. The percentage of volatile solids, which is an indication of organic matter present, substantiated the COD results very well. For example, Pond B, which had a total solids value of 747 mg/l and a volatile solids percentage of 55% (VS = 410 mg/l), showed a corresponding COD value of 496 mg/l.

The suspended solids values were low (4 to 122 mg/l) for all the ponds except Pond B (162 to 266 mg/l) which had a very heavy algal growth. All four ponds were fairly quiescent, and thus they acted as huge settling basins. Therefore, most of the undissolved material would settle out and not be resuspended.

Nitrogen

All of the ponds, with the exception of Pond C, showed high values for both total Kjeldahl (organic plus ammonia) nitrogen (2.4 to 10.4 mg/l) and nitrate nitrogen (0.6 to 1.5 mg/l). The nitrogen values increased as the degree of pollution (in terms of COD, total solids, and BOD) increased. This certainly suggests that some of the nitrogen must be coming from the logs, although neither pine nor fir contain much of this element. This nitrogen may come from sanitary wastes which discharge from each mill into the ponds.

Perhaps another important source of nitrogen is the bottom deposits in the ponds. All the ponds are fairly old and have extensive deposits. These deposits consist of bark, wood, dead algae, and aquatic vegetation which has settled to the bottom. As these materials undergo decomposition, (aerobic or anerobic) nitrogen and phosphates are released resulting in a "feed-back" of these nutrients. Pond D must also obtain nitrogenous compounds in the irrigation water which feeds the pond. Other sources would include surface runoff and the source water. In any event, there was ample nitrogen available in the ponds studied to support biological growth.

Phosphates

Ponds A, B and D showed significant concentrations of phosphates which ranged from 0.5 to 2.0 mg/l. Phosphorus is a very important nutrient in an aquatic environment, especially in terms of algal growth. When sufficient phosphorus (plus nitrogen and certain trace elements) is present, algal blooms can occur which can cause serious nuisance conditions. Sawyer states that such blooms can be triggered with phosphorus levels as low as 0.01 mg/l (20. p. 167). By this criterion, Ponds A, B and D have more than enough phosphorus to support and encourage biological growth.

Should these nutrient rich pond waters be discharged into a lake or slow moving stream, considerable damage could occur to the natural waters. This nutrient influx could cause an algal bloom which would considerably inhibit the use of the lake or stream for recreational or water supply purposes.

The sources of the phosphates present in the log ponds would be the same as previously discussed for nitrogen.

PBI

The Pearl-Benson Index or Nitroso method was developed to estimate the concentration of spent sulfite liquor (lignin sulfonates) in water. However, most phenolic compounds, tannins and some amines interfere and give similar reactions with the reagents as the lignin sulfonates (10). This is quite important in the case of log ponds since lignin is insoluble in cold water. Therefore, the PBI results are probably indicating concentrations of the interfering substances (mostly tannins) rather than lignin.

In all cases the PBI values were closely related with the COD values. The COD values for the four ponds ranged from 20 to 504 mg/l and the corresponding PBI values ranged from 35 to 545 mg/l. This could be expected since the same compounds detected by the PBI test would also contribute to the COD.

Dissolved Oxygen

In all cases the DO was quite low (0.0 to 0.7 mg/l), even close to the surface. The DO of Pond C was somewhat higher (1.5 mg/l) due to the constant recharge with fresh water.

The low DO values reflect the extensive biological activity taking place within the ponds. The quiescent condition of the ponds also contributed to the low DO values since oxygen transfer is much more effective when surface turbulence exists.

The constant evolution of gas bubbles indicated that anaerobic conditions prevailed at the bottoms of the ponds which contributed to their malodorous state.

Biological Treatability of Log Pond Water

COD Removal

Considering the nature of the waste, a reasonably high level of COD removal was obtained by the two pilot plant units. Total COD removals varied from 49% for a one-day detention period to 62% for five-days detention. Soluble COD removals were 38% and 52%, respectively. The results listed in Table 4 show how closely the two units performed; consequently, only the results for Unit 1 are depicted by Figure 9.

Table 4. Total and Soluble COD Removals by Aeration Units Treating Log Pond Water

Detention Time, days	Sampling Period	Total COD: Influent COD, mg/l	Total COD: Aeration Unit 1 Effluent: COD, mg/l	Total COD: Aeration Unit 1 Effluent: % Removal	Total COD: Aeration Unit 2 Effluent: COD, mg/l	Total COD: Aeration Unit 2 Effluent: % Removal	Soluble COD: Influent Soluble COD, mg/l	Soluble COD: % Soluble COD	Soluble COD: Aeration Unit 1 Effluent: COD, mg/l	Soluble COD: Aeration Unit 1 Effluent: % Removal	Soluble COD: Aeration Unit 2 Effluent: COD, mg/l	Soluble COD: Aeration Unit 2 Effluent: % Removal
1	1	440	224	49	224	49	248	56	152	39	152	39
	2	424	216	49	216	49	280	66	184	34	184	34
	3	424	216	49	216	49	252	60	156	38	156	38
2	1	450	220	51	225	50	270	60	157	42	157	42
	2	430	210	51	210	51	262	61	157	40	157	40
	3	454	227	50	227	50	258	57	157	39	157	39
3	1	440	204	54	204	54	252	57	140	44	140	44
	2	440	204	54	204	54	248	56	140	43	140	43
	3	452	224	51	224	51	264	59	160	39	160	39
5	1	440	156	65	156	65	260	59	124	52	124	52
	2	464	176	62	176	62	264	57	128	52	128	52
	3	456	168	63	168	63	256	56	124	52	120	53

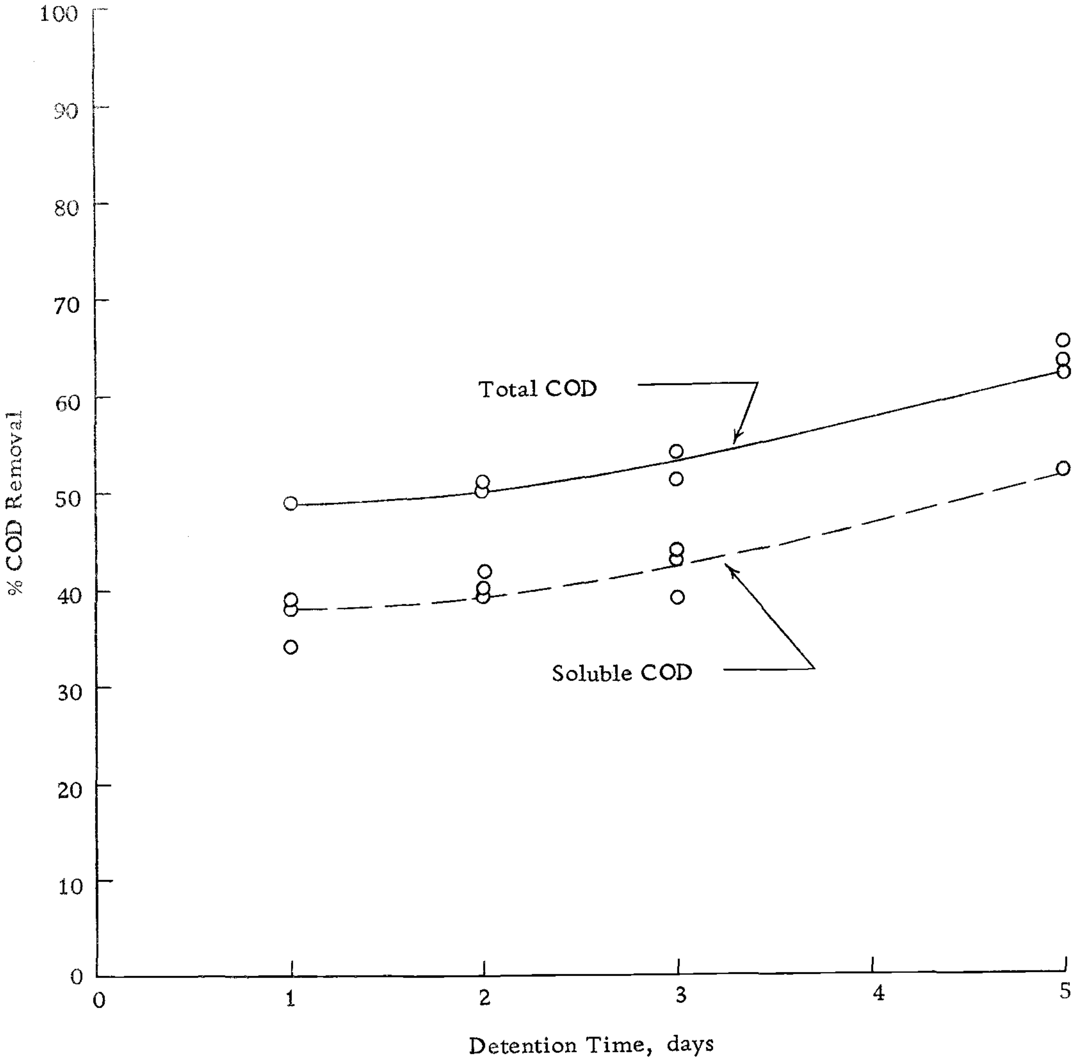


Figure 9. Total and soluble COD removals obtained by Aeration Unit 1 treating log pond water.

As could be expected, the longer detention periods produced the highest COD removals. However, the differential between the COD removed for a one-day and a five-day detention period was only about 12% for both total and soluble COD. This indicates that a portion of the waste (probably the wood sugars) was assimilated rapidly by the microorganisms. Once these easily degradable substances were depleted the more complex compounds were attacked, resulting in slightly higher COD removals at the longer contact times.

The soluble COD values are quite important since they represent the fraction of total COD that is in solution and, therefore, more readily assimilable by microorganisms. In this case the influent soluble COD values averaged 260 mg/l which is 60% of the average influent total COD value of 443 mg/l. The soluble COD fraction represents the organic compounds extracted from the logs. The remaining 40% probably represents insoluble materials as bacterial cells, algal cells, wood fragmentc, etc.

The percentages of soluble COD removal represent removal by microbiological activity only, whereas the total COD removals can also include removal by physical methods such as settling. Therefore, the total COD removals were 10 to 12% higher than the soluble COD removals for all the detention periods. Even after five days detention the effluent still had total and soluble COD values of 176 mg/l and 128 mg/l, respectively, which further demonstrates the chemical complexity of log pond water. Figure 9 does indicate that longer detention periods might have resulted in more COD removal. Any additional removal would not have been substantial since only slightly degradable or non-degradable materials remained. Therefore, the COD removals would have leveled off.

BOD_5 Removal

As listed by Table 5, BOD_5 removals varied from 80% for a one-day detention period to 93% (Aeration Unit 1) for a five-day detention period. The corresponding total COD removals were 62% and 49%. The large difference in removals is related, once again, to what the two tests measure. The microorganisms were removing practically all the biodegradable material; therefore, the BOD_5 removals were quite high. However, many non-biodegradable substances remained. These substances are measured by the COD test but not by the BOD_5 test, thus the respective COD removals were lower.

The initial high BOD_5 removal (80%) was due to the microorganisms assimilating the easily degradable substances (such as wood sugars) first. When these were depleted the more complex compounds were attacked, which resulted in only slightly higher removals at the longer detention times.

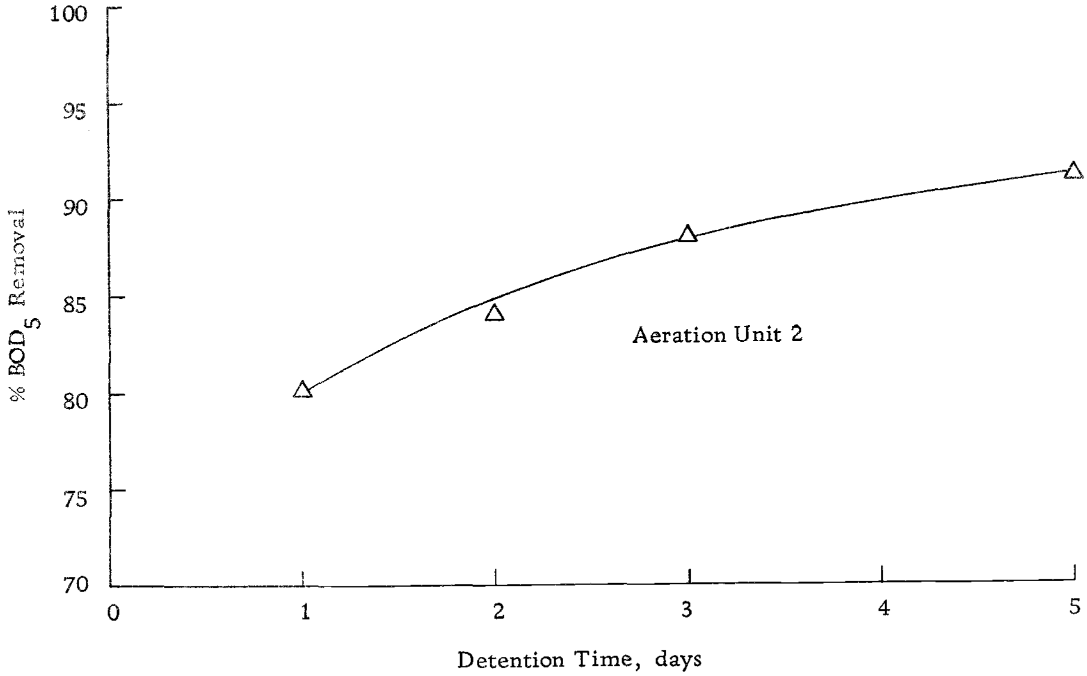
Table 5. BOD_5 Removals Obtained by Aeration Units Treating Log Pond Water

Detention Time, days	Influent BOD_5, mg/l	Aeration Unit 1		Aeration Unit 2	
		Effluent BOD_5, mg/l	% Removal	Effluent BOD_5, mg/l	% Removal
1	54	11	10	10	80
2	54	8	85	9	84
3	51	6	88	6	88
5	57	4	93	5	91

Figure 10 indicates that further BOD_5 removal could be accomplished with detention times longer than five days. However, since 93% of the BOD_5 had been removed after five days, any further removal would not be substantial.

PBI Removal

Table 6 indicates that the PBI was reduced by biological action, but a detention period of three days was required to produce a significant reduction of 58%. At the end of five days only 64% of the PBI had been removed. Furthermore, as Figure 11 clearly illustrates, detention periods longer than five days would not have increased the removal to any appreciable extent. This



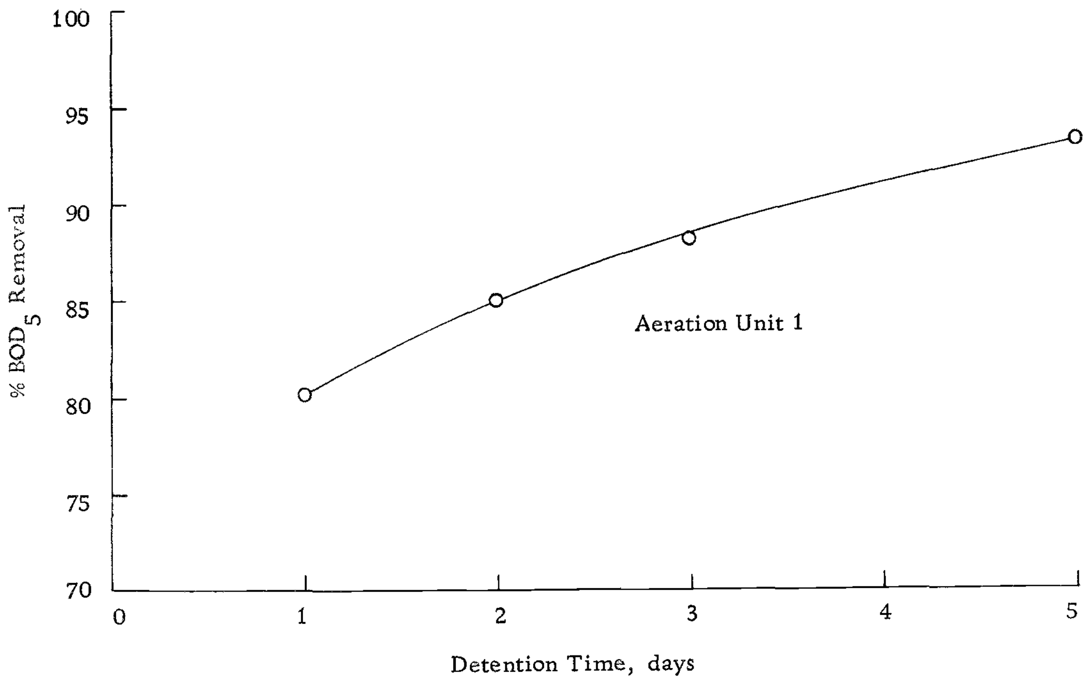
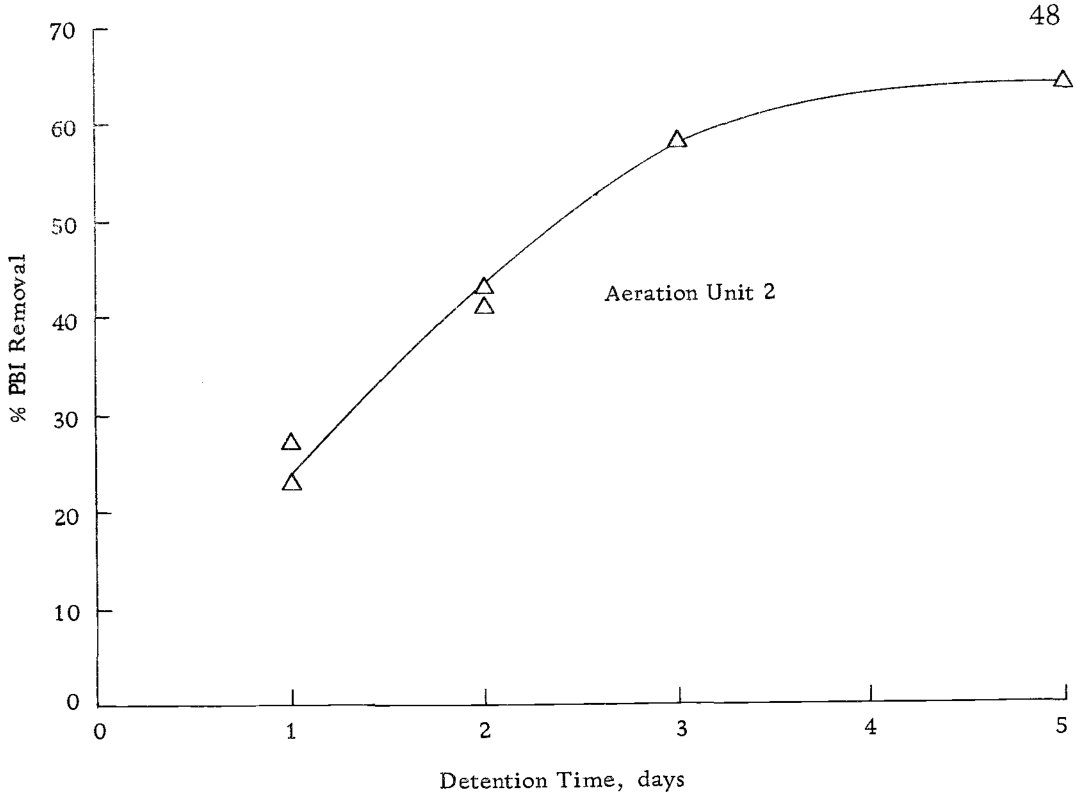


Figure 10. BOD_5 removals obtained by aeration units treating log pond water.

Table 6. PBI Removals Obtained by Aeration Units Treating Log Pond Water

Detention Time, days	Sampling Period	Influent PBI, mg/l	Aeration Unit 1		Aeration Unit 2	
			Effluent PBI, mg/l	% Removal	Effluent PBI, mg/l	% Removal
1	1	537	409	24	413	23
	2	545	405	26	401	27
2	1	540	297	45	308	43
	2	535	302	44	314	41
3	1	522	224	57	222	58
	2	522	222	58	222	58
5	1	545	197	64	195	64
	2	545	197	64	195	64



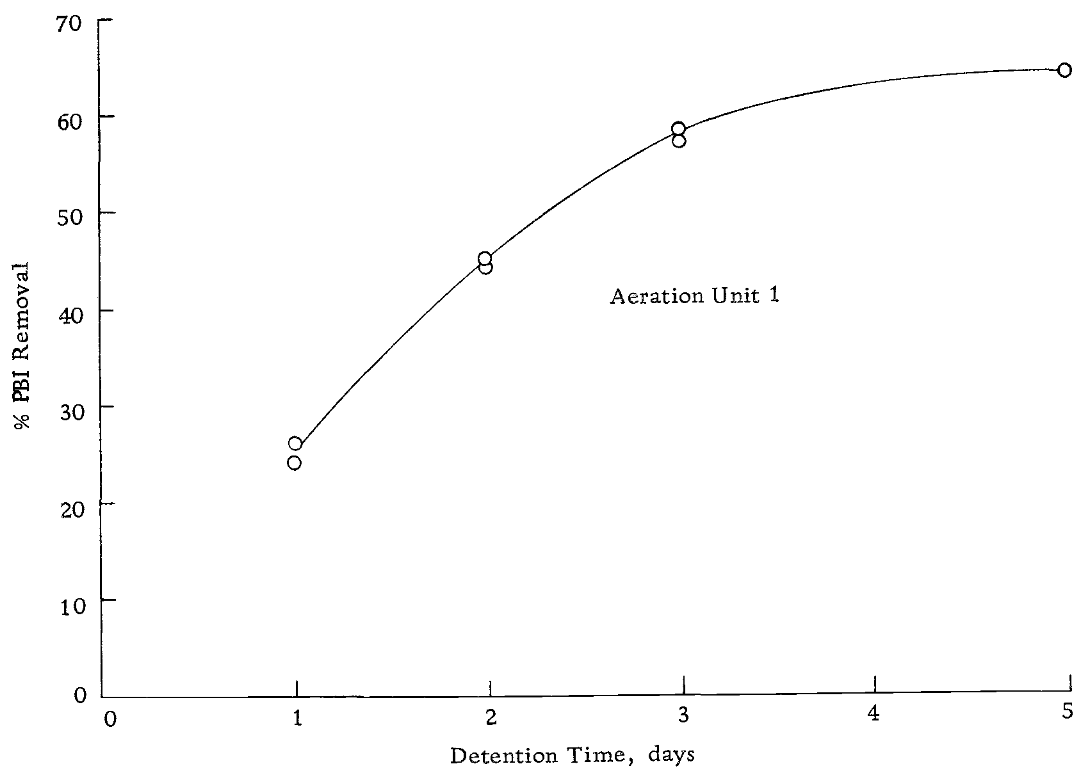


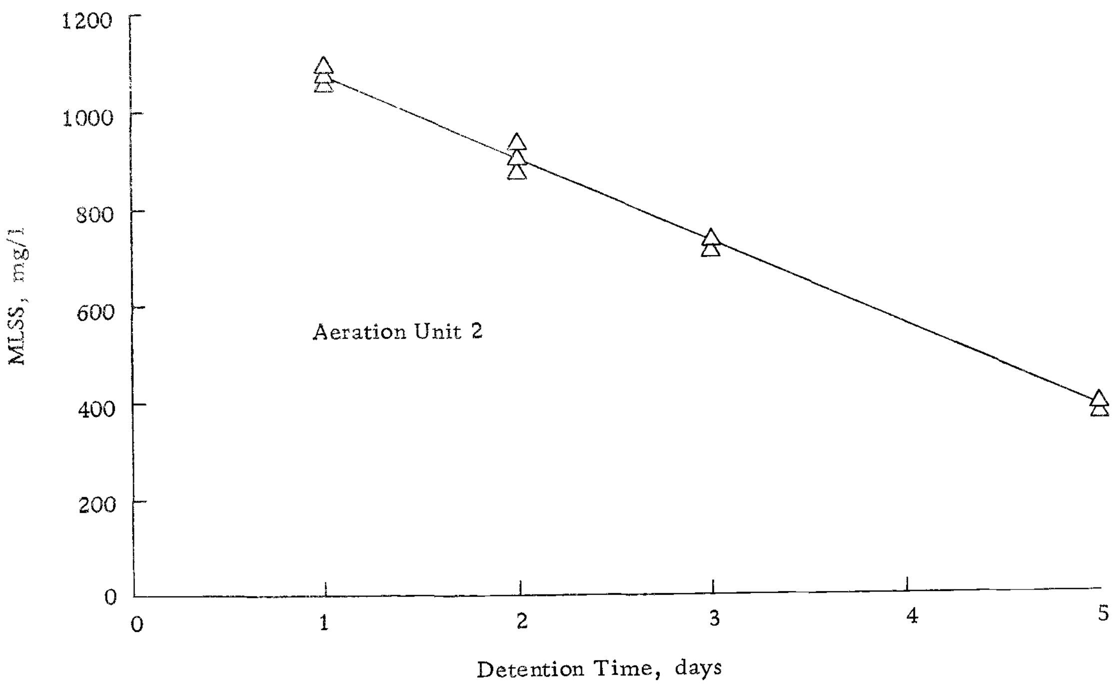
Figure 11. PBI removals obtained by aeration units treating log pond water.

was due to the complex nature of the compounds contributing to the PBI (tannins and other phenolic substances). The fact that nearly 40% of these compounds were non-biodegradable helps explain the high effluent COD values.

Mixed Liquor Suspended Solids (MLSS)

A linear, arithmetic relationship was established between MLSS level and detention time as shown by Figure 12. The MLSS increased from an average of 378 mg/l at a five-day detention time to an average of 1070 mg/l at a one-day detention period (figures are for Aeration Unit 1). This was to be expected since as the detention time decreased the food to microorganism ratio increased resulting in higher MLSS. Even at a contact period of one day, the MLSS value was only 1070 mg/l. This is quite small when compared to MLSS levels of 3000 to 5000 mg/l maintained in extended aeration processes treating domestic sewage and other wastes which are easily degraded.

The low MLSS levels were partly due to the fact that log pond water was not an ideal substrate for optimum biological growth. The BOD_5 values were low which resulted in a low food to microorganism ratio. Furthermore, as listed in Table 7, the sludge ages (i.e., the average time a particle of suspended solids is under aeration) ranged from 6.5 to 11.6 days. The large amount of endo-



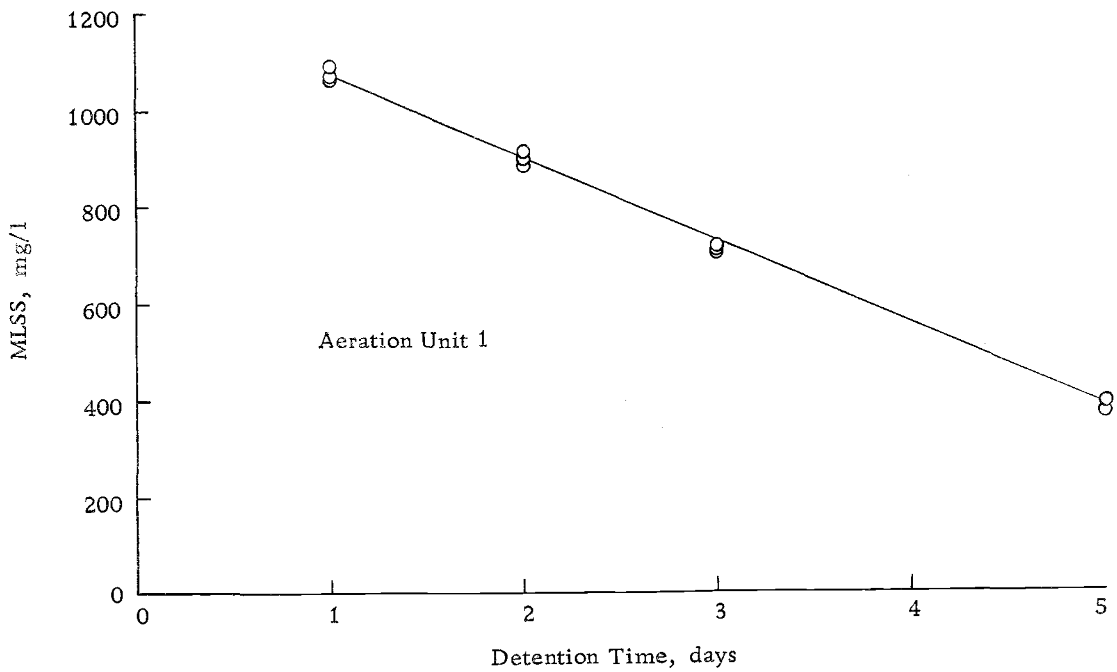


Figure 12. MLSS accumulation in aeration units treating log pond water

Table 7. Influent Suspended Solids, MLSS, Effluent Suspended Solids and Sludge Ages for Aeration Units Treating Log Pond Water

Detention Time, days	Sampling Period	Influent SS, mg/l	Aeration Unit 1			Aeration Unit 2		
			MLSS, mg/l	Effluent SS, mg/l	Sludge Age, days	MLSS, mg/l	Effluent SS, mg/l	Sludge Age, days
	1	158	1058	86		1056	94	
1	2	158	1064	76	6.5	1076	92	6.6
	3	162	1086	90		1090	86	
	1	178	910	67		930	75	
2	2	164	880	61	11.0	870	72	11.1
	3	180	895	65		900	70	
	1	180	714	44		712	52	
3	2	184	708	50	13.1	722	56	13.1
	3	158	704	54		708	56	
	1	176	374	24		370	26	
5	2	162	384	22	11.6	388	26	11.7
	3	170	378	30		384	26	

genous respiration which took place at these high sludge ages resulted in little net growth in the system.

Effluent Suspended Solids

The effluent suspended solids varied from 90 to 26 mg/l for detention periods of one and five days, respectively. As the MLSS increased, so did the effluent suspended solids, as shown by Figure 13. For each detention period from 5 to 8% of the MLSS were discharged in the effluent. One of the reasons for this condition was the turbulence in the settling basin. In addition, the sludge probably did not have very good settling qualities because of the high sludge ages. Furthermore, at low food to microorganism ratios (long detention periods) bacteria tend to remain dispersed which also inhibits good settling.

Total Solids Removal

Only 23 to 35% of the influent total solids (averaging 730 mg/l) were removed in the treatment units, with the highest removal occurring at a detention period of five days. Data in Table 8 points out that approximately 50% of the total solids discharged were volatile which contributed to the high effluent COD values. The majority of the total solids must have been in dissolved or colloidal form since the effluent suspended solids never rose above 94 mg/l.

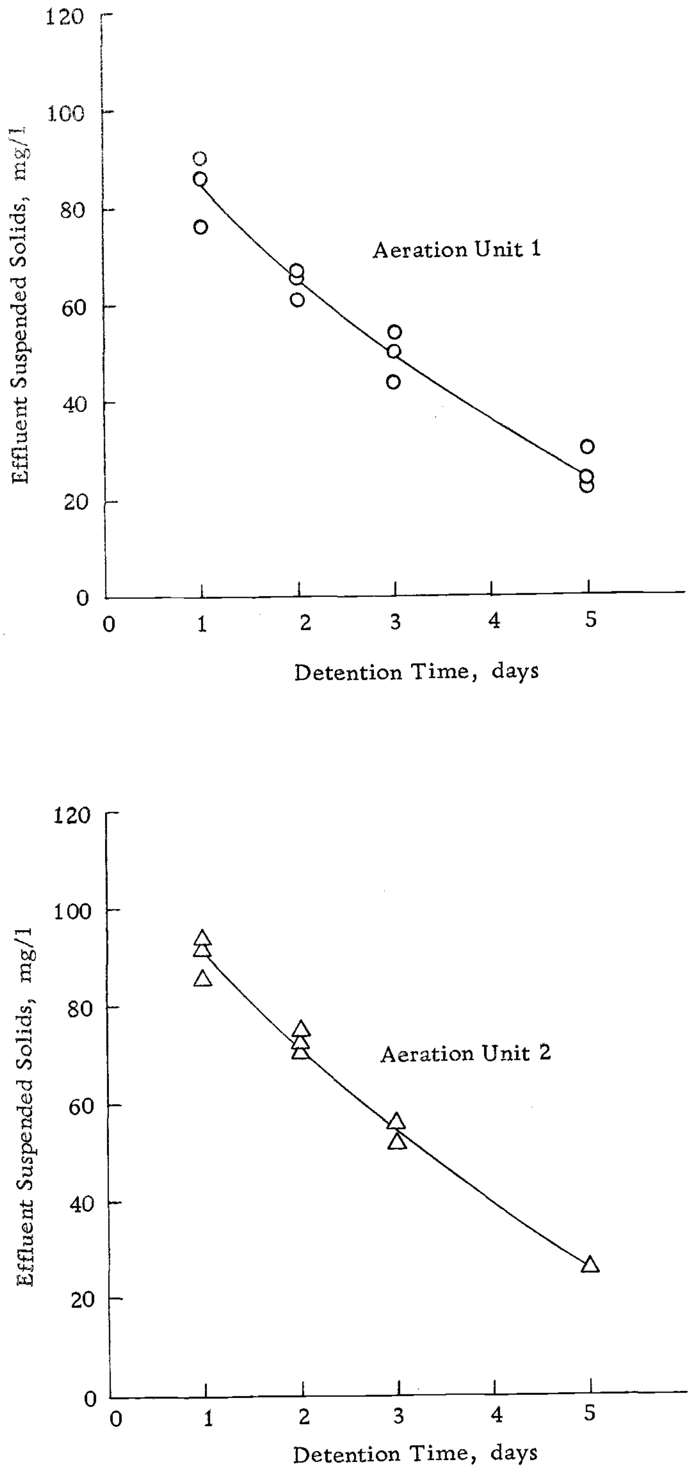


Figure 13. Effluent suspended solids for aeration units treating log pond water

Table 8. Total Solids Removal and Percent Volatile Solids for Aeration Units Treating Log Pond Water

Detention Time, days	Sampling Period	Influent		Aeration Unit 1 Effluent			Aeration Unit 2 Effluent		
		TS, mg/l	% VS	TS, mg/l	% VS	% TS Removal	TS, mg/l	% VS	% TS Removal
	1	769	54	594	47	23	581	50	24
1	2	716	55	553	42	23	565	47	21
	3	715	55	558	42	22	567	47	21
	1	735	51	545	51	26	530	49	28
2	2	729	51	532	52	27	554	52	24
	3	720	55	525	50	27	540	48	25
	1	731	51	512	51	30	513	52	30
3	2	729	51	520	52	29	520	52	29
	3	740	55	525	48	29	530	55	28
	1	717	51	468	57	35	466	57	35
5	2	718	52	470	57	34	466	56	35
	3	719	52	467	57	35	464	57	36

Oxygen Transfer Coefficients

In any aerobic biological waste treatment system the rate of oxygen transfer to the waste is an important parameter. Equation 1 is an expression for the rate of oxygen transfer to any liquid. This equation is derived from basic oxygen transfer theory (7. p. 79-82).

$$\frac{dC}{dt} = K_{La}(C_s - C) \qquad (1)$$

where

$\frac{dC}{dt}$ = Rate of oxygen transfer to the liquid, mg/1/min.

K_{La} = Overall transfer coefficient, min.^{-1}

C_s = Saturation concentration of dissolved oxygen at temperature of the liquid, mg/1.

C = Concentration of dissolved oxygen in liquid at any time, mg/1.

A unitless parameter, α, is often used to compare the overall transfer coefficient for a given waste to that for a standard such as distilled water. Therefore, in this case:

$$\alpha = (K_{La})\text{ log pond water}/(K_{La})\text{distilled water} \qquad (2)$$

Using the procedure outlined earlier (p. 25-28) in this thesis, data were obtained as presented in Table 9.

Table 9. Oxygen Transfer Data

Air Flow Rate = 2 scfh   Temperature = 25°C

C_s = 8.4 mg/l

Time, min.	Distilled Water		Log Pond Water	
	C, mg/l	C_s-C, mg/l	C, mg/l	C_s-C, mg/l
0.0	2.0	6.4	1.8	6.6
0.5	3.8	4.6	2.4	6.0
1.0	4.4	4.0	3.6	4.8
1.5	5.2	3.2	4.5	3.9
2.0	5.5	2.9	5.2	3.2
2.5	6.0	2.4	5.7	2.7
3.0	6.3	2.1	6.2	2.2
3.5	6.7	1.7	6.6	1.8
4.0	6.9	1.5	6.9	1.5
4.5	7.1	1.3	7.2	1.2
5.0	7.3	1.1	7.4	1.0
5.5	7.5	0.9	7.55	0.85
6.0	7.6	0.8	7.7	0.7
6.5	7.7	0.7	7.8	0.6
7.0	7.8	0.6	7.9	0.5
7.5	7.9	0.5	8.0	0.4
8.0	7.95	0.45	8.05	0.35

A semilogarithmic plot was made of $(C_s - C)$ versus time (for each set of data) and a straight line of best fit drawn through the points. The slope of this line equalled the overall transfer coefficient, K_{La}. Biological uptake of DO was found to be negligible, thus no correction factor was applied to K_{La}. Examples of these plots are shown by Figures 14 and 15. The α values were then obtained by using equation 2. Table 10 presents a summary of these calculations.

Table 10. Results of Oxygen Transfer Tests

Test	Liquid	Air Flow Rate, scfh	K_{La}, min^{-1}	α
1	Distilled Water	1	0.102	1.10
	Log Pond Water	1	0.112	
2	Distilled Water	2	0.135	1.16
	Log Pond Water	2	0.157	

The slopes of the lines of best fit on the semilogarithmic plots were determined by using the "method of least squares" described by Wine (23. p. 420). Wine states that "the 'method of least squares' is the same as the method of maximum likelihood, the most widely accepted general procedure for estimation at this time."

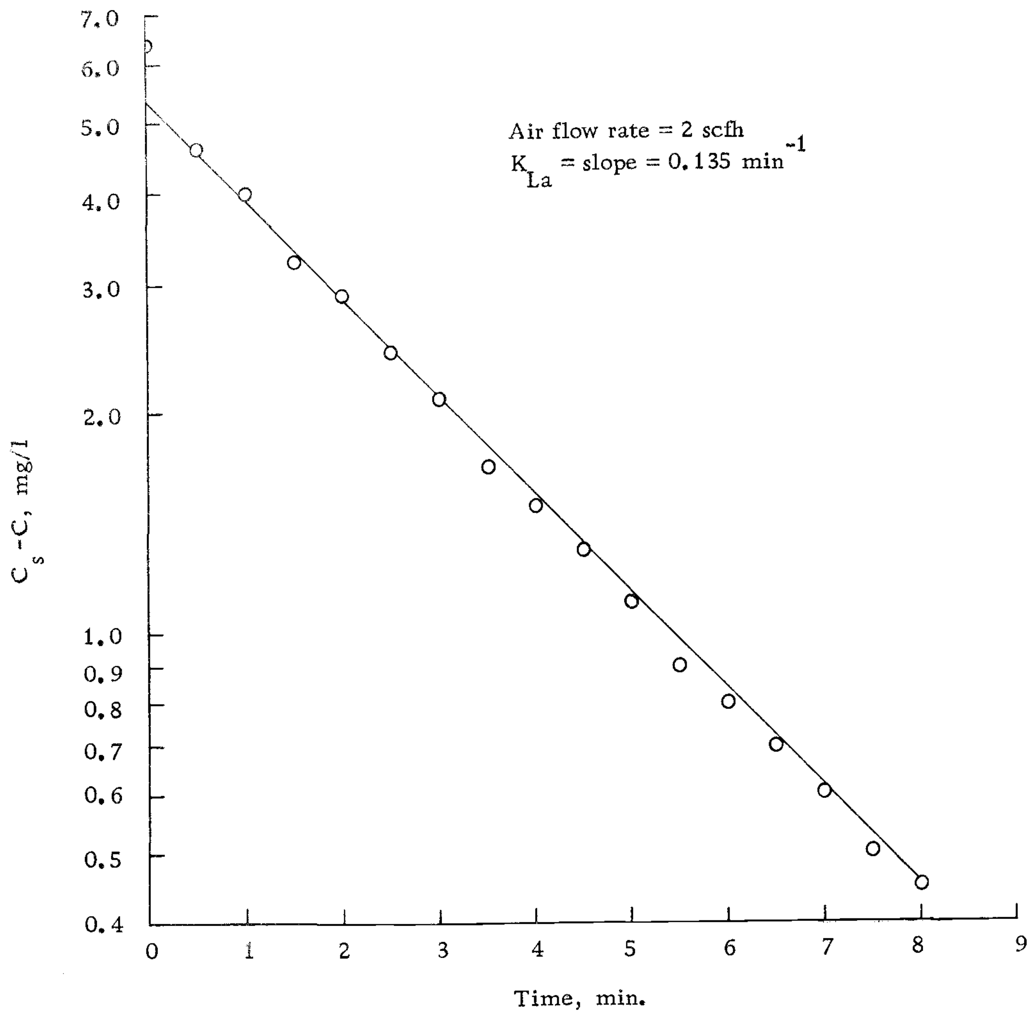


Figure 14. K_{La} determination for distilled water

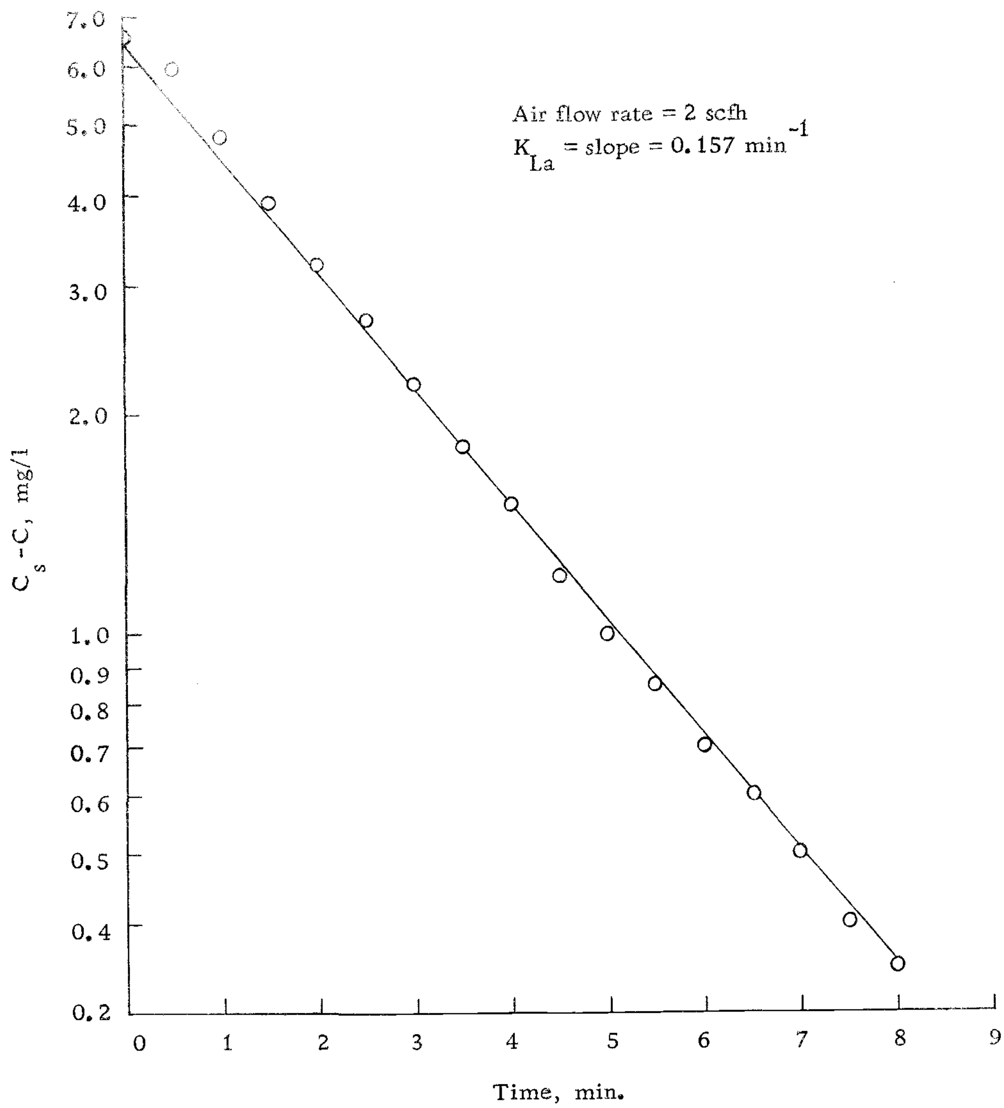


Figure 15. K_{La} determination for log pond water

The α values obtained were greater than one. This indicates that the oxygen transfer rate would be greater in log pond water than in distilled water. The explanation for this must be attributed to the chemical characteristics of the log pond water since other variables (temperature, air flow rate, container size and mixing speed) were kept constant. Eckenfelder has reported values greater than one for pulp and paper, pharmaceutical and synthetic fiber wastes. He maintains that this condition is due to high concentrations of certain organic compounds in the wastes (5). This could also be the case with log pond water since it contains organic compounds similar to those found in pulp and paper wastes.

Oxygen Uptake

The rate of oxygen uptake by the microorganisms is another important consideration in any biological system. Oxygen uptake data is used in conjunction with oxygen transfer data in order to specify aeration requirements for treatment processes. Table 11 lists oxygen uptake data for sludge taken from both treatment units. The curves plotted from this data are illustrated by Figures 16 and 17. Once again the "method of least squares" was used to find the slope of the line of best fit. The results are summarized in Table 12.

Table 11. Oxygen Uptake Data

Unit 1 MLSS		Unit 2 MLSS	
Time, min.	DO, mg/l	Time, min.	DO, mg/l
0	7..8	0	7.1
11	7.6	5	6.9
15	7.3	10	6.6
25	7.1	15	6.4
35	6.7	20	6.1
45	6.2	25	5.8
60	5.75	30	5.65
70	5.3	35	5.3
80	4.9	40	5.2
90	4.5	50	4.8
100	4.1	60	4.2
110	3.7	70	3.7
120	3.2	80	3.1
130	2.8	90	2.7
140	2.3	100	2.2
		110	1.6
		120	1.2

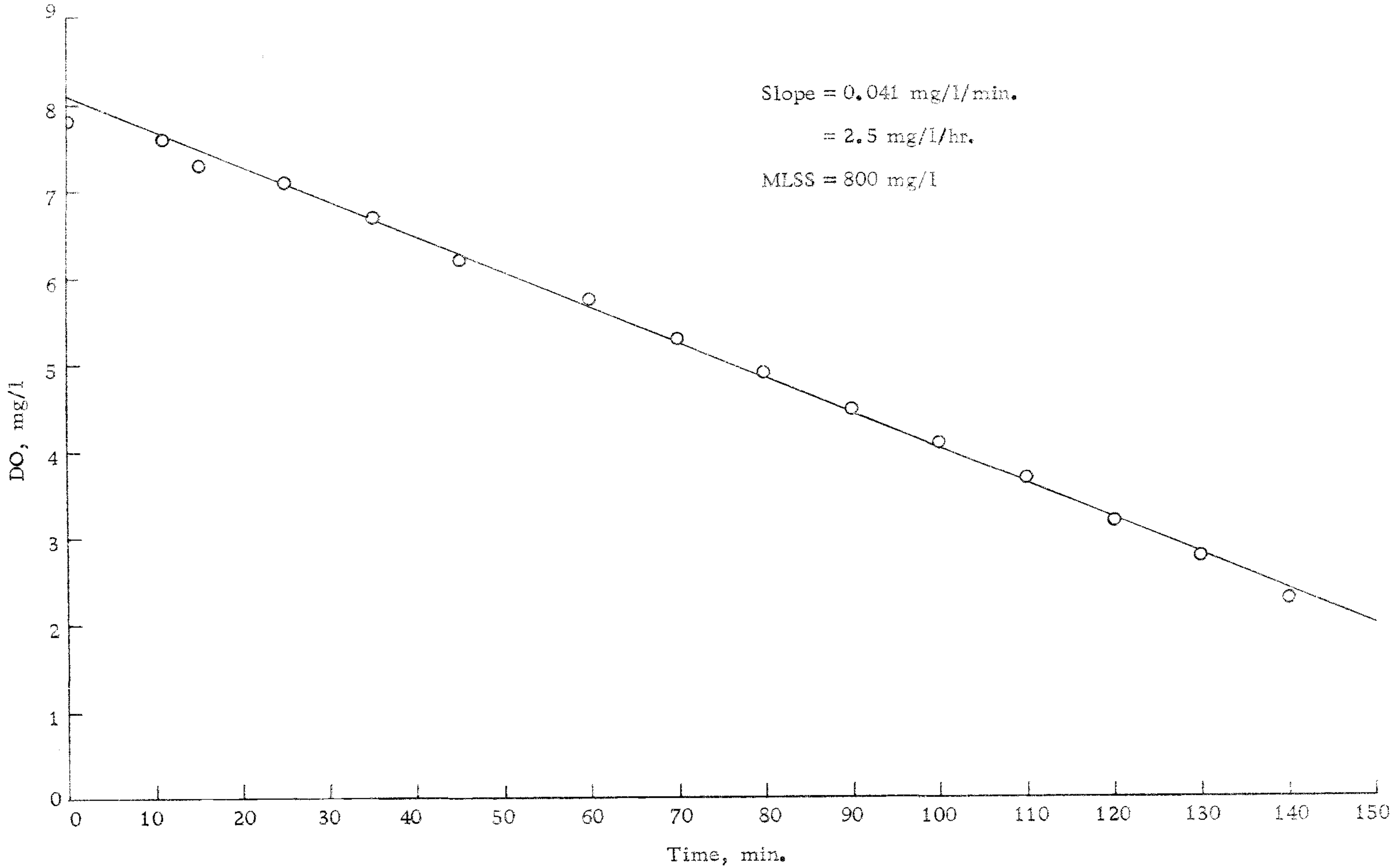


Figure 16. Oxygen uptake by MLSS from Aeration Unit 1.

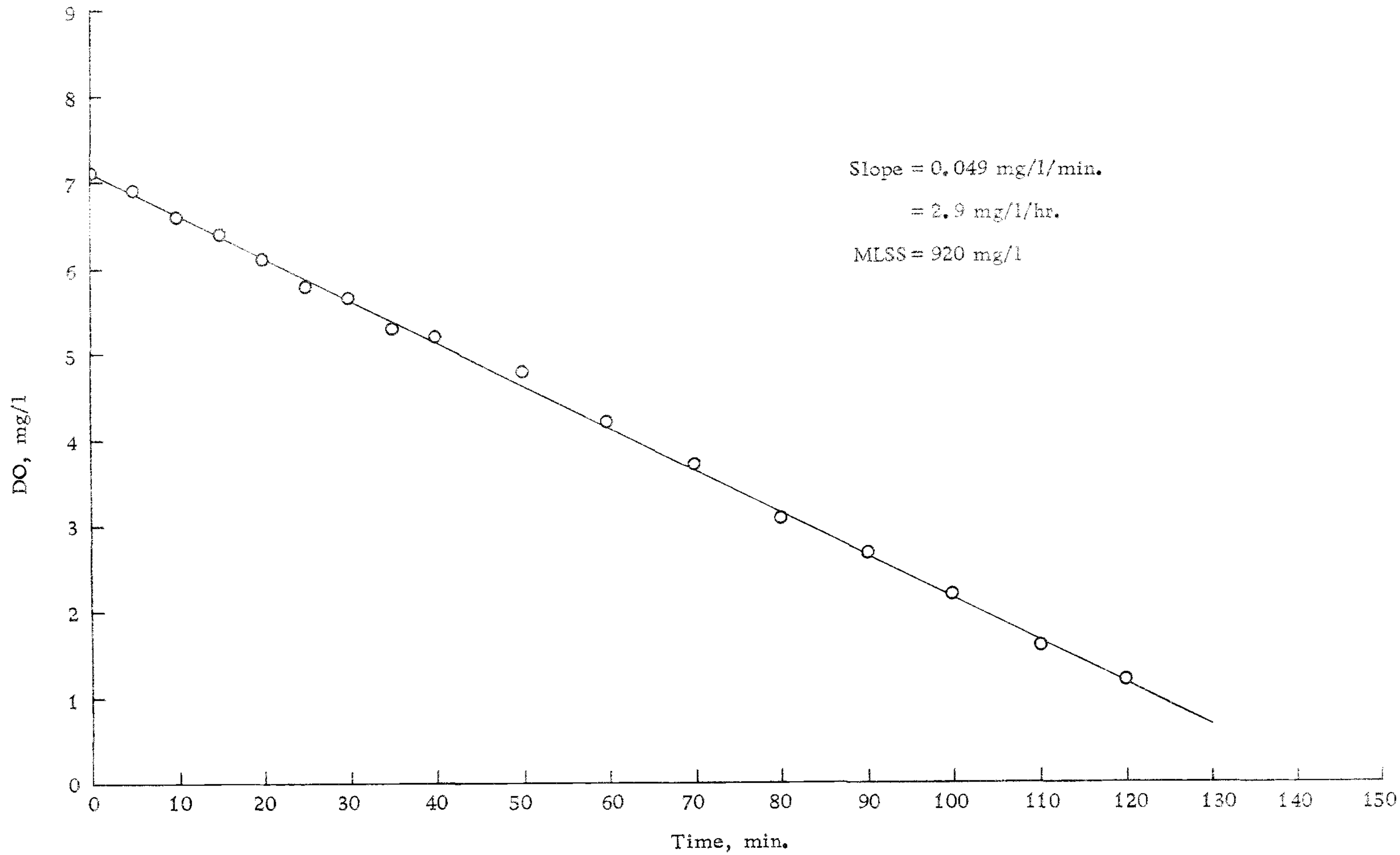


Figure 17. Oxygen uptake by MLSS from Aeration Unit 2

Table 12. Results of Oxygen Uptake Tests

Unit	MLSS, mg/l	Uptake Rate, $\frac{mg/l\ O_2}{hr}$	Uptake Rate, $\frac{mg\ O_2/hr}{gm\ MLSS}$
1	800	2.5	3.1
2	920	2.9	3.2

The oxygen depletion with respect to time exhibited a straight line relationship. This shows that the biological systems were quite stable.

The uptake rates per gram of MLSS were very low. By comparison, Eckenfelder and O'Conner have reported uptake values of 10 to 20 mg O_2/hr/gm MLSS for activated sludge treating domestic sewage and 10 to 15 mg O_2/hr/gm MLSS for activated sludge treating pulp and paper wastes (7. p. 42).

The low uptake rates were partly due to the fact that the log pond water contained many non-biodegradable substances which resulted in a low BOD loading. The long detention periods also contributed to the low uptake rates.

SUMMARY

The purpose of this study was to characterize log pond water chemically and to determine if this water could be biodegraded under aerobic conditions.

Four log ponds from different locations and storing different species of logs were selected for the chemical characterization portion of the study. Various chemical analyses including total solids, volatile solids, suspended solids, dissolved oxygen, pH, COD, BOD_{20}, BOD_5, total Kjeldahl nitrogen, nitrate nitrogen, phosphate, and PBI were performed on water samples from each of these ponds. Generally, the ponds were found to be quite homogeneous with respect to the tests performed. The degree of pollution was found to be related to the average length of log storage time, the overflow rate, and the amount of logs stored per unit pond surface area.

In all cases the BOD_5 values were quite low in comparison to the COD values, indicating that many of the substances present in the log pond water were non-biodegradable. For example, one pond had a COD of 450 mg/l and a BOD_5 of only 54 mg/l. Therefore, the water from this log pond must have contained primarily non-biodegradable organic compounds extracted from the stored logs or the degradable portion had been metabolized.

The log pond water studied also contained sufficient nitrogen and phosphorus to sustain biological growth. All the ponds had very low values of dissolved oxygen showing that some form of biological degradation was taking place within the ponds.

In order to determine to what extent log pond water could be biodegraded, two bench scale extended aeration units were set up. The water from the log pond with the highest COD and BOD_5 (COD = 450 mg/l, BOD_5 = 54 mg/l) was used exclusively for this study. This water was fed to the pilot plants containing acclimated sludge and the resulting mixed liquor was aerated. Liquid detention times of one, two, three, and five days were used. Various tests were performed on the effluent from the units to determine the extent that the log pond water was being biodegraded.

The pilot plants performed quite well and produced similar results. Generally, the longer the detention period, the higher the COD, BOD_5 and PBI removals. However, these removals leveled off at the five-day detention period so a further increase in detention time would not have increased the removals substantially. With a five-day detention period the following removals were obtained: total COD = 63%, soluble COD = 52%, BOD_5 = 93%, PBI = 64%.

A straight line relationship existed between the detention period and the MLSS level present in the aeration tank. The MLSS level ranged from about 380 mg/l at a five-day detention period to

1060 mg/1 at a one-day detention period. The oxygen uptake of the sludge was 3.1 mg 0_2 per hour per gram MLSS. As the MLSS level increased the quality of the effluent was affected since more suspended solids were discharged. The effluent suspended solids varied from 26 mg/1 at a five-day detention time to 90 mg/1 at a one-day detention time.

The unitless oxygen transfer parameter, α, was found to be 1.1 for log pond water, showing that the rate of oxygen transfer into log pond water was greater than into distilled water.

The results of this study clearly indicate that log pond water can be effectively treated using aerobic biological processes.

CONCLUSIONS

1. Length of log storage time, hydraulic overflow rate, and the quantity of logs stored per unit pond surface area affect the chemical nature of the log ponds.

2. Log pond water is generally homogeneous throughout the pond.

3. Low BOD_5 to COD ratios are typical for log pond water, indicating a high proportion of non-biodegradable organic substances.

4. Nitrogen and phosphorus are present in sufficient quantities in log pond water to support biological activity.

5. BOD_5 and COD can be effectively removed from log pond water by aerobic biological treatment processes.

6. Oxygen transfer into log pond water is more rapid than into distilled water.

BIBLIOGRAPHY

1. Agardy, F. J. and M. L. Kiado. Effects of refrigerated storage on the characteristics of waste. In: Proceedings of the Twenty First Industrial Waste Conference, Purdue University, 1966. Lafayette, Indiana, 1966. p. 226-233. (Purdue University. Engineering Extension Series no. 121)

2. American Public Health Association. Standard methods for the examination of water and wastewater. 12th ed. New York, 1965. 769 p.

3. Bailey, E. L. Water supply and effluent treatment at Kamloops Pulp and Paper Company. Pulp and Paper Magazine of Canada 67: 85-86. 1966.

4. Barnes, C. A. et al. A standardized Pearl-Benson, or nitroso, method recommended for estimation of spent sulfite liquor or sulfite waste liquor concentration in waters. Tappi 46: 347-351. 1963.

5. Eckenfelder, W. W., Jr. Factors affecting the aeration efficiency of sewage and industrial wastes. Sewage and Industrial Wastes 31: 60-70. 1959.

6. Eckenfelder, W. W., Jr. Industrial water pollution control. New York, McGraw-Hill, 1966. 275 p.

7. Eckenfelder, W. W., Jr. and D. J. O'Conner. Biological waste treatment. New York, Pergamon, 1961. 299 p.

8. Ellwood, E. L. and B. A. Ecklund. Bacterial attack of pine logs in pond storage. Forest Products Journal 9: 283-292. 1959.

9. Farmer, R. H. Chemistry in the utilization of wood. London, Pergamon, 1967. 193 p.

10. Felicetta, V. F. and J. L. McCarthy. The Pearl-Benson or nitroso, method for the estimation of spent sulfite liquor concentration in water. Tappi 48: 337-347. 1963.

11. Gellman, Isaiah. Aerated stabilization basin treatment of mill effluents. Tappi 48: 106A-110A. 1965.

12. Henriksen, A. and J. E. Samdal. Centralized log barking and water pollution. Vattenhygien 2:55-60. 1966.

13. Hubbard, J. K. and E. F. Kurth. Douglas fir bark tannin. Journal of the American Leather Chemists' Association 44:604-612. 1949.

14. Jeris, J. S. A rapid COD test. Water and Wastes Engineering 4:89-91. May, 1967.

15. Kurth, E. F. Chemicals from Douglas fir bark. Tappi 36:119A-122A. 1953.

16. Kurth, E. F. and J. K. Hubbard. Extractives from ponderosa pine bark. Industrial and Engineering Chemistry 43:896-897. 1951.

17. Kurth, E. F., J. K. Hubbard and J. D. Humphrey. Chemical composition of ponderosa and sugar pine barks. Paper presented at the Third Annual National Meeting of the Forest Products Research Society, Grand Rapids, Michigan, May 3, 1949.

18. McHugh, R. A., L. S. Miller and T. E. Olsen. The ecology and naturalistic control of log pond mosquitoes in the Pacific Northwest. Portland, Oregon State Board of Health, 1964. 87 p.

19. Middlebrooks, E. J. et al. Combined wood storage and waste treatment for the paper industry. Tappi 51:93A-97A. 1968.

20. Sawyer, C. N. Chemistry for sanitary engineers. 2d ed. New York, McGraw-Hill, 1967. 518 p.

21. U. S. Forest Service. Timber resource statistics for the Pacific Northwest as of January, 1963. Portland, 1965. 38 p. (Pacific Northwest Forest and Range Experiment Station. U. S. Forest Service Resource Bulletin PNW-9).

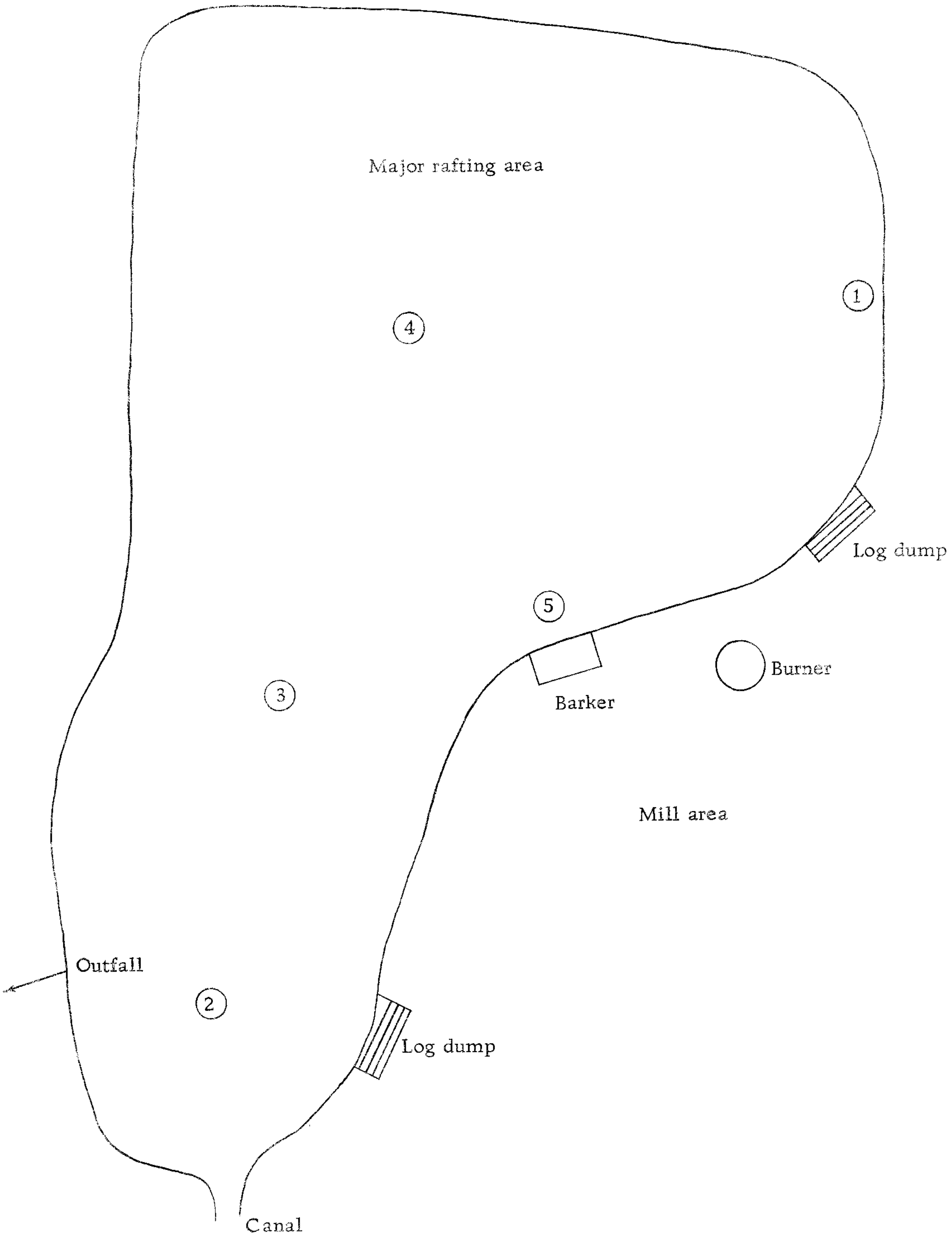
22. White, M. T. Long term aeration of kraft pulp and paper wastes. Paper presented at the Twenty-third Industrial Waste Conference, Purdue University, Lafayette, Indiana, May 8, 1968.

23. Wine, R. L. Statistics for scientists and engineers. Englewood Cliffs, N. J., Prentice-Hall, 1964. 691 p.

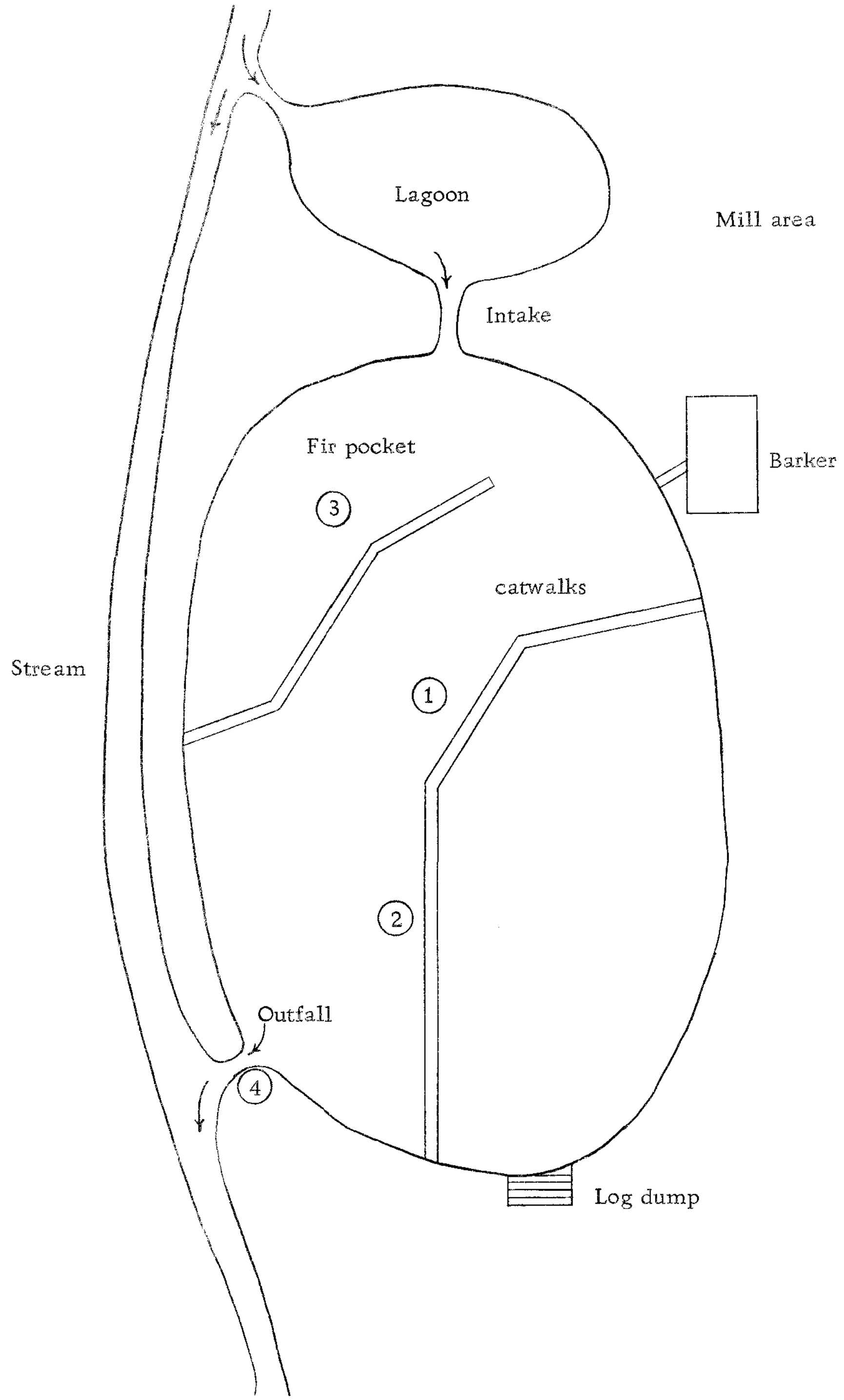
24. Wise, L. E. Extraneous materials of wood. In: Wood chemistry, ed. by L. E. Wise and E. C. Jahn. Vol. 1. New York, Reinhold, 1952. p. 543-648.

25. Wyckoff, B. M. Rapid solids determination using glass fiber filters. Water and Sewage Works 111 (Reference number): R-349-R-352. November, 1964.

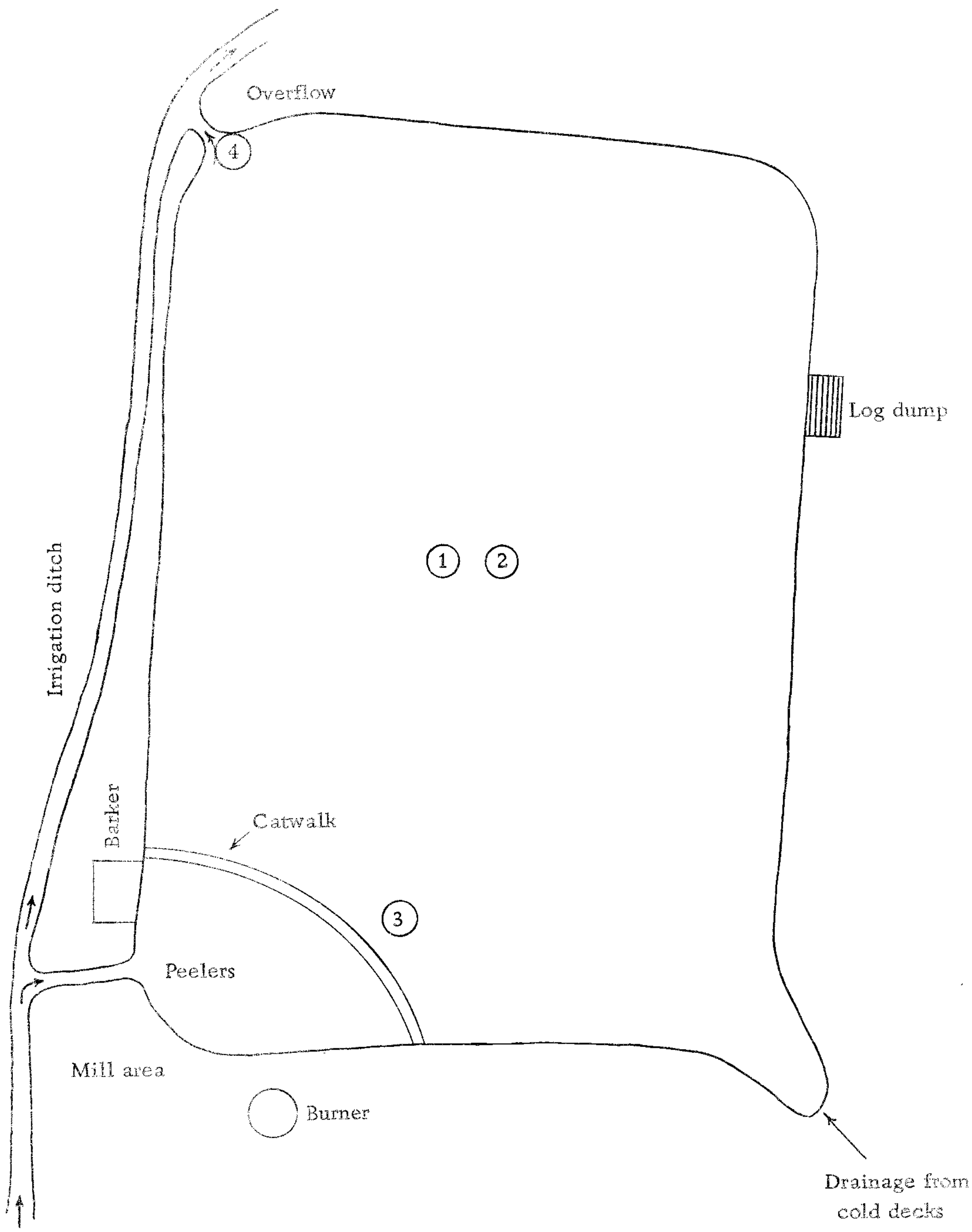
APPENDIX


Major rafting area
1
4
Log dump
5
Burner
3
Barker
Mill area
Outfall
2
Log dump
Canal

Pond A


Lagoon
Mill area
Intake
Fir pocket
Barker
3
catwalks
Stream
1
2
Outfall
4
Log dump

Pond C


Overflow
4
Log dump
1
2
Irrigation ditch
Barker
Catwalk
3
Peelers
Mill area
Burner
Drainage from
cold decks

Pond D