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An Assessment of Kraft Bleachery Effluent Toxicity Reduction Using Activated Sludge

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AN ASSESSMENT OF KRAFT BLEACHERY EFFLUENT TOXICITY REDUCTION USING ACTIVATED SLUDGE

by

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ABSTRACT

Bleach plant effluent is considered to be one of the major contributors to toxicity in kraft pulp and paper mill operations. A pilot scale two-stage activated sludge system was operated on the six-stage kraft bleachery effluent at Eddy Forest Products Limited, Espanola, Ontario, to study the practicability of using a two-stage biological system to meet effluent requirements specified in the Pulp and Paper Effluent Regulations (1971). For comparison purposes a conventionally loaded single-stage activated sludge system was operated in parallel with the two-stage system. Emphasis was placed on an assessment of the capabilities of the activated sludge systems for the reduction of acute toxicity to juvenile rainbow trout.

The results showed that the two-stage system was consistently achieving greater toxicity reduction than the single-stage system even at considerably higher volumetric loadings. At similar volumetric loadings the two-stage system also provided greater BOD_5 removal than the single-stage system. Treatment efficiency and toxicity reduction were both shown to be affected by wood species.

Effluents from both activated sludge systems treating kraft bleachery effluent would not meet the toxicity requirements specified in the Pulp and Paper Effluent Regulations (1971).

RESUME

Dans les usines de pâtes et papiers kraft, le procédé de blanchiment est réputé l'une des principales sources de toxicité des effluents. On a fait l'essai d'un traitement pilote en deux stades pour les boues activées de l'effluent du procédé de blanchiment en six stades de l'Eddy Forest Products Limited, à Espanola (Ontario). L'expérience avait pour but d'estimer si le système biologique en deux stades satisfait au Règlement sur les effluents des fabriques de pâtes et papiers (1971). Aux fins de comparaison, on a installé un système monostade classique en parallèle avec le distade. On s'est appliqué à évaluer l'efficacité de ces installations à réduire la toxicité aigue des effluents se manifestant chez les truites arc-en-ciel juvéniles.

Le système distade s'est toujours révélé plus efficace, même quand les charges volumiques étaient considerablement plus élevées. Lorsque ces dernières étaient similaires, le traitement en deux stades réduisait davantage la DBO_5. L'efficacité du procédé et la reduction de la toxicité varaient toutes deux selon l'essence ligneuse formant la matière première.

Cependant, les effluents de l'un ou l'autre système ne satisfaisaient pas aux exigences de détoxication du Règlement sur les effluents des fabriques de pâtes et papiers (1971).

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CONCLUSIONS

The results of a field study involving pilot scale single-stage and two-stage activated sludge treatment of kraft bleachery effluent are presented in this report. Emphasis was placed on an assessment and comparison of the capabilities of the activated sludge systems for the reduction of acute toxicity to juvenile rainbow trout. The following conclusions can be made:

1. The two-stage activated sludge system was capable of removing a greater portion of the toxicity than the single-stage system. Increased toxicity removal was achieved during periods when the organic and volumetric loadings to the two-stage system were much higher than for the single-stage system.
2. Effluents from the single-stage and two-stage activated sludge systems treating kraft bleachery effluent did not meet the toxicity requirements specified in the Pulp and Paper Effluent Regulations (1971); i.e., there must be 80% survival of rainbow trout for 96 hours in a 65% effluent solution.
3. For the two-stage activated sludge system, overall volumetric loadings of 3.8 and 1.6 kg $BOD_5/m^3 \cdot day$ (235 and 100 lb $BOD_5/1000\ ft^3 \cdot day$) provided BOD reductions of 67% and 89%, respectively; to provide a similar BOD_5 reduction, the single-stage system was operated at volumetric loadings of 1.6 and 0.7 kg $BOD_5/m^3 \cdot day$ (100 and 45 lb $BOD_5/1000\ ft^3 \cdot day$).
4. There was considerable fluctuation in toxicity of untreated kraft bleachery effluent; similar fluctuations were reported for single-stage and two-stage effluents during periods when there was minimal fluctuation in effluent BOD_5 and suspended solids concentrations.

5. Effluents produced during the bleaching of softwood were consistently more toxic than those produced during the bleaching of hardwood pulp.

RECOMMENDATIONS

Based on the results of the pilot scale study, the following recommendations can be made:

1. For bioassay testing of effluents from activated sludge systems operated at either conventional or high rate loadings, composite sampling is required.
2. For comparison of toxicity levels in effluents from more than one treatment system, it is recommended that 24-hour composite samples be collected, median survival times using 100% effluent be determined and probability distribution plots for median survival times prepared.
3. Additional studies are required to establish whether a combined physical-chemical-biological system incorporating the two-stage activated sludge process will remove toxicity.
4. Additional pilot scale information is required to establish engineering design criteria for activated sludge systems treating kraft bleachery effluent.

1 INTRODUCTION

Biological waste treatment systems have found wide acceptance in the pulp and paper industry for the reduction of oxygen consuming materials in various waste streams. In the treatment of wastewater from kraft pulp mill operations, aerated lagoon and extended aeration activated sludge systems have been used successfully to reduce the biochemical oxygen demand (Gehm, 1973 and NCASI Tech. Bull. No. 220, 1968) and have had a certain degree of success in the reduction of toxicity (EPS Report No. 3-WP-73-6, 1973 and Charles and Decker, 1970). These systems have lower capital and operating costs than most conventional or high rate treatment processes. However, because of potential operating problems and space limitations at many mills, there is a need to look at other process alternatives.

It is well documented in the literature that multi-stage biological processes provide process stability even when subjected to shock loading (EPA Report No. 12040 EMY 12/71, 1971). The Wastewater Technology Centre (WTC) of the Environmental Protection Service initiated an experimental program to study the practicability of using a two-stage activated sludge system to meet effluent requirements specified in the Pulp and Paper Effluent Regulations (1971). Of particular concern was the ability of the system to remove toxicity. For comparison purposes, bench scale two-stage and single-stage activated sludge systems were operated in parallel using kraft bleachery effluent. The bleach plant effluent was selected as it was known to be one of the most toxic streams in the total kraft mill discharge.

Bench scale results indicated that even though the characteristics of the wastewater were highly variable, BOD_5 and suspended solids removal were within an acceptable range. While reliable toxicity results were limited, there was sufficient evidence that the toxicity reductions were significant. The results indicated that there was a need to define the variability in the process effluent stream with respect to time and process operation, and to determine to what extent the high rate two-stage biological system could remove the toxicity. To this end, a field study was initiated at Eddy Forest Products Limited, Espanola, Ontario, in June 1973. This study involved the operation of two pilot scale activated sludge treatment systems. Although the majority of the project was funded and carried out by WTC personnel, Eddy Forest Products Limited assisted in the project by providing support staff, equipment and a separate building to locate the pilot plants and laboratories.

The Eddy Forest Products Limited mill in Espanola is an integrated kraft pulp and paper mill producing approximately 590 tonnes (650 tons) of pulp per day. At the time of the study, the mill was processing both hardwood and softwood species which were shipped to the mill by land in either log or wood chip form. Following the kraft pulping process, the product was bleached in one of two bleach plants. The six-stage bleach plant consisting of chlorination, caustic extraction, hypochlorite, chlorine dioxide, caustic extraction and chlorine dioxide stages (CEHDED) was selected for the study.

2 STUDY OBJECTIVES

The specific objectives which were established for this field project were as follows:

1. Evaluate the capability of a two-stage activated sludge system to reduce acute toxicity of kraft bleachery effluent.
2. Compare the efficiency of a two-stage activated sludge system with a conventionally operated, single-stage activated sludge plant for the removal of BOD_5 and toxicity.
3. Investigate the variability in toxicity of the treated and untreated kraft bleachery effluent with respect to time and treatment process operation.

3 MATERIALS AND METHODS

The field installation at Eddy Forest Products Limited, Espanola, Ontario, was divided into three sections: a pilot plant treatment area, an analytical testing area and a bioassay testing area. The pilot plant treatment area housed the chemical pretreatment system, a two-stage activated sludge system, a single-stage activated sludge system and support equipment such as air blowers and refrigerated automatic samplers. The analytical area accommodated all equipment required to perform daily routine testing such as BOD_5, COD, suspended solids, etc. In the bioassay testing area, units such as fish stock tanks, temperature controlled water baths, diluting apparatus and an air compressor were located. A general layout of the equipment located in the storage building is shown in Figure 1, followed by a description of the identifying symbols in Table 1.

3.1 Experimental Schedule

The study involved the operation of a two-stage and a single-stage activated sludge system treating neutralized kraft bleachery effluents. Three different loading conditions were investigated in each treatment system. The experimental schedule is presented in Table 2. As indicated, during the initial operating period, both systems were operated at loadings in the range of a conventional activated sludge process. In the second and the third operating periods, the loading was increased for the two-stage system and decreased for the single-stage system. The changes were made in order to investigate the BOD and toxicity removal capabilities of the treatment systems under a wide range of loading conditions.

3.2 Wastewater Characteristics

The waste stream used for the study was the effluent from a six-stage bleach plant having a CEHDED bleaching sequence. The bleach plant, processing both hard and softwood, bleached an average of 340 air-dry tonnes (375 tons) of kraft pulp with a wastewater flow of approximately 13.6 m^3/min (3000 Igpm). Wastewater characteristics for

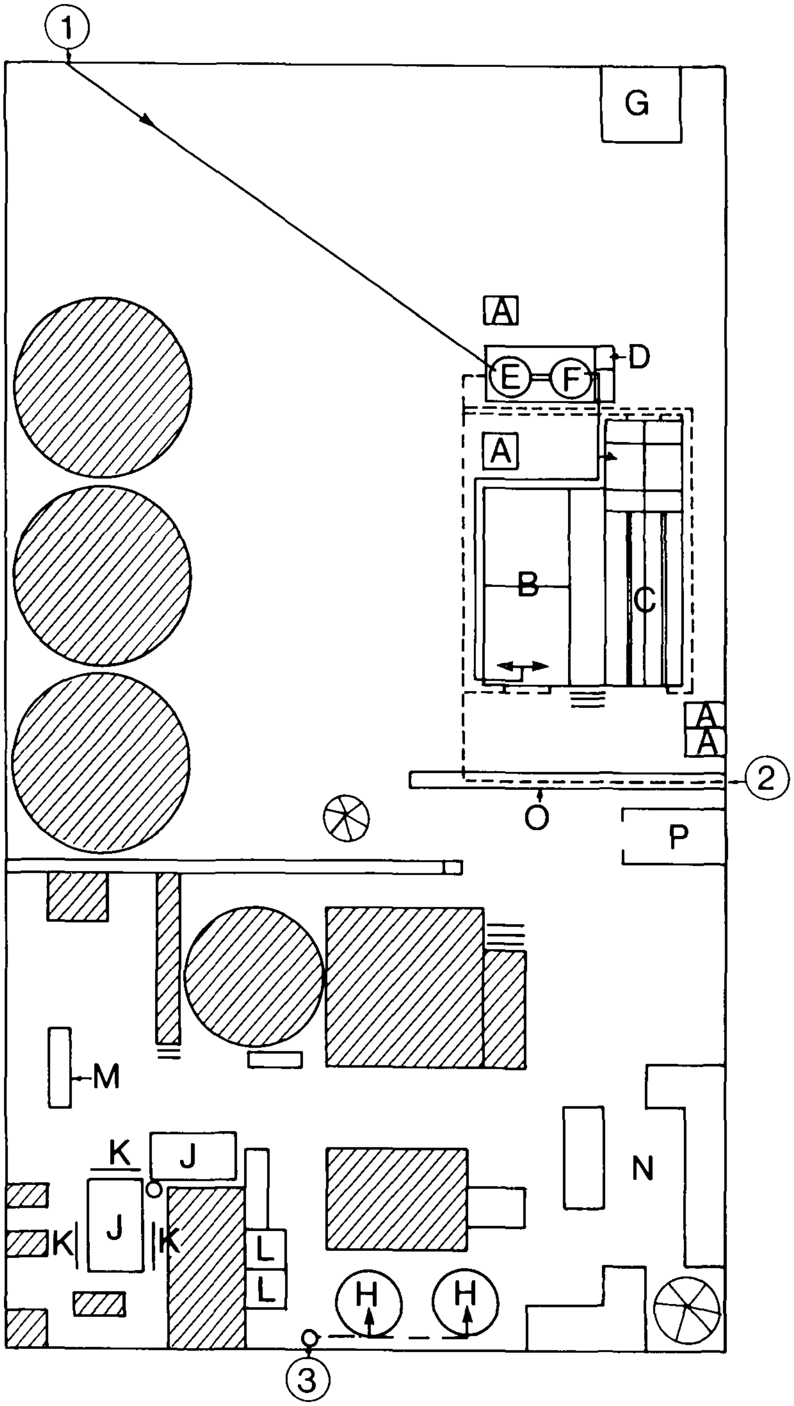

FIG. 1 GENERAL LAYOUT OF PILOT PLANT FACILITY

TABLE 1. IDENTIFICATION OF SYMBOLS USED IN FIGURE 1

A.	Refrigerated Sampler
B.	Single-Stage Reactor and Clarifier
C.	Two-Stage Reactor and Clarifier
D.	pH Control System
E.	Bleachery Effluent Overflow
F.	Mixing Tank
G.	Air Blower System
H.	Fish Stock Tank
J.	Cooling Bath
K.	Dilution Apparatus
L.	Refrigerator and Incubator
M.	Air Compressor
N.	Analytical Area
O.	Drain Line
P.	Power House
1	Bleach Plant Effluent
2	Drainage
3	Water For Fish Stock
(hatched box)	Mill Equipment and Storage Tanks

TABLE 2. EXPERIMENTAL SCHEDULE

Date	Feed Rate (m^3/day)		Retention Time in Reactors (hr)			Volumetric Loading (kg $BOD_5/m^3 \cdot$day)			Organic Loading (kg BOD_5/kg MLSS•day)		
From To	Two-Stage	Single Stage	1st Stage	2nd Stage	Single Stage	1st Stage	2nd Stage	Single Stage	1st Stage	2nd Stage	Single Stage
Nov. 22/73 - Jan. 25/74 (Day 326 to 25)	6.5	15.4	1.4	1.4	2.7*	3.2	1.1	1.6	0.5	0.5	0.4
Jan. 26/74 - Mar 6/74 (Day 26 to 65)	13.1	15.4	0.7	0.7	5.5	5.6	2.7	0.7	1.3	1.2	0.3
Mar 7/74 - Mar. 28/74 (Day 66 to 87)	19.6	22.9	0.5	0.5	3.7	9.9	7.0	1.2	2.0	6.1	0.3

* Aeration tank volume at this flow was 1.7 m^3 which was half of the designed capacity.

unfiltered, 24-hour composite samples collected from the bleach plant are presented in Table 3. The tabulated results include the mean, the standard deviation and the minimum and maximum values measured.

TABLE 3. WASTEWATER CHARACTERISTICS

Parameter	Mean	Standard Deviation	Minimum	Maximum
BOD_5 (mg/l)	177	44	81	349
COD (mg/l)	990	239	437	1891
TSS (mg/l)	63	31	10	154
Temperature (°C)	43	3	17	49

There was considerable variability in characteristics of the wastewater. Total Kjeldahl nitrogen ranged from 0.4 to 5.6 mg/l and orthophosphate from 0.8 to 1.5 mg/l, indicating that nutrient supplementation was a pre-requisite for biological treatment. The pH values of the wastewater varied from 2.0 to 9.3, with the median value being 3.7. This suggested that pH adjustment was required before the wastewater was fed to the activated sludge systems. The bleachery effluent had a light golden colour, but would change to dark brown after neutralization. No significant difference in BOD_5, suspended solids and pH between wood species was observed during the study. However, the quantity of caustic soda required to raise the pH to a neutral range was slightly higher for softwood than for hardwood effluents. Generally, 0.30 kg NaOH/m^3 (3.0 lb/1000 gal) was required when the softwood effluent was neutralized whereas hardwood effluent only required 0.22 kg/m^3 (2.2 lb/1000 gal).

As shown in Table 3, the wastewater had a mean temperature of 43°C with a standard deviation of 3°C. Because of the high temperature, potential problems of obtaining sufficient oxygen in the treatment systems as well as establishing a desirable bacterial population were of some concern. These problems were not encountered during the study.

Significant difference in toxicity was observed between untreated softwood and hardwood effluents. The 96-hour LC_{50} ranged from 6% to 13% for softwood and 13% to 17% for hardwood effluents. The significance of these values will be discussed in Section 4.2.2

3.3 Pilot Plant Equipment

The single-stage reactor, constructed by Napanee Industries Limited, Napanee, Ontario, was a conventional activated sludge package plant consisting of an aeration cell, settling chamber and aerobic digestion cell. The aeration cell was 1.6 m (5.25 ft) by 1.2 m (4.0 ft) by 2.2 m (7.25 ft) deep with approximately 0.4 m (1.35 ft) of freeboard; the cell could be divided in half by means of a bolted partition. The total aeration cell volume was approximately 3.5 m^3 (124 ft^3). The settling chamber was approximately 1.2 m (4 ft) by 1.4 m (4.5 ft) for a surface area of 1.7 m^2 (18 ft^2) and weir length of 1.0 m (3.3 ft). Mechanical equipment consisted of a variable speed Sterling drive Moyno pump and rotary-type blower. The blower provided air through rotameters and control valves to the aeration cells, air lift sludge return system and aerobic digester.

The two-stage system, manufactured by Cellulose Attisholz AG, Luterbach, Switzerland, consisted of a first stage aeration cell and settling chamber located in parallel with a second stage aeration cell and settling chamber. Aeration cells were 0.80 m (2.6 ft) by 0.47 m (1.55 ft) by 1.0 m (3.3 ft) deep with a volume of 0.38 m^3 (13 ft^3). Clarifiers were 2.97 m (9.75 ft) by 0.46 m (1.5 ft), yielding a surface area of approximately 1.36 m^2 (14.7 ft^2) and an overall weir length of 4.7 m (15.5 ft). Two additional cells approximately 0.46 m (1.5 ft) by 0.47 m (1.55 ft) by 1.0 m (3.3 ft) could be used for aerobic digestion or sludge storage. Mechanical equipment consisted of a variable speed progressing cavity feed pump (similar to a Moyno pump), a fan-type blower and a mechanical scraper in each clarifier. Aeration capacity was provided through diffusers and air lift pumps were used for sludge return and return of first stage clarifier effluent to the second stage aeration cell.

Two 455-litre (100-gallon) fibreglass tanks were installed ahead of the activated sludge systems. The first acted as an overflow tank and the second was used for mixing of chemicals and housing a pH probe, temperature probe and mixing apparatus. Temperature of raw influent and neutralized wastewater as well as clarifier effluents on the two-stage reactors were monitored continuously on a 12-point Foxboro-YEW Recorder.

The pH neutralization system consisted of a submersible electrode probe assembly and Model 940 pH analyser by Beckman Instruments, a Honeywell Currentronik Vertical Scale Indicator-Controller, a Honeywell Currentronik Recorder and a BIF pump with automatic controls. The pH probe was located just ahead of the discharge line from the mixing tank, so that the wastewater would receive chemical addition before this point. The signal from the indicator-controller to the caustic feed pump was set so that sufficient chemical would be added to produce a wastewater pH of approximately 7.0 going to the aeration cells.

3.4 Operation of Pilot Plant Facility

The start-up of the activated sludge pilot plants involved seeding with mixed liquor from the Sudbury Municipal Sewage Treatment Plant. After the aeration tanks had received the desired quantity of sludge and the clarifiers filled with river water, the system was put into operation. The KBE was pumped to the holding tank from where it flowed to the mixing tank for neutralization and nutrient addition. Ammonium chloride (NH_4Cl) and ammonium phosphate ($(NH_4)_3PO_4$) were added to ensure that the BOD_5:N:P ratio of 100:5:1 was maintained. The wastewater was then pumped from the mixing tank to the treatment systems using variable speed positive displacement pumps.

Untreated bleachery effluent and effluents from the first, second and single-stage clarifiers were sampled daily; 24-hour composite samples were collected using timer-controlled refrigerated samplers. Contents of each of the three aeration cells were sampled once a day on a grab basis.

The analyses for the process effluents included five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total and volatile suspended solids (TSS and VSS), pH, toxicity, total Kjeldahl nitrogen (TKN), orthophosphate and free residual chlorine. The last three tests were performed on an intermittent basis only. Analyses of aeration cell contents included total and volatile mixed liquor suspended solids (MLSS and MLVSS), dissolved oxygen (DO), sludge volume index (SVI) and oxygen uptake rate (OUR)

3.5 Analytical Procedures

To monitor the treatment systems, an analytical laboratory was set up on site to measure the parameters mentioned in Section 3.4. General procedures for all tests followed those outlined in "Standard Methods" with the following qualifications. The BOD_5 testing was carried out using an acclimatized seed which was obtained from a batch fed activated sludge reactor maintained for this purpose. Dilution water was seeded at 1 ml/l with the supernatant from this reactor. A YSI Model 54 dissolved oxygen meter equipped with self-stirring probe and calibrated daily using the Winkler method was used for dissolved oxygen determinations. Phosphate determinations were made using a Hach chemical kit.

Chlorine analyses were conducted using a slight modification of the iodometric method outlined in "Standard Methods". Due to the inherent colour of the samples, addition of sodium thiosulphate never resulted in a colourless solution at the end point. For these determinations, the end point was considered to be when the blue colour disappeared, that is, when the solution returned to its original colour. For the purposes of the field study, this method was found to be both replicable and most expeditious.

3.6 Bioassay Facilities and Procedures

The bioassay testing facility was located in the storage building so that water for fish holding tanks and dilution water for bioassays could readily be pumped from a power canal adjacent to the building. This section describes the testing facilities, and procedures used for evaluating the toxicity of both untreated and treated effluents.

3.6.1 Testing facilities

The test fish used for the study were juvenile rainbow trout, *Salmo gairdneri*. They were held in circular, 800-litre fibreglass tanks at fish densities in excess of 2 l/g/day. Fresh water was continuously supplied to each tank at 6 to 8 l/min from the power canal outside the laboratory. This canal was fed directly from the Spanish River. Analyses of the river water are reported in Appendix 1.

During the initial phase of the experiment, fish were held at 14°C; however, the Spanish River water began to cool and by November 23 the water temperature had dropped to 5°C. During this time, all bioassays were operated at ambient river water temperatures. A water heater was installed on November 26, so that holding tanks and bioassays could be operated at 15±1°C. Fish were acclimated to 15°C at a rate not exceeding 1°C/day. Fish were held under constant light conditions as it was not possible to regulate the photo period in the laboratory.

Bioassay test vessels were 20-litre round polyethylene tote buckets lined with polyethylene bags to facilitate cleaning. Fibreglass screened baskets were placed in the buckets to permit observation in coloured effluents with minimum stress to the fish. The 20-litre bioassay containers were maintained at 15°C in two, 900-litre water baths cooled by means of a one horsepower Min-o-cool compressor.

3.6.2 Bioassay methodology

Both continuous flow and static bioassays were carried out in the study. The former was used to establish whether treated effluents met the toxicity requirements specified in the Pulp and Paper Effluent Regulations (1971). The latter was used to determine and compare the toxicity reduction capabilities of the two activated sludge treatment systems.

3.6.2.1 Continuous flow bioassays. Untreated, neutralized bleachery effluent from the mixing tank and treated effluents from the single and two-stage treatment systems were pumped continuously to the bioassay testing area. Since effluent temperatures exceeded 30°C when collected, it was necessary to cool the effluent by pumping through tygon tubing coiled around the inside of the 15°C water baths. From the water bath, the effluent fed the toxicant cell of a modified Mount-Brungs diluter (Mount and Brungs, 1967). All continuous flow bioassays were operated at 100 ml/min and had a 90% molecular replacement in eight hours. Time from sample collection to the bioassay test vessel never exceeded 10 minutes.

Initially, it was decided to maintain a relatively narrow range of concentrations in the diluter to ensure precision in LC_{50} determinations. It was soon realized that fluctuations in toxicity inherent in the bleach plant operation made it impossible to predict with any certainty the 96-hour LC_{50}'s. Consequently, wide ranges of concentrations were used in all continuous flow bioassays. Concentrations for the untreated effluent were 50%, 32%, 22%, 12.5% and 6.25% by volume. Concentrations for the single and two-stage effluents were 100%, 65%, 45%, 25% and 12.5% effluent by volume.

Since dissolved oxygen levels in treated effluents were less than 3 mg/l, the bioassay containers were aerated at approximately 250 ml/min to raise and maintain dissolved oxygen above 8 mg/l. Hicks and DeWitt (1971) indicated that a reduction of dissolved oxygen from 8 to 6 mg/l substantially increased the toxicity of bleach kraft mill effluent. Since the treated effluent had been subjected to vigorous aeration in the aeration cell of the reactors, it was assumed that there was little possibility of further reducing the toxicity by air stripping. Untreated effluents were tested in a similar manner in order to maintain sufficient dissolved oxygen.

In all continuous flow bioassays, 10 fish were used per concentration. Since the incoming waste fluctuated considerably it was necessary to maintain frequent observations on the bioassays. Initial observations were made at ¼, ½, 1, 2, 4 and 8 hours and at least every eight hours thereafter. Dead fish were removed when observed, and the weight and fork lengths recorded. Dissolved oxygen and pH readings were made before fish were introduced to the test containers, and at least twice daily during the test.

Since differences in toxic substances between wood species have been observed (Marier, 1973) and the bleachery operation varied with regard to quantities of chemicals required to bleach a particular wood species pulp, continuous flow bioassays were planned to begin and continue when the mill was processing one species for at least 96 hours. Every effort was made to avoid test periods which would include a change in wood species. Even though wood schedules were obtained from the mill one month in advance, production changes were necessary and consequently some tests were in progress when changes in wood species occurred. These changes have been recorded on the appropriate toxicity curves presented in Appendix VII.

3.6.2.2 Static bioassays. Daily fluctuations in acute toxicities for treated and untreated kraft bleachery effluents were determined by exposing fish to a 100% concentration in static bioassays. During November and December, comparisons of the toxicity of treated and untreated samples were made on one-hour composite 20-litre samples. As there was considerable variability in the toxicity of one-hour composite samples, the method of sample collection was changed and from February 19 until March 28, 20-litre, 24-hour composite samples were collected daily using the refrigerated samplers. The samples were heated to 15°C with a stainless steel heater and gently aerated until the dissolved oxygen was greater than 8 mg/l. Fish were then introduced and equilibrium loss and mortality times monitored as frequently as possible.

To investigate the variability in toxicity within a 24-hour sampling period, static bioassays were carried out on three separate occasions. Composite samples were collected from the untreated kraft bleachery effluent on November 7 at hourly intervals for 24 hours. A similar technique was used for treated and untreated samples on December 15 and March 24; however, composite samples on March 24 were collected over two-hour intervals.

4 EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Engineering Related Data

Performance of the activated sludge systems was determined by daily analyses of 24-hour composite samples of the untreated KBE and the three reactor effluents. Grab samples of aeration cell contents were also analyzed daily. The results for BOD_5, COD, TSS, VSS, pH and wood species are presented for the four streams in Appendix II. Data for TKN and phosphorus analyses which were performed on an intermittent basis are included in Appendix III. Effluent temperatures, caustic soda requirements and the daily log comments concerning various operating conditions of the plants are shown in Appendix IV. The statistical summary of process effluent and aeration cell data is presented in Tables 4 and 5, respectively.

Using the results in the tables, the loading conditions for each operational period can be calculated. The relationship of BOD_5 removal, in terms of percent and quantity, to applied volumetric loading is shown in Figure 2. For the range of loadings evaluated in this study, it appears that a linear relationship exists for percentage removal in each reactor. Removal efficiency in the single-stage unit drops off faster than for the two-stage reactor, decreasing from 89% at a loading of 0.7 kg $BOD_5/m^3 \cdot day$ (45 lb $BOD_5/1000\ ft^3 \cdot day$) to 67% at 1.6 $kg/m^3 \cdot day$ (100 $lb/1000\ ft^3 \cdot day$). By comparison, the overall BOD_5 removal efficiency of the two-stage reactor decreases from 89% at an applied loading of 1.6 kg $BOD_5/m^3 \cdot day$ (100 lb $BOD_5/1000\ ft^3 \cdot day$) to 67% at 3.8 $kg/m^3 \cdot day$ (235 $lb/1000\ ft^3 \cdot day$), the latter being taken from Figure 2.

In terms of quantity of organic material removed, the general relationship is increasing removal of BOD_5 with increasing applied load; however, the rate of increase in removal decreases as the load increases. It would also appear that there is a maximum quantity of BOD_5 which can be removed by the two-stage system. The curve becomes asymptotic to 2.9 kg $BOD_5/m^3 \cdot day$ (180 lb $BOD_5/1000\ ft^3 \cdot day$). Applied loadings, in terms of volumetric, organic and hydraulic loading, as well as removal efficiencies as percent reduction and quantity of BOD_5 removed, are shown in Table 6.

TABLE 4. STATISTICAL SUMMARY OF PROCESS EFFLUENT DATA

Period and Parameter	Bleachery Effluent			First Stage Effluent			Second Stage Effluent			Single-Stage Effluent		
	Npts	Mean	S.D.	Npts	Mean	S.D.	Npts	Mean	S.D.	Npts	Mean	S.D.
Nov 22 to Jan 25												
BOD_5	30	187	50	30	62	44	30	21	10	18	61	28
COD	37	1060	217	38	825	205	38	725	182	31	829	201
TSS	36	75	37	38	44	46	38	75	46	29	98	53
VSS	34	49	28	35	64	31	35	54	39	27	67	35
Jan 26 to Mar 6												
BOD_5	35	161	44	35	79	29	34	36	15	32	17	10
COD	32	877	244	31	750	213	31	698	196	29	580	185
TSS	36	55	31	35	64	37	35	64	31	32	58	29
VSS	35	41	25	35	50	28	35	44	29	32	40	26
Mar 7 to Mar 28												
BOD_5	21	190	35	20	135	22	21	82	29	20	43	28
COD	17	1040	278	16	1000	187	17	893	203	16	785	271
TSS	21	55	22	19	65	39	21	80	38	21	65	26
VSS	21	36	18	29	47	31	21	57	28	21	44	24

Note: Npts refers to number of data points.
Units are mg/l.

TABLE 5. STATISTICAL SUMMARY OF AERATION CELL DATA

Period and Parameter	First Stage			Second Stage			Single-Stage		
	Npts	Mean	S.D.	Npts	Mean	S.D.	Npts	Mean	S.D.
Nov. 22 to Jan. 25									
MLSS (mg/l)	43	6150	1190	45	2200	750	39	4350	1570
MLVSS (mg/l)	42	5050	960	44	1630	620	39	3570	1340
DO (mg/l)	24	1.6	1.4	23	6.2	1.2	21	0.9	1.1
SVI (ml/g)	36	101	28	37	57	21	31	88	29
OUR (mg O_2/g MLSS•hr)	37	32	24	36	32	16	30	21	15
Jan. 26 to Mar. 6									
MLSS (mg/l)	40	4290	1100	40	2210	1220	38	2850	500
MLVSS (mg/l)	40	4370	1020	40	1730	960	38	2360	490
DO (mg/l)	38	2.2	2.3	38	6.0	1.7	36	5.1	1.7
SVI (ml/g)	40	77	20	37	82	29	38	88	14
OUR (mg O_2/g MLSS•hr)	38	36	17	37	52	29	30	20	7
Mar. 7 to Mar. 28									
MLSS (mg/l)	22	4660	1720	22	1060	760	22	4780	920
MLVSS (mg/l)	22	4210	1660	22	820	630	22	4520	1420
DO (mg/l)	22	3.5	2.1	22	7.1	0.7	22	2.6	2.1
SVI (ml/g)	22	68	17	21	90	66	22	99	22
OUR (mg O_2/g MLSS•hr)	22	24	18	22	91	63	22	14	5

Note: Npts refers to number of data points.

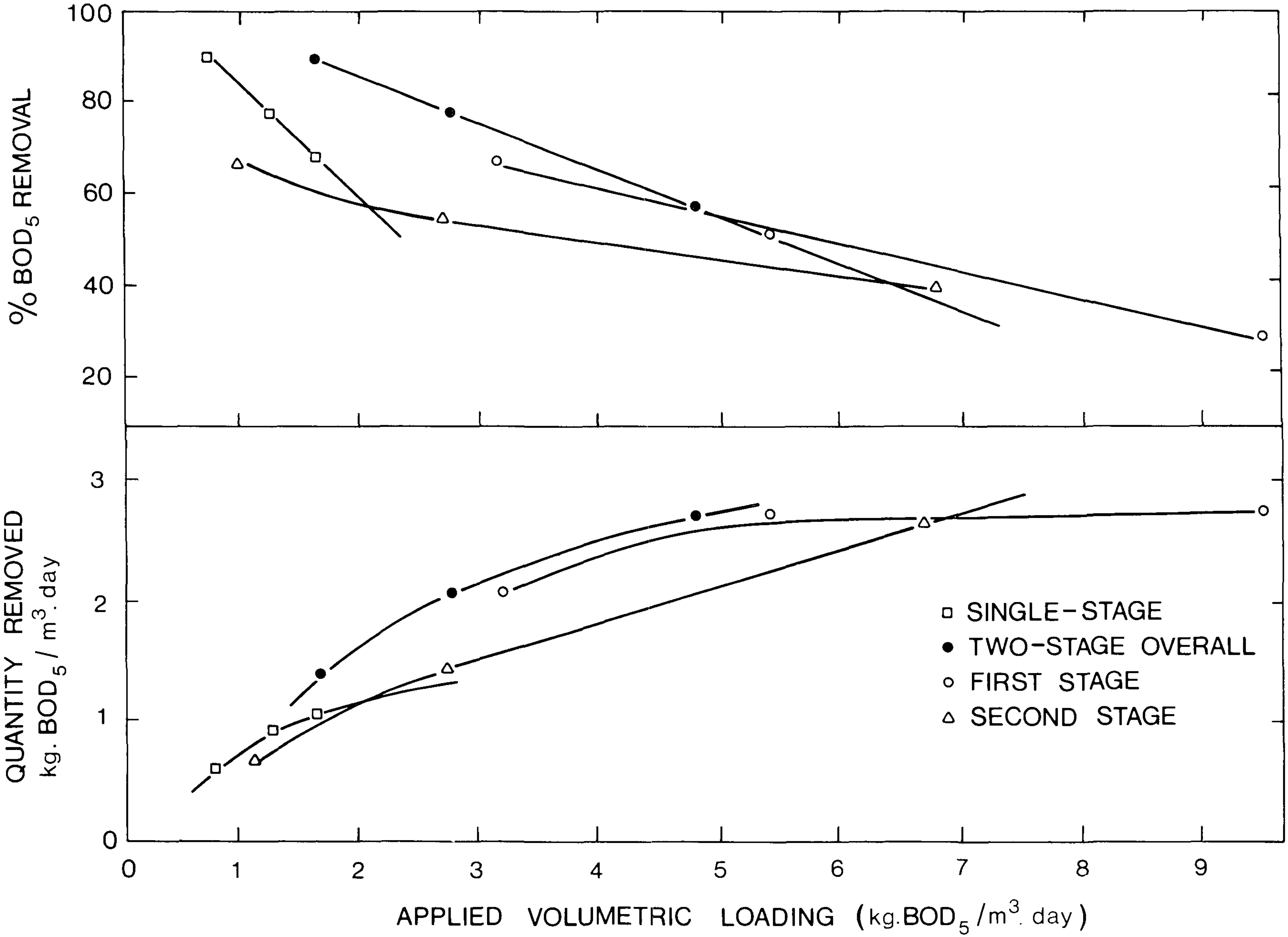

FIG. 2 BOD_5 REMOVAL OVER A RANGE OF APPLIED VOLUMETRIC LOADINGS

TABLE 6. SUMMARY OF APPLIED LOADINGS AND REMOVAL RELATIONSHIPS

Description	Stage	Operational Period		
		November 22 to January 25	January 26 to March 6	March 7 to March 28
1. Applied Loadings:				
1.1 Organic ($kg\ BOD_5/kg\ MLSS \cdot day$)	First	0.5	1.3	2.0
	Second	0.5	1.2	6.1
	First & Second	---	---	---
	Single	0.4	0.3	0.3
1.2 Volumetric ($kg\ BOD_5/m^3 \cdot day$)	First	3.2	5.6	9.9
	Second	1.1	2.7	7.0
	First & Second	1.6	2.8	5.0
	Single	1.6	0.7	1.2
1.3 Hydraulic (m^3/day)	First & Second	6.5	13.1	19.6
	Single	15.4	15.4	22.9
2. BOD_5 Removal Relationship:				
2.1 Percent	First	67	51	29
	Second	66	54	39
	First & Second	89	78	57
	Single	67	89	77
2.2 Quantity Removed ($kg\ BOD_5/m^3 \cdot day$)	First	2.2	2.9	2.9
	Second	0.7	1.5	2.8
	First & Second	1.4	2.2	2.8
	Single	1.1	0.5	1.0

Distribution plots for final effluent BOD_5 of the two-stage and single-stage systems are presented in Figures 3 and 4, respectively. The straight lines in the figures are obtained from the mean and standard deviation values presented in Table 4 and the assumption that the data is normally distributed. Although this assumption may be valid for the two-stage system, it is not necessarily so for the single-stage system. The results for the single-stage unit presented in Figure 4, show that for two of the loading conditions there are two distinct phases. For the first or highest loading, the effluent quality deteriorates significantly about 50% of the time, and for the third loading condition, about 30% of the time. No specific factors could be identified to explain the variability in effluent quality.

Probability or frequency distribution plots have also been prepared for total effluent suspended solids from the two-stage and single-stage units, as shown in Figures 5 and 6, respectively. There is only a slight difference in the three curves for the second stage of the two-stage unit. Effluent suspended solids concentration does not appear to be a function of hydraulic flow rate through the second stage clarifier for the two-stage unit.

For the single-stage system operated at the second and third loading conditions, there again appears to be only a slight increase in the median effluent suspended solids concentration with an increased hydraulic loading. At an overflow rate of 9.3 $m^3/m^2 \cdot day$ (190 gpd/ft^2) the mean TSS concentration was 58 mg/l and increased to 65 mg/l at an overflow rate of 13.7 $m^3/m^2 \cdot day$ (280 gpd/ft^2). The slopes of the two lines are parallel indicating a similar degree of variability in expected solids concentration. The slope of the line for the first operational period is slightly greater than for the other two operational periods. Although the surface loading on the clarifier was 9.3 $m^3/m^2 \cdot day$ (190 gpd/ft^2), which was the same as for the second operational period, the plant operation was not stable during this period, causing the effluent quality to vary significantly.

Data on MLSS, DO and SVI has been averaged over a three-day period and are presented in Figure 7. Rapid changes in MLSS

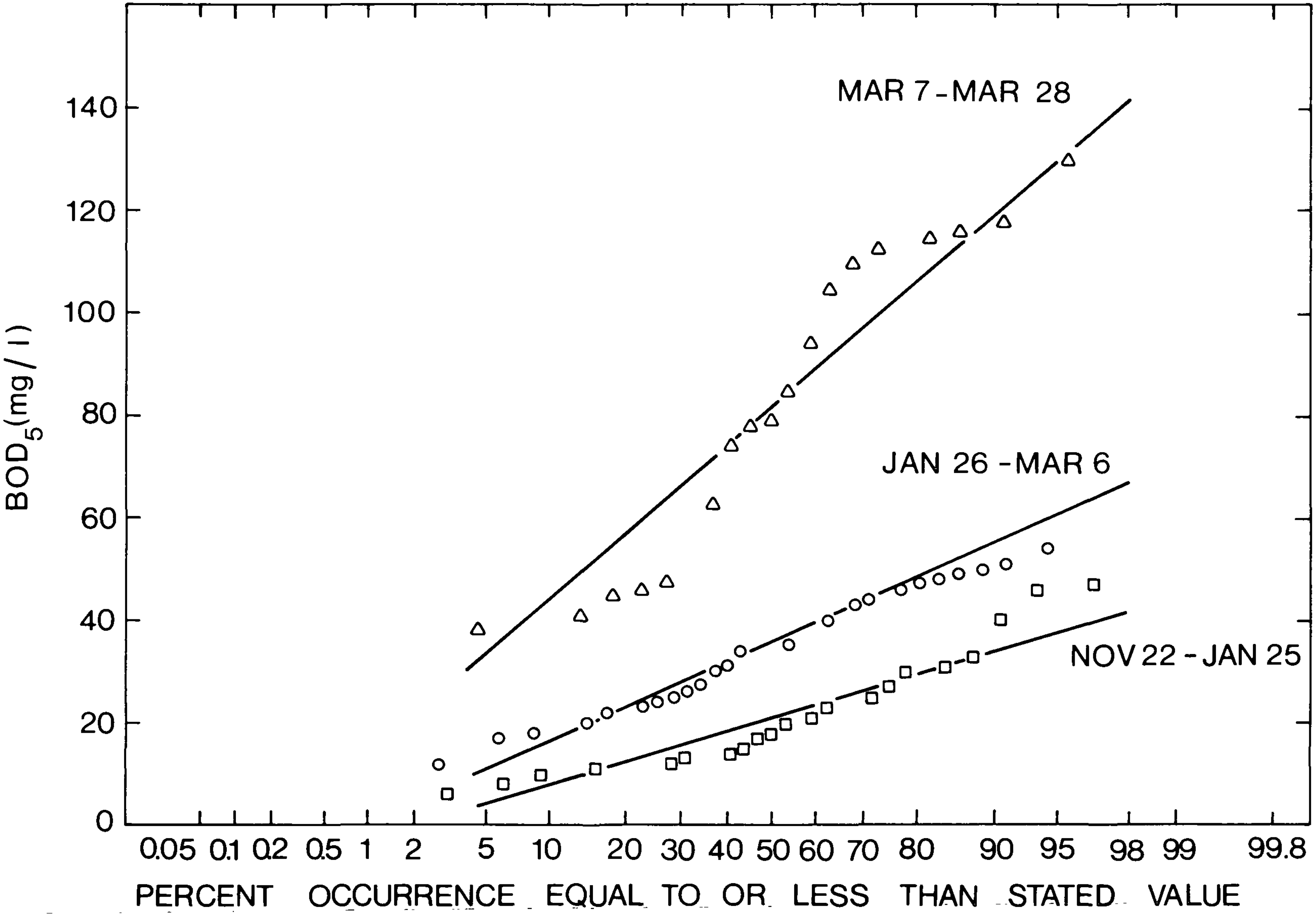

FIG. 3 PROBABILITY DISTRIBUTION FOR FINAL EFFLUENT BOD_5 FROM TWO-STAGE SYSTEM

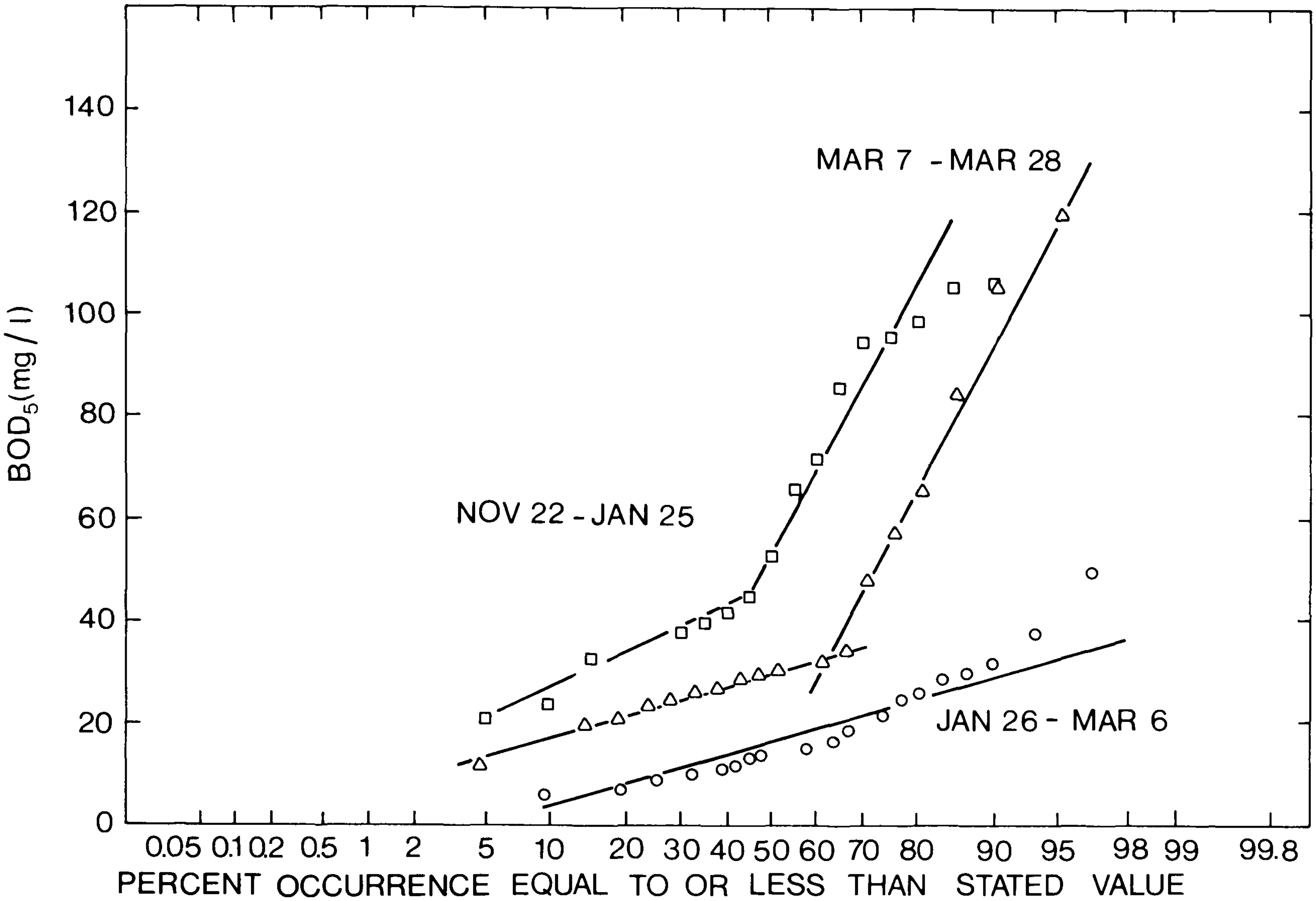

FIG. 4 PROBABILITY DISTRIBUTION FOR EFFLUENT BOD$_5$ FROM THE SINGLE-STAGE SYSTEM

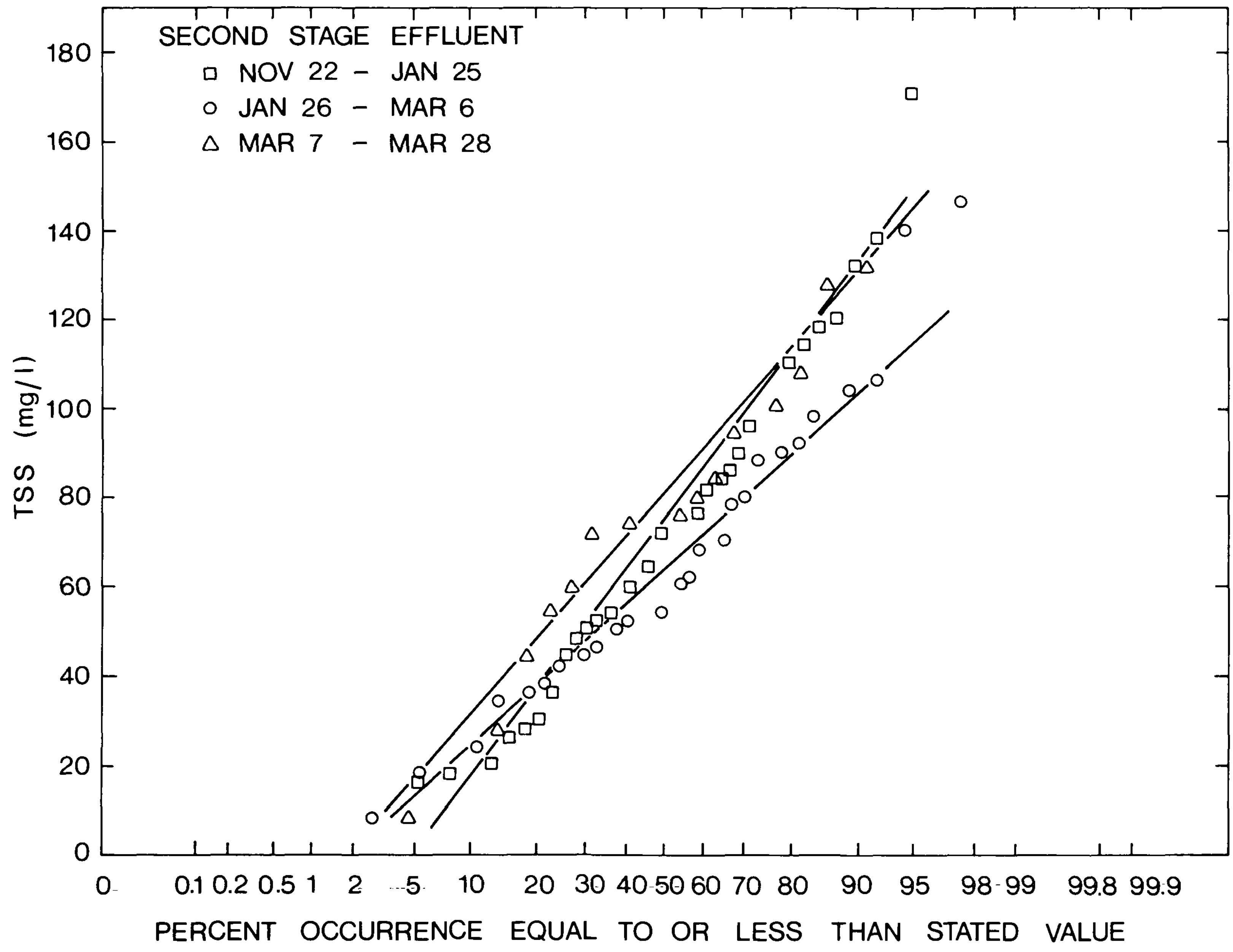

FIG. 5 PROBABILITY DISTRIBUTION FOR FINAL EFFLUENT TSS FROM TWO-STAGE SYSTEM

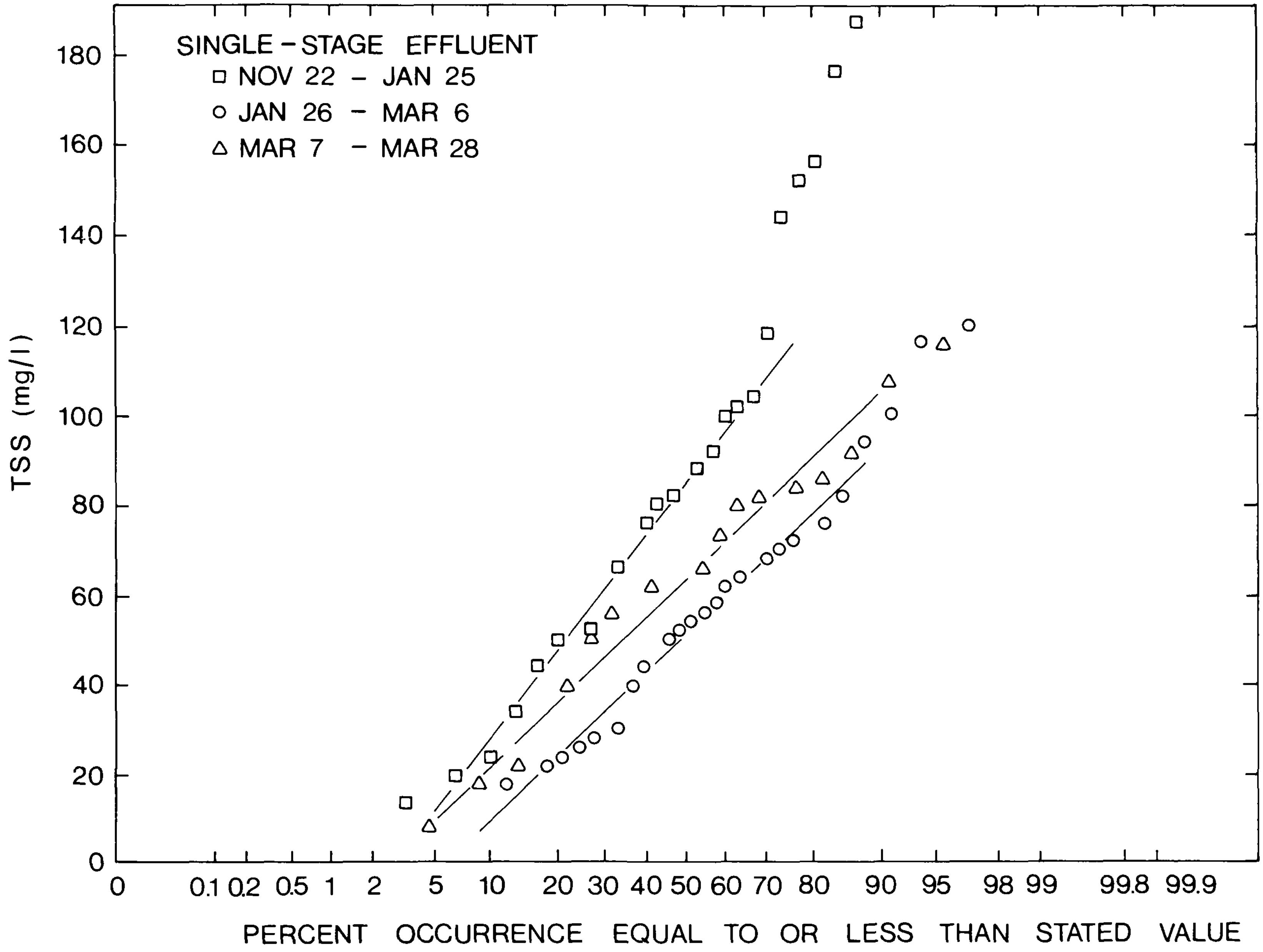

FIG. 6 PROBABILITY DISTRIBUTION FOR EFFLUENT TSS FROM SINGLE-STAGE SYSTEM

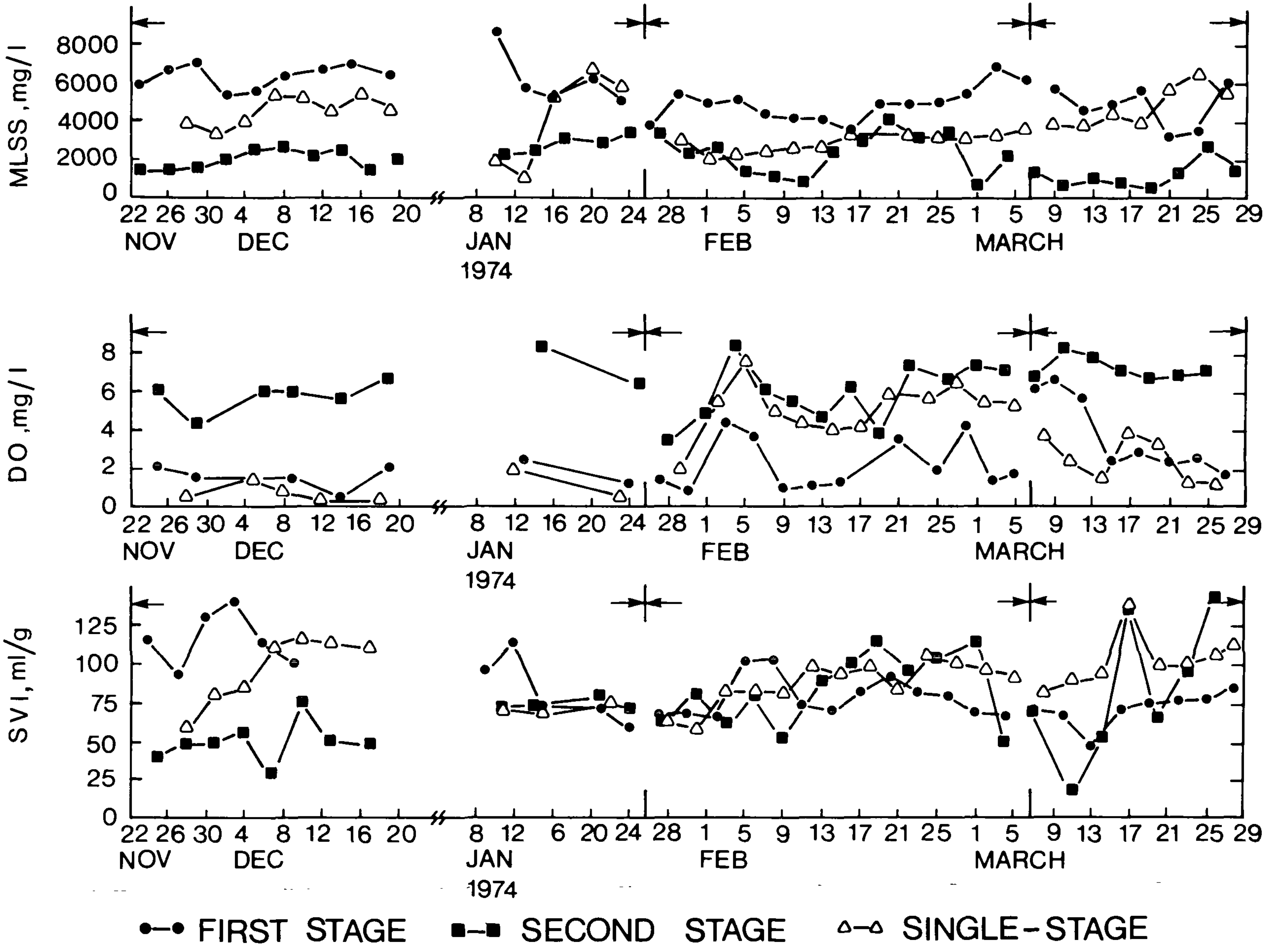

FIG. 7 DAILY VARIATION OF AERATION CELL PARAMETERS

concentrations are generally due to wasting or, in the case of the two-stage unit, returning sludge from the second stage clarifier to the first stage aeration cell. A summary of the quantity of sludge wasted or returned is included with the plant operator's remarks in Appendix IV.

High fluctuations in dissolved oxygen content in the aeration cells were generally linked with interruptions of feeding due to pump failures or bleach plant breakdowns.

Day-to-day fluctuations in SVI were generally not excessive indicating that the biological process was relatively stable.

Sludge return rates for both cells of the two-stage unit and the single-stage unit could not be properly controlled with the air lift pumps. The sludge return rate was set at a level which would prevent the return sludge lines from becoming plugged. Consequently, the return sludge flow rate was not set at a constant percentage of the influent wastewater flow for the duration of the program. The approximate sludge return rates for the three aeration cells are presented as percentage of wastewater flow in Table 7.

TABLE 7. SLUDGE RETURN RATES

Operational Period	First Stage %	Second Stage %	Single-Stage %
Nov. 22 - Jan. 25	300	150	100
Jan. 26 - Mar. 06	200	100	100
Mar. 07 - Mar. 28	100	100	50

A preliminary study was carried out to investigate the dewaterability and filterability of the sludge produced in the activated sludge systems treating KBE. Results of the study are presented in Appendix VIII.

Efforts were made to establish the standard engineering design parameters, i.e., the specific BOD removal rate, the rate of oxygen utilization and sludge production. These efforts were unsuccessful mainly due to the variability of the data collected.

Problems encountered during the operation of the pilot plant were primarily responsible for the variability.

Three major operational problems were encountered. The first was the failure to obtain a continuous source of bleach plant effluents due to feed pump failures and bleach plant breakdowns. The pump failures were caused by occasional flooding of motors by accidental spills in the bleach plant area. In addition, the corrosive nature of the untreated KBE resulted in deterioration of feed pumps and regular replacement was required. Shutdowns in mill operation, due either to breakdown or planned maintenance, occurred frequently. On several occasions, information regarding these disruptions in mill operation was not received in time to prevent the treatment systems from receiving slugs of extremely toxic wastewater.

The second problem resulted from the accumulation of foam on the surface of the aeration cells. This is a common occurrence, with pulp mill effluents, which has been encountered by other investigators (Carpenter, 1966) and has led to studies of processes such as foam fractionation. In view of the limited time available for evaluating various defoaming agents with regard to possible toxicity, the problem was corrected by increasing the freeboard on all aeration tanks. Although this relieved the problem to a certain degree, it may not be the most feasible solution in full scale operation. In addition to being an aesthetic problem, the foaming caused losses of mixed liquor suspended solids from the treatment systems.

A third operation problem involved the return sludge systems on all three reactors. The problem was associated with the control of the air lift pump. Too much air increased the volume of return sludge to an unacceptable limit and disrupted compaction of the sludge in the settling tank. If the air supply was set at a low level, the high concentration of solids being transferred clogged the sludge return lines; this occurred on several occasions with the first stage of the two-stage system. The end result was a fluctuation in concentration of mixed liquor solids in the aeration cells. It should also be realized that this problem is inherent in the pilot plant system and would be solved in a full scale system with the use of proper pumps.

4.2 Bioassay Results

As indicated previously, the major objectives of bioassays were to establish to what extent the activated sludge systems could reduce the toxicity of KBE and to determine the 96-hour LC_{50} of the treated effluent. Results of static and continuous flow bioassays carried out to achieve these objectives are presented in the following sections.

4.2.1 Results of static bioassays

Static bioassays were used to determine median survival time (MST) in 100% effluent for composite samples. During November and December, MST's were conducted on one-hour composite samples. Results indicated that the hourly variation in MST's for a 24-hour period for treated and untreated effluents was significant. Consequently, the experimental program was changed to use 24-hour composite samples to monitor process performance.

MST's for hourly and daily composite samples are presented in Appendix V. The wood species being processed, the time and duration of sample collection, bioassay test conditions and MST's with confidence limits are presented in tabular form.

A plot of the daily MST's for untreated and treated effluents for the period February 19 to March 28 has been presented in Figure 8. MST's for untreated KBE ranged from 30 minutes to 370 minutes and there was considerable fluctuation in the results. For treated effluents, MST's ranged from 35 minutes to no mortality for single-stage effluents and from 95 minutes to no mortality for two-stage effluents, respectively. Using this graphical presentation, MST's could be compared for specific sampling times; however, it was difficult to compare the toxicity removal capabilities of the single-stage and two-stage activated sludge systems.

In analysing the data, a frequency distribution plot was established for a specific set of MST's. This method of presentation was used to compare the efficiency of the two treatment systems in removing toxicity and to establish the differences between the toxicity of softwood and hardwood.

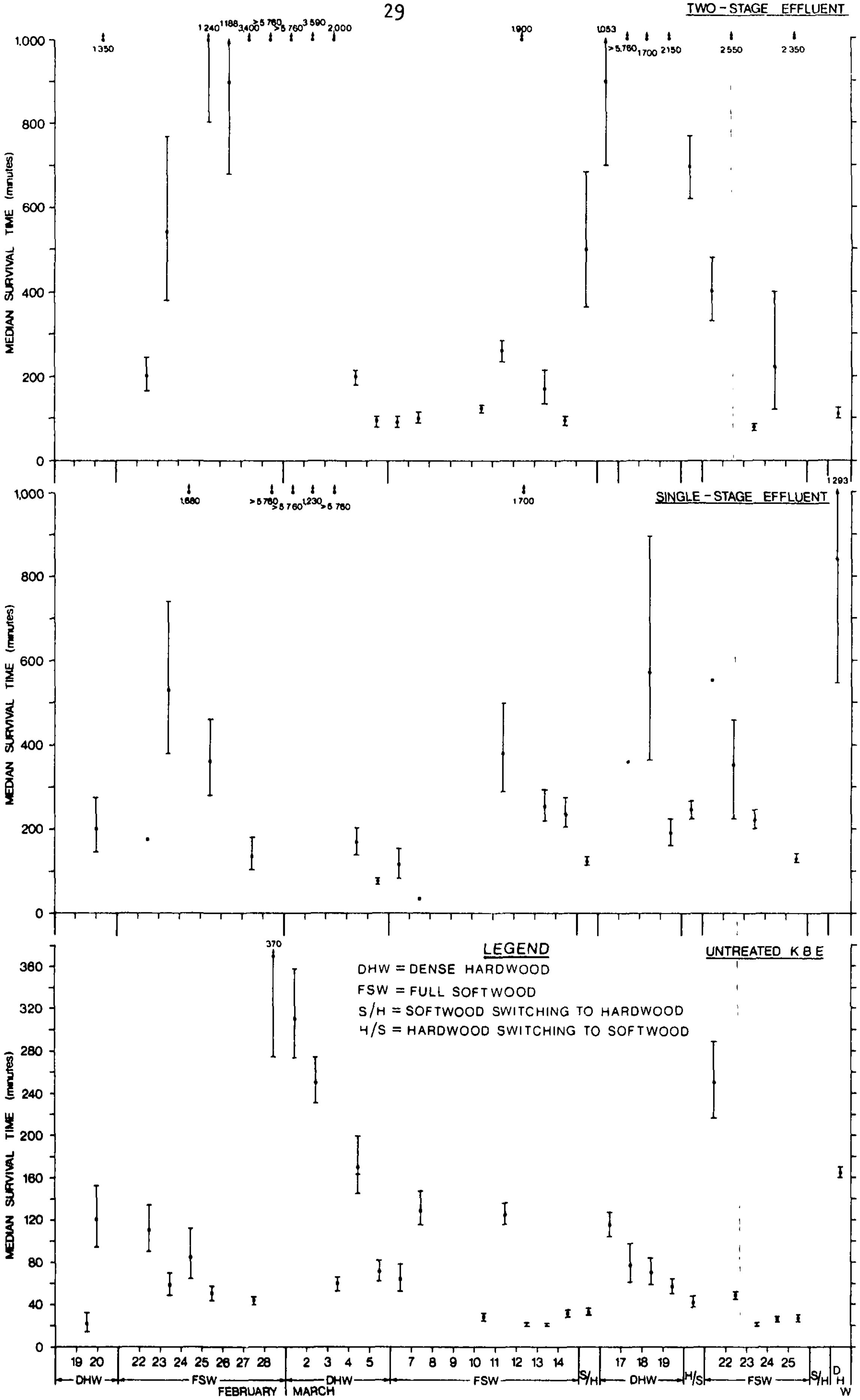

FIG 8 MST RESULTS FOR DAILY 24-HOUR COMPOSITE SAMPLES FROM FEB 19 TO MAR 28, 1974

The probability distribution of MST's for untreated, single-stage and two-stage effluents for the second operational period is presented as Figure 9. For the period February 19 to March 6 the medians of the MST's for untreated, single stage and two-stage effluents were 94, 400 and 1300 minutes, respectively. This relationship shows that both treatment systems reduce the toxicity of the KBE; however, the effluent from the two-stage system is considerably less toxic than that of the single-stage system.

The probability distribution of MST's for the third operational period is presented as Figure 10. The medians of the MST's for the untreated, single-stage and two-stage effluents were 45, 300 and 450 minutes, respectively. Effluent from the two-stage system was only slightly less toxic than that of the single-stage system. Since the volumetric loading to the two-stage system was much greater than for the single-stage system, it is concluded that the toxicity removal capabilities of the two-stage system are considerably greater than that of the single-stage system.

For the third operational period, the medians of the MST's for both treatment systems were less than those of the second operational period. This increase in toxicity can be partially attributed to the fact that the untreated KBE was much more toxic during the third operational period (i.e., 94 versus 45 minutes). Increased toxicity may be related to the wood species being processed in the bleachery at the time of sample collection. It can be seen from Figure 8 that from February 19 to March 6 the bleach plant processed eight days of dense hardwood and five days of full softwood. From March 6 to March 28 there were only four days of dense hardwood and fifteen days of full softwood. These ratios indicated that the increased toxicity for the third operational period might be directly related to the bleaching of softwood pulp.

To verify that the toxicity could be related to wood species, probability distributions for MST's were prepared for samples collected during the bleaching of dense hardwood and during the bleaching of full softwood for the period of February 19 to March 28. Median survival times from the second and third operational period were

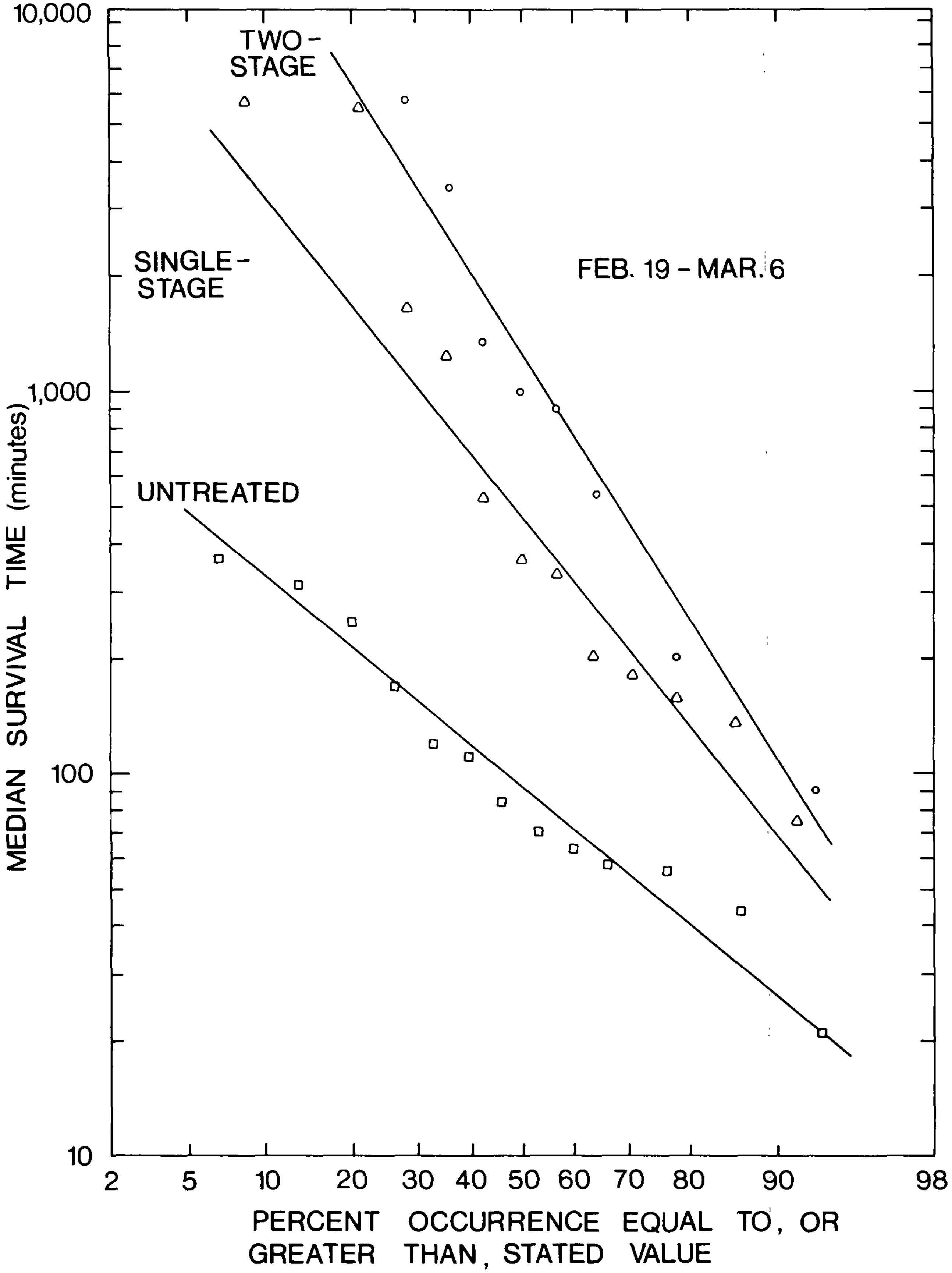

FIG. 9 PROBABILITY DISTRIBUTION FOR MST FOR THE SECOND OPERATIONAL PERIOD FOR ALL WOOD SPECIES

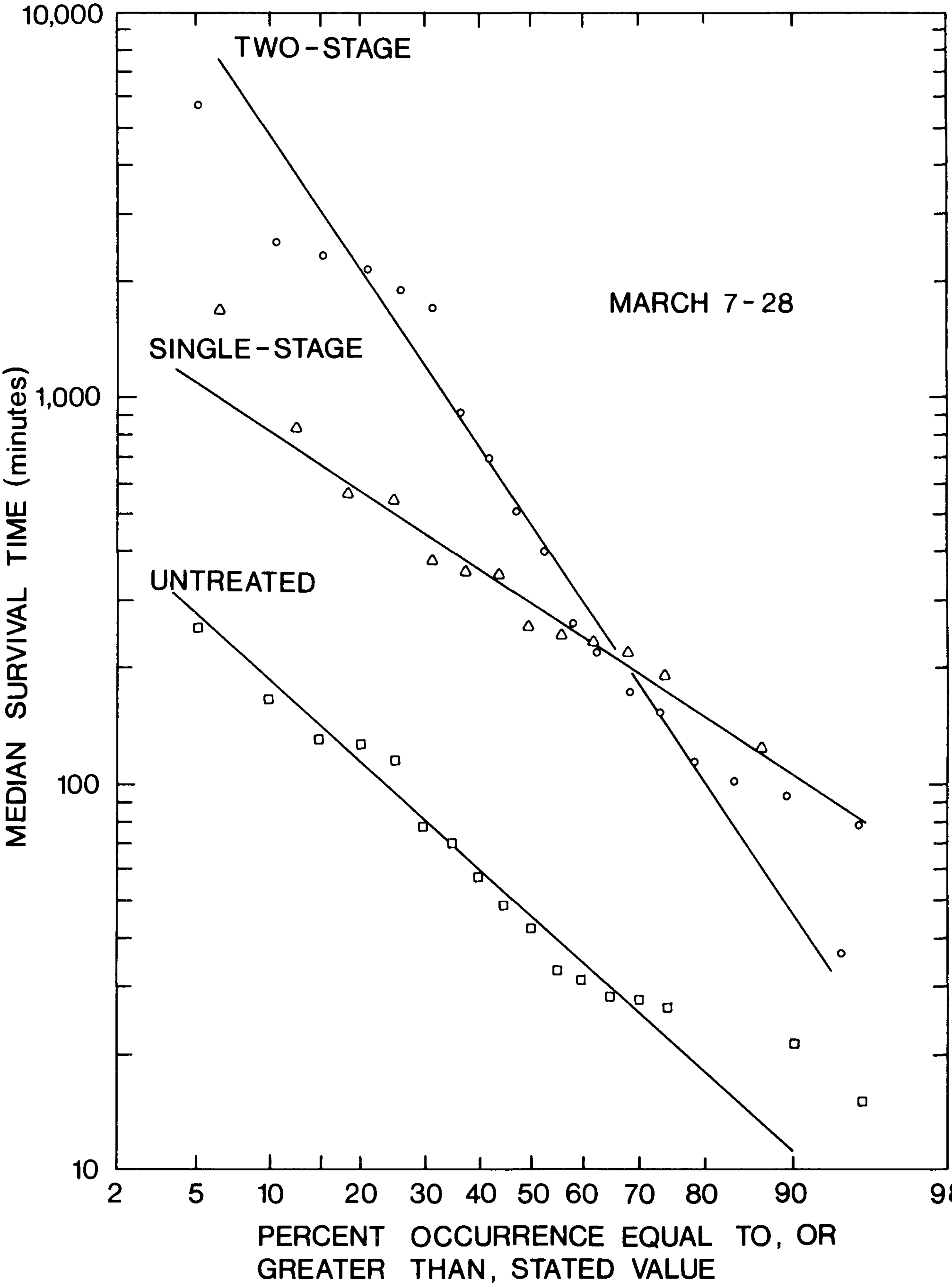

FIG. 10 PROBABILITY DISTRIBUTION FOR MST FOR THE THIRD OPERATIONAL PERIOD FOR ALL WOOD SPECIES

combined to provide a sufficient number of values for the frequency distributions. From the results presented in Figure 11, the medians of the MST's for softwood for untreated, single-stage and two-stage effluents were 55, 250 and 350 minutes, respectively, and for hardwood, 120, 600 and 2200 minutes, respectively. These results support the hypothesis that the effluents discharged during the bleaching of softwood were significantly more toxic than effluents discharged during the bleaching of hardwood.

It was suspected that the increased toxicity of softwood could be related to the residual chlorine in the effluent since softwood pulps require more chlorine during the bleaching process than hardwood pulps. Residual chlorine concentrations tabulated in Table V-2 of Appendix V were compared with the corresponding MST's; however, no relationship between toxicity and chlorine residual could be determined.

The results presented in Figure 11 also verify that the two-stage activated sludge process produced an effluent which was much less toxic than the single-stage system. It was apparent that in the treatment of softwood bleach plant effluent, the toxicity removal capabilities of the two-stage system were reduced approaching the level of toxicity removal attained by the single-stage system.

Using the limited number of MST's measured during the first operational period, a probability distribution, Figure 12, was established for untreated and two-stage effluents. The medians of the MST's for untreated and two-stage effluents were 70 and 650 minutes, respectively. As the majority of samples were collected during the processing of softwood, MST's for both effluents were slightly higher than for the final operational periods. The variation in MST's might be attributed to differences in test temperature.

During the monitoring of the first operational period (November 7 to December 1), the temperature of the fish holding tanks and dilution water decreased from 10 to 5°C. At lower temperatures, it has been shown that rainbow trout are more resistant to bleached kraft mill effluent (Loch and MacLeod, 1974); i.e., MST's should be greater at 5°C than 15°C. It is questionable whether this trend was

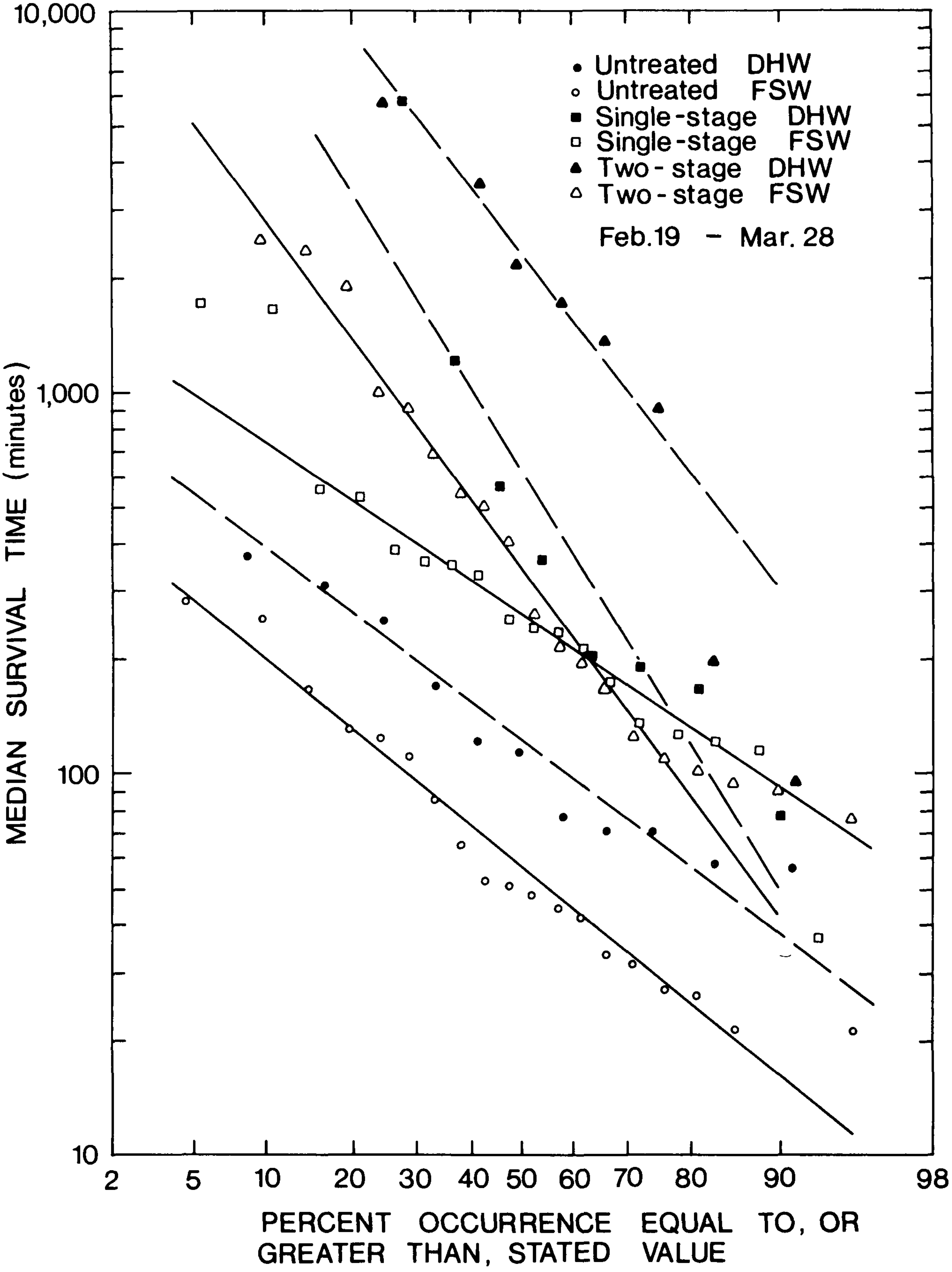

FIG. 11 PROBABILITY DISTRIBUTION FOR MST FOR HARDWOOD AND SOFTWOOD EFFLUENTS

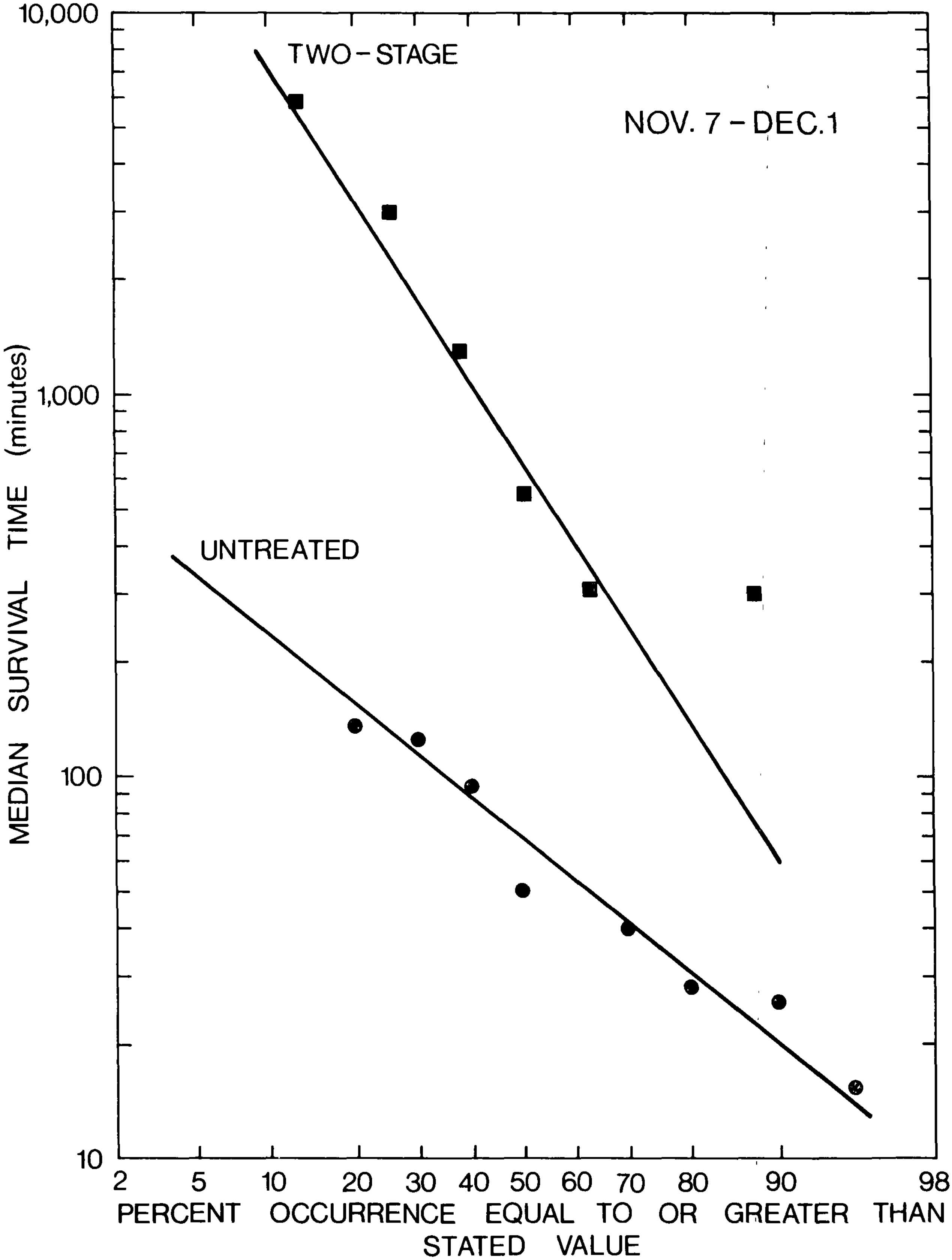

FIG. 12 PROBABILITY DISTRIBUTION FOR MST FOR THE FIRST OPERATIONAL PERIOD FOR ALL WOOD SPECIES

exhibited as the results from the limited number of samples collected during operation at 5°C were not significantly greater than the MST's measured at 15°C.

Since MST's were determined on 20-litre effluent samples, changes in fish size influenced the loading density (litres of effluent per grams of fish) in the bioassay containers. The importance of loading density has been reported by Davis and Mason (1973) who found that loadings greater than 2.5 litres of solution per gram of fish did not affect the MST and that values as low as 0.5 litres increased the MST's by a factor of 1.5. During the first operational period, loadings averaged 0.3 l/g per test which should again have resulted in higher MST's. Loading density during the second and third operational periods ranged from 3 to 10 l/g, exceeding the level of effect (2.5 l/g) suggested by Davis and Mason (1973) and Sprague (1969).

The MST may have been affected by the different ages of the fish used. Servizi et al (1966) found that adult salmon were less resistant to bleached kraft mill effluent than juvenile salmon. A similar response may exist for KBE, which would tend to reduce the MST's for the first operational period. Thus, the effect of the use of older fish would tend to compensate for the effect of the lower loading densities.

The toxicity removal capabilities of the single-stage and two-stage activated sludge systems should be compared at the loading conditions which provided a similar BOD_5 removal. For the single-stage and two-stage systems, this occurred during the second and first operational periods, respectively. There are insufficient bioassay results to make a comparison for the first operational period and thus, the comparison for both systems will be made using results from the second operational period. During the second period, the two-stage activated sludge system was operated at organic and volumetric loadings approximately four times that of the single-stage system and yet, the median of the MST's for the two-stage system was 1300 minutes, compared to 400 minutes for the single-stage system. This relationship held for all loading conditions studied, verifying that the two-stage activated sludge system was capable of greater toxicity reduction than the single-stage system.

4.2.2 Results of continuous flow bioassays

The purpose of continuous flow testing was to determine the 96-hour LC_{50} of each waste stream for each operating period. Median survival time in 100% effluent served as a useful monitoring procedure to facilitate comparison between treated effluents; however, this method was unsuitable for predicting acceptable effluent toxicity levels as specified by the Pulp and Paper Effluent Regulations (1971). The regulations state that there must be 80% survival of rainbow trout after 96 hours in a 65% solution of effluent.

Effluent regulations do not require calculation of the 96-hour LC_{50}; however, they were determined to provide a comparison between effluent streams. A 65% effluent concentration was included in each continuous flow test to provide an indication of compliance with effluent regulations.

Continuous flow bioassays were carried out as frequently as possible for each operating condition. The 96-hour LC_{50}'s were determined by plotting on logarithmic probability paper the percent mortality versus survival time for each concentration. The median survival time and its confidence limits were calculated (Litchfield, 1949) and toxicity curves drawn for each bioassay (Sprague, 1969). The toxicity curves for each bioassay, along with the fish weight, wood species being processed, dissolved oxygen levels and pH are presented in Appendix VII. A summary of the 96-hour LC_{50}'s for untreated, single-stage and two-stage effluents is shown in Table 8.

The 96-hour LC_{50}'s for untreated kraft bleachery effluent ranged from 6.6% to 16.7%. The 96-hour LC_{50}'s for single-stage treated effluents ranged from 13.5% to 39% while two-stage treated effluents ranged from 26% to 65%. The effluents from the single-stage activated sludge system would not meet the requirements of the effluent regulations. For the two-stage system, only one out of the eight samples would have met the regulations; the reduced toxicity of this effluent may be due in part to a reduction in the toxicity of the influent sample. The untreated KBE collected during this sampling period was less toxic than at any other time during the study.

TABLE 8. SUMMARY OF CONTINUOUS FLOW 96-HOUR LC_{50} RESULTS

Operational Period	Continuous Flow 96-Hour LC_{50}			Wood Species	Date	Temp.°C
	Untreated	Single-Stage	Two-Stage			
1	6-13%	---	---	Softwood	Nov 07-11	9.5
	10%	---	---	Softwood	Nov 10-16	9.5
	9.4%	---	30%	Softwood	Nov 23-27	5
	No mortality @ 14%	---	65%	Hardwood	Dec 15-19	15
2	12.8%	28%	43%	Hardwood	Feb 19-23	15
	8.2%	34%	28%	Softwood	Feb 22-26	15
	16.7%	39%	42%	Hardwood	Mar 02-06	15
3	6.6%	18%	26%	Softwood	Mar 07-11	15
	8.8%	13.5%	26%	Mixed Softwood and Hardwood	Mar 15-19	16
	13%	18%	40%	Softwood	Mar 23-27	15

Throughout the study, toxicity in the 100% continuous flow tests appeared to be greater than in the 100% static tests. Although the two tests were never carried out on identical samples, i.e., samples collected during the same sampling period, over the duration of the experimental program, one would expect the results to be comparable. The MST's for the continuous flow and static tests were plotted on logarithmic probability paper for single-stage and two-stage effluents in Figures 13 and 14. The graphs show that MST values (100% effluent) for static bioassays were greater than for continuous flow bioassays for both the single-stage and two-stage treated effluents, i.e., 300 versus 150 minutes for single-stage effluents and 500 versus 160 minutes for two-stage effluents.

This is in keeping with the results reported by Loch and MacLeod (1974) and Davis and Mason (1973) who found continuous flow bioassays to be more toxic than static tests for bleached kraft mill effluent. This increased toxicity of continuous flow tests has usually been attributed to the higher effluent volume to fish weight ratio provided by continuous effluent replacement. During the present study, the static tests provided 10 litres of effluent per gram of fish as compared to 12 l/g of fish in the continuous flow bioassay. Both values were well above the no effect level of 2.5 l/g observed for bleached kraft mill effluent by Davis and Mason (1973). It is doubtful whether the increased toxicity in the continuous flow test could be attributed to fish loading density. The increased toxicity might be related to the fact that the bioassays were fed continuously from the treatment systems as opposed to the grab or composite sample used for the static tests.

Howard and Walden (1965) attributed toxicity to the initial shock of exposure to kraft bleachery effluent and demonstrated that juvenile sockeye salmon were able to acclimate to stepwise changes in bleach plant effluent if the changes occurred gradually. Possibly, the continuous feed from the treatment systems exposed the fish to incremental increases in toxic concentrations too great to permit acclimation.

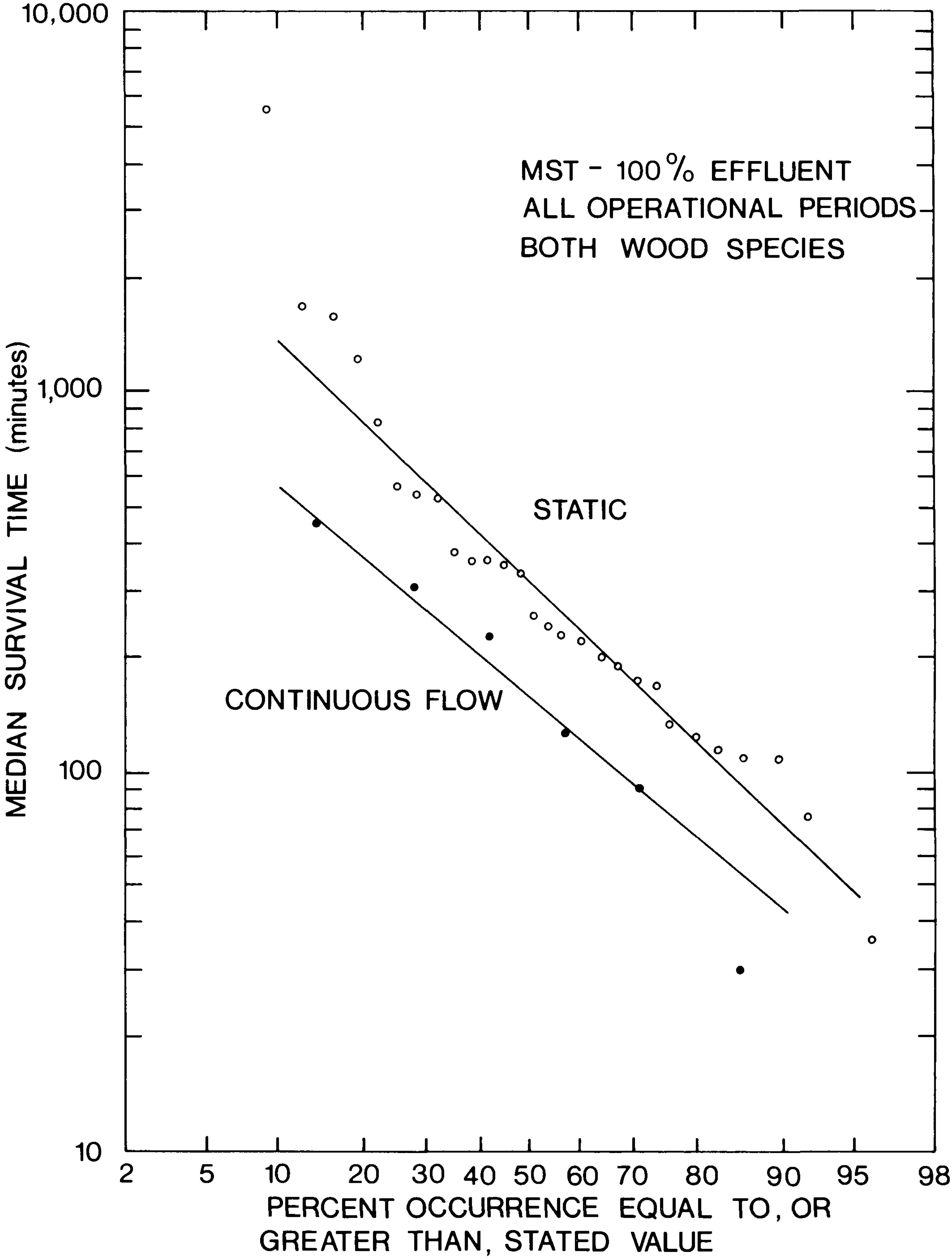

FIG. 13 COMPARISON OF CONTINUOUS FLOW AND STATIC MST's FOR SINGLE-STAGE EFFLUENTS

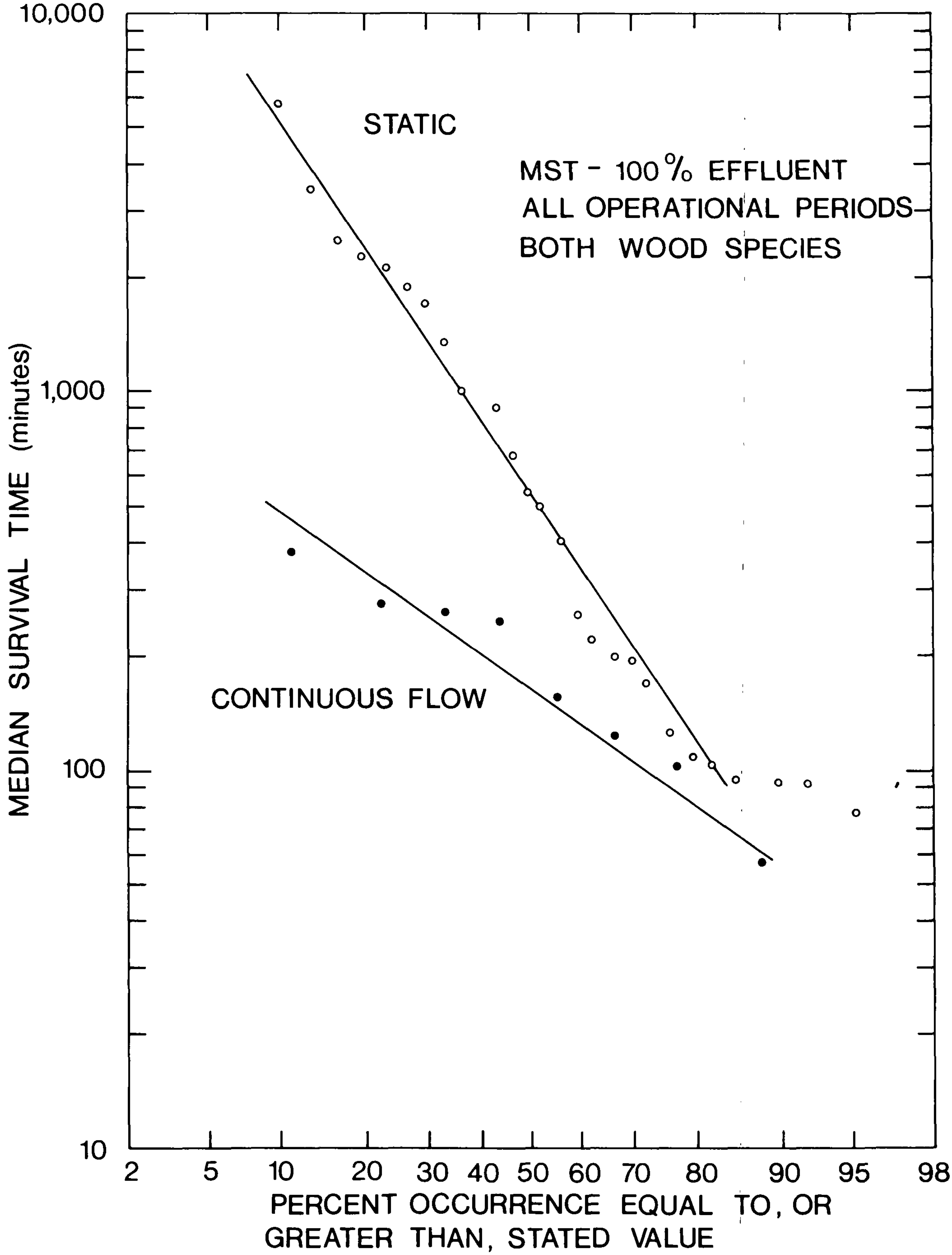

FIG. 14 COMPARISON OF CONTINUOUS FLOW AND STATIC MST'S FOR TWO-STAGE EFFLUENTS

From these observations, it can be concluded that effluents from the single-stage and two-stage activated sludge systems would not meet the requirements specified in the Pulp and Paper Effluent Regulations (1971). The continuous flow results verified the fact that the two-stage system was capable of a greater toxicity reduction than the single-stage system. The 96-hour LC_{50}'s for untreated effluents collected during the processing of softwood were in the range of 6% to 13% and for hardwood in the range of 13% to 17%, confirming that hardwood effluents were less toxic than the softwood effluents.

4.3 Program for Measuring Influent and Effluent Variability

The purpose of conducting sampling programs to establish sample variability was two-fold. The first was to determine whether it was necessary to provide an equalization basin or establish a specific mode of operation for the treatment system which would provide a relatively consistent effluent quality. This involved relating changes in the bleach plant operation as measured in the untreated KBE and the ability of the treatment system to adapt to these changes. The second was to indicate the sampling frequency which would be required in future tests to properly evaluate the waste streams of interest, i.e., either untreated effluent or final effluent from a biological treatment system.

Three 24-hour sampling programs were conducted during the field study. The first, involving static bioassay testing, was carried out before the treatment systems were operational. It was set up to establish the variation in toxicity of untreated bleachery effluent which one might expect to encounter during the study. In addition, it was to aid in determining the frequency at which future tests should be performed. The other two 24-hour sampling programs, in addition to static bioassay testing, included monitoring of the BOD_5, COD and TSS of the treated effluent. The bioassay results from the three 24-hour sampling programs are presented in Appendix VI and include a tabulation of MST's, test temperature, fish size, oxygen levels, pH and wood species.

The initial study was conducted from November 7-8, 1973, when the mill was processing softwood. Variation in MST is illustrated graphically in Figure 15. MST's ranged from 15 minutes to 105 minutes with an average MST of 55 minutes. Temperatures during this run were approximately 10°C. This variability in bleach plant MST's was not totally unexpected as B.C. Research (1971) reported that, "the toxicity of the first chlorination effluent varied abruptly over short periods," and that the reasons for this were unknown. The first sampling program verified the suspicion that the treatment systems would be subjected to rapid fluctuations in toxicity and that grab samples of untreated effluent would not be representative of a daily toxicity pattern.

The second 24-hour study was conducted from December 15-16, 1973 when hardwood was being processed. For this study, effluent was collected from the two-stage system as well as untreated neutralized bleachery wastewater. At the time, the single-stage system was not producing a satisfactory effluent in terms of BOD_5 quality. Hence it was considered impractical to evaluate the stream for toxicity reduction. Samples were collected on a one-hour composite basis for bioassay testing and a quantity combined to provide two-hour composites for chemical analysis.

Results of BOD_5, COD and TSS for this second study are presented in Figure 16 for the two effluent streams. Little fluctuation in either COD or BOD_5 of bleachery effluent occurred throughout the day and the treated effluent also appeared stable. However, there was considerable variation in TSS of the untreated effluent and these fluctuations were reflected to a certain degree in the treated effluent.

MST results for the second run, as shown in Figure 17 again indicated fluctuations in toxicity on an hour to hour basis for untreated KBE. There was considerable difference between the mean MST's for the December 15 and the November 7 runs as the mean MST value for untreated KBE during the processing of hardwood was 304 minutes and during the processing of softwood, 55 minutes. This confirms the results presented in Section 4.2.1, i.e., the toxicity of untreated bleach plant waste for hardwood was considerably less than for softwood.

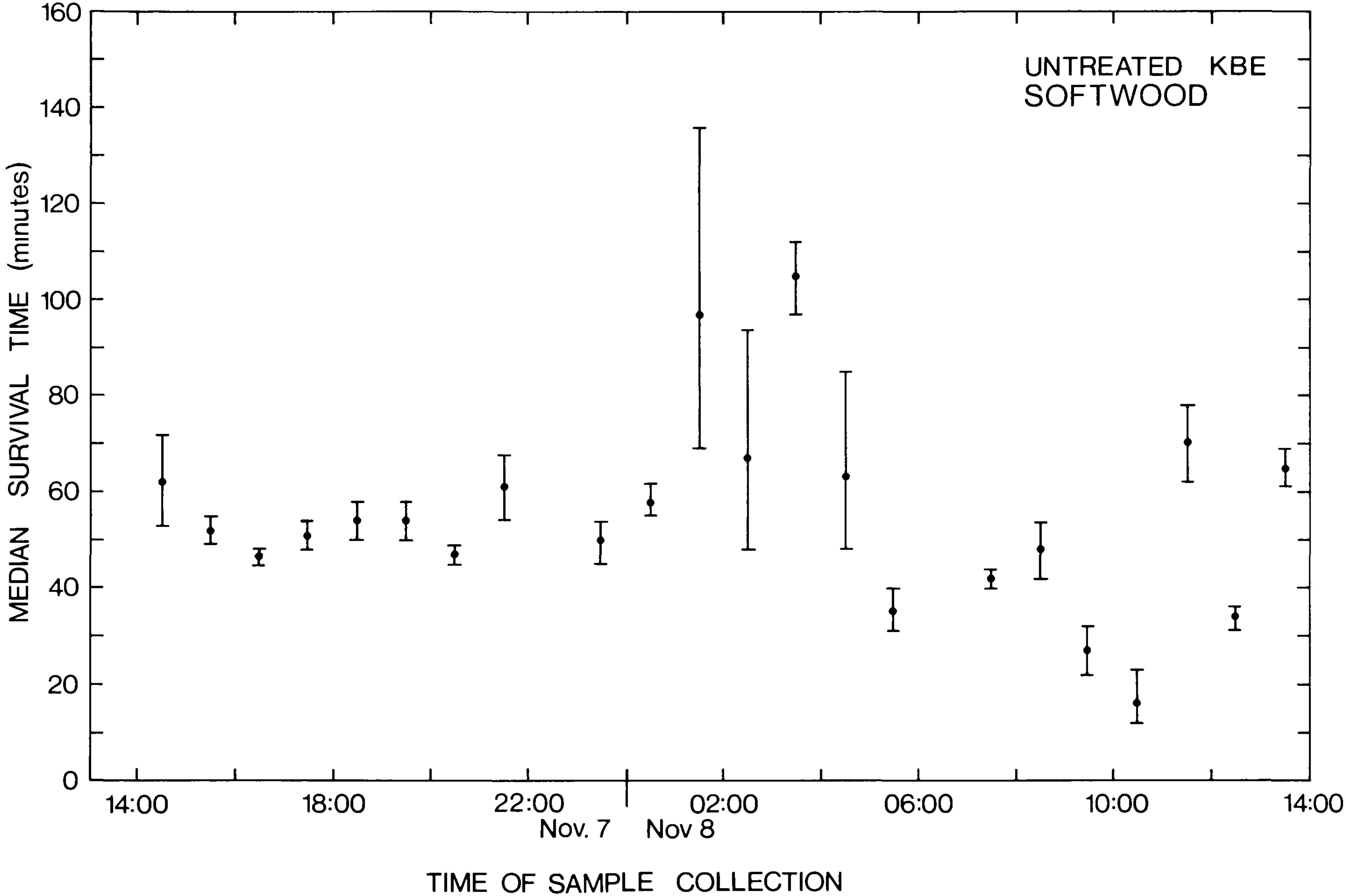

FIG. 15 HOURLY VARIATION IN MST THROUGHOUT NOV. 7 AND 8, 1973

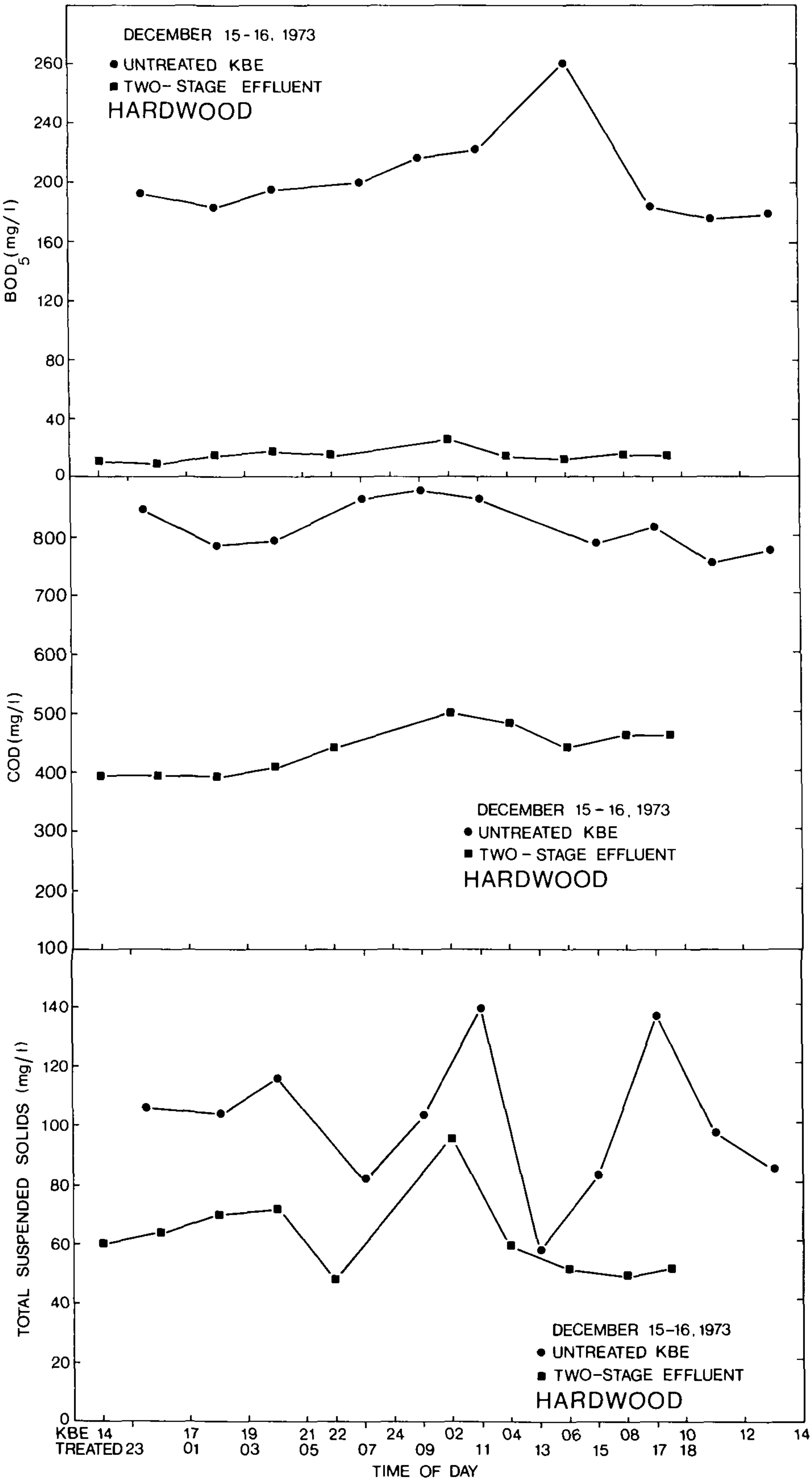

FIG 16 VARIATION IN BOD_5, COD AND TSS THROUGHOUT DEC 15 & 16, 1973

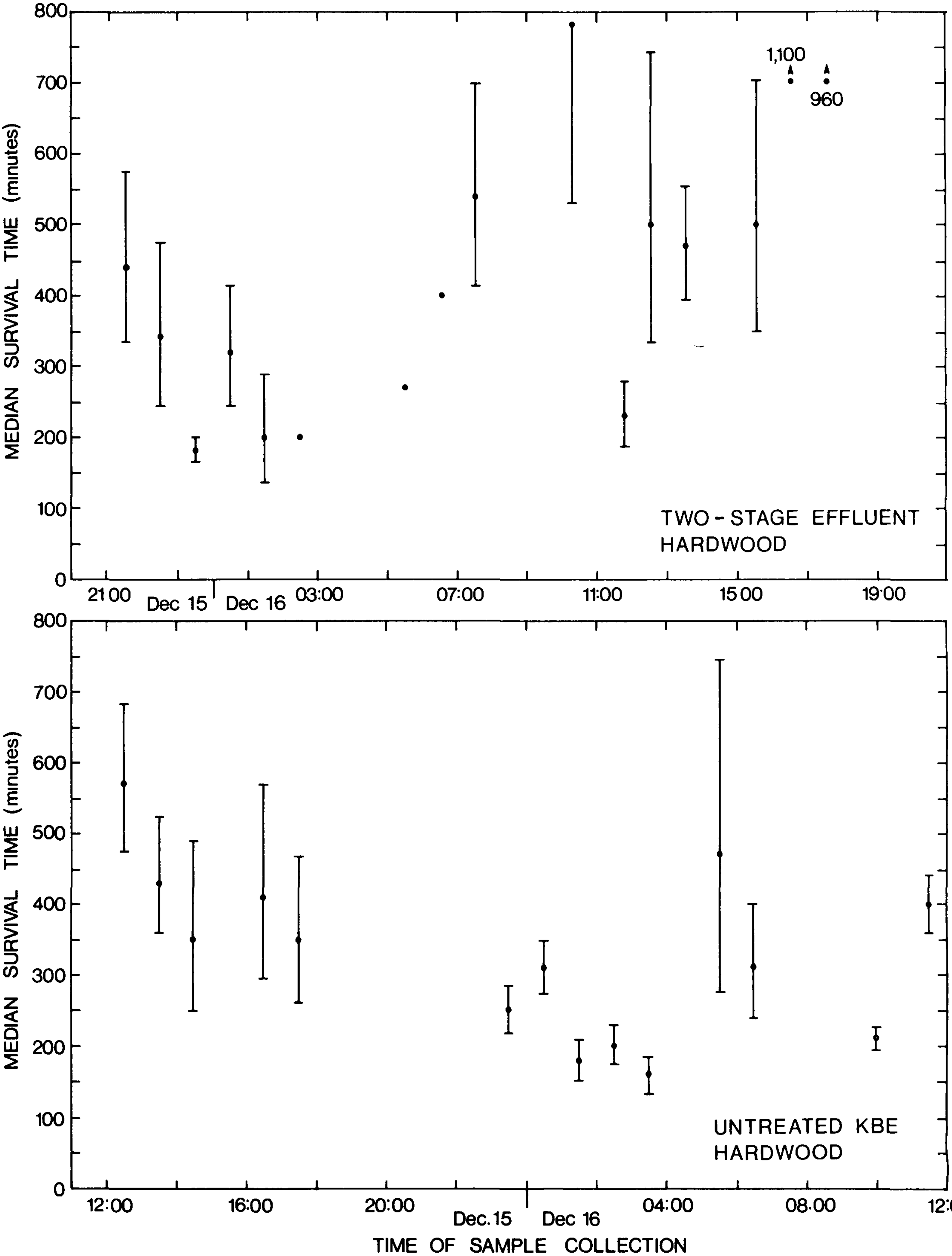

FIG. 17 HOURLY VARIATION IN MST THROUGHOUT DEC. 15 & 16, 1973

For the second run, the two-stage effluent was sampled with an eight-hour lag period to compensate for the residence time in the aeration tanks and clarifiers. MST results shown in Figure 17 for the two-stage treated effluent indicated that the two-stage treatment system was unable to smooth out hourly fluctuations in toxicity in spite of complete mixing in the aeration cells.

The third sampling study, carried out from March 24-25, 1974, provided results for single-stage effluent in addition to bleachery and two-stage effluents. The mill was processing softwood at this time. Samples were collected on a two-hour composite basis for bioassay testing as there was insufficient space in the water baths to do hourly composites on all three effluents simultaneously. Two, two-hour composite samples were combined to provide a four-hour composite sample which was used for analytical testing. Results of BOD_5 and TSS for the three effluents are presented in Figure 18. Again, there is little fluctuation in untreated KBE BOD_5 throughout the day and effluents of both systems were relatively stable although the single-stage effluent BOD_5 decreased as the sampling progressed. Whereas, in the December run, TSS showed considerable variation, results for the March run indicated less fluctuation, with the TSS in the treated effluent about equal to the incoming bleachery effluent solids.

MST results, shown in Figure 19, indicate wide variability in the MST's for the untreated, single-stage and two-stage effluent streams. Untreated MST's ranged from 22 minutes to 450 minutes for one-hour samples over a 24-hour period. Similarly, effluent from the single-stage system had MST's between 45 minutes and 7000 minutes and effluent from the two-stage system had MST's ranging from 100 minutes to 5000 minutes.

The previous results show that there was generally little fluctuation in bleachery waste strength during the test period. In addition, effluent quality in terms of BOD_5 and TSS was also relatively constant throughout the day, indicative of stable treatment system operation. One would conclude that in the design of a two-stage system for BOD_5 reduction, there is no requirement for implementation

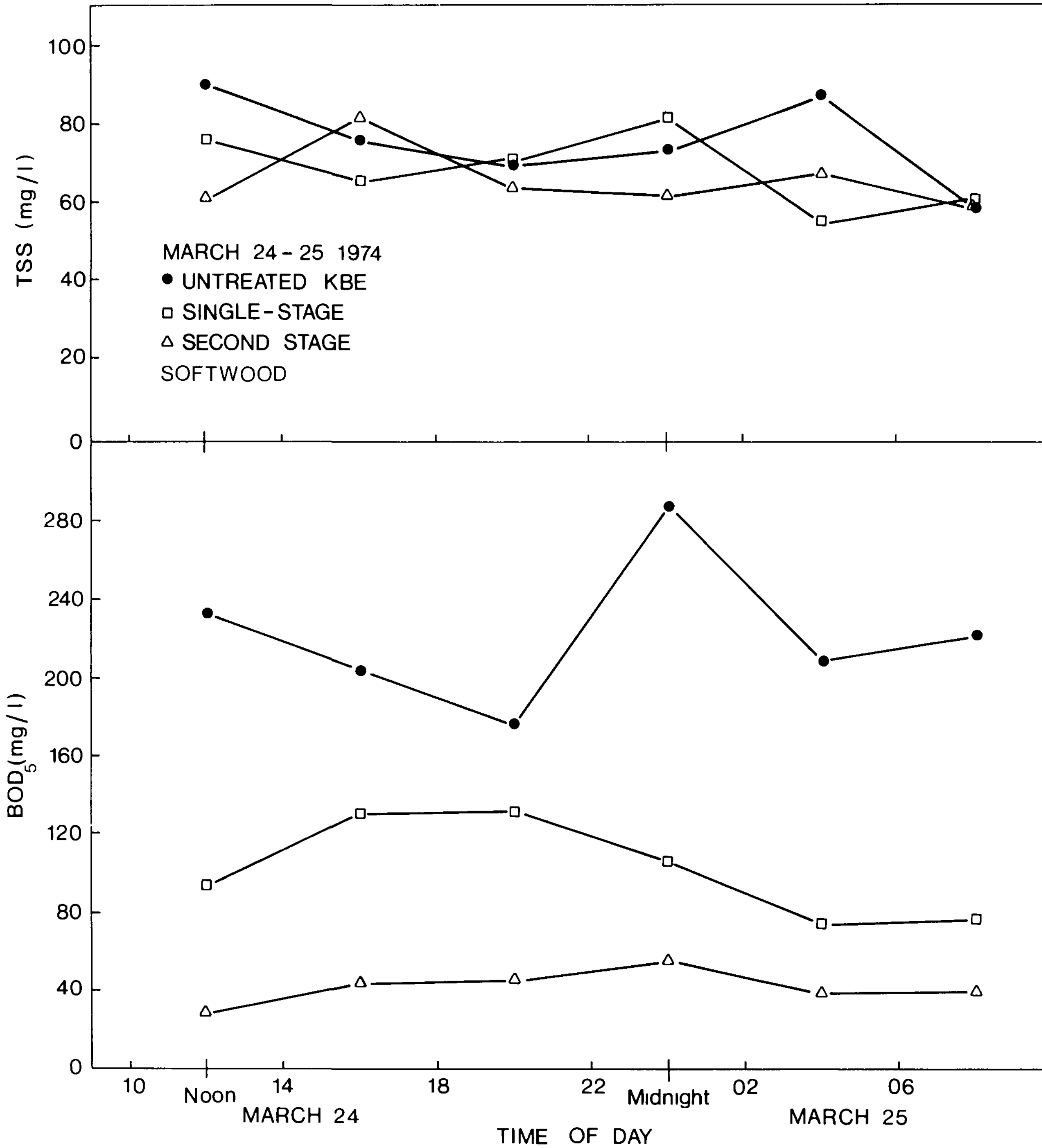

FIG 18 VARIATION IN BOD_5 AND TSS THROUGH MARCH 24 & 25, 1974

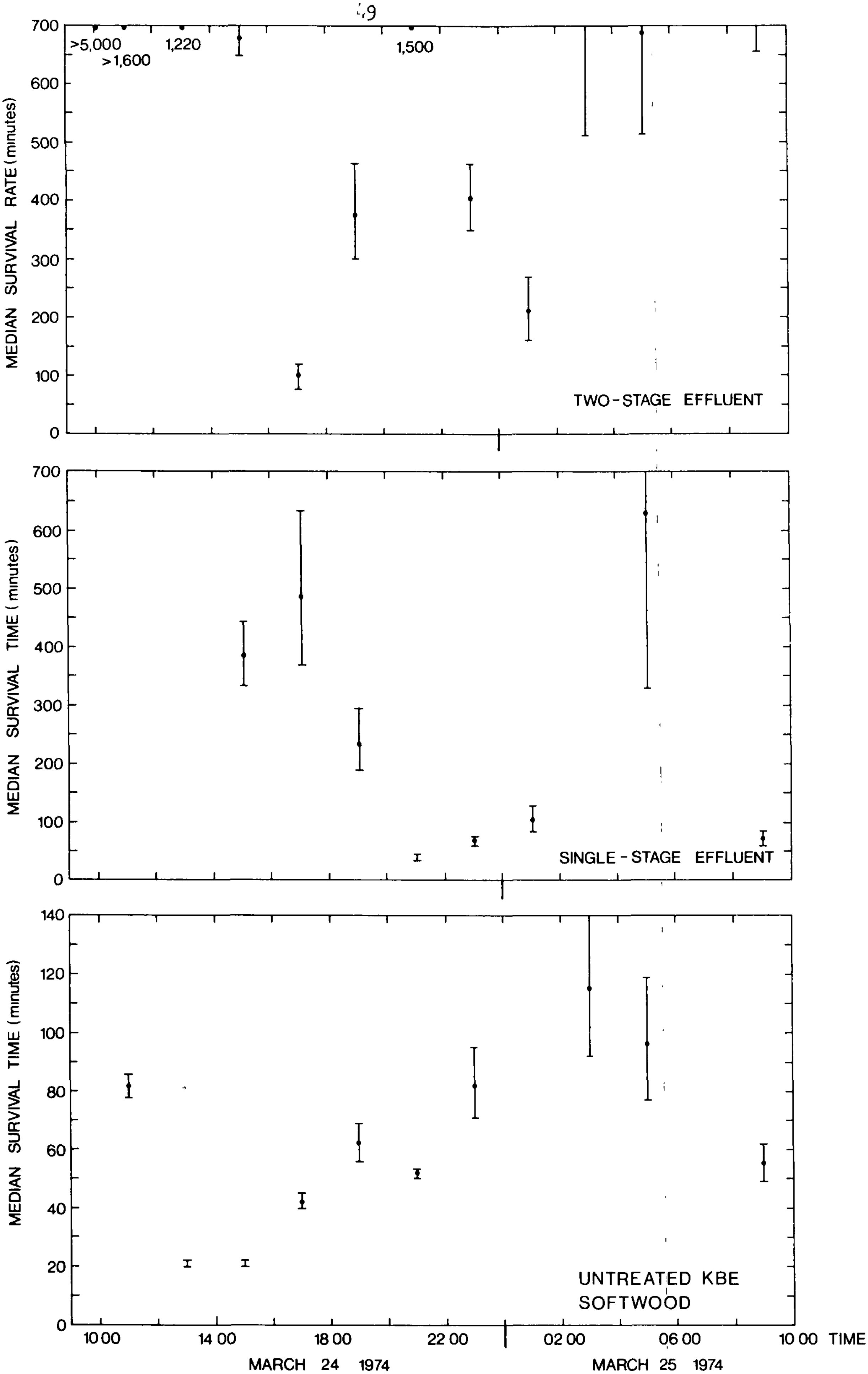

FIG 19 VARIATION IN MST THROUGHOUT MAR 24 & 25, 1974

of special operating conditions or provision of a holding basin to equalize BOD_5 loadings. It should be noted that for minimum protection of the biological system, a storage facility will be required as a spill basin.

With respect to bioassay testing, there were two significant conclusions which may be drawn from the 24-hour studies. The first was the extreme fluctuation in MST's for the hourly composite samples collected over the 24-hour period. The second was the fact that both activated sludge systems were incapable of reducing toxicity to a consistent level and were subject to hourly fluctuations.

The Pulp and Paper Effluent Regulations (1971) outline procedures for obtaining samples to monitor effluent quality, stating that, "If the wastewaters have been biologically treated, having in mind that current systems are well mixed and have long detention times, it will suffice to take a single grab sample of a size required for the test at the outfall of the treatment system". At the time of writing of these guidelines the only systems operating in Canada were aerated lagoons; the feasibility of shorter detention time systems had not been investigated. It can be seen from the results of this study that grab samples of effluent would only be suitable for BOD_5 and possibly suspended solids analyses. Grab samples for bioassay evaluations would not be acceptable. The guidelines do state that "composite samples may be required by the regulatory agency where deemed appropriate".

From the results of this sampling program, it is evident that composite sampling is necessary to properly evaluate effluents from a conventional or high rate activated sludge treatment system.

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APPENDIX I

CHEMICAL AND PHYSICAL CHARACTERISTICS OF SPANISH RIVER WATER

APPENDIX I

CHEMICAL AND PHYSICAL CHARACTERISTICS OF SPANISH RIVER WATER

Analysis of Spanish River water used for fish stock tanks and dilution water.

Ca*	6.3 mg/l
Mg*	1.0 mg/l
Al*	95 µg/l
Cd*	3 µg/l
Cr*	4 µg/l
Cu*	10 µg/l
Fe*	136 µg/l
Mn*	34 µg/l
Ni*	35 µg/l
Pb*	15 µg/l
Zn*	55 µg/l
BOD_5	0.5-1 mg/l
DO	7.8-11 mg/l
pH	6.6-7.2

The parameters marked with an asterisk are the average of the analytical results for two samples collected in the power canal at Eddy Forest Products Limited in October and November, 1973.

APPENDIX II

DAILY PERFORMANCE AND OPERATIONAL DATA

APPENDIX II

DAILY PERFORMANCE AND OPERATIONAL DATA

1. First stage Effluent
2. Second stage Effluent
3. Single-stage Effluent
4. Bleach Plant Effluent

<u>Wood Species</u>

DHW - 100% Dense Hardwood

FSW - 100% Full Softwood

S/H - Softwood Switching to Hardwood

H/S - Hardwood Switching to Softwood

TABLE II-I PERFORMANCE DATA - Nov. 22, 1973 to Jan. 25, 1974

		BOD MG/L				COD MG/L				TSS MG/L				VSS MG/L				PH				
DAY	WOOD	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
326	FSW	84	40		136	843	930		608	48	96		42	8	34		28	8.00	7.80		6.60	*
327	FSW	50	33		163	704	848		1083	106	100		62	94	86		50	7.40	7.60		2.50	*
328	FSW	19	13		179	864	814		1136	120	86		86	70	50		42	7.50	7.75		2.50	*
329	FSW	48	25		207	973	857		1167	124	100		90	90	70		68	7.50	7.80		3.30	*
330	FSW	49	18		234	1420	1142		1891	148	20		152									*
331	FSW	66	21		198	1170	1041		1407	170	132		96	120	94		78	7.60	7.80		2.30	*
332	FSW	40	27		340	1090	1327		1423	144	120		50	118	92		23	7.65	7.75		2.30	*
333	FSW	43	46		227	886	886	1267	1086	104	138	190	88	76	86	132	72	7.55	7.80	7.75	2.40	*
334	FSW	42	31			860	895	1080		66	54	66										*
335	FSW																					*
336	FSW																					*
337	S/H																					*
338	DHW	31	12			835	710	764	1067	126	82	52	74	106	78	52	74	7.95	8.20	8.00	2.95	*
339	DHW	50	25		135	764	729	1181	1161	98	114	228	98	38	68	160	36				3.40	*
340	DHW	43	31	36	219	587	577	597	798	90	118	164	116	66	78	60	96	7.80	8.20	7.90	3.50	*
341	DHW	41	25	40	222	556	522	562	792	56	76	50	38	28	36	30	24	7.35	7.75	7.50	3.50	*
342	DHW	65	14	107	226	580	480	604	966	112	48	102	80	84	42	70	62	7.50	7.85	7.85	3.40	*
343	H/S					670	552	787	1002	102	76	118	100	74	40	80	74	7.20	7.50	7.20	2.60	*
344	FSW	39	14	38	227	503	636	872	1072	70	246	152	92	50	210	88	18	7.10	7.40	7.40	2.70	*
345	FSW	35	11	53	153	763	727	1000	1018	78	76	156	88	72	54	144	88	7.20	7.50	7.10	2.50	*
346	FSW	56	11	106	150	872	709	964		210	76	190		118	26	114						*
347	S/H	44	12	42	146	754	644	826	1081	14	16	24	12					7.30	7.80		2.00	*
348	DHW			96	219			1065	1249			88	82			42	20			7.35	2.90	*
349	DHW	73	20	99	309	730	686	756	984	72	44	52	150	52	28	38	116	7.15	7.50	7.15	3.70	*
350	DHW					801	452	543	817	96	90	66		78	70	62		7.25	7.65	7.30		*
351	H/S					698	491	615	840	98	60	76	110	60	34	50	76	7.10	7.65	7.40	5.05	*
352	FSW					640	480	608	860	34	16	34	52	22	14	34	38					*
353	FSW					1080	780	1080	1258	38	20	80	40	10	10	40	20					*
354	FSW					1160	1122	1178	1214	50	18		20	44	6		8					*
009	FSW	96	30	21	180	1078	809	809	1057	92	72	84	190	54	24	38	100	7.00	7.40	7.30	3.00	*
010	FSW	224	23	33	147	1184	815	630	1166	124	36	20	20	82	34	12	12	7.20	7.60	7.60	3.60	*
011	FSW																					*
012	FSW																					*
013	FSW	152	6	86	156	806	623	800	1181	120	170	92	62	94	134	82	58	7.10	7.50	7.10	2.30	*
014	FSW	167	21		171	963	774	926	1050	94	26	44	40	44	20	32	36	7.10	7.50	7.10	3.20	*
015	FSW	89		72	119	870	722	814	999	58	28	14	10	52	20	8	8	7.20	7.50	7.10	3.00	*
016	FSW	38	10	66	150	726	712	979	1104	162	060	176	68	114	30	80	56	7.10	7.40	7.20	4.00	*
017	S/H	53	15	95	183	1110	965	1147	1147	210	110	186	90	90	68	76	20	7.20	7.60	7.10	4.00	*
018	DHW		47	45	183	655	710	728	819	28	84	76	68	20	76	58	56					*
019	DHW																					*
020	DHW																					*
021	FSW	38	17	38	162	702	558	684	720	20	64	100	72	12	46	74	46					*
022	FSW	38	12		186	566	418		1362	68	52		80	16	44		55					*
023	FSW					600	564	619	801	44	50	144	82	70	38	112	68	7.15	7.40	7.20	3.70	*
024	FSW	26	12	24	82	609	560	620	855	100	64	62	40	66	42	48	16	7.20	7.40	7.20	4.50	*
025	FSW	27	8		140	660	574	589	897	82	30		54	40	4		34	7.00	7.30		3.40	*

TABLE II-2 OPERATIONAL DATA - Nov. 22, 1973 to Jan. 25, 1974

DAY	MLSS MG/L			MLVSS MG/L			DO MG/L			SVI ML/GM			OUR MG/G·DAY			
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
326	5730	3040								118			21	13		*
327	5620	540		4400	360		1.50	7.30					14	36		*
328	5940	1090		4810	770					115	37		10	12		*
329	5430	1050		4410	780		3.30	5.80		116	42		27	54		*
330	6160	1370		5120	860					30	41		19	15		*
331	8310	1990	4810	6830	1460	4180	1.50	4.30	0.50	91	44	58	29	32	17	*
332	8340	1630	3470	6760	1150	2490	2.00	4.10	0.60	98	44	46	45	44	11	*
333	6630	1690	3540	5460	1260	2730	2.70	4.20	0.65	118	57	73	12	28	20	*
334	5990	1500	3280	4280	1130	2650				129	53	80				*
335	6340	1120	3310	6170	750	2390				139	43	75				*
336	4990	1270	3440	3930	750	2490				172	50	84				*
337	4670	1770	3240	3890	1260	2540	0.60	5.00	0.50	137	54	72	137		23	*
338	4220	2220	3330	3740	1740	3130				108	61	86				*
339	6630	2480	5370	5510	1670	4240	0.90	5.20	2.50	112	55	96	56	46	28	*
340	5360	2830	4920	4980	2090	3990	1.60	6.40	1.50	115	44	116	31	33	17	*
341	5610	2840	5440	4630	2120	4500	1.60	6.50	1.60	113	21	103	33	31	11	*
342	6680	3180	5560	5540	2450	4570	1.70	6.30	0.45	105	18	114	44	39	35	*
343	6660	2000	4600	5570	1410	3900	2.30	6.40	0.70	107	40	146	17	31	22	*
344		2770	4870		2520	3550					51	93				*
345	7340	1830	5850	5910	1310	4330	0.60	4.90	0.30		127	108	20	68	8	*
346	7210	2010	4850	5640	1410	4190	0.60	5.90	0.50	83	45	82	72	27	9	*
347	5240	1850	4470	4550	1480	4080				118	65	134				*
348	6380	2520	4130	4720	1690	3060	0.60	5.30	0.40				71	63	60	*
349	7070	3170	5990	5990	2630	5600	0.50	5.55	0.50	110	41	122	50	43	8	*
350	7240	2400	5690	6110	1390	4510				105	38	124	43	41	8	*
351	7680	520	4520	6370	400	3980				103	38	155	41	79	10	*
352		1280	4370		1010	4200	5.00	6.60	0.35					41	37	*
353	5520	1280	4420	4450	840	4040	0.60	6.20	0.40				31	31	19	*
354	5620	1570	4620	4500	1310	4160	0.80	7.10	0.40				25	33	13	*
009	9440	3292	2560	7330	2340	1990				93	64	52	10	25	24	*
010	9540	2450	1210	7570	1750	990				91	73	76	3	14	23	*
011	6360	2310	1940	5080	1800	1670				148	76	66	3	12	13	*
012	5790	1910	1410	4700	1370	1190	6.10		5.10	137	67	68	12	5	12	*
013	6010	2740	1200	4880	2050	960	0.50	9.70	0.40	55	62	50	21	21	67	*
014	5240	2340	440	4370	1880	400				85	68		34	26		*
015	5000	1850	5860	4300	1430	4750	0.50	8.50	0.25	90	86	88	34	33	39	*
016	4790	2960	5240	4010	2000	4110							38	10	34	*
017	5720	2890	4480	4540	1960	3410				44			37			*
018	6810	3170	6120	5570	2430	4870										*
019																*
020	6060	2800	7980	5310	2330	6940				96	100	63	31	16	15	*
021	5370	3020	5580	4170	2000	4420				56	66	43	12	27	12	*
022	5100	2610	5940	4320	1890	4830				59	69	61	10	33	2	*
023	5320	3500	5940	4300	2750	4810	0.80	6.30	0.90	62	77	120	21	25	15	*
024	4590	2770	5600	3700	2120	4470	0.85	6.40	0.60	63	84	71	13	18	8	*
025	4200	3660		3440	2840		1.80	6.40		50	46		55	28		*

TABLE II-3 PERFORMANCE DATA - Jan. 26, 1974 to Mar. 6, 1974

		BOD MG/L				COD MG/L				TSS MG/L				VSS MG/L				PH				
DAY	WOOD	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
026	S/H	59	25		162	744	714		943	108	98		48	68	60		38	6.85	7.20		2.75	*
027	DHW	51	31		138	590	545		588	84	54		60	80	42		58	6.85	7.30		4.75	*
028	DHW	57	18		132	505	324		541	50	78		68	50	36		62	6.90	7.30		5.80	*
029	DHW	56	35	14	187	662	575	435	660	86	90	78	70	62	40	40	32	6.70	7.20	7.15	4.55	*
030	DHW	31	35	29	86					32	54	18	26	30	50	14	24	7.00	7.25	7.40	9.35	*
031	H/S	53	27	30	170	642	625	608	705	6	8	50	12	4	6	34	10	6.90	7.20	7.20	2.90	*
032	FSW	41	20	17	128	642	625	608	705	12	74	22	16	8	24	16	8	6.80	7.20	7.40	2.90	*
033	FSW	51	23	7	169	765	661	609	1096	30	68	18	10	20	36	10	6	6.90	7.30	7.30	2.50	*
034	FSW	63	24	51	167	940	870	835	1149	156	24	120	34	76	10	44	26	6.90	7.30	7.30	2.40	*
035	S/H																					*
036	DHW																					*
037	DHW	133		25	187	685		633	705	144	70	92	82	134		84	80					*
038	DHW	67	40	22	81	595	582	480	638	56	104	68	60	66	96	52	60	7.00	7.30	7.30	5.45	*
039	H/S	115	30	17	126					46	44		10	32	24		0	7.10	7.50	7.40	6.15	*
040	FSW	41	17	38	129	325	366	301	513	24	62	22	42	22	24	14	36	7.00	7.40	7.40	4.00	*
041	FSW	61	25	12	175	822	721	600	1005	58	50	40	48	54	34	32	42	6.95	7.40	7.30	2.95	*
042	FSW	91	43	9	163	920	940	800	1040	56	58	50	58	50	54	48	56	6.90	7.30	7.35	2.80	*
043	FSW	96	48	5	165					24	44	30	76	22	34	24	20	6.80	7.20	7.35	2.70	*
044	FSW	71	35	32	162	870	837	700	994	46	42	18	26	44	38	10	24	6.80	7.20	7.35	2.70	*
045	S/H	66	20	13	157	730	672	576	920	64	36	28	30	52	14	20	8	6.90	7.20	7.30	3.50	*
046	H/S	104	46	26	216	921	902	712	1195	46	52	30	30	18	22	18	22	7.00	7.20	7.20	2.80	*
047	H/S	108	54	15	193		673	777	1107	43	50	44	48		44	18	30		7.20	7.30	3.00	*
048	H/S	110	51	9	123	738	660	369	796	40	70	78	70	10	18	26	34					*
049	DHW	130	50	19	217	990	893	641	1029	62	54	66	66	36	30	38	50	7.20	7.20	7.40	4.90	*
050	DHW	116	46	15	168	835	700	322	966	66	78	100	154	60	62	74	126	7.10	7.20	7.40	4.35	*
051	DHW	107	40	15	252	1015	837	596	1192	88	104	116	82	80	94	100	74	7.20	7.40	7.50	4.50	*
052	FSW	111	43	6	153	856	772	545	815	106	36	94	82	86	32	64	62	7.00	7.40	7.50	4.00	*
053	FSW																					*
054	FSW	73	40	10	165	858	580	645	602	68	106	62	52	52	78	44	34	6.95	7.30	7.30	3.95	*
055	FSW	127	47	11	285	1130	355	750	1360	38	46	86	54	36	42	80	46	7.10	7.25	7.30	2.50	*
056	FSW	123	44	11	207					94	60	72	68	62	26	22	40	7.00	7.20	7.20	2.50	*
057	FSW	102	34	10	167	1040	942	805	1160	80	140	80	88	72	112	74	82	7.00	7.20	7.30	2.60	*
058	FSW																					*
059	FSW	118	95	22	228	1256	1221	960	1396	30	18	26	8	28	12	24	6	7.00	7.30	7.20	2.40	*
060	S/H	47	22	7	134	751	843	843	899	26	24	18	20	22	18	14	16	6.90	7.10	7.20	4.60	*
061	DHW	42	12	15	136	500	500	407	592	126	88	74	78	82	50	70	52	7.10	7.30	7.40	6.00	*
062	DHW	52	35	6	88	527	509	304	673	138	92	64	116	78	16	12	34	7.10	7.30	7.50	6.10	*
063	DHW	64	43	7	96	382	382	273	437	118	146	86	92	90	136	86	82	7.10	7.30	7.60	6.50	*
064	DHW	66	23	6	137	545	582	347	600	40	80	24	56	32	72	22	30	7.00	7.30	7.50	6.90	*
065	DHW					473	436	327	691	20	90	82	36	18	64	70	32					*

TABLE II-4 OPERATIONAL DATA - Jan. 26, 1974 to Mar. 6, 1974

DAY	MLSS MG/L			MLVSS MG/L			DO MG/L			SVI ML/GM			OUR MG/G·DAY			
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
026	3440	3690		2440	2740		2.80	6.40		64	57		44	25		*
027	3700	3620		3100	2400		6.80	3.00		73	66		30	56		*
028	4370	3120	2950	3760	2430	2260	1.00	2.60	1.30	62	68	54	52	41	23	*
029	6730	1140	3090	5570	800	2340	0.30	4.70	0.45	84		61	58	55	21	*
030	4370	880	2560	4130	730	1960	1.20	3.30	4.45	62	114	63	42	77	35	*
031	5330	1820	2080	4560	1610	1630				56	63	63				*
032	4410	1940	1910	3710	1320	1540	1.00	5.50	5.00	61	62	73	40	66	23	*
033	4350	1660	2130	3720	1160	1420	0.70	5.60	5.00	64	72	70	37	89	23	*
034	5850	4120	2350	4530	1370	1770	4.40	7.00	6.50	70	29	72	8	18	10	*
035	5460	1510	1880	4900	1250	1580	8.10	8.90	8.60	152	79	101	6	19	11	*
036	3800	1310	2360	3110	1070	1660	9.20	9.40	9.40	74	92	76	25	15	2	*
037	3860	930	2320	3290	640	2020	1.10	6.00	5.20	75	54	82	31	11	17	*
038	5130	830	2190	4680	810	1950	6.80	6.00	4.80	119	96	82	19	51	13	*
039	3750	1410	2600	3380	1120	2120	0.80	5.80	4.50	67	32	73	81	68	22	*
040	4240	1060	2380	3910	861	1990	1.60	5.50	5.70	120	71	90	28	57	17	*
041	4730	390	2580	4250	320	2130	0.80	5.00	4.00	57		81	59	77	17	*
042	3250	690	2420	3600	680	2100	1.40	6.20	4.50	73	43	91	38	65	28	*
043	4420	1330	2550	3370	1110	2090	0.90	4.60	4.80	90	90	98	25	66	7	*
044	3970	2500	2370	3610	2280	2080	1.10	4.30	4.00	71	76	105	45	46	29	*
045	3500	2020	2710	3370	1400	2030	1.20	5.40	4.10	71	94	103	69	80	24	*
046	4040	2400	3270	3440	1750	2360	1.40	5.10	3.60	64	104	86	63	68	19	*
047	3290	2490	2920	2370	2050	2270	1.40	6.30	4.40	64	137	89	56	6	21	*
048	3000	3640	3350	2380	3000	2530	2.60	7.30	4.00	113	60	84	64	38	36	*
049	5060	2420	3340	4620	2080	2820	2.85	5.40	4.00	59	136	90	32	50	30	*
050	4310	5420	3980	4390	4600	3440	1.40	2.70	4.40	62	79	118	26	80	21	*
051	4390	3990	3680	3970	3190	3260	1.10	3.30	4.50	103	120	76	60	95	21	*
052	7550	2750	3360	7060	2320	2970	8.20	9.00	8.70	107	115	95	8	15	24	*
053	4650	2370	3130	4280	2060	2750	1.10	7.10	7.00	111	101	89	38	23	14	*
054	5410	3300	3200	5020	2830	2770				55	67	122	30		17	*
055	5810	3650	2610	5110	2890	2460	1.50	5.90	5.20	72	71	105	25	62	37	*
056	5000	2340	3280	4350	1780	2640	2.20	4.70	4.60	74	124	88	24	51	13	*
057	4000	3520	3340	3720	3030	2790	2.00	5.20	5.30	83	111	99	30	42	22	*
058	6120	4470	3220	5330	3620	2550	9.80	9.80	9.80	78	89	93	10	5	13	*
059	5680	280	2930	5550	230	2570	1.40	6.90	4.30	69		99				*
060	5290	770	2750	5170	740	2630	1.40	7.60	5.60	68	130	102	25	130	20	*
061	6780	660	3100	6170	570	2410	1.20	7.40	5.70	66	121	90	28	121	17	*
062	6700	1240	3230	5820	1064	2650	1.50	6.90	5.00	58	65	90	25	13	17	*
063	6600	1600	3210	6130	1380	2910	1.30	7.40	5.50	64	63	93	27	38	16	*
064	5360	3640	3430	5180	2450	2980	1.60	6.80	5.80	71	16	90	35	45	18	*
065	6630	1920	3430	5320	1430	3100	1.80	7.30	4.80	77	63	90	29	65	16	*

TABLE II-5 PERFORMANCE DATA - Mar. 7, 1974 to Mar. 28, 1974

		BOD MG/L				COD MG/L				TSS MG/L				VSS MG/L				PH				
DAY	WOOD	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
066	FSW	66	46	58	243	1074	887	807	1162	98	128	116	68	76	98	94	54	6.60	6.95	7.10	2.80	*
067	FSW	109	45	85	158					82	76	108	44	52	46	80	44	6.00	6.00	6.65	2.60	*
068	FSW																					*
069	FSW	113	41	27	183	865	904	785	950	64	76	82	62	58	72	68	48	6.80	6.90	7.00	4.10	*
070	FSW	124	115		99	914	362		741	40	84	84	64	22	76	64	24	6.60	6.80		5.10	*
071	FSW	128	43	49	237					6	8	22	12	4	6	14	10	6.70	7.10	7.20	2.70	*
072	FSW	146	105	25	161	1130	1095	831	1165	80	100	66	32	66	54	36	22	7.10	7.30	7.50	2.60	*
073	FSW	162	118	35	175	1339	1270	1061	1364	52	28	40	50	28	16	16	4	7.40	7.40	7.40	2.70	*
074	FSW	151	110	120	226	1276	1138	1207	1310	34	100	84	36	28	72	64	32	7.20	7.40	7.30	3.20	*
075	S/H	137	85	26	209	1017	1189	1466	1845	12	44	8	20	10	38	6	12	7.10	7.30	7.50	3.20	*
076	DHW	147	116	31	237	828	862	603	948	40	94	86	84	26	52	54	56	7.20	7.50	7.60	4.10	*
077	DHW	126	94	106	157	603	741	396	741	196	192	62	34	156	152	46	48	7.10	7.10	7.30	4.50	*
078	DHW		63	20	153		569	336	655		108	50	100		42	10	32		7.00	7.10	4.20	*
079	DHW	125	74	12	162					106	132	74	72	62	68	54	42	6.80	7.00	7.20	4.70	*
080	H/S	172	115	33	209	825	686	466	861	62	74	66	90	48	68	56	80	6.90	7.05	7.20	3.60	*
081	FSW	145	130	24	146	900	996	613	615	64	76	62	55	48	66	54	42	7.70	7.05	7.30	6.20	*
082	FSW	146	113	29	197	1060	900	720	1040	52	72	66	66	38	54	40	36	6.80	7.10	7.20	2.70	*
083	FSW	153	38	20	234	1052	1018	912	1233	84	74	56	70	40	50	40	32	6.85	7.15	7.15	2.60	*
084	FSW	159	79	66	216	1345	993	926	1162	40	60	60	66	32	48	62	46	6.90	7.10	7.20	2.70	*
085	FSW	143	78	33	258					50	28	92	26	28	18	10	12					*
086	S/H	133	63	30	178	975	876	790	1044	80	54	40	26	68	52	38	20	6.90	7.20	7.20	2.90	*
087	DHW	105	41	21	180	818	783	579	924		80	18	50		52	14	40	7.00	7.30	7.20	3.00	*

TABLE II-6 OPERATIONAL DATA - Mar. 7, 1974 to Mar. 28, 1974

DAY	MLSS MG/L			MLVSS MG/L			DO MG/L			SVI ML/GM			OUR MG/G·DAY			
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
066	6060	1320	4040	5630	1160	3390	5.10	4.70	1.10	51	114	77	21	12	13	*
067	3700	310	3740	3300	190	3250	7.30	8.30	1.40	84		78	5	69	22	*
068	9800	550	4030	9210	420	3560	5.70	9.10	8.80	86	36	84	7	47	7	*
069	3270	520	3850	3060	510	3470	6.60	7.80	4.20	61	19	73	96	185	15	*
070	4530	660	3670	3390	430	3180	6.20	7.50	1.30	44	15	82	24	136	13	*
071	3640	1070	3150	3250	750	2950	7.30	7.70	1.30	36	9	105	32	85	13	*
072	4980	1000	4220	4560	740	3810	3.80	7.70	1.50	55	20	76	19	11	20	*
073	6050	660	3900	5200	260	3450	2.80	7.60	1.50	48	68	103	32	91	14	*
074	3650	1070	4420	3250	950	4000	2.75	6.60	1.40	49	65	94	33	52	15	*
075	4340	740	4520	4090	670	4270	1.30	6.50	1.70	67	135	88	53	76	16	*
076	6430	410	4550	6000	260	4110	4.40	7.80	6.30	87	171	180	9	98	9	*
077	4530	410	4720	4330	220	4330	2.10	6.90	2.80	55	98	127	15	244	25	*
078	5170	840	5230	4530	310	4570	1.50	6.60	1.30	58	36	99	22	135	12	*
079	2500	420	5500	2380	320	4990	1.20	6.30	2.00	104	95	96	20	248	7	*
080	3160	540	5690	2870	430	5140	0.80	7.30	6.20	83	56	97	27	68	23	*
081	3380	810	5510	3180	630	4990	4.50	6.40	1.10	77	49	82	1	15	16	*
082	3850	2110	5620	3600	1680	5070	2.90	6.60	1.20	57	52	109	12	80	16	*
083	3210	1080	6050	2960	870	5360	2.60	5.80	1.50	81	176	101	16	134	14	*
084	3000	3090	7080	2830	2510	5660	1.60	7.10	0.90	67	84	99	18	78	10	*
085	3070	3220	5820	2630	2460	5610	1.30	7.00	1.50	81	118	122	26	31	11	*
086	5330	1080	5170	2940	920	4780	0.80	6.20	1.10	74	222	97	15	56	8	*
087	8890	1340	4770	8690	1210	4430	2.70	7.30	6.40	92	254	109	18	42	3	*

APPENDIX III

NITROGEN AND PHOSPHORUS ANALYSES

APPENDIX III

NITROGEN AND PHOSPHORUS ANALYSES

DATE	1		2		3		4	
	TKN*	ORTHO-PHOSPHATE**	TKN	ORTHO-PHOSPHATE	TKN	ORTHO-PHOSPHATE	TKN	ORTHO-PHOSPHATE
JAN. 09				4.8				
13		5.3		4.3		4.5		0.8
23		3.8		3.6		3.3		1 0
26					11.8		2.2	
30	13.4		9.0		11.1			
FEB. 12	8.0		5.2		3.9		0.4	
20		3.1		2.9		3.2		1 5
25	2.2		2.0		3.6		3.1	
MAR. 07		2.6		2.2		2.4		0.8
12	10.6	2.9	2.1	2.9	5.1	3.0	5.6	1 0
20	6.4	1.1	3.7	1.5	1.6	1.6	2.2	1.1
26	2.4	2.1	3.0	0.9	2.6	1.5	0.6	1.0

* TKN as N, mg/l
** Orthophosphate as P, mg/l

1. First Stage Effluent
2. Second Stage Effluent
3. Single-stage Effluent
4. Bleachery Effluent

APPENDIX IV

CAUSTIC USAGE, TEMPERATURE AND PLANT OPERATOR REMARKS

APPENDIX IV

CAUSTIC USAGE, TEMPERATURE AND PLANT OPERATOR REMARKS

Day - 326 (November 22, 1973) to 354 (December 20, 1973)
- 4 (January 4, 1974) to 87 (March 28, 1974)

Wood - FSW - Softwood
DHW - Hardwood
S/H, H/S - Mixed wood species

NaOH - Caustic Stock Tank Requirement lb/day
- 1 lb/day = 0.454 kg/day

Temp. 1 - Bleachery Overflow Tank, °C
2 - Mixing Tank, °C
3 - First stage Effluent, °C
4 - Second stage Effluent, °C

DAY	WOOD	NAOH	TEMP.1	2	3	4	REMARKS
326	FSW	9	21	42	28		FIRST-STAGE SLUDGE RECYCLE BLOCKED IN A.M.
327	FSW	13	43	41	37		ENCLOSE NO.1 THERMOCOUPLE IN STAINLESS STEEL TUBE
328	FSW	0	43	41	37		
329	FSW	0	45	42	36		
330	FSW	42	42	42	37		NEW BLOWER SYSTEM INSTALLED.SINGLE STAGE AT 2.35 GPM.AERATION CELL 390 GAL
331	FSW	55	47	45	34	32	
332	FSW	44	46	46	36	33	
333	FSW	44			32	31	PLANT ON RECYCLE AT 1600 HRS.DUE TO BLEACH PLANT BREAKDOWN
334	FSW	0			26	25	RECYCLE CONTINUED
335	FSW	0			21	20	RECYCLE CONTINUED - REPLACED HYDROMATIC FEED PUMP
336	FSW	33	46	46	24	23	PLANT BACK ON LINE AT 1300 HRS
337	S/W	0	44	44	33	31	
338	DHW	0	44	43	35	33	PH CONTROL ELECTRONIC FAILURE
339	DHW	0	44	43	36	33	BLEACH PLANT SHUT DOWN FROM 1200 TO 1630 HRS
340	DHW	11	44	43	34	33	
341	DHW	22	43	42	34	32	
342	DHW	22	41	39	33	31	
343	H/S	0	46	44	35	33	
344	FSW	11	48	47	35	34	
345	FSW	11	49	49	42	34	RETURN SLUDGE FROM 2ND CLARIFIER TO 1ST AERATION CELL FOR 1 HOUR
346	FSW	11	48	48	37	35	
347	S/H	0	44	44	35	33	
348	DHW	15	44	42	33	32	BLEACH PLANT SHUT DOWN 2300 HRS
349	DHW	15	48	46	34	32	BLEACH PLANT SHUT DOWN UNTIL 0500 HRS
350	DHW	15	47	46	34	32	
351	H/S	0	46	45	34	32	
352	FSW	0					CAUSTIC SUPPLY SUFFICIENT TO DEC.20
353	FSW	0					
354	FSW	0					PILOT PLANT SHUT DOWN
4							TWO STAGE UNIT START UP AT 1700 HRS.RESUME FLOW AT 1.0 GMP.
5							SINGE STAGE STAGE START UP AT 1400 HRS. FLOW 2.35 GMP.AERATION CELL 390
9	FSW	0			32	31	PLANT ON RECYCLE.BLEACH PLANT SHUT DOWN AT 1300 HRS
10	FSW	0			26	24	BLEACH PLANT SHUT DOWN CONTINUED
11	FSW	0			18	17	BLEACH PLANT SHUT DOWN CONTINUED
12	FSW	0	42	42	21	21	BLEACH PLANT RESTARTED AT 1200 HRS.FEED PLANT MOTOR BURNED OUT
13	FSW	0	43	42	26	29	REPLACED MAIN FEED PUMP
14	FSW	26	42	41	29	31	
15	FSW	0	40	39	31	30	
16	FSW	20	37	37	31	29	
17	S/H	0	38	37	30	29	
18	DHW	0					BLEACH PLANT SHUT DOWN AT 0500 HRS.FEED PLANT MOTOR BURNED OUT - REPLACED
19	DHW	15					FEED LINE AND DRAIN FROZEN 1100 HRS
20	DHW	0	44	44	26	25	PLANT START UP AT 0500 HRS
21	FSW	0	46	45	35	33	
22	FSW	13	47	46	36	33	NO.3 SAMPLER OFF NO.4 SAMPLER PLUGGED WITH FIBRES
23	FSW	0	46	46	36	34	
24	FSW	0	46	44	37	35	
25	FSW	0	46	45	39	38	TWO-STAGE FLOW INCREASED TO 2.0 GPM
26	S/H	0	46	44	37	35	BLEACH PLANT DOWN FOR 6 HRS.FEED PUMP SEAL BROKEN SO PUMP REPLACED
27	DHW	0	45	43	38	37	SINGLE STAGE AERATION CELL PARTITION REMOVED
							PLANT RESTARTED AT 2.35 GPM WITH 780 GAL AERATION CAPACITY
28	DHW	0	39	39	37	36	RETURN SLUDGE FROM 2ND STAGE CLARIFIER TO 1ST STAGE AERATION FOR 1 HR
29	DHW	22					BLEACH PLANT SHUT DOWN 2345 HRS -
							REPAIRS TO 1ST STAGE CLARIFIER - SOME SLUDGE LOSS
30	DHW	0					BLEACH PLANT ON AT 1045 HRS
31	H/S	0	43	42	38	37	SEVERE FOAMING ON ALL AERATION CELLS WITH SWITCH TO FRESH SOFTWOOD
32	FSW	11	43	42	38	36	
33	FSW	33	43	42	38	36	FOAMING PROBLEM STILL SEVERE ON 2ND AERATION CELL
34	FSW	0					PLANT ON RECYCLE DUE TO FEED PUMP BREAKDOWN

DAY	WOOD	NAOH	TEMP.1	2	3	4	REMARKS
35	S/H	0					FEED PUMP REPLACED BUT DRAIN LINES FROZEN
36	DHW	0	39	38	25	24	PLANT IS BACK ON LINE AT 1400 HRS
37	DHW	31	39	38	34	33	
38	DHW	0					BLEACH PLANT SHUT DOWN 0900 TO 2000 HRS
39	H/S	0	43	43	35	33	
40	FSW	-	42	42	35	33	BLEACH PLANT SHUT DOWN FOR 8 HRS - MAIN FEED PUMP REPLACED
41	FSW	22	43	42	38	36	
42	FSW	44	42	41	37	35	
43	FSW	22	42	41	37	35	
44	FSW	0	41	40	36	34	
45	S/H	0	39	38	35	33	ADDED NEW SLUDGE TO SINGLE STAGE UNIT
46	H/S	0	38	38	34	33	
47	H/S	0	38	38	35	33	NO.1 SAMPLE LINE FROZEN
48	H/S	0	38	38	34	33	
49	DHW	0	39	39	34	33	
50	DHW	33	39	39	36	34	RETURN 30 GAL SLUDGE AT 4000 MG/L FROM 2ND CLARIFIER TO 1ST AERATION -
							SEVERE FOAMING ON AERATION CELLS
51	DHW	0					WASTE FROM 2ND AERATION 110 GAL AT 3250 MG/L
52	FSW	0					BLEACH PLANT SHUT DOWN - PLANT ON RECYCLE
53	FSW	0					PLANT RESTARTED IN A.M.
54	FSW	33	42	43	38		
55	FSW	44	42	43	38	37	
56	FSW	22	43	42	38	36	
57	FSW	22	39	38	36	35	BLEACH PLANT BREAK DOWN AT 2300 HRS
58	FSW	0					WASTED 100 GAL FROM 2ND CLARIFIER AT 2250 MG/L
							PLANT BACK IN OPERATION AT 1700 HRS USING VIKING FEED PUMP
59	FSW	13	39	39	34	32	
60	S/H	0	42	42	37	36	
61	DHW	0	43	42	37	36	
62	DHW	0	43	44	37	37	BLEACH PLANT SHUT DOWN FOR 10 HRS
63	DHW	13	44	43	36	34	
64	DHW	0	46	46	39	37	
65	DHW	13	44	46	39	39	INCREASED FLOW IN SINGLE STAGE TO 3.5 GPM AND TWO STAGE TO 3.0 GPM
66	FSW	112	39	39	37	37	PH CONTROL INCREASED TO COMPENSATE FOR INCREASED FLOW
67	FSW	0	42	41	34	36	BLEACH PLANT SHUT DOWN AT 1500 HRS - PLANT PLACED ON RECYCLE
68	FSW	22	42	42	38	32	PLANT BACK ON LINE AT 1400 HRS VIKING FEED PUMP REPLACED
69	FSW	22	46	44	41	39	BLEACH PLANT DOWN FOR 8 HRS
70	FSW	22	47	47	42	41	BLEACH PLANT FEED PUMP LINE COLLAPSED
71	FSW	35	46	46	41	39	
72	FSW	31	47	46	42	39	
73	FSW	40	43	43	39	38	
74	FSW	26	43	43	41	39	
75	S/H	0	41	41	38	37	BLEACH PLANT SHUT DOWN 2200 HRS
76	DHW	0					BLEACH PLANT STARTED AT 1400 HRS
77	DHW	18	45	45	41	39	
78	DHW	18	46	46	41	39	
79	DHW	9	46	46	42	40	
80	H/S	0					BLEACH PLANT SHUT DOWN 0700 TO 1930 HRS
81	FSW	33	46	46	41	43	
82	FSW	44	46	46	42	39	
83	FSW	44	46	45	41	38	
84	FSW	44	45	45	41	38	
85	FSW	26	45	44	37	37	SINGLE STAGE WASTE SLUDGE 135 GAL AT 6850 MG/L -
							2ND STAGE WASTE SLUDGE TO FIRST STAGE FOR ONE HOUR
86	S/H	22	44	44	38	37	SINGLE STAGE WASTE SLUDGE 100 GAL AT 1950 MG/L
87	DHW	0					PILOT PLANT SHUT DOWN

APPENDIX V

MEDIAN SURVIVAL TIMES FOR

1-HOUR AND 24-HOUR COMPOSITE SAMPLES

APPENDIX V

MEDIAN SURVIVAL TIMES FOR 1-HOUR AND 24-HOUR COMPOSITE SAMPLES

TABLE V-1 MST'S FOR 1-HOUR COMPOSITE SAMPLES OF UNTREATED KBE
COLLECTED BETWEEN NOVEMBER 23 AND DECEMBER 18

DATE	WOOD SPECIES	TREAT-MENT	VOL. (l)	D.O. (mg/l)	pH	NO. OF FISH	LENGTH (cm)	WEIGHT (g)	MST (MIN)	95% CONFIDENCE LIMITS		S*	TEMP. (°C)	SAMPLE TIME
										UPPER	LOWER			
NOVEMBER														
23	FSW	U	20	8.3	8.3	6	9.2	10.2	135	152	119	1.18	5	19.00 - 20:00
24	FSW	U	20	8.2	8.0	6	10.3	13.3	240	271	212	1.17	5	13.30 - 14:30
26	FSW	U	20	7.0	7.4	6	9.8	12.6	94	100	89	1 07	5	01:00 - 02:00
DECEMBER														
13	S/H	U	20	8.7	7.8	4	10.8	13.4	28	40	19	1.45	15	11.15 - 12.15
13	S/H	U	20	8.7	7.5	4	10.2	13.4	40	43	37	1.07	15	15.00 - 16:00
13	S/H	U	20	8.0	7.2	4	10.5	13.0	50	77	33	1.53	15	21:00 - 22.00
17	DHW	U	20	-	-	6	10.8	13.2	125	161	97	1.35	15	10 30 - 11.30
18	FSW	U	20	7.8	7.5	6	10.7	13.4	40	60	27	1.68	15	10:30 - 11.30
18	FSW	U	20	7.8	7.5	6	10.5	13.2	16	18	14	1.16	15	14:00 - 15:00
NOVEMBER														
23	FSW	T-S	20	7.5	7.9	6	10.7	13.4	300	447	201	1 56	5	19:00 - 20:00
24	FSW	T-S	20	10.2	8.0	6	11.4	15.0	310	372	258	1.26	5	13:30 - 14.30
26	FSW	T-S	20	7.0	8.4	6	10.0	11.7	550	720	420	1.41	5	01 00 - 02.00
DECEMBER														
13	S/H	T-S	20	8.0	7.9	4	10.2	13.0	300	372	242	1.24	15	20.30 - 21.30
17	S/H	T-S	20	-	-	6	10.4	12.4	3000	3300	2720	1.13	15	10:30 - 11.30
18	FSW	T-S	20	-	-	6	-	-	No Mortality in 96 Hours				15	18.30 - 19:30
18	FSW	T-S	20	8.0	7.5	6			1300	2093	807	1.85	15	22:00 - 23:00

* $S = (ET_{84}/ET_{50} + ET_{50}/ET_{16})/2$ (Litchfield, 1949)

TABLE V-2 MST'S FOR 24-HOUR COMPOSITE SAMPLES OF UNTREATED KBE
COLLECTED BETWEEN FEBRUARY 19 AND MARCH 28

DATE	WOOD SPECIES	VOL (l)	D O (mg/l)	pH	Cl. (mg/l)	NO OF FISH	LENGTH (cm)	WEIGHT (g)	MST (MIN)	95% CONFIDENCE LIMITS UPPER	LOWER	S'	TEMP (°C)	SAMPLE TIME
FEBRUARY														
19-20	DHW	10	-	-	-	7	3 3	.40	21	32	14	1 71	15	9·00 - 8 00
20	DHW	10	8 5	7 2		5	3 3	40	120	152	94	1 31	15	9 00 -21 00
22-23	FSW	20	10 8	7 4	1 94	5	3 3	40	110	134	90	1 26	15	9 00 - 9 00
23-24	FSW	20	-	7 2	2 96	5	-	-	58	69	48	1 24	15	9 00 - 9 00
24-25	FSW	20	10 6	7 3		5	3.6	53	84	111	64	1 37	14	9 00 - 9 00
25-26	FSW	20	8 5	7 4	0 4	10	4 0	77	50	57	44	1 23	14	9 00 - 9 00
27-28	FSW	10	8 3	7 3	0	10	4 8	60	44	46	41	1 11	14	20 00 -08 00
28-MARCH 1	DHW	20	9 2	7 7	4 7	10	4 3	.70	370	499	274	1 63	16	9 00 - 9 00
1-2	DHW	20	9 8	7 0	8 8	10	4 4	75	310	352	273	1 23	16	9 00 - 9 00
2-3	DHW	20	11 2	7 0	11 8	10	4 1	60	250	272	229	1 15	15	9 00 - 9 00
3-4	DHW	20	11 4	6 8	6 4	10	3 9	65	59	65	53	1 18	15	9 00 - 9 00
4-5	DHW	20	11 6	7 8	16 8	10	2.5	15	170	199	145	1 30	16	9 00 - 9 00
5-6	DHW	20	10 8	6 2	18 8	10	2 6	15	71	81	62	1 23	16	9 00 - 9 00
6-7	FSW	20	8 2	7 2	0	10	2 4	14	64	78	52	1 37	15	9 00 - 9 00
7-8	FSW	10	11 6	7 0	0	10	2 5	15	130	147	115	1 19	14	9 00 - 9 00
10-11	FSW	20	12 0	7 1	0	10	2 5	15	28	31	26	1 15	14	9 00 - 9 00
11-12	FSW	10	11 4	7 8	0	10	2 6	15	125	136	115	1 15	14	21 00 - 9 00
12-13	FSW	20	11 8	7 2	0	10	2 5	15	21	22	20	1 10	13	9 00 - 9 00
13-14	FSW	20	10 4	7 2	0	10	2 6	16	21	22	20	1 10	15	9 00 - 9 00
14-15	FSW	20	11 4	7 9	0	10	2 7	16	31	34	28	1 15	14	9 00 - 9 00
15-16	FSW	20	9 6	6 9	0	10	2 6	20	33	36	30	1 13	14	9 00 - 9 00
16-17	DHW	<10	11 0	6 6	0	5	2 7	23	115	127	104	1 12	14	9 00 - 8 00
17-18	DHW	10	8 6	6 9	4 2	5	2 7	20	77	97	61	1 30	15	9 00 - 9 00
18-19	DHW	20	-	7 5	3 4	10	2 7	19	70	84	58	1 34	14	9 00 - 9 00
19-20	DHW	20	10 0	6 6	1 4	10	3 0	35	57	64	51	1 20	14	9 00 - 9 00
20-21	FSW	20	9 2	6 9	0	10	3 0	27	42	47	37	1 22	15	9 00 - 9 00
21-22	FSW	10	9 2	6 2	8 6	10	3 0	40	250	288	217	1 26	14	21 00 - 9 00
22-23	FSW	20	9 2	7 3	0	10	3 1	40	48	51	45	1 11	13	9 00 - 9 00
23-24	FSW	20	10 2	7 4	-	10	3 3	32	21	22	20	1 10	13	9 00 - 9 00
24-25	FSW	20	9 8	6 7	0	10	3 0	33	26	28	24	1 16	13	9 00 - 9 00
25-26	FSW	20	9 8	6 8	0	10	3 2	36	27	30	24	1 21	13	9 00 - 9 00
27-28	FSW	20	11 4	7 9	0	10	3 3	35	165	169	160	1 03	11	9 00 - 9 00

' $S = (ET_{84}/ET_{50} + ET_{50}/ET_{16})/2$ (Litchfield, 1949)

TABLE V-3 MST'S FOR 24-HOUR COMPOSITE SAMPLES OF TWO-STAGE EFFLUENT COLLECTED BETWEEN FEBRUARY 20 AND MARCH 28

DATE	WOOD SPECIES	VOL. (l)	D.O. (mg/l)	pH	Cl. (mg/l)	NO. OF FISH	LENGTH (cm)	WEIGHT (g)	MST (MIN)	95% CONFIDENCE LIMITS		S	TEMP (°C)	SAMPLE TIME
										UPPER	LOWER			
FEBRUARY														
20-21	DHW	10	12 4	7.6	-	5	3.2	32	1350	1674	1088	1.28	15	09.00 - 21.00
22-23	FSW	20	10 9	7.6	0	5	-	-	200	244	164	1.25	15	09 00 - 09 00
23-24	FSW	20	-	7.5	-	4	-	-	540	772	378	1 44	15	09 00 - 09 00
24-25	FSW	20	11.0	7 2	0	5	-	-	1000	1240	807	1.28	14	09 00 - 09 00
25-26	FSW	20	8 9	7 2	0	10	-	-	900	1188	682	1.57	14	09 00 - 09 00
27-28	FSW	10	9.3	7 3	0	10	3 5	56	3400	60% Mort. Only			14	20.00 - 08 00
28-	DHW	20	7.5	7 4	0	10	-	-	No Mortality in 5,760 Min				16	09 00 - 09 00
MARCH														
01-02	DHW	20	8.9	7.9	0	10	-	-	No Mortality in 5,760 Min.					09 00 - 09 00
02-03	DHW	20	10.0	7.2	0	10	-	-	10% Mortality in 3,590 Min					09 00 - 09 00
03-04	DHW	20	9.4	7.8	0	10	3 9	73	20% Mortality in 2,000 Min.					09 00 - 09 00
04-05	DHW	20	10.6	8.2	0	10	2.6	.25	198	215	182	1.14	17	09 00 - 09.00
05-06	DHW	20	9 0	7.7	0	10	2.5	20	93	107	81	1.26	17	09.00 - 09 00
06-07	FSW	20	10.8	6.5	0	10	2.4	18	92	103	82	1.20	15	09 00 - 09 00
07-08	FSW	20	11.0	6.8	0	10	2.3	.18	102	117	89	1 25	14	09 00 - 09.00
08-09	FSW	20												
09-10	FSW	20												
10-11	FSW	20	10.0	6 8	0	10	2.2	.20	125	135	116	1 14	14	09 00 - 09.00
11-12	FSW	20	11.8	7.4	0	10	2 6	.13	260	285	237	1 16	14	09 00 - 09 00
12-13	FSW	10	11.6	7.5	0	10	-	-	1900	-	-	-	14	09 00 - 21 00
13-14	FSW	20	8.5	7.3	0	10	2.5	14	170	216	134	1.47	15	09 00 - 09 00
14-15	FSW	20	9 2	7 7	0	10	2.5	15	94	104	85	1.18	14	09 00 - 09 00
15-16	FSW	20	9.2	7 3	0	10	2.5	.15	500	685	365	1 66	14	09 00 - 21 00
16-17	DHW	10	11.6	7.9	0	5	2.5	.15	900	1053	770	1.19	14	09 00 - 09 00
17-18	DHW	10	7 6	7.3	0	5	-	-	No Mortality in 5,760 Min			-	15	09 00 - 09 00
18-19	DHW	20	7.4	7 1	0	10	2 5	15	1700	-	-	-	14	09.00 - 09 00
19-20	DHW	20	10.0	7.5	0	10	2.5	15	2150	2760	1674	1 51	14	09 00 - 09.00
20-21	FSW	20	9.0	7.0	0	10	2.5	16	696	769	619	1 19	15	09 00 - 09.00
21-22	FSW	10	9.6	7.4	0	10	2.8	.20	400	480	333	1.34	14	21 00 - 09 00
22-23	FSW	20	9.2	7 2	0	10	2.8	.20	2550	3266	1990	1.50	13	09 00 - 21 00
23-24	FSW	20	7.5	7.5	0	10	2.9	.25	78	83	74	1.10	13	09 00 - 09 00
24-25	FSW	20	8.6	7 3	0	10	3.0	26	220	402	120	2.67	13	09 00 - 09 00
25-26	FSW	20	10.0	7.3	0	10	3.0	26	2350	-	-	-	13	09 00 - 09 00
26-27														
27-28	FSW	20	8.4	7.2	0	10	3.0	.26	112	124	101	1 18	13	09.00 - 09 00

' S = $(ET_{84}/ET_{50} + ET_{50}/ET_{16})/2$ (Litchfield, 1949)

TABLE V-4 MST'S FOR 24-HOUR COMPOSITE SAMPLES OF SINGLE-STAGE EFFLUENT
COLLECTED BETWEEN FEBRUARY 20 AND MARCH 28

DATE	WOOD SPECIES	VOL. (l)	D.O. (mg/l)	pH	Cl. (mg/l)	NO. OF FISH	LENGTH (cm)	WEIGHT (g)	MST (MIN)	95% CONFIDENCE LIMITS UPPER	95% CONFIDENCE LIMITS LOWER	S*	TEMP. (°C)	SAMPLE TIME
FEBRUARY 20	FSW	10	13	8.2	-	5	3.3	0.41	200	276	145	1.44	15	09:00 - 21:00
22-23	FSW	20	10.4	7.6	0	5	3.3	0.41	175	Incomplete Mort.		-	15	09:00 - 09.00
23-24	FSW	20	-	7.5	-	5	-	0.70	530	743	379	1.47	15	09:00 - 09.00
24-25	FSW	20	10.6	7.2	0	5	-	-	1680	Incomplete Mort.		-	14	09:00 - 09.00
25-26	FSW	20	8.5	7.1	0	10	-	-	335	352	318	1.10	16	09:00 - 09.00
26-27	FSW	20	8.5	7.1	0	10	-	-	360	462	280	1.29	16	09·00 - 09:00
27-28	FSW	10	9.3	7.2	0	10	4.1	.86	135	187	101	1.34	14	20:00 - 08.00
28-MAR.1	DHW	20	9.2	7.6	0.4	10	-	-	No Mortality in 5,760 Min.			-	14	09:00 - 09:00
01-02	DHW	20	9.7	7.7	1.64	10	2.9	.28	No Mortality in 5,760 Min.			-	14	09.00 - 09:00
02-03	DHW	20	10.4	7.8	2.2	10	3.5	.35	1230	-	-	-	14	09:00 - 09:00
03-04	DHW	20	10.8	7.8	0.6	10	-	-	No Mortality in 5,760 Min.				14	09·00 - 09.00
04-05	DHW	20	11.4	8.1	1.8	10	2.5	.23	169	206	139	1.39	16	09.00 - 09 00
05-06	DHW	20	10.4	7.8	6.36	10	2.7	.16	76	85	68	1.20	16	09.00 - 09:00
06-07	FSW	20	10.4	6.2	0	10	2.5	.14	115	155	85	1.35	15	09:00 - 09:00
07-08	FSW	20	11.6	6.0	0	10	2.9	.18	36	40	33	1.16	14	09:00 - 09.00
11-12	FSW	10	11.4	7.8	0	10	2.6	.16	380	498	290	1.55	14	21.00 - 09:00
12-13	FSW	20	12.6	7.6	0	10	2.6	.16	1700	2295	1259	1.64	13	09:00 - 09·00
13-14	FSW	20	10.4	7.3	0	10	2.9	.19	255	295	221	1.32	15	09.00 - 09:00
14-15	FSW	20	10.6	7.7	0	10	2.7	.18	237	275	204	1.27	14	09:00 - 09·00
15-16	FSW	20	9.6	7.4	0	10	2.9	.20	125	133	117	1.11	14	09:00 - 09.00
16	DHW	10	11.6	7.8	0	5	-	-	115	-	-	-	14	08.00 - 21:00
17-18	DHW	10	8.0	7.2	0	5	-	-	360	-	-	-	15	21 00 - 09:00
18-19	DHW	20	8.2	7.3	1.4	10	-	-	570	895	363	2.10	14	09:00 - 09:00
19-20	DHW	20	10.0	7.7	0	10	2.9	.26	190	225	160	1.32	14	09:00 - 09:00
20-21	FSW	20	9.0	7.2	0	10	2.9	.26	245	268	224	1 16	15	09:00 - 09:00
21-22	FSW	10	9.4	7.2	0	10	-	-	550	-	-	-		21:00 - 09:00
22-23	FSW	20	9.4	7.3	0	10	-	-	350	462	224	1.56	13	09:00 - 09.00
23-24	FSW	20	11.0	7.1	0	10	-	-	220	244	199	1.18	13	09:00 - 09:00
25-26	FSW	20	8.4	7.2	0	10	-	-	127	135	120	1 10	13	09:00 - 09:00
27-28	FSW	20	12.0	7.2	0	10	-	-	840	1293	546	2.02	11	09:00 - 09:00

* $S = (ET_{84}/ET_{50} + ET_{50}/ET_{16})/2$ (Litchfield, 1949)

APPENDIX VI

VARIATIONS IN MEDIAN SURVIVAL TIMES DURING 24-HOUR SAMPLING PERIODS

APPENDIX VI

VARIATIONS IN MEDIAN SURVIVAL TIMES DURING 24-HOUR SAMPLING PERIODS

TABLE VI-1 VARIATIONS IN MST'S FOR 1-HOUR COMPOSITE SAMPLES COLLECTED NOVEMBER 7-8

DATE	TREATMENT	VOL. (1)	D.O. (mg/1)	pH	NO. OF FISH	LENGTH (cm)	WEIGHT (g)	MST (MIN)	95% CONFIDENCE LIMITS		S*	TEMP. (°C)	SAMPLE TIME
									UPPER	LOWER			
NOVEMBER													
7	U	20	7.9	7.4	6	9.9	9.7	62	72	53	1.13	10	14:00 - 15:00
7	U	20	8.4	7.0	6	9.9	9.7	52	55	49	1.08	9	15:00 - 16.00
7	U	20	8.1	6.8	6	9.4	8.6	47	48	45	1.04	10	16:00 - 17:00
7	U	18	7.6	6.9	6	9.0	8	51	54	48	1.08	9	17:00 - 18.00
7	U	18	7.6	6.9	6	9.3	9.7	54	58	50	1.10	9.5	18:00 - 19:00
7	U	18	8.2	6.9	4	9.4	9.5	54	58	50	1.10	9.0	19.00 - 20:00
7	U	18	7.9	7.6	4	9.4	9.2	47	49	45	1.05	9.0	20:00 - 21.00
7	U	18	8.4	7.0	4	8.1	6.5	61	68	54	1.11	8.5	21.00 - 22:00
7	U	18	8.3	7.3	4	10.6	11.5	50	54	46	1.08	9.0	23:00 - 24:00
7	U	9	8.5	7.5	4	8.4	5.9	58	62	55	1.06	9.5	00:00 - 01:00
7	U	9	8.2	8.0	4	9.5	10.1	97	136	69	1.40	9.5	01:00 - 02:00
8	U	18	8.3	7.0	4	8.4	6.1	67	94	48	1.40	8.5	02:00 - 03.00
8	U	9	9.4	7.6	4	8.4	6.2	105	112	97	1.07	9.0	03·00 - 04:00
8	U	9	8.1	7.4	4	9.0	8.2	63	85	47	1.35	9.5	04:00 - 05:00
8	U	20	7.7	7.6	4	8.1	5.8	35	40	31	1.14	9.5	05:00 - 06:00
8	U	18	7.5	8.0	4	7.5	7.0	42	44	40	1.05	9.0	07:00 - 08:00
8	U	18	8.4	7.4	4	8.4	5.8	48	54	42	1.14	9.5	08:30 - 09.30
8	U	18	7.4	-	4	8.9	7.8	27	34	22	1.26	9.5	09:30 - 10:30
8	U	18	7.4	-	4	9.2	8.9	16	23	12	1.41	9.5	10·30 - 11:30
8	U	18	9.2	-	4	9.0	9.4	70	78	62	1.11	9.5	11.30 - 12:30
8	U	18	7.5	-	4	9.0	7.6	34	36	32	1.06	9.5	12:30 - 13:30
8	U	18	7.2	7.8	4	-	-	65	69	61	1.07	10.5	13:30 - 14:30
7	T-S	18	9.0	7.5	6	-	-	116	-	-	-	-	21:30 - 22:30
8	T-S	18	6.8	6.6	6	-	-	310	390	246	1.33	-	03:00 - 04:00

- WOOD SPECIES - FSW

* $S = (ET_{84}/ET_{50} + ET_{50}/ET_{16})/2$ (Litchfield, 1949)

TABLE VI-2 VARIATIONS IN MST'S FOR 1-HOUR COMPOSITE SAMPLES COLLECTED DECEMBER 15-16

DATE	TREATMENT	VOLUME (l)	D.O. (mg/l)	pH	MST (MIN)	95% CONFIDENCE LIMITS		S'	SAMPLE TIME
						UPPER	LOWER		
DECEMBER									
15	U	20	7.9	7.0	570	684	475	1.25	12 00 - 13 00
15	U	20	8.2	8.2	430	525	352	1 29	13 00 - 14:00
15	U	20	9.1	7.4	350	490	250	1.52	14 30 - 15 30
15	U	20	8.6	7 5	410	569	295	1.50	16 00 - 17 00
15	U	20	7.6	7.5	350	469	261	1.44	17 00 - 18 00
15	U	20	8.0	7.2	250	285	219	1 18	23 00 - 24 00
16	U	20	7 8	7.2	310	350	274	1.17	00.00 - 01 00
16	U	20	8.0	7.2	180	209	155	1 21	01 00 - 02 00
16	U	20	8.4	7.2	200	230	174	1 18	02 00 - 03·00
16	U	20	9 2	7 5	160	186	138	1 20	03.00 - 04 00
16	U	20	-	-	470	749	278	1.93	05 00 - 06:00
16	U	20	8 9	7.4	310	400	240	1.36	06.00 - 07 00
16	U	20	-	-	210	225	196	1 08	09:00 - 11 00
16	U	20	-	-	400	444	360	1.13	11.00 - 12:00
16	U	20	-	-	210	227	194	1.10	12 00 - 13.00
16	U	20	-	-	205	242	174	1.23	13 00 - 14.00
16	U	20	-	-	160	200	128	1.32	16·00 - 17.00
DECEMBER									
15	T-S	18	-	-	-	-	-	-	20 00 - 21 00
15	T-S	18	8.7	7.2	440	576	336	1.40	21 00 - 22 00
15	T-S	18	7.8	7 6	340	476	243	1.51	22 00 - 23 00
15	T-S	18	7.8	7.0	180	198	164	1.14	23 00 - 24:00
16	T-S	18	8.2	7.1	320	416	246	1 39	00 00 - 01·00
16	T-S	18	-	-	200	290	138	1.60	01 00 - 02:00
16	T-S	18	9.2	7.8	200	-	-	-	02 00 - 03 00
16	T-S	18	-	-	270	-	-	-	05 00 - 06.00
16	T-S	20	-	-	400	-	-	-	06 00 - 07 00
16	T-S	20	8.0	-	540	702	415	1.39	07:00 - 08 00
16	T-S	20	-	-	780	1146	531	1.63	09 30 - 11:00
16	T-S	20	-	-	230	280	189	1 29	11.30 - 12 00
16	T-S	20	-	-	500	740	337	1.65	12 00 - 13.00
16	T-S	20	-	-	·470	557	397	1 24	13 00 - 14 00
16	T-S	20	-	-	500	710	352	1.56	15:00 - 16 00
16	T-S	20	-	-	1100	1441	840	1 41	16:00 - 17.00
16	T-S	20	-	-	960	1248	739	1.40	17 00 - 18.00

Wood Species - DHW

Average Fish Length, 10.8 cm

Average Fish Weight, 13.4 g

Number of Test Fish, 6

Test Conducted at 15oC

* $S = (ET_{84}/ET_{50} + ET_{50}/ET_{16})/2$ (Litchfield, 1949)

TABLE VI-3 VARIATIONS IN MST'S FOR 2-HOUR COMPOSITE SAMPLES COLLECTED MARCH 24-25

DATE	TREATMENT	D.O. (mg/l)	pH	Cl. (mg/l)	LENGTH (cm)	WEIGHT (g)	MST (Min)	95% CONFIDENCE LIMITS		S*	TEMP (°C)	SAMPLE TIME
								Upper	Lower			
MARCH												
24	U	9.8	7.3	-	3 1	35	82	86	78	1.07	14	10 00 - 12 00
24	U	8.4	7 0	-	3 1	31	21	22	20	1.10	13	12 00 - 14 00
24	U	7.0	7.3	0	3 0	29	21	22	20	1.10	13	14 00 - 16.00
24	U	8.0	7.3	-	3.1	26	42	45	40	1 10	15	16.00 - 18 00
24	U	8.0	7.4	-	2.9	.27	62	69	56	1.19	13	18 00 - 20 00
24	U	7.5	7.1	-	2 8	26	52	53	51	1.04	-	20 00 - 22·00
24	U	7.0	7.1	-	2.8	26	82	95	70 7	1.27	13	22 00 - 24 00
25	U	8.2	7.6	-	2.8	26	450	482	421	1.12	13	24 00 - 02 00
25	U	10.0	7.2	-	2 8	26	115	144	92	1.44	13	02 00 - 04 00
25	U	8.7	7.5	-	-	-	96	119	77	1 42	13	04.00 - 06 00
25	U	8.9	7.4	-	-	-	55	62	49	1.22	14	08 00 - 10 00
24	S-S	10.4	7.3	0	-	-	No Mortality at 4,170 Min.			-	14	09 00 - 11 00
24	S-S	10 0	7 4	-	-	-	4000	Incomplete Mortality			14	10 00 - 12 00
24	S-S	8.2	7 5	-	-	-	No Mortality at 7,500 Min.				13	12 00 - 14 00
24	S-S	8.2	7.2	0	-	-	385	445	333	1.26	13	14 00 - 16 00
24	S-S	8.0	7.3	-	-	-	485	635	370	1.55	13	16 00 - 18 00
24	S-S	8.0	7.3	-	-	-	235	294	188	1.95	14	18 00 - 20 00
24	S-S	8.0	7.4	-	-	-	40	44	37	1 16	13	20 00 - 22 00
24	S-S	7.0	7.1	-	-	-	68	74	62	1.15	13	22 00 - 24 00
25	S-S	8.0	7.5	-	-	-	105	130	85	1.42	13	24 00 - 02 00
25	S-S	8.2	7.5	-	-	-	30% Mortality at 6,030 Min				13	02 00 - 04 00
25	S-S	8 7	7.3	-	-	-	630	1197	332	2.93	13	04.00 - 06 00
25	S-S	8.4	7 1	-	-	-	72	84	63	1.27	12	08.00 - 10 00
24	T-S	9.2	7.6	0	3 1	.35	5000	Incomplete Mortality			14	09 00 - 11 00
24	T-S	8.2	7.2	0	3 2	.35	1600	Incomplete Mortality			14	10.00 - 12 00
24	T-S	7 6	7.3	0	3.5	.35	1220	1342	1109	1.17	13	12.00 - 14.00
24	T-S	8 2	7.2	0	-	-	680	714	648	1.09	13	14.00 - 16 00
24	T-S	8.0	7.3	-	2.9	33	99	121	81	1.39	13	16 00 - 18 00
24	T-S	8.3	7.4	-	2 9	32	375	465	302	1.41	13	18 00 - 20 00
24	T-S	7.0	7.3	-	-	-	1500	-	-	-	13	20 00 - 22 00
24	T-S	7.5	7 4	-	2 8	.33	405	466	352	1.25	13	22 00 - 24 00
25	T-S	7 0	7.4	-	-	-	210	271	163	1 53	13	24 00 - 12 00
25	T-S	7 2	7.3	-	-	-	730	1036	514	1.76	13	02 00 - 04 00
25	T-S		7.4	-	-	-	690	925	515	1 61	13	04 00 - 06 00
25	T-S	8.0	7.4	-	-	-	900	1233	657	1 67	12	08 00 - 10 00

Wood Species - FSW   Number of Test Fish - 10   Volume of Effluent - 20 l

* $S = (ET_{84}/ET_{50} + ET_{50}/ET_{16})/2$ (Litchfield, 1949)

APPENDIX VII

TOXICITY CURVES FOR CONTINUOUS FLOW BIOASSAYS

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TOXICITY CURVES FOR CONTINUOUS FLOW BIOASSAYS

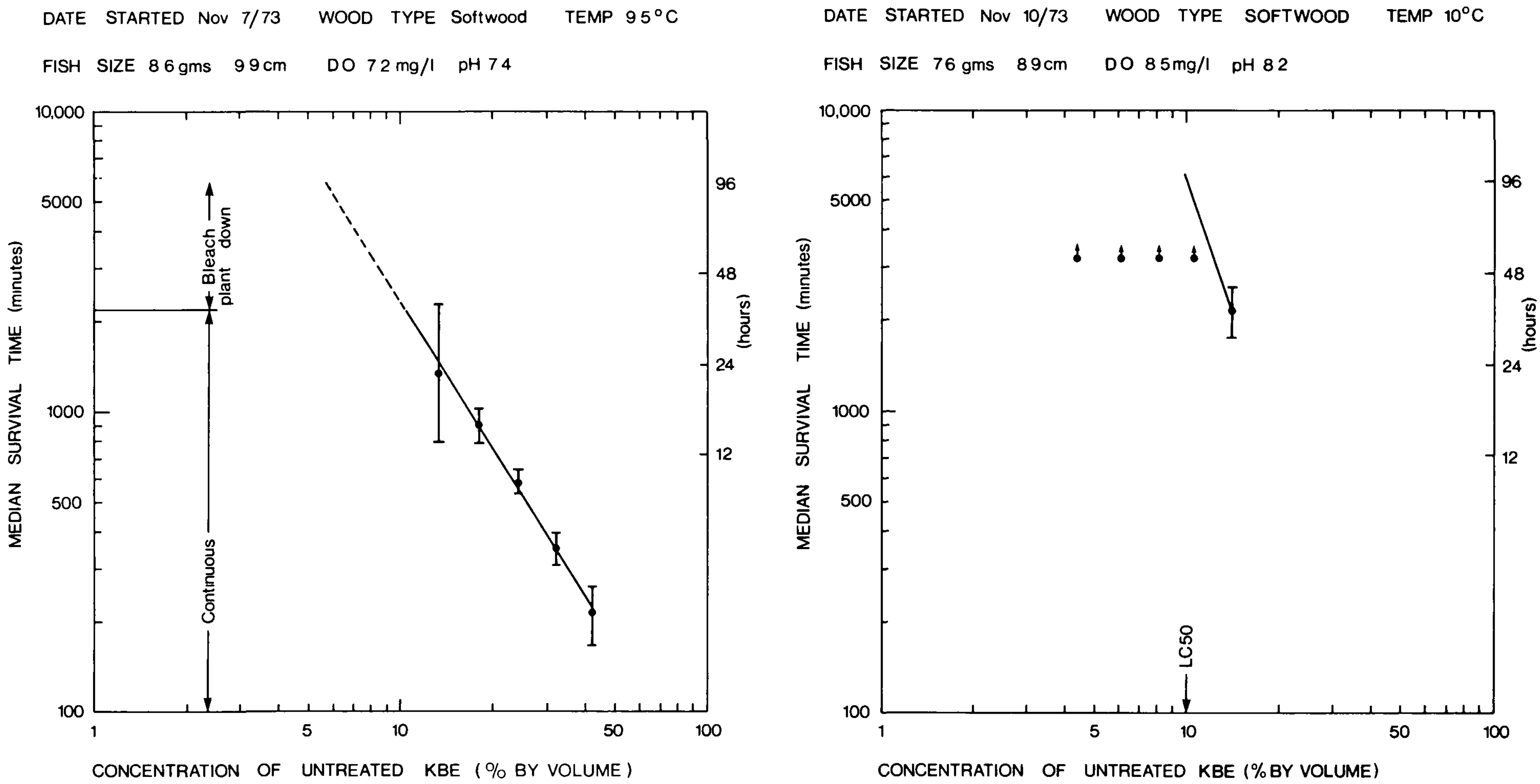

FIGURE VII-1. TOXICITY CURVES FOR CONTINUOUS FLOW BIOASSAYS INITIATED ON NOV 7 & 10, 1973

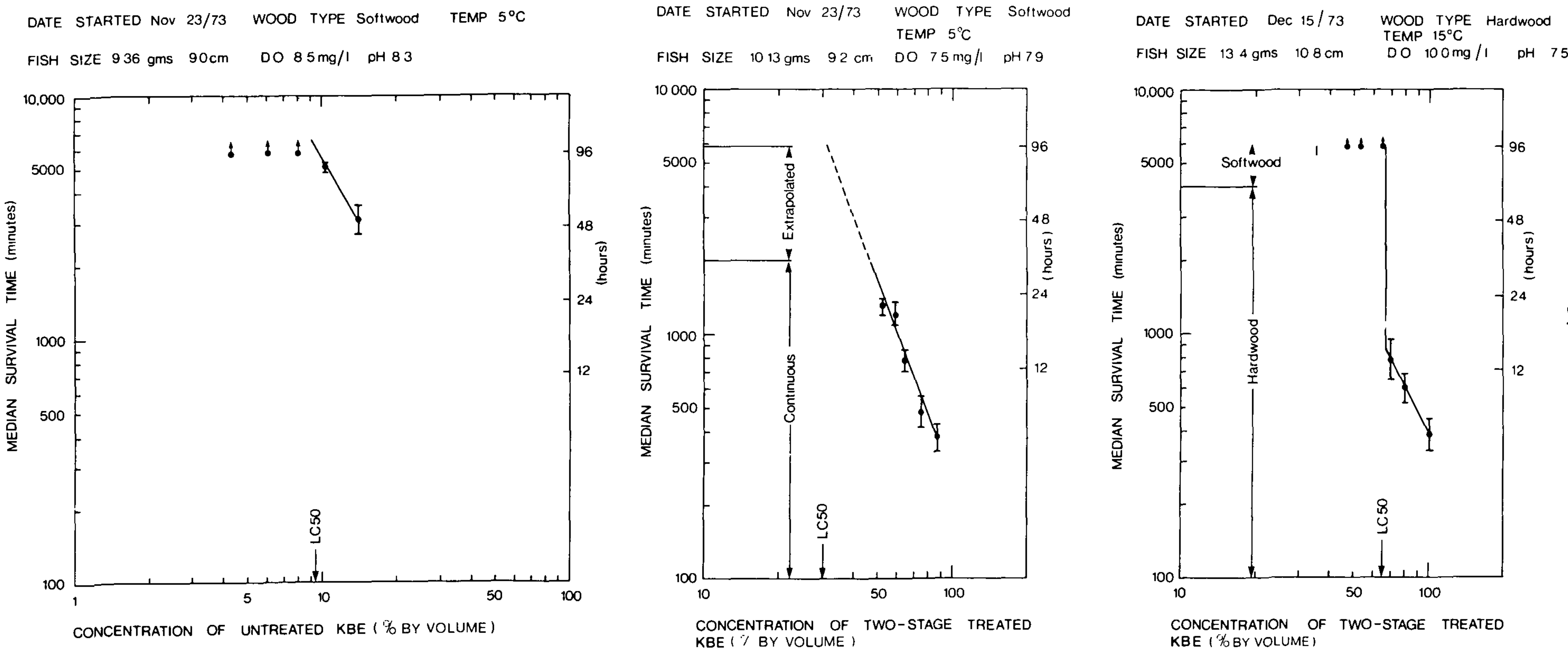

FIGURE VII-2 TOXICITY CURVES FOR CONTINUOUS FLOW BIOASSAYS INITIATED ON NOV 23, AND DEC 15, 1973

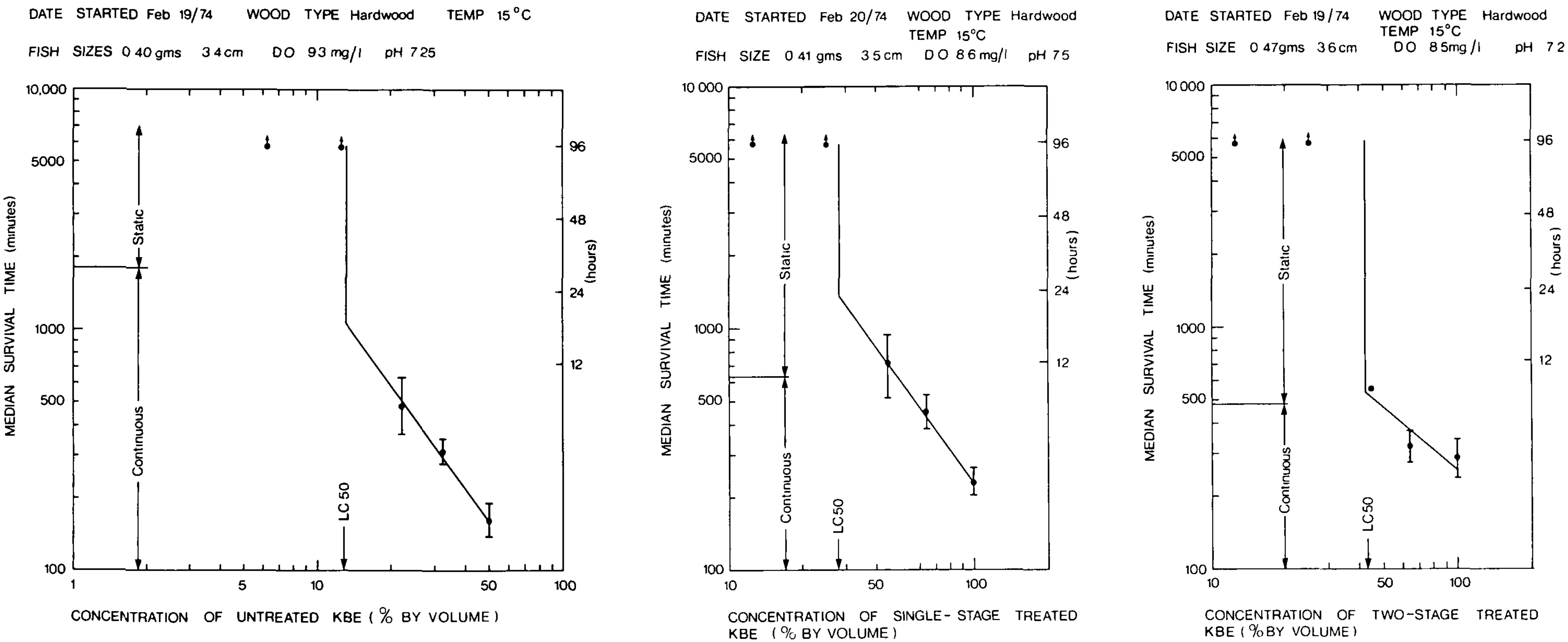

FIGURE VII-3 TOXICITY CURVES FOR CONTINUOUS FLOW BIOASSAYS INITIATED ON FEB 19 & 20, 1974

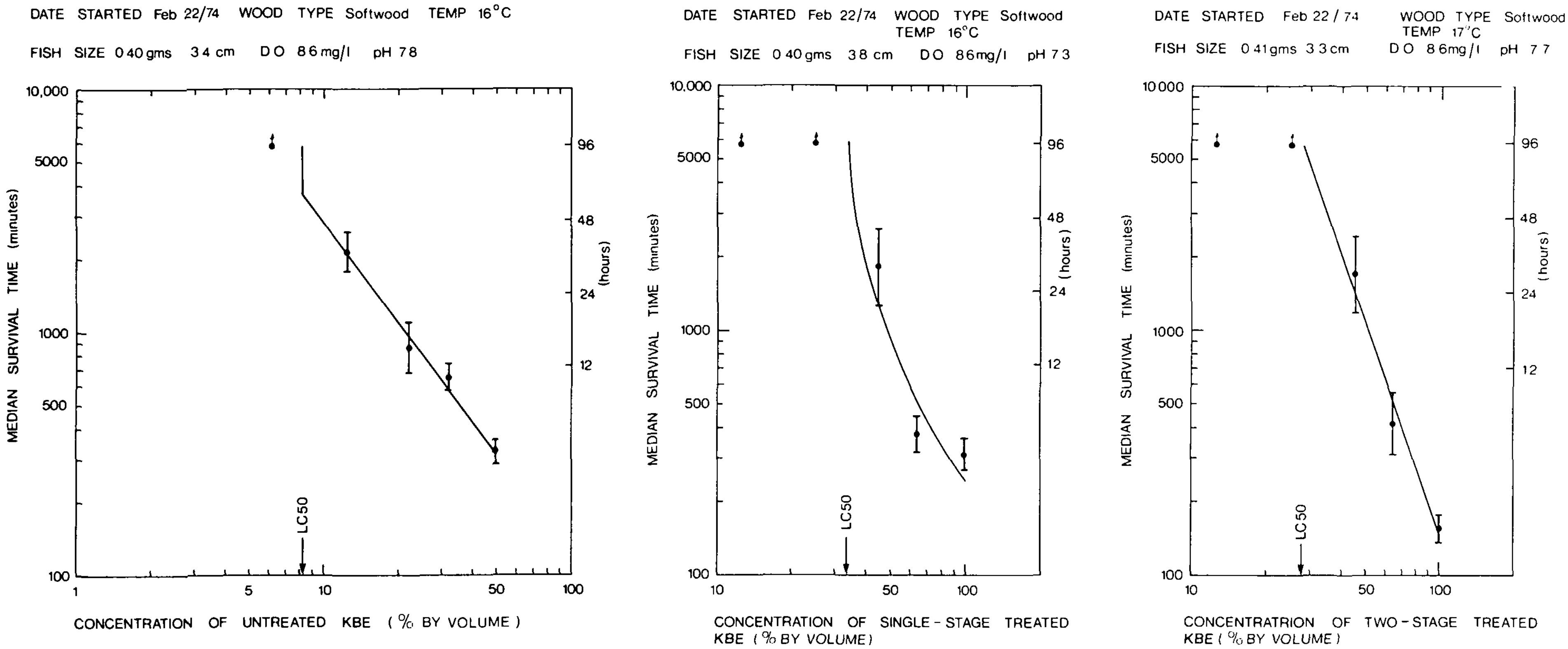

FIGURE VII-4 TOXICITY CURVES FOR CONTINUOUS FLOW BIOASSAYS INITIATED ON FEBRUARY 22, 1974

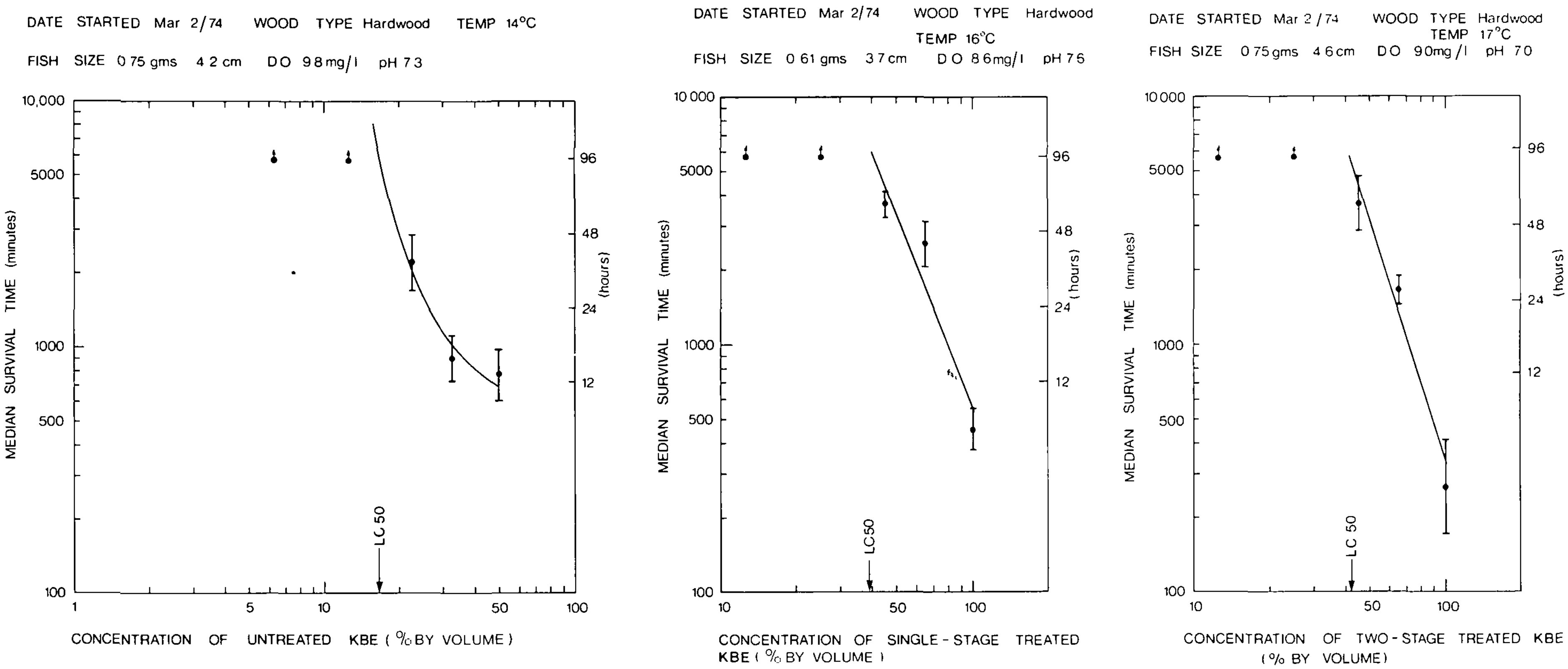

FIGURE VII-5 TOXICITY CURVES FOR CONTINUOUS FLOW BIOASSAYS INITIATED ON MARCH 2,1974

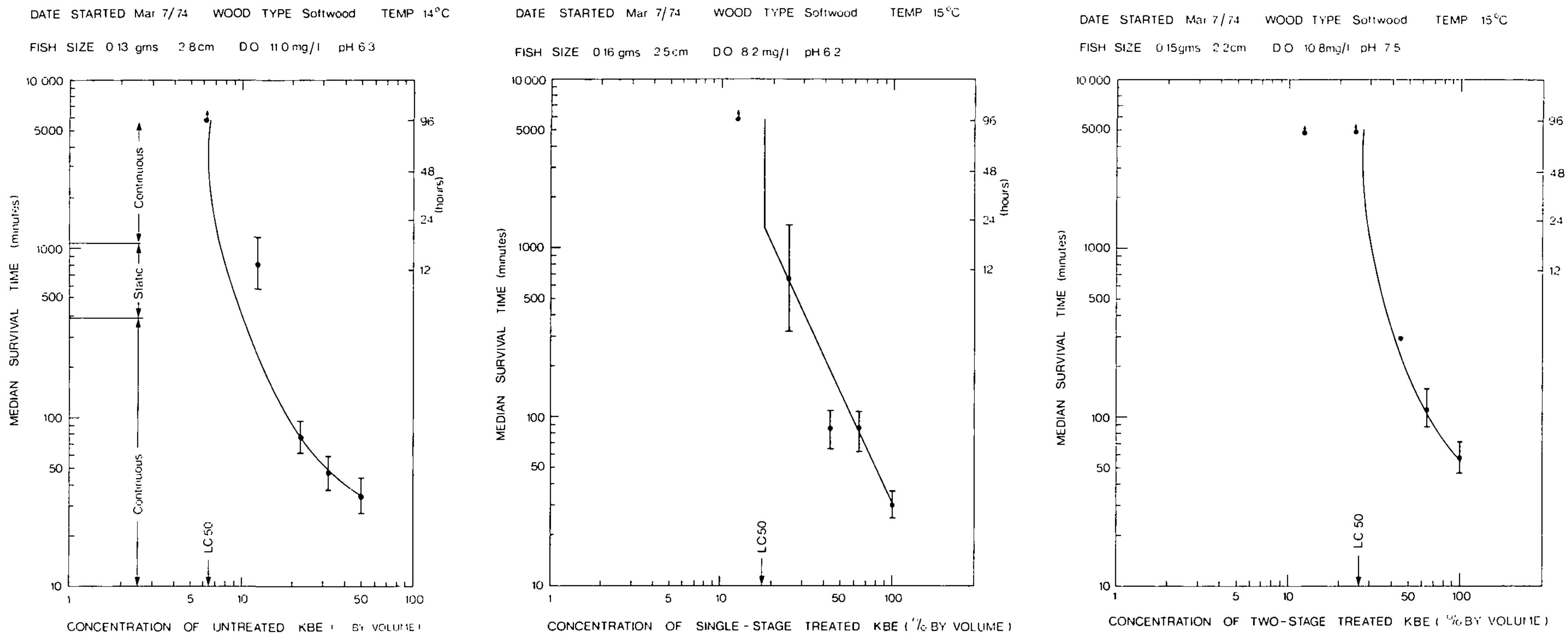

FIGURE VII-6 TOXICITY CURVES FOR CONTINUOUS FLOW BIOASSAYS INITIATED ON MARCH 7, 1974

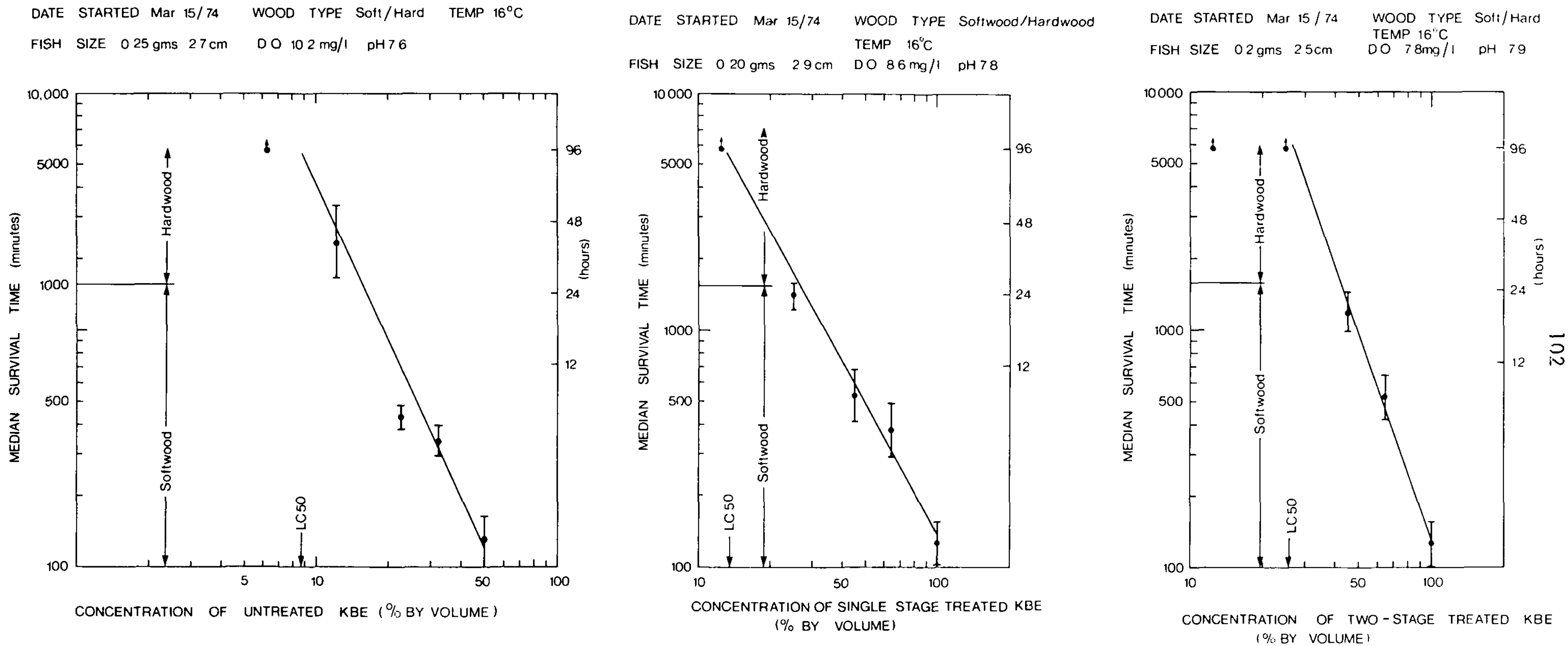

FIGURE VII -7 TOXICITY CURVES FOR CONTINUOUS FLOW BIOASSAYS INITIATED ON MARCH 15, 1974

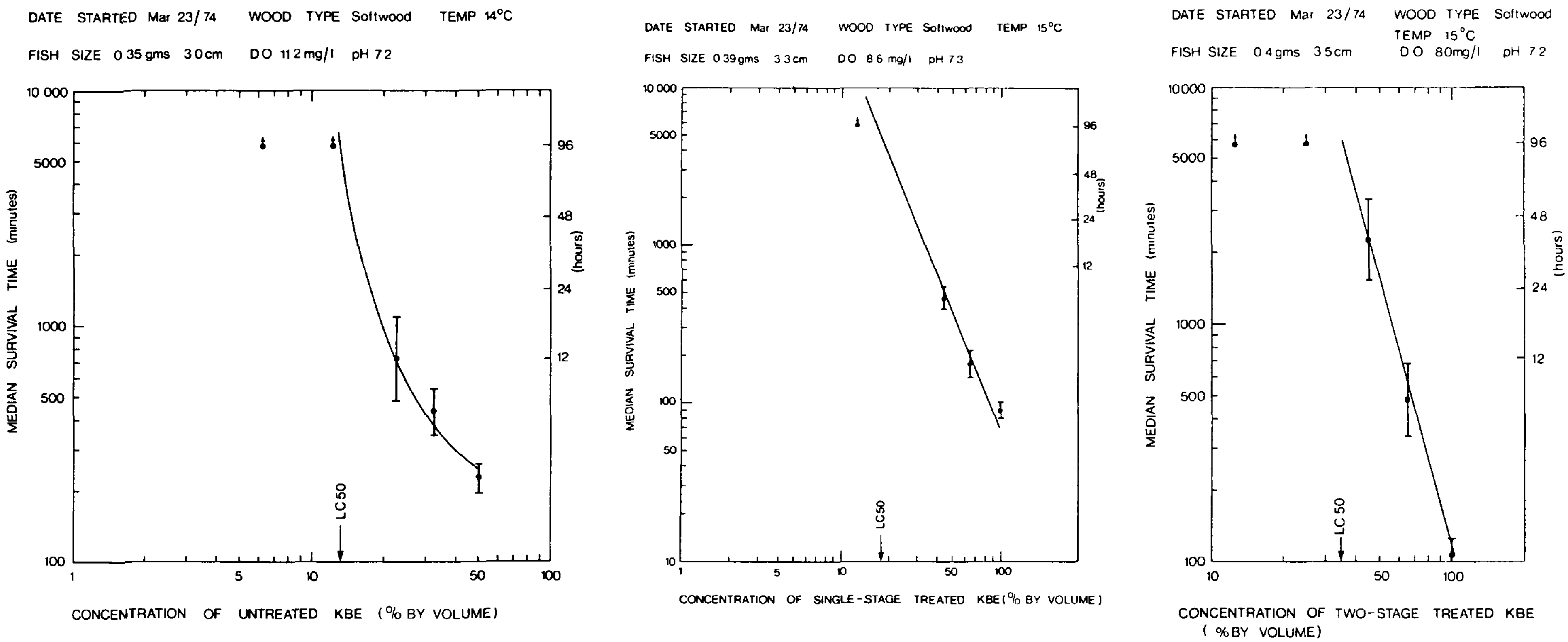

FIGURE VII-8 TOXICITY CURVES FOR CONTINUOUS FLOW BIOASSAYS INITIATED ON MARCH 23, 1974

APPENDIX VIII

DEWATERABILITY AND FILTERABILITY OF SLUDGES

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DEWATERABILITY AND FILTERABILITY OF SLUDGES

A major factor in the evaluation of activated sludge systems is the handling and disposal of excess or waste sludge. In the activated sludge treatment of pulp and paper mill effluents, waste sludges have been characterized as difficult to dewater and of a hydrous or gelatinous nature (Edde, 1968 and Caron, 1968). A study of the dewaterability and filterability of the sludge produced during this operation was not considered within the scope of the project, at this time. However, preliminary testing was conducted to evaluate parameters such as specific resistance and, if possible, filter loadings.

Using return sludge from the first stage clarifier of the two-stage unit, Buchner funnel tests were conducted according to procedures outlined in Eckenfelder and Ford (1970) and WPCF Manual of Practice No. 20. Initial sludge concentrations ranged from 5,000 to 18,000 mg/l. Specific resistance values varied between 2.8×10^8 and 9.1×10^8 sec^2/gram at a pressure of 63.5 cm of mercury.

A second series of tests involved the addition of $FeCl_3$ up to 10% by weight to the return sludge. Specific resistance values were found to decrease from 11.67×10^7 sec^2/gram with no chemical addition to 3.67×10^7 sec^2/gram with 10% $FeCl_3$ addition. Initial sludge concentration was 11,000 mg/l. These specific resistance values are slightly lower than those normally reported for domestic waste activated sludge which range near 3×10^{10} sec^2/gram.

An experiment was conducted to determine the filterability of this sludge. Sludge concentration was 10,000 mg/l and $FeCl_3$ was added to 10% by weight. The procedure outlined in Eckenfelder and Ford (1970) was followed using a standard filter-leaf apparatus. Filter loadings or rates were found to vary from 2.4 to 4.4 $kg/m^2 \cdot hr$ (0.5 to 0.9 $lb/ft^2 \cdot hr$) for form times ranging from 0.5 to 2.5 minutes, dry times from 0.5 to 2.5 minutes and a vacuum of 51 cm of mercury. Cake thicknesses were, at the most, 0.3 cm. These filtration rates show the futility of attempting to dewater this sludge by vacuum filtration, even using a substantial coagulant dose. The sludge was too thin and of such a gelatinous nature that it could not easily be dewatered.

Since the return sludge used in the dewatering tests had a consistency ranging from 1.0% to 1.8%, consideration was given to the problem of settleability or thickening of the sludge. Unfortunately, no apparatus was available to carry out the thickening test and so only gravity settling was measured. An activated sludge sample with a concentration of 5670 mg/l and a return sludge with a concentration of 14,350 mg/l, were used for these tests. Each sample was placed in a one-litre graduate cylinder and measurements of interface height with time were made. The results of these two tests are shown graphically in Figure VIII-1.

The settlement of the return sludge is slow, resulting in a compaction of only 70% after four hours. This result indicates that gravity thickening, yielding an underflow concentration of approximately 20,000 mg/l or 2% after four hours, is not really advantageous. Slow stirring of the sludge may result in a higher compressibility for the return sludge.

The settleability of the activated sludge produced a classical-type settling curve. After four hours, the sludge had compressed to about 30%, achieving an underflow concentration in excess of 1.8% from an initial concentration of 5670 mg/l.

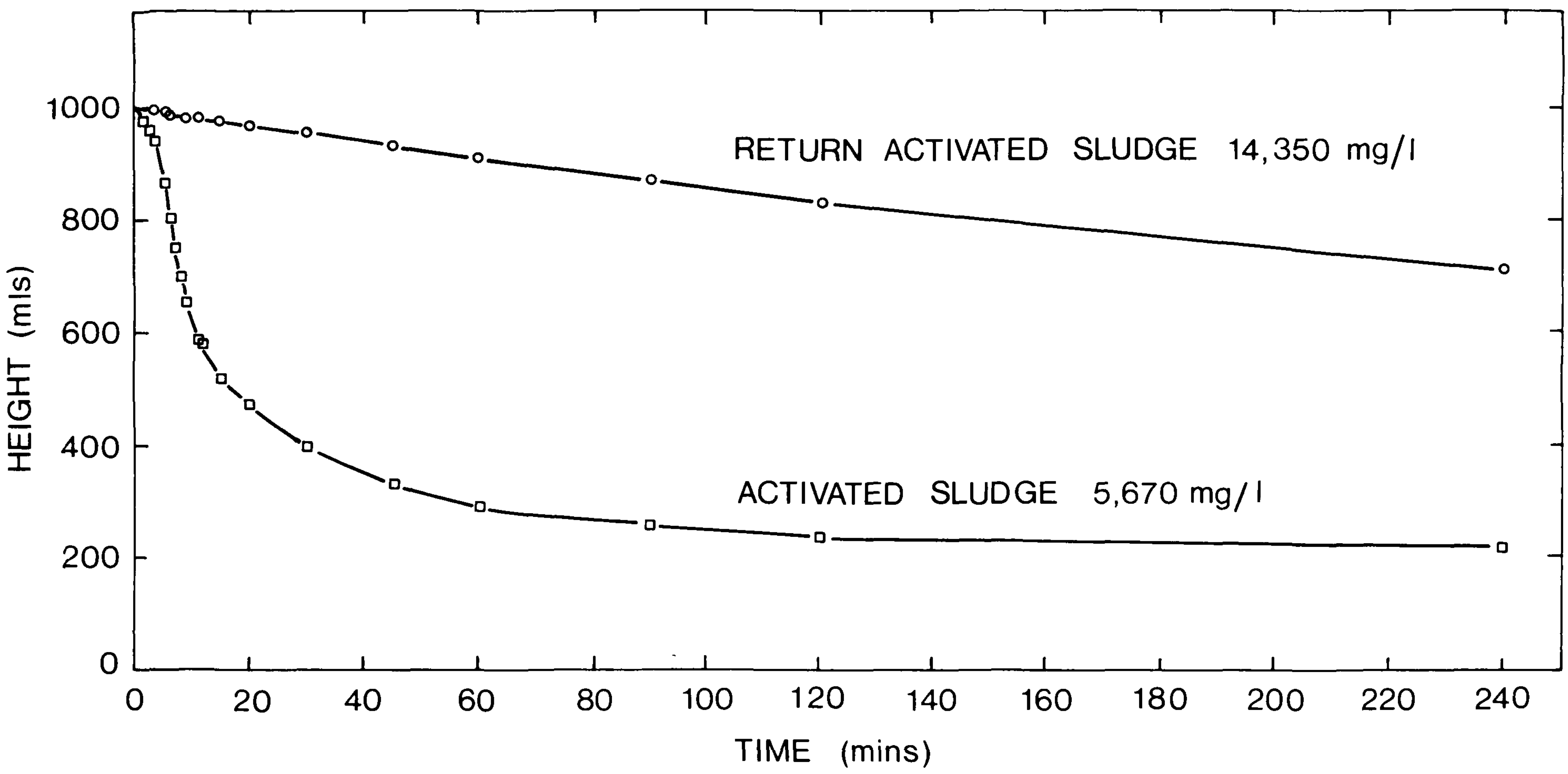

FIG. VIII-1 SETTLING CURVES FOR ACTIVATED SLUDGE

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