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ANAEROBIC TREATMENT OF KRAFT MILL BLEACH PLANT WASTEWATERS:

PROGRESS REPORT

WTC-BIO-05-1988

REVIEW NOTICE

ANAEROBIC TREATMENT OF KRAFT MILL BLEACH PLANT WASTEWATERS: PROGRESS REPORT

A Report By

Environment Canada
Conservation and Protection
Wastewater Technology Centre

September 1988

Report WTC-BIO-05-1988

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Environment Canada
Wastewater Technology Centre
Burlington, Ontario, Canada

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1 BACKGROUND

Between 1969 and 1980, expenditures by the Canadian pulp and paper industry for pollution abatement amounted to about C$ 661 million (1). As a result of these measures, in 1980, 72% of Canadian production was in compliance with federal regulations governing the discharge of BOD (biochemical oxygen demand) in liquid effluents. However, at the same time, only 25% of Canadian mills were in compliance with the federal toxicity requirement. There has been considerable change in the Canadian pulp and paper industry over the last one or two decades to improve the compliance status of Canadian mills. These changes have involved the installation of ex-plant wastewater treatment facilities as well as the improvement of manufacturing practices to reduce the quantity and frequency of discharges from pulping operations (2)

In the kraft pulping sector, the recovery of cooking chemical from black liquor greatly reduces the potential loading of organic material from pulping operations. However, the condensates produced in kraft thermal recovery plants can represent a significant residual source of pollution. Pulp washing also generates a high BOD effluent that is usually sewered. Perhaps the most problematic wastewaters originating in kraft mills are the effluents from bleaching operations. These streams are often of relatively high organic concentration, and are known to contain high levels of colour and toxicity (2,3). Recently, several new approaches to pulp bleaching have been developed to reduce the BOD and toxicity loading associated with conventional chlorine bleaching (2).

As a whole, the Canadian pulp and paper industry has invested considerable resources to make in-plant changes and to construct ex-plant treatment facilities to meet the federal pulp and paper effluent regulations. In spite of this investment, the current levels of compliance are still not acceptable. In the kraft industry, many of the remaining BOD and toxicity problems are associated with high strength effluents from pulp washing, liquor recovery and bleaching. In order to improve upon current compliance levels in the Canadian pulp and paper industry, programs for the development and demonstration of treatment processes for high strength, toxic waste streams are required.

1.1 Anaerobic Treatment of Pulp and Paper Wastewaters

The requirement for cost-effective treatment of concentrated organic wastewaters leads logically to the consideration of anaerobic biological technology as a primary treatment option. Several advantages of anaerobic treatment over conventional aerobic treatment are summarized in Table 1. These advantages have already been recognized in many other countries where active anaerobic research and development programs for pulp and paper applications have been underway for some time (4). In a small number of cases, this development activity has resulted in the construction and start-up of full scale facilities which

incorporate anaerobic treatment technology. These advantages have also been recognized in Canada, where several pilot scale and full scale development projects are currently in progress (Table 2).

Table 1. Advantages of Anaerobic Treatment Technology

. Reduced Capital Cost for High Rate Anaerobic Treatment
. No Power Requirement for Aeration
. Reduced Biosludge Production
. Reduced Nutrient Requirements for Biological Treatment
. Fuel Grade Biogas Produced as Bioproduct
. Reductive Dehalogenation of Organochlorines

Table 2. Canadian Pilot and Full Scale Scale Studies, August, 1988.

1. STURGEON FALLS, ONTARIO (NSSC & Hardboard)
. Negotiations for full scale plant in progress
2. BATHURST, NEW BRUNSWICK (CTMP & NSSC)
. Full Scale UASB system under construction
3. ST. GEORGE, N.B. (NSSC)
. Full Scale UASB system under construction
4. MISSISSAUGA, ONTARIO
. UASB pilot study
5. KAPUSKASING, ONTARIO (TMP & Magnefite)
. Hybrid reactor pilot study
6. QUESNEL RIVER, B.C. (CTMP & TMP)
. Full scale UASB under construction
7. PORT ALICE, B.C. (Bleached Sulfite)
. Hybrid reactor pilot study under development

1.2 Status of Research

Research and demonstration work carried out in Canada and other countries has confirmed the potential for anaerobic treatment of pulp and paper wastewaters. However, considerable additional information is required to insure that further Canadian development activities will result in cost-effective treatment technology that can significantly increase the effluent compliance status of pulp and paper mills. Some of the major points to be considered are indicated below.

1. Data from laboratory screening studies confirms the potential of anaerobic treatment technology for a variety

of pulp and paper wastewaters, including many of those currently exceeding Canadian compliance levels.

2. Available data also indicate that anaerobic treatment may be associated with problematic phenomena such as inhibition of anaerobic microorganisms, sulfide production, precipitation or adsorption of organics under anaerobic conditions, and the presence of residual COD and toxic material.

3. Although a number of anaerobic pilot scale studies are in the planning or operational stages, the majority of the data available at the present time deal with wastewaters from semichemical and CTMP pulping. Studies of many of the other high strength and toxic effluents in the pulp and paper industry have not been undertaken.

4. Data on the chemical constituents, sources of toxicity, and treatability of high yield pulping effluents is very limited.

5. Almost no information is available on toxicity reduction or generation during anaerobic treatment. Limited experience from Scandinavia suggests an advantage for anaerobic detoxification of chlorination effluents.

6. The anaerobic treatability characteristics of non-conventional pulp bleaching effluents have not been determined. Innovative bleaching sequences may produce less toxic, more easily biodegradable wastewaters.

7. Although it is generally assumed that aerobic post-treatment will be required to produce non-toxic effluents, design data for integrated anaerobic-aerobic systems do not exist.

8. Information is not available to confirm that anaerobic + aerobic treatment is more cost-effective for high strength, toxic pulp and paper effluents than aerobic treatment alone.

2 OBJECTIVES

The overall goal of Environment Canada's anaerobic program is to develop and demonstrate technically-effective, least-cost treatment systems for the high strength wastewaters produced by existing and emerging pulp and paper manufacturing processes. To be considered technically satisfactory, these treatment approaches must result in compliance with federal and provincial effluent regulations for the pulp and paper industry. For wastewaters produced in kraft mill bleach plants the program objectives are:

1. To produce chemical characterization data on the

conventional and toxic constituents of wastewaters from kraft mills using different bleaching sequences, and to determine the toxicity of the wastewaters using a variety of bioassay procedures.

2. To compare the effluent characteristics and loadings from bleach plants utilizing conventional bleaching, to those from bleach plants which incorporate oxygen delignification, or substantial chlorine dioxide substitution.

3. Determine the ability of an anaerobic system to tolerate or adapt to the inhibitory characteristics of the selected wastewaters.

4. Determine the comparative anaerobic treatability characteristics of effluents from non-conventional bleaching sequences.

5. Determine the fate of toxic wastewater components during anaerobic treatment.

6. Determine the levels and types of toxicity produced during anaerobic treatment, ie sulfide, ammonia, biosolids, etc.

7. Determine criteria for selecting and blending specific waste streams from kraft mills to facilitate anaerobic treatment and detoxification of the final effluent.

8. Determine co-treatment and post-treatment design requirements to ensure compliance with BOD, SS and toxicity regulations.

The following material summarizes the interim results from experimental work carried out under objectives 1 and 2 above.

3 MATERIALS AND METHODS

3.1 Sample Collection, Preservation and Storage

Water and pulp samples were collected over single, 6-8 hour shifts during periods of normal operation of the bleach plants on softwood pulp. At one mill, samples were also collected from a parallel plant that was bleaching hardwood pulp. Each sample was obtained by compositing 3 equal manually collected grap samples taken over the 6-8 hour period. The composite samples were then split and preserved as required for specific chemical analyses or toxicity testing as noted below.

Samples that were collected for the more routine or common wastewater analyses were preserved using standard Wastewater Technology Centre (WTC) procedures (5). For resin and fatty acid measurements, split samples were transported and stored unpreserved, in 1 litre glass bottles. Water samples for adsorbable organic halogen (AOX) were collected in 250 ml glass bottles. For most AOX samples, 1.0 ml of 0.1 N Na_2SO_3 was added to each bottle before the sample was taken. The amount of Na_2SO_3 added was determined from measurements of the residual chlorine levels in the samples. The contents were acidified to pH 2 with nitric acid after sample collection was completed. For chlorination stage filtrates, 4.0 ml of the Na_2SO_3 solution was added. Volatile chlorinated organics were determined in samples that were collected in headspace-free 40 ml septum bottles. Toxicity testing was done on 1 litre unpreserved samples transported in glass bottles. Samples of brownstock and bleached pulp were collected and shipped in 5 litre glass bottles. All samples were transported to the WTC in Burlington, Ontario, or, to the toxicity testing laboratory in Brampton, Ontario, within 24 hours of collection. Upon arrival at the laboratory, samples were stored for 1 or 2 days at $4^{o}C$ while they were prepared for analysis. Samples requiring longer term storage prior to testing or analysis, were frozen and stored at $-10^{o}C$.

3.2 Routine Analytical Procedures

Unless otherwise noted below, all chemical analyses were conducted using standard WTC procedures (5). Total sulfur concentrations were measured with a combustion/titration procedure using a Leco Furnace. Inorganic sulfur compounds were determined using ion chromatography with a conductivity detector. Carbohydrates were measured by a colorimetric method employing phenol and sulfuric acid/hydrazine sulfate. The resulting complex was read at 4900 A. For lignin, TAPPI Standard T13 method was used without the solvent extraction step. Hydrolysis with 73% H_2SO_4 was followed by gravimetric quantification. Chloride concentrations were determined by single column ion chromatography with a conductivity detector using a 5 mM p-hydroxybenzoic acid eluant. Chlorate was measured in a similar fashion but with a 0.5 mM KOH eluant. Extractives were estimated by extraction of an acidified sample with Freon (1,1,2,-trichloro-1,2,2-trifluoroethane) followed by gravimetric

quantification (6).

Resin and fatty acid concentrations were measured by a modification of the method described by Voss and Rapsomatiotis (7). Samples, at pH 9, were partitioned with methyl t-butyl ether, dried, and derivatized with diazomethane. Derivatized compounds were then analyzed by gas chromatography with a flame ionization detector. The resin and fatty acids reported were: linoleic, oleic, pimaric, sandaracopimaric, o-methylpodocarpic, isopimaric, palustric, dehydroabietic, abietic, neoabietic, 12-chlorodehydroabietic and 14-chlorodehydroabietic, and 12,14,-dichlorodehydroabietic. This method is currently under investigation by the Ontario Ministry of the Environment for monitoring of resin and fatty acids levels in pulp and paper wastewaters.

Chloroform and carbon tetrachloride were analyzed by purging the samples with helium and adsorbing the volatile components onto a tenax trap. The volatiles were thermally desorbed and injected onto a GC column in a Varian 3700 gas chromatagraph with an electron capture detector.

3.3 Measurement of Organic Halogen

Halogenated organic compounds were measured by two techniques. The first method is capable of measuring combined organic halides (chlorine, bromine and iodine) in waters and wastewaters. Fluorine-containing species are not determined by this method. For analysis, up to 50 ml of an acidified sample was passed under pressure through a granular activated carbon column at a prescribed flowrate of 3-4 mL per minute. The column was then washed with nitrate solution (5 g NO_3^-/L) to remove trapped inorganic halides. The activated carbon containing the adsorbed organic halides was then combusted and the resulting HX gas generated was trapped in acetic acid and titrated microcoulometrically. The estimated organic halogen is referred to as "adsorbable organic halogen", AOX. The adsorption and combustion/titration (DX-20) equipment were manufactured by Dohrmann.

Neutron activation analysis (NAA) was used as an alternative for the specific measurement of organic chlorine. An appropriate aliquot of a well mixed, properly preserved sample, of up to 30 ml in volume, was poured into a pyrex culture tube containing 80 mg granular activated carbon. The tube was capped and placed on a shaker for one hour. The contents were then filtered, washed with nitrate solution, and placed in a scintillation vial. The content of organic chlorine was then determined with neutron activation analysis. Since chlorine was expected to be the dominant halogen appearing in pulp and paper samples, the adsorbable organic chlorine, AOCl, determined by neutron activation, should be very similar to the AOX determined by combustion/titration.

The organochlorine content of pulp samples was analyzed by a combination of the two techniques. An aliquot of wet pulp was filtered and washed with nitrate solution. The AOX content of the liquid filtrate and the nitrate washings was then determined using the combustion/titration method. The washed

pulp was placed in a scintillation vial, and the AOCl content of the pulp solids was measured by neutron activation analysis.

Detailed descriptions of the two methods for halogenated organics are presented in Appendix A. Both methods are currently under investigation by Environment Canada for application to pulp and paper wastewaters.

3.4 Toxicity and Mutagenicity Testing

Wastewater aquatic toxicity was determined by Beak Consultants Ltd. with a standardized acute lethality toxicity testing protocol (8) using Daphnia magna. Several microbial toxicity and mutagenicity tests were conducted by the National Water Research Institute (NWRI) in Burlington. Brief descriptions of the NWRI protocols used are contained in Appendix A.

4 RESULTS AND DISCUSSION

4.1 Comparison of AOX Methods

During the preliminary stages of this study, two different methods were used for the measurement of the organochlorine content of wastewater samples. Figure 1 summarizes the results obtained with both methods for approximately 25 different samples collected from kraft bleach plant streams and from combined kraft mill effluent sewers. Each sample was analyzed by both combustion/titration and by neutron activation. A data point shown in Figure 1 represents the resulting AOX concentration obtained by each method for a specific wastewater sample. Replicate analyses completed on all of the samples are also included in the data presented in Figure 1.

When both analytical techniques produced identical measurements of the AOX concentrations, the resulting point was located on the diagonal of Figure 1. Any systematic deviation from the diagonal represents consistent over- or under-prediction by one of the techniques. In both the high and low concentration ranges, the AOX concentrations determined by both methods showed excellent agreement. The random distribution of the data about the diagonals indicates that this agreement was consistent over a range of sample types and concentrations between 0.8 and 279 mg AOX/L.

Table 3 further compares the two methods by presenting the relative deviations, or coefficients of variation, at high and low AOX concentrations. In this case the same sample was analyzed 20 times with one of the methods and the reproducibility was reported as a coefficient of variation. The variability of the neutron activation technique appeared to be slightly greater than that of the combustion/titration method. However, both methods were considered to be satisfactory since, in all cases, the coefficients of variation were less than 8%.

Table 3. Reproducibility of AOX Measurement Techniques

Measurement Technique	N	AOX Concentration Mean (mg/L)	Coefficient of Variation (%)
Combustion/Titration	20	11.0	2.85
Combustion/Titration	20	209.3	3.22
Neutron Activation	20	15.4	4.32
Neutron Activation	20	178.5	7.40

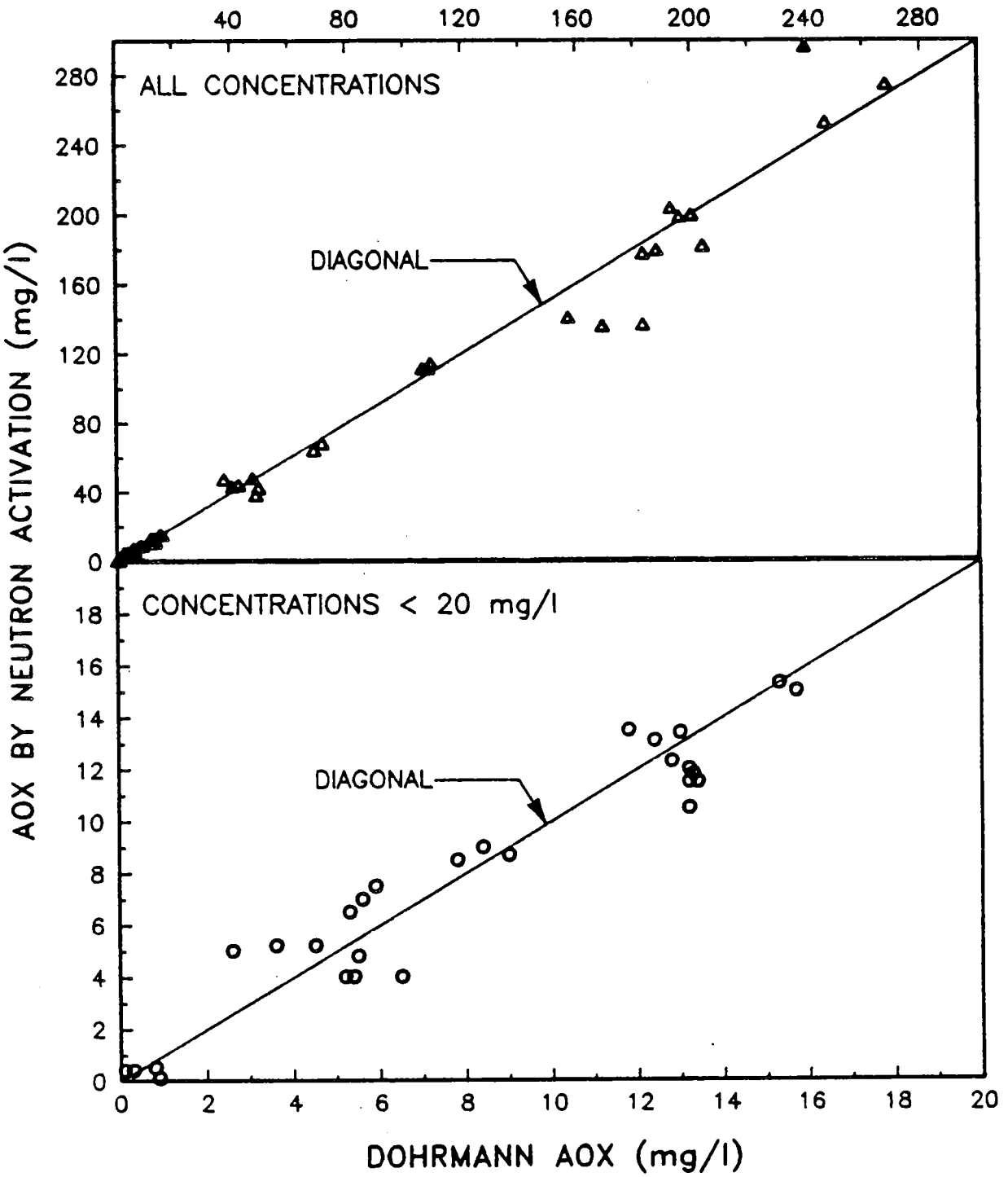


Figure 1. Comparison of Adsorbable Organic Halogen (AOX) determined by combustion/titration (Dohrmann) and neutron activation.

4.2 Bleach Plant Descriptions

Wastewater samples were collected from several process streams within four kraft mill bleach plants (Table 4). With the exception of plant "D", all mills were pulping softwood at the time of sampling, and in the opinion of mill personnel, were operating under normal conditions (Table 5).

Table 4. Characteristics of Bleach Plants

Plant "A":	C/D Eo H E2 D , Spruce and Jack Pine
Plant "B":	D/C Eo D1 E2 D2 , Jack Pine (80%), Spruce (20%)
Plant "C":	O, C/D Eo H D , Mixed Softwood
Plant "D":	O, C/D Eo H D , Hardwood

Table 5. Selected Bleach Plant Operating Parameters

Parameter*	Bleach Plant A	B	C	D
Incoming K Number	23.5	19	11.1	8.4
Chlorine Charge	77.3	32.3	34.1	20.5
Chlorine Dioxide Charge	20.2	44.8	15.7	13.8
Hypochlorite Charge	3.7	--	2.9	4.1

* Chemical charges expressed as equivalent chlorine (kg/adt).

The specific bleach plants sampled were selected to generate wastewater characterization and anaerobic treatability data for a range of available bleaching technologies. Bleach plant "A" most closely resembled a conventional chemical bleach plant, with 7% ClO_2 substitution in the chlorination stage. Bleach plant "B" utilized 50% ClO_2 substitution. Plants "C" and "D" used oxygen delignification followed by bleaching lines with 10% and 20% ClO_2 substitution respectively. The latter two plants also provided an opportunity to compare data for the bleaching of hardwood and softwood pulps under similar process conditions.

4.3 Wastewater Chemical Characteristics

Within any one bleach plant, samples were taken from several interstage process streams, from incoming make-up water

sources, from all sewered wastewater streams, and at the request of one mill, from the influent and effluent of the biological treatment plant. Samples of brownstock and bleached stock were also collected. Although the objective of the program was to obtain data for the sewered bleach plant wastewaters only, the additional samples were taken to determine whether the wastewater contaminants of interest originated inside or outside of the bleach plant. Bleached pulp samples were collected to assess the quantity of chlorinated organics that exit the bleach plant with the bleached stock, and that could ultimately be sewered elsewhere in the mill. Samples were also collected from at least one condensate at each mill. The condensate characteristics were of interest in the event that future treatability studies indicate that anaerobic treatment of the bleach plant wastewaters requires a supplementary source of relatively high strength biodegradable material. With the exception of the biological treatment plant effluent referred to above, none of the sampled streams are discharged directly to the environment. These streams undergo downstream blending and/or dilution, and in some cases, treatment, prior to final discharge.

The complete set of chemical characterization data obtained for all streams sampled is presented in Appendix B. Since none of the make-up water sources contained significant quantities of contaminants, the discussion below concentrates primarily on selected characteristics of the sewered wastewater streams in the four bleach plants. The characteristics highlighted are those considered to be the most relevant to the ongoing investigation of anaerobic treatability.

4.3.1 Wastewaters From Softwood Bleaching. There were a total of 8 sewered streams from the 3 plants that were bleaching softwood at the time of sampling (Table 6). In plant "A", bleed flows from the Eo- and H-stage seal tanks are discharged to a combined alkaline sewer. At each of the softwood bleach plants, most of the sewered streams contain sufficient Chemical Oxygen Demand (COD > 1000 mg/L) to consider anaerobic treatment technology. However, as indicated by the relatively low BOD/COD ratios (BOD is Biochemical Oxygen Demand), most of this COD is poorly biodegradable. At the present time, the intent of the current study is to focus on the application of anaerobic technology for dechlorination of the wastewater organochlorine compounds. In other locations, this has been accomplished to varying extents without the production of methane (9). It may therefore be erroneous to assume that the usual criterion of high COD concentration is a requirement for an application of anaerobic biotechnology in which dechlorination, rather than methanation, is the primary goal.

With two exceptions, all of the streams were toxic as determined by static bioassays with Daphnia magna. Although a pattern in aquatic toxicity is difficult to discern, chlorination filtrates appeared to be more toxic than the alkaline filtrates. The two non-toxic streams were both alkaline filtrates from the bleach plant that was preceded by oxygen delignification.

The wastewater organochlorine concentrations (Adsorbable Organic Halogen, AOX) did not differ significantly between mills.

AOX concentrations were highest in the acid filtrates (180 to 218 mg/L), and slightly lower in the alkaline extraction filtrates (139 to 176 mg/L). For the two mills with hypochlorite bleaching, the alkaline hypochlorite filtrates contained much lower levels of AOX (22 to 42 mg/L).

Table 6. Selected Characteristics of Softwood Bleaching Wastewaters.

DESCRIPTION	AOX (mg/L)	TOXICITY (LC 50)	COD (mg/L)	BOD (mg/L)	BOD/COD (%)
Plant A, Softwood					
C-STAGE SEAL TANK	218	6.3	1120	330	29.5
COMBINED ALK. FILT.	109	20.1	1320	360	27.3
Eo-STAGE SEAL TANK	166	17.9	2200	540	24.5
H-STAGE SEAL TANK	22	3.85	80	3	4
Plant B, Softwood					
D/C SEAL TANK	180	17.6	2800	450	16.1
Eo SEAL TANK	139	16.6	8000	975	12.2
Plant C, Softwood					
C-STAGE SEAL TANK	198	8.7	1450	330	22.8
E-STAGE SEAL TANK	176	100	2330	330	14.2
H-STAGE SEAL TANK	42	N.L.	605	90	14.9

ND = Not Determined; N.L. = Non-Lethal.

4.3.2 Comparison of Wastewater Characteristics from Softwood and Hardwood Pulp Bleaching. Selected analytical characteristics for samples from the parallel softwood and hardwood bleach plants with oxygen delignification are presented in Table 7. The softwood data are the same as those shown in Table 6 above. As expected, the AOX, COD and BOD concentrations were all lower for hardwood bleaching than for softwood bleaching. Using the conventional COD concentration criterion, the strengths of the hardwood wastewasters are only marginally suitable for anaerobic treatment. As indicated by the BOD/COD ratios, there was some variablility in biodegradability within each bleach plant, but on average, there was no major difference in the apparent wastewater biodegradability between the two plants. AOX levels in hardwood wastewaters were significantly lower than those of the softwood effluents. The measured AOX concentrations for hardwood ranged from 27% to 54% of the corresponding concentrations measured for softwood bleaching. In contrast to the data from all of the softwood bleach plants, the LC_{50} results from hardwood bleaching indicated that the chlorination filtrates were significantly less toxic (43.6%) than the alkaline extraction filtrates (21.2%). For both softwood and hardwood bleaching, the hypochlorite filtrates were the least toxic

streams. The LC_{50} for hardwood hypo filtrate was 54.7%. Surprisingly, the softwood hypochlorite filtrate was the only sewered stream from any of the bleach plants that was not acutely lethal to Daphnia magna.

Table 7. Comparison of Selected Wastewater Characteristics From Softwood and Hardwood Bleaching.

DESCRIPTION	AOX (mg/L)	TOXICITY (LC 50)	COD (mg/L)	BOD (mg/L)	BOD/COD (%)
Plant C, Softwood					
C-STAGE SEAL TANK	198	8.7	1450	330	22.8
E-STAGE SEAL TANK	176	100	2330	330	14.2
H-STAGE SEAL TANK	42	N.L.	605	90	14.8
Plant D, Hardwood					
C-STAGE SEAL TANK	108	43.6	740	84	11.4
E-STAGE SEAL TANK	48	21.2	1160	236	20.3
H-STAGE SEAL TANK	16	54.7	302	6	2

ND = Not Determined; N.L. = Non-Lethal.

4.4 Toxicity Correlations

4.4.1 Acute Toxicity vs Chemical Parameters. One of the objectives of this study was to assess the correlation between chemical composition and aquatic toxicity of bleach plant wastewaters, and between aquatic toxicity determined with Daphnia magna and a series of microbial toxicity and mutagenicity tests. For all of the seal tank samples collected in this study, a preliminary examination of the relationship between chemical composition and aquatic toxicity was carried out. Figures 2, 3 and 4 indicate that there was essentially no correlation between Daphnia magna LC_{50} and wastewater strength as measured by BOD, COD or TOC (Total Organic Carbon).

The relationship between total resin and fatty acids (RFA) and aquatic toxicity is shown in Figure 5. Although the statistical correlation between the two parameters is not strong ($r^2 = - 0.33$), in general, there is a trend to lower toxicity with lower RFA concentrations. This trend did not hold for the five data points located close to the origin. The acute toxicities of these bleach plant process streams were very high, even though they contained low concentrations of resin and fatty acids. The RFA method used in this study included only three chlorinated resin acids in the target list of compounds. In many of the samples summarized in Figure 5, there may have been additional chlorinated RFAs present that were not quantified, but which might have contributed to sample toxicity.

The use of a more general measure of chlorinated organic compounds might be expected to produce a better correlation to

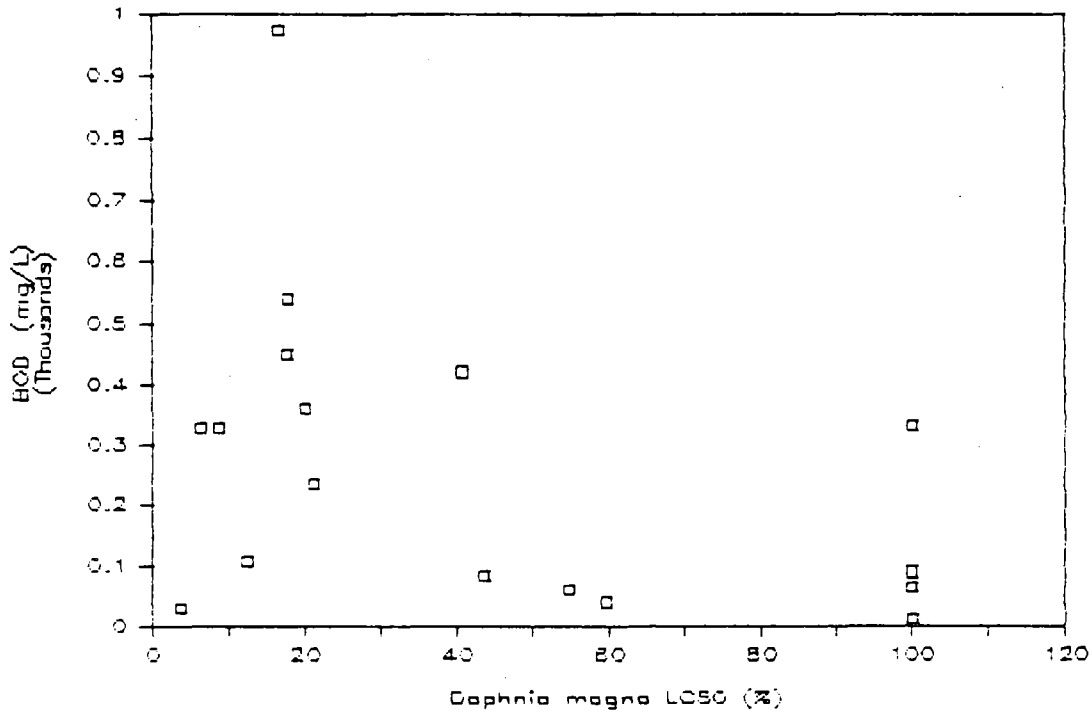


Figure 2. Relationship between BOD and toxicity in bleach plant seal tank samples.

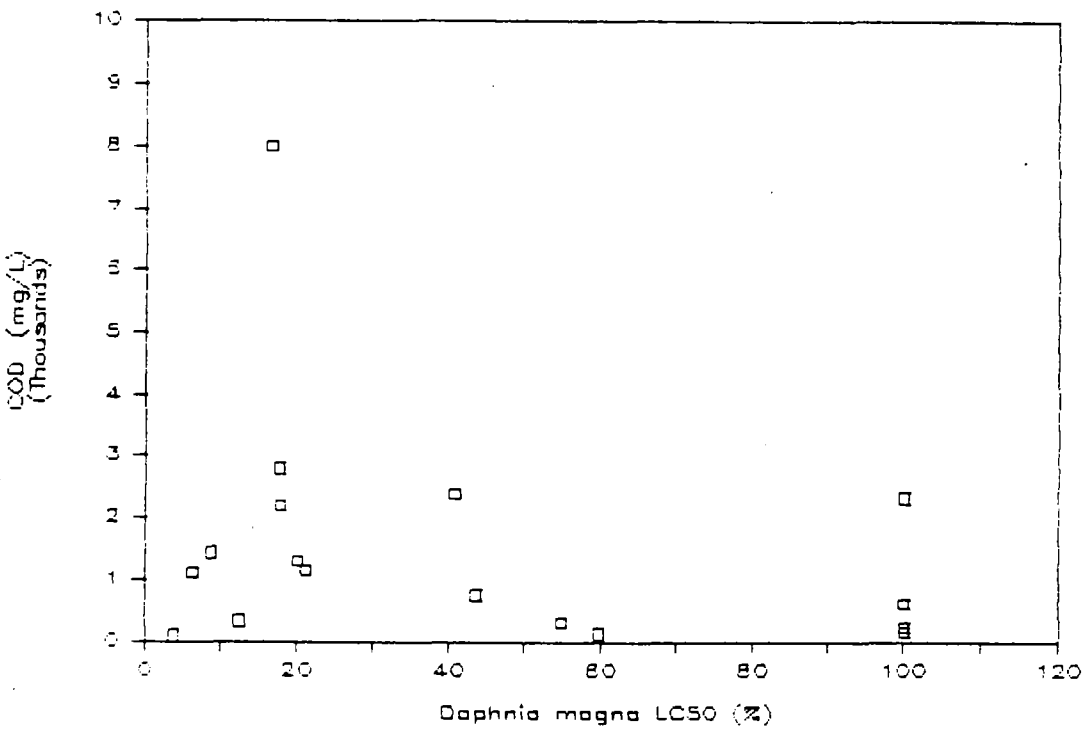


Figure 3. Relationship between COD and toxicity in bleach plant seal tank samples.

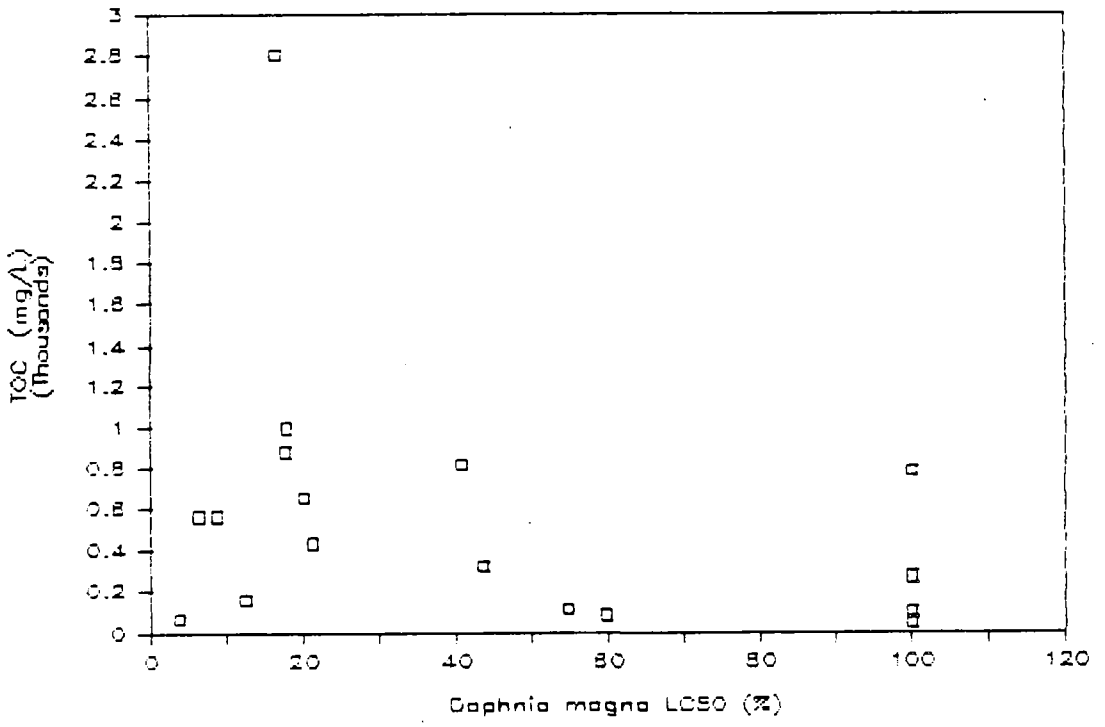


Figure 4. Relationship between TOC and toxicity in bleach plant seal tank samples.

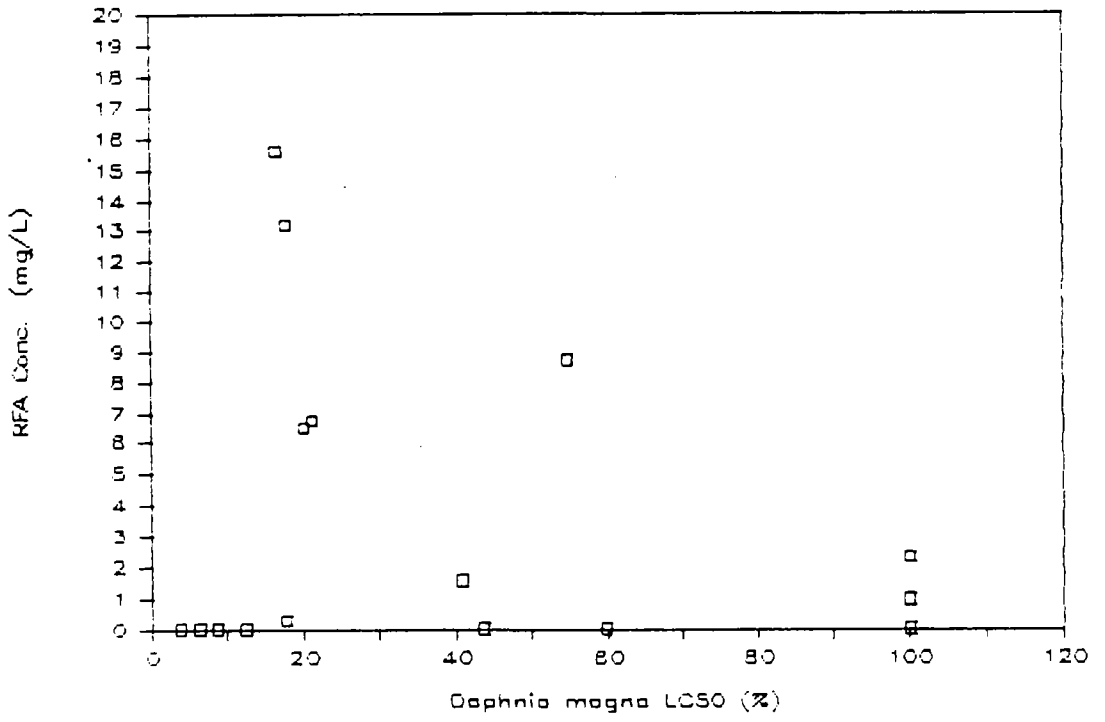


Figure 5. Relationship between RFA concentration and toxicity in bleach plant seal tank samples.

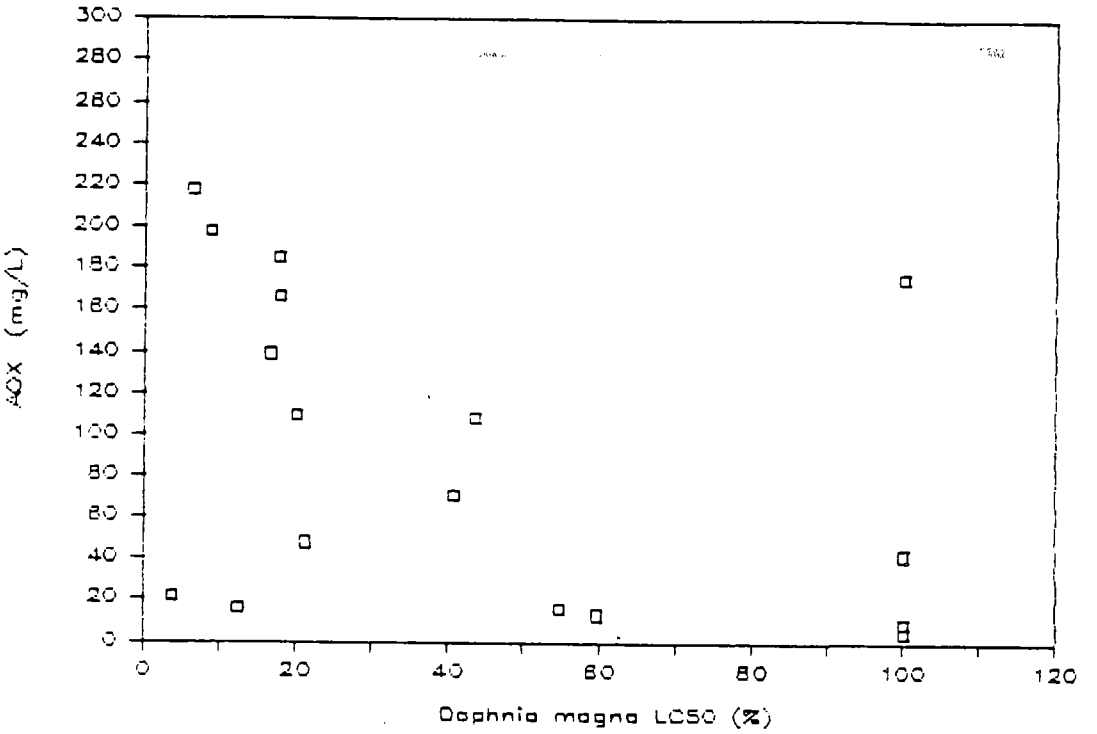


Figure 6. Relationship between AOX and toxicity in bleach plant seal tank samples.

wastewater toxicity. Figure 6 shows the correlation between measured AOX concentrations and Daphnia magna toxicity. With the exception of the data point farthest from the origin, there appears to be an indication of a weak negative correlation between AOX and LC_{50} (r^2 = - 0.57). Even though the evidence for a statistically significant relationship is not convincing, the correlation of toxicity to AOX was higher than that to any of the other chemical parameter examined. Additional data will be required to assess this issue further.

4.4.2 Microbial Toxicity and Genotoxicity. As described in more detail in Appendix A, several microbial toxicity assays, and one microbial genotoxicity test, were applied to all of the wastewaters collected during the kraft bleach plant sampling programs (Appendix B). These tests were of interest to determine whether the Daphnia magna acute toxicity bioassay could be replaced by one or more microbial tests that require smaller sample volumes for toxicity determination. This would allow toxicity measurements to be made after the completion of many of the small volume anaerobic treatability tests that are planned for later stages of the study. The microbial tests used were:

- Microtox,
- Algal ATP,
- Bacterial ATP-TOX,
- Spirillum volutans, and,
- SOS Chromotest.

Figure 7 shows scatterplot diagrams of the results of all pairs of tests, including those using Daphnia magna. This type of plot makes it fairly easy to track a trend in the data from plot to plot, and to compare all the test procedures against one another. It is important to note that each of the tests defines significant toxicity in different terms. For instance, an induction factor of 0.2 is considered to be non-mutagenic in the SOS Chromatest, while a similar LC_{50} value in a Daphnia bioassay, or an EC_{50} for Microtox, would indicate very high toxicity. In the case of the Spirillum test, results are either positive [0], indicating toxicity, or negative [1].

A thorough analysis of the toxicity characteristics measured by these tests has not yet been completed. However, Figure 7 indicates that Spirillum produced both toxic and non-toxic responses for wastewaters that covered a wide range of toxicities as determined by the other tests. However, it is difficult to assess a correlation between positive/negative data from the Spirillum test and the scaled results of the other tests. The Microtox test appeared to be the most sensitive indicator of toxicity. That is, there were predominantly low EC_{50} results for almost every data value produced by the other tests. These low Microtox values may be partially attributable to difficulties encountered in correcting for the high background colour in many of the bleach plant samples.

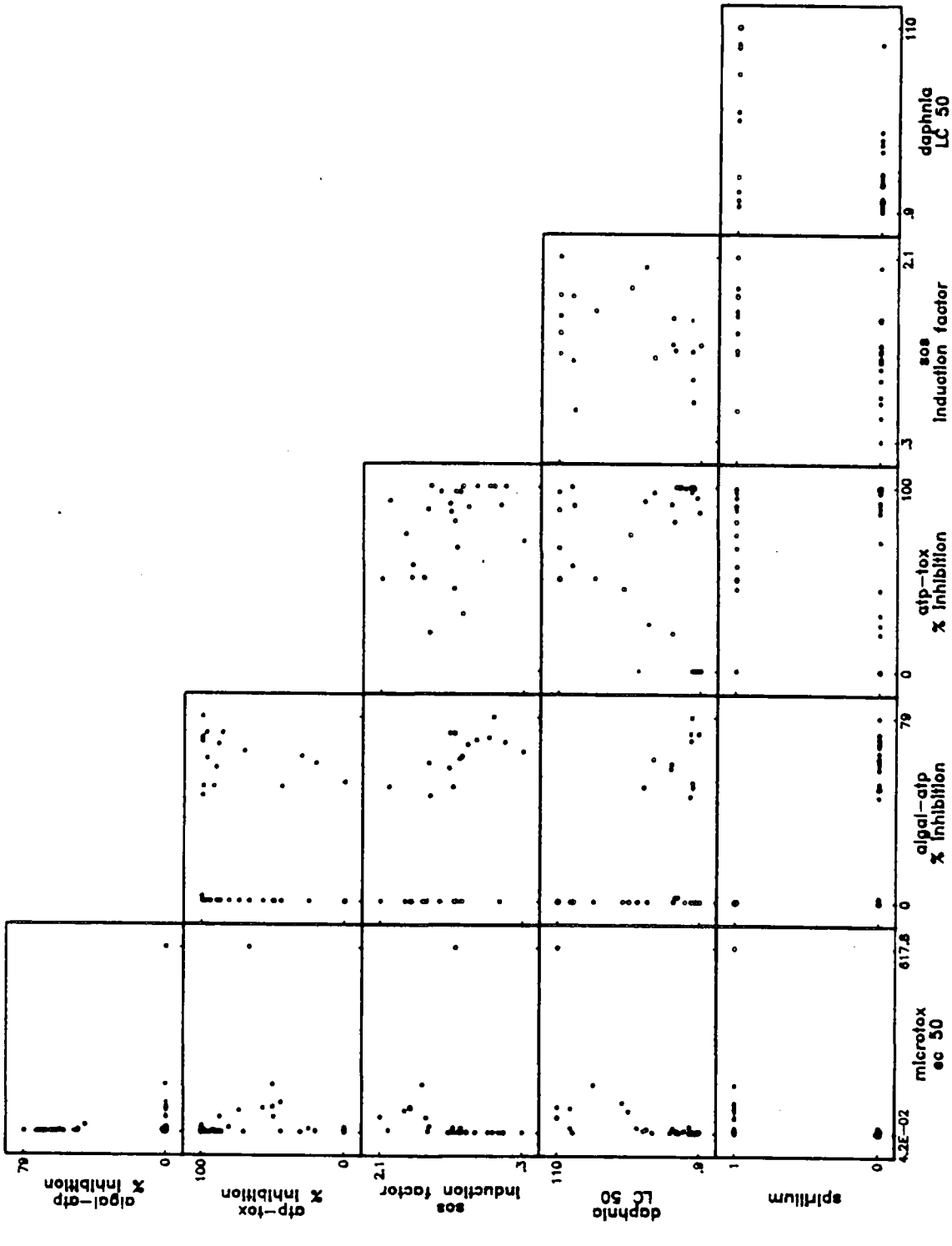
It is apparent from the plots of Figure 7, that none of the tests produced results that correlated strongly to those of any other procedure, including Daphnia. Work will be continued to determine whether more significant correlations can be drawn to selected chemical measurements that were made for these wastewaters.

4.5 Organochlorine Discharges.

The major objective of current study is to examine the potential for applying anaerobic biological treatment technology for the removal of BOD, toxicity and organochlorine compounds from kraft mill bleach plant wastewaters. To avoid the requirement for making expensive and time-consuming measurements of specific chlorinated organic compounds to assess the performance of an anaerobic system, it was decided that a lumped-parameter estimate of organochlorine content would be utilized. For water samples, Adsorbable Organic Halogen (AOX) using either combustion/titration, or neutron activation, was chosen as the most applicable method. Samples containing few suspended solids were analyzed by either AOX approach. For higher particulate concentrations, and for pulp samples, the neutron activation technique was routinely used. Both techniques measured the non-volatile organochlorine components of pulp mill wastewaters.

At the time of sample collection, it was also of interest to determine the concentrations and types of volatile chlorinated organics in bleach plant process streams. Therefore, grab samples were collected in headspace-free septum bottles for analysis by a purge and trap, gas chromatographic technique. As shown in Table 8 for the sewered streams, only chloroform and carbon tetrachloride were identified routinely in

Figure 7 Toxicity and Mutagenicity Results



significant quantities. In several samples, additional peaks were obtained on the chromatograph, but at such low concentrations as to be negligible. The sum of the measured concentrations of chloroform and carbon tetrachloride, expressed in terms of chlorine, were assumed to be approximately equal to the Purgeable Organic Halogen (POX).

Figures 8 through 11 illustrate the POX and AOX concentrations of the samples collected from several washer seal tanks. These sources included both sewered and recycled streams. The highest POX concentration measured was 10 mg/L in the chlorination stage filtrate from Plant "A", however, a number of other samples from plants "A", "C" and "D" contained similar levels of POX. Three of the four hardwood bleach plant (Plant "D") filtrates exhibited POX levels of 6 to 8 mg/L. The fourth hardwood filtrate, from the chlorine dioxide stage, was much lower in volatile organochlorines (< 1 mg/L). The bleach plant with the highest degree of chlorine dioxide substitution produced filtrates that were consistently low in POX (< 1.3 mg/L).

Table 8. Volatile Organo-Chlorine Compounds and AOX in Bleach Plant Wastewaters

DESCRIPTION	PURGEABLES $CHCl_3$ (mg/L)	PURGEABLES CCl_4 (mg/L)	AOX (mg/L)
Plant A, Softwood			
C-STAGE SEAL TANK	10	0.0018	218
COMBINED ALKALINE FILTRATE	1.6	0.01	109
Eo-STAGE SEAL TANK	0.78	0.0058	166
H-STAGE SEAL TANK	7.8	0.008	22
Plant B, Softwood			
D/C SEAL TANK	1.2	0.0004	180
Eo SEAL TANK	0.18	0.0004	139
Plant C, Softwood			
C-STAGE SEAL TANK	7.8	ND	198
E-STAGE SEAL TANK	1.4	0.008	176
H-STAGE SEAL TANK	0.5	0.24	42
Plant D, Hardwood			
C-STAGE SEAL TANK	6.8	0.23	108
E-STAGE SEAL TANK	8	0.038	48
H-STAGE SEAL TANK	6.6	0.01	16

ND = Not Determined; N.L. = Non-Lethal.

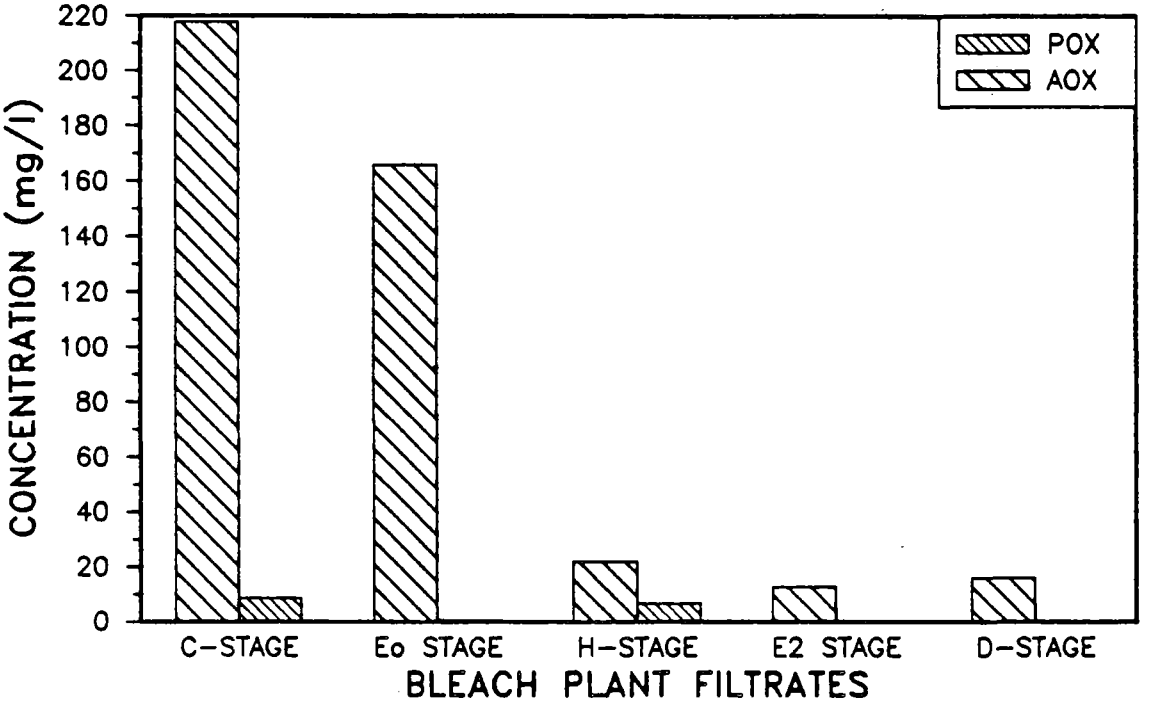


Figure 8. AOX and POX content of filtrates from softwood bleach plant "A".

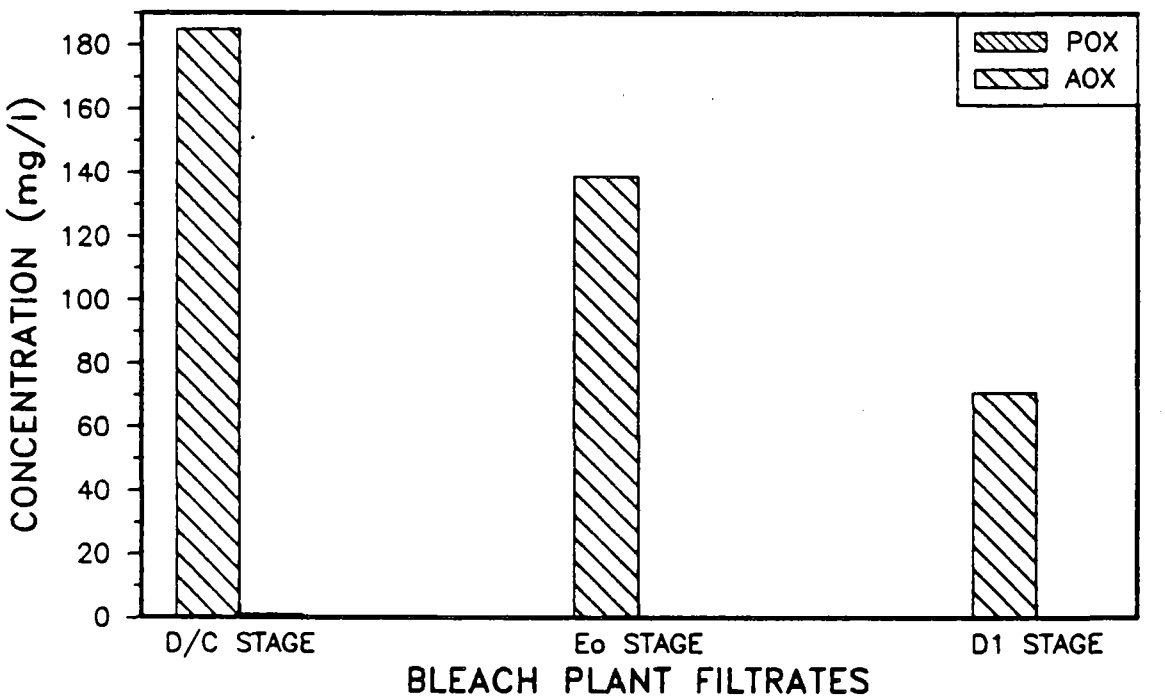


Figure 9. AOX and POX content of filtrates from softwood bleach plant "B".

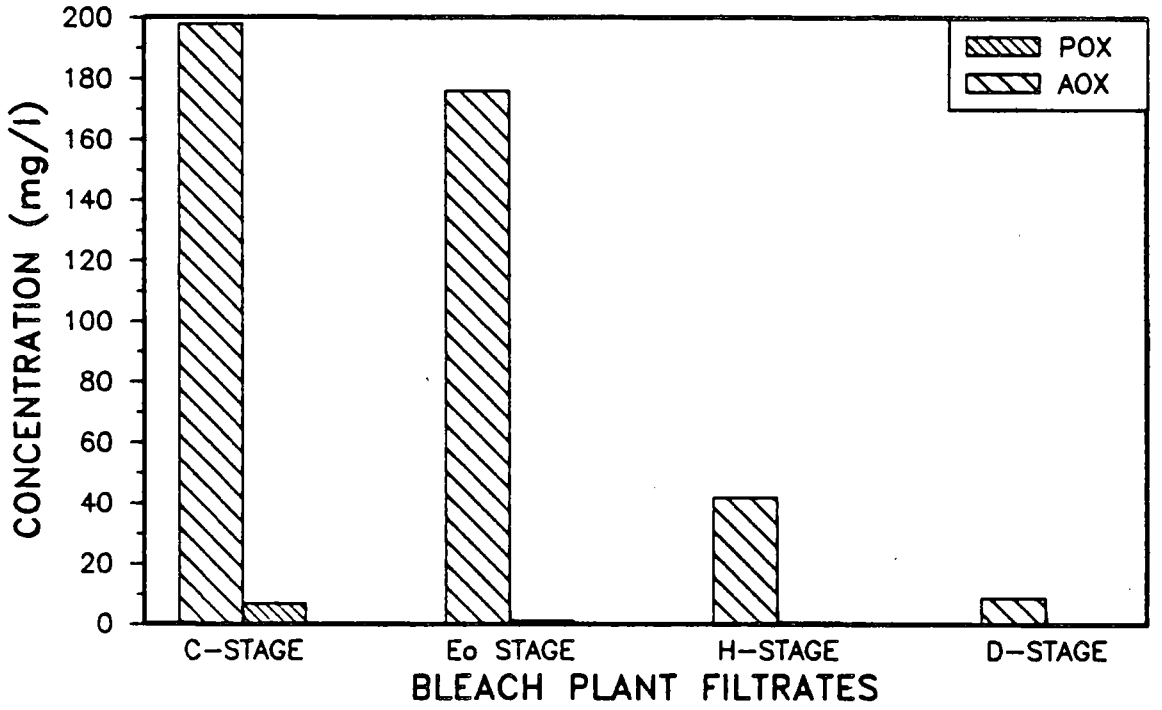


Figure 10. AOX & POX content of filtrates from softwood bleach plant "C".

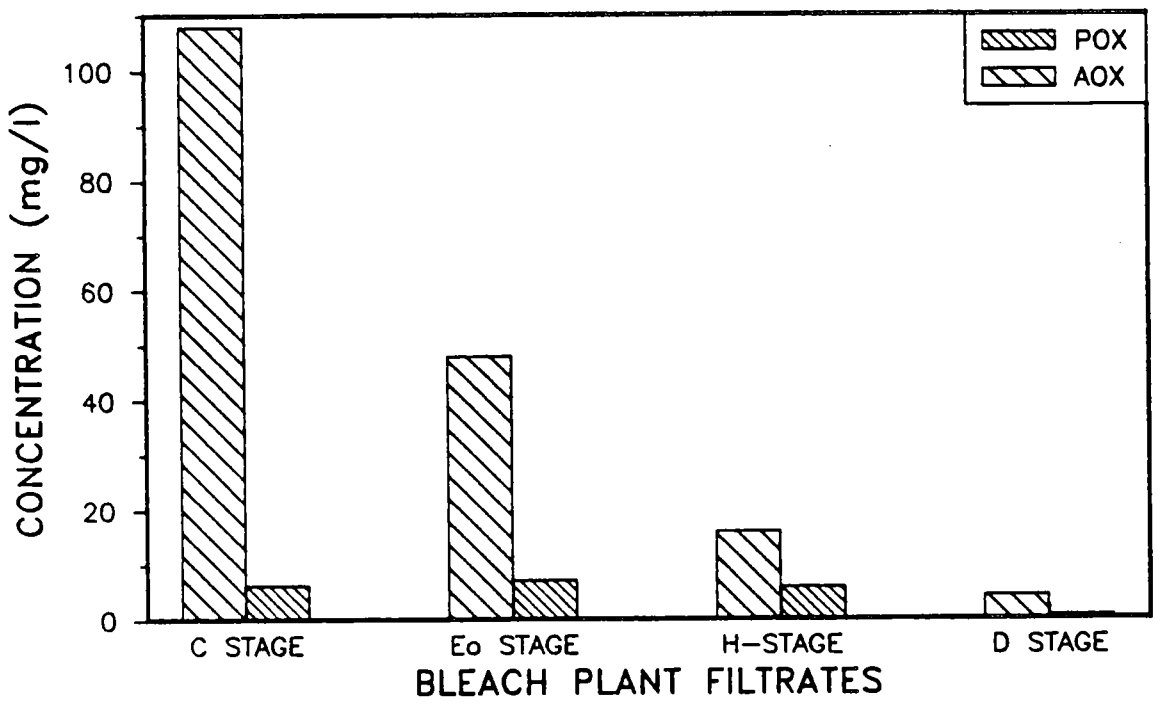


Figure 11. AOX & POX content of filtrates from hardwood bleach plant "D".

The contributions of volatile compounds to the total concentrations of organic halogen measured in the individual filtrates were highly variable. In most cases, the POX comprised less than 5% of the total organic halogen. The notable exceptions were the filtrates from the hardwood bleach plant, in which the percentage of POX ranged from 5.3% in the C-stage filtrate, to 26% in the hypochlorite stage. The hypochlorite stage from the softwood bleach plant "A" also contained about 24% POX. The higher contributions observed for the two hypochlorite filtrates are due primarily to the low concentrations of AOX present in these samples, rather than to high concentrations of POX.

It has recently been recommended that the discharge rates of organically bound chlorine be used as a regulatory parameter for Ontario kraft mills (Bonsor et al., 10). The contributions of POX to the total discharge rates of organochlorine compounds from the four bleach plants are shown in Figure 12. For the three softwood bleach plants, the POX constituted less than 3% of the total mass of organochlorine discharged. At these levels the contribution of POX was considered to be negligible. In the hardwood bleach plant, volatile compounds were far more significant, comprising 12.4% of the total organochlorines discharged in the sewered filtrates.

Figure 13 summarizes the measured and predicted AOX + POX discharge rates for the four bleach plants surveyed. The measured rates were determined from measurements of the sewered streams in each bleach plant, as well as the water associated with the bleached stock. At one mill, the discharge rate measured in the bleach plant was compared to a measurement over the same period in the untreated combined mill effluent. The combined mill effluent value was within 10% of that measured in the bleach plant. The predicted values were calculated from the Germgard equation as proposed by Bonsor et al. (10).

$$\text{Organic Chlorine} = k \times (C + H/2 + D/5) \text{ kg/adt}$$

where k is a constant assumed to be 0.12 kg/adt,
C is the total chlorine charge, kg/adt,
H is the hypochlorite charge as equivalent chlorine, kg/adt, and,
D is the chlorine dioxide charge as equivalent chlorine, kg/adt.

The measured organochlorine discharge rates ranged from a high of 8.0 kg/adt for softwood bleach plant "A" with 7% ClO_2 substitution, to a low of 1.1 kg/adt for oxygen delignification and 20% ClO_2-substituted hardwood bleaching at Plant "D". Plants "B" and "C" discharged intermediate quantities, of AOX + POX, 2.0 and 3.5 kg/adt respectively. Among the softwood bleach plants, the high degree of ClO_2 substitution at Plant "B" appears to be more effective in reducing organochlorine discharges than the use of oxygen delignification with a lower ClO_2 substitution (Plant "C"). Samples from the two parallel bleach plants ("C" and "D") indicated that the organochlorine discharged from hardwood bleaching was less than one-third of

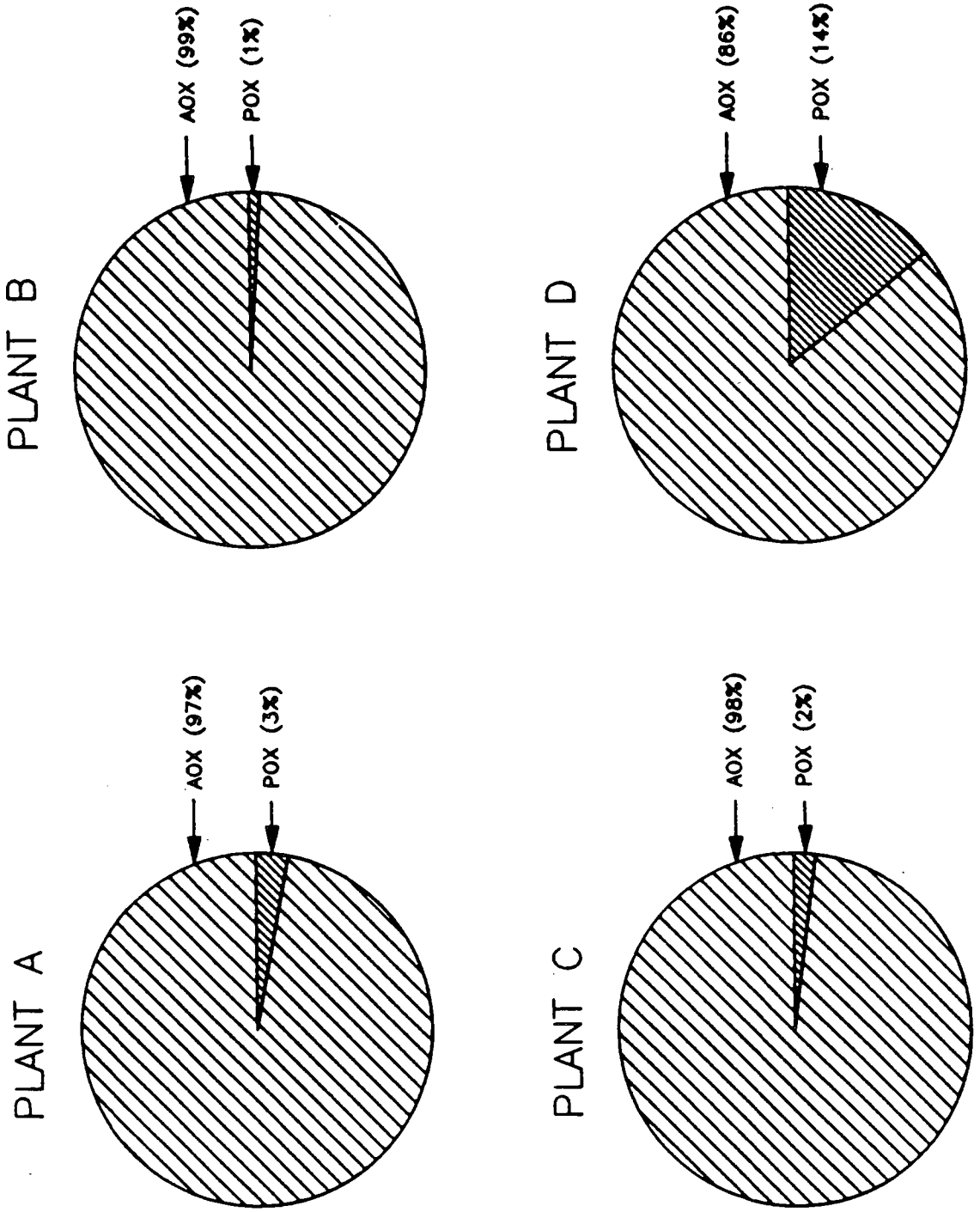


Figure 12. Percent contributions of AOX and POX to total organochlorine discharges.

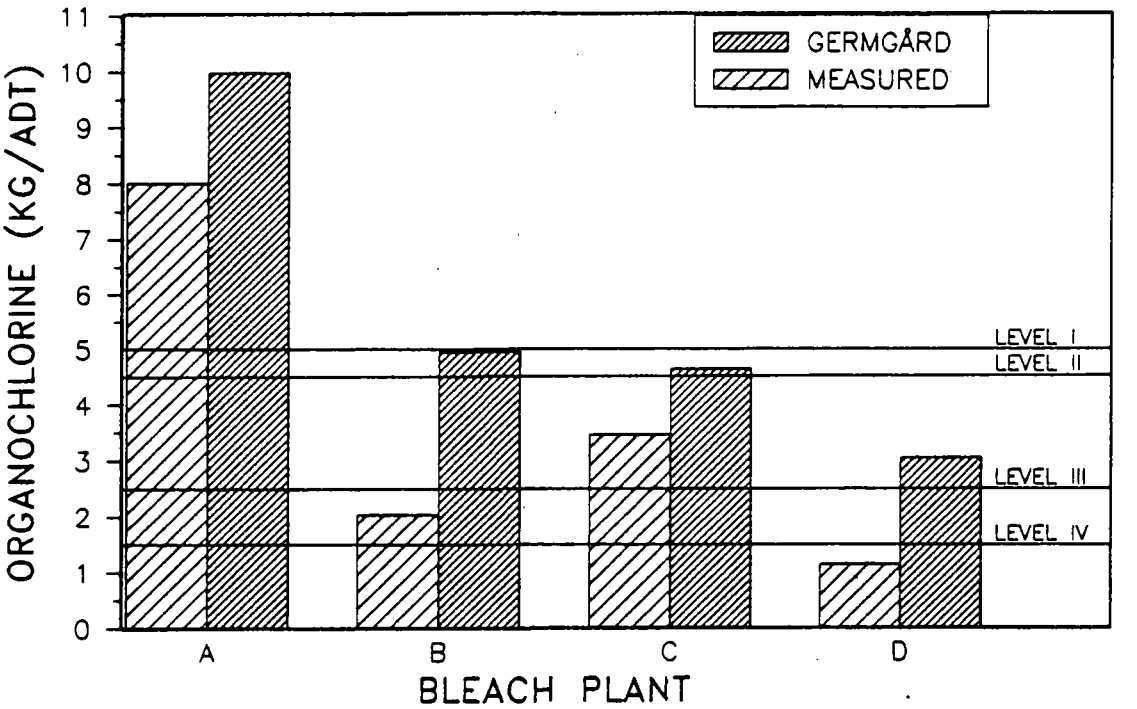


Figure 13. Measured and predicted unit organochlorine (AOX + POX) discharge rates.

that generated with softwood.

Figure 13 also demonstrates that the Germgard equation consistently overpredicted the measured organochlorine discharges. For softwood bleaching the predicted values exceeded the measured values by 25%, 144% and 34% for plants "A", "B" and "C" respectively. Better agreement can be obtained for "A" and "C" by adjustment of the value of the constant in the Germgard equation as discussed by Bonsor et al. (10). However, for bleach plant "B" an unrealistic extent of adjustment would be necessary to produce reasonable agreement between the measured and predicted results. It has been suggested that the Germgard relationship has only a limited capability for predicting the benefits of high degrees of ClO_2 substitution on the AOX discharge rate. The Germgard equation is inherently simplistic. As more empirical data is reported it may be shown to be an inadequate predictor of organochlorine production (McCubbin, N., Personal Communication).

The extent of overprediction by the Germgard equation appeared to be most significant for the hardwood bleach plant. In this case the Germgard value was 166% of the measured organochlorine discharge rate. The reason for this large discrepancy is not known at present.

Individual sources of organochlorine are detailed in Table 9. Figure 14 summarizes the relative contributions of each stream leaving the bleach plant to the total organochlorine discharged. In every case, the chlorination and extraction filtrates accounted for at least 86% of the total. In the softwood bleach plants, the chlorination filtrates appeared to be the largest single source. The alkaline extraction seal tank was the dominant source in the hardwood plant. For plants "C" and "D", in which hypochlorite filtrates are sewered separately, these relatively dilute streams contributed 13% and 8% of the respective totals.

Table 9. Summary of Organochlorine Discharges by Source.

DESCRIPTION	DISCHARGE RATES (kg/adt) AOX	POX	TOTAL
Plant A, Softwood			
C-STAGE SEAL TANK	4.19	0.17	4.36
COMBINED ALKALINE FILTRATE	3.54	0.05	3.59
BLEACHED STOCK WATER	0.06	--	0.06
Totals	7.79	0.22	8.01
Plant B, Softwood			
D/C SEAL TANK	1.34	0.008	1.35
Eo SEAL TANK	0.68	0.001	0.68
BLEACHED STOCK WATER	0.01	--	0.01
Totals	2.03	0.009	2.04
Plant C, Softwood			
C-STAGE SEAL TANK	1.39	0.05	1.42
E-STAGE SEAL TANK	1.51	0.011	1.52
H-STAGE SEAL TANK	0.45	0.007	0.46
BLEACHED STOCK WATER	0.03	--	0.03
Totals	3.38	0.068	3.43
Plant D, Hardwood			
C-STAGE SEAL TANK	0.39	0.026	0.42
E-STAGE SEAL TANK	0.54	0.09	0.63
H-STAGE SEAL TANK	0.06	0.025	0.08
BLEACHED STOCK WATER	0.01	--	0.01
Totals	1.0	0.14	1.14

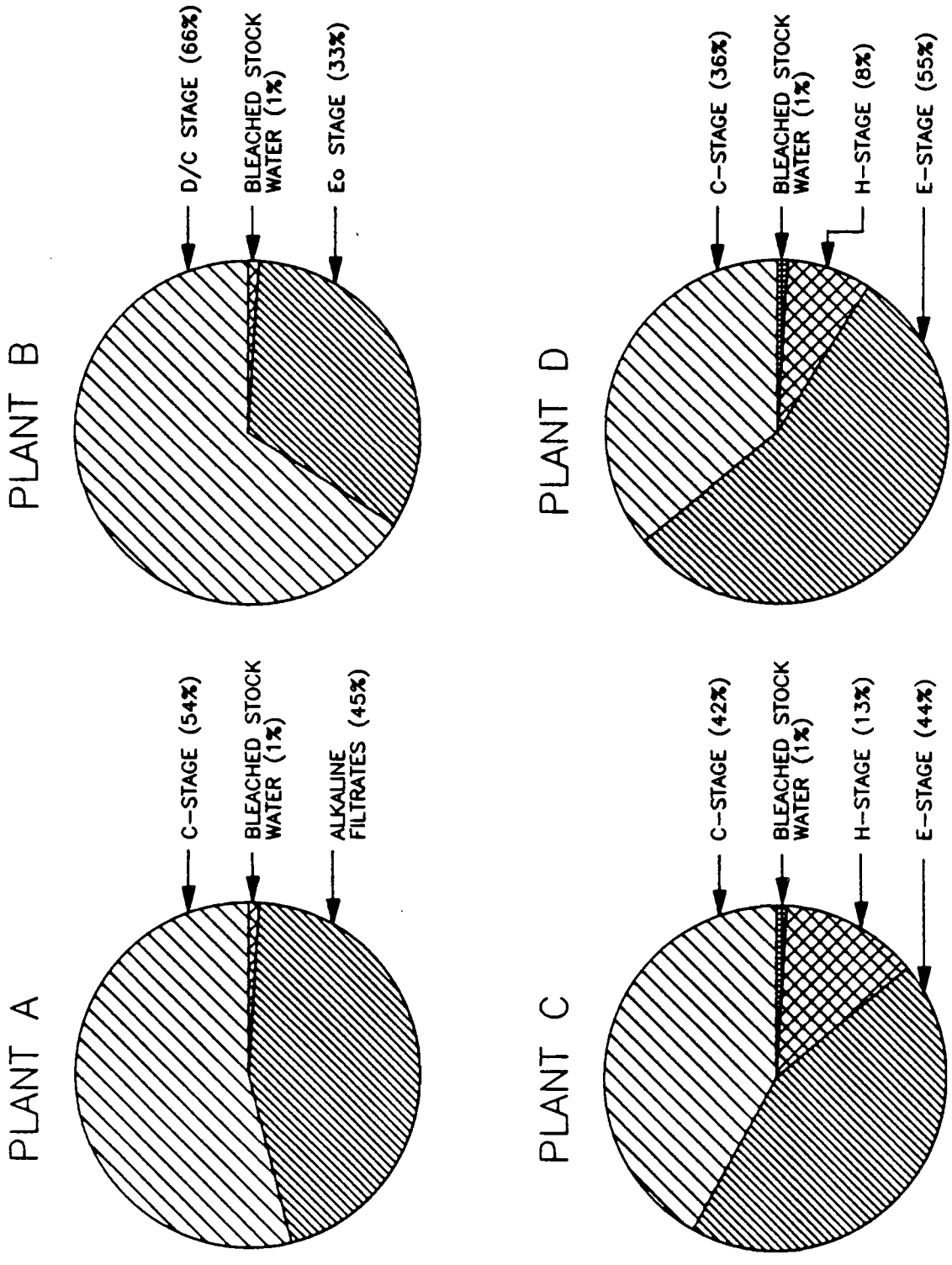


Figure 14. Contributions by source to total organochlorine discharge.

5 WORK IN PROGRESS

5.1 Anaerobic Biomass Acclimation.

Laboratory scale chemostats are being used to develop cultures of anaerobic bacteria acclimated to the presence of kraft mill bleach plant wastewaters. Two, 4-liter chemostats are operating at retention times between 30 and 50 days with a feed consisting of a neutralized mixture of chlorination and alkaline extraction filtrates from bleach plants "A", "B" and "C". The mixture is also being supplemented with acetic acid, which serves as a readily biodegradable substrate for methane-forming bacteria. To date, the quantity of methane produced in each chemostat has been approximately equal to that expected from the amount of acetate added in the feed. Data on AOX removal has not yet been obtained.

5.2 Batch Treatability Testing of Bleach Plant Filtrates.

Batch anaerobic treatability tests of each of the sampled filtrates are currently in progress. The significance of biomass acclimation for fermentation of the filtrates is being examined by comparing the treatability characteristics with unacclimated biomass, to those obtained with the acclimated biomass produced in the chemostats described above.

5.3 Activated Carbon Adsorption Studies.

It was initially hypothesized that activated carbon might be the best choice of support medium for the development of a fixed film high rate anaerobic process. This assumption was based on the fact that in previous studies with toxic wastewaters, the activated carbon served both as a biomass support medium, and as a sink for toxic compounds. By removing some of the toxics through adsorption, the wastewater toxicity was reduced enough to permit the growth of anaerobic bacteria. Preliminary experiments have been completed to determine the extent of adsorption obtained with bleach plant wastewaters, and to assess whether this adsorption increases the activity of anaerobic bacteria. Data from these experiments are under review. Negotiations are also underway with researchers at Bayer AG in West Germany, to obtain samples of a chemically-modified polyurethane carrier material developed for anaerobic treatment of industrial wastewaters. The German researchers have had considerable success in applying this material to bleached sulfite mill effluents.

5.4 Continuous Flow Treatability Studies.

Laboratory scale reactors for continuous flow anaerobic treatability studies are under design and construction. The continuous flow studies will be started after a source of bleach plant wastewater has been finalized from the batch experiments described above. The bleach plant demonstrating the highest

degree of wastewater treatability in the batch tests will be chosen for more extensive study in the continuous flow experiments.

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APPENDIX A

. DETERMINATION OF AOX

. MICROBIAL TOXICITY AND MUTAGENICITY TESTS

ADSORBABLE ORGANIC HALOGEN - COMBUSTION METHOD

Scope and Application

This method is capable of measuring organic halides (chlorine, bromine and iodine) in waters and wastewaters. Fluorine-containing species are not determined under these conditions.

Summary of Method

Up to 50 mL of an acidified sample (pH2 with HNO_3) is passed under pressure through a granular activated carbon column at a prescribed flow rate. The column is then washed with nitrate solution to remove any trapped inorganic halides. The carbon containing the adsorbed organic halides is combusted and the resulting Hx gas generated is trapped in acetic acid and titrated microcoulometrically.

Interferences

Contamination is the main source of interference upon this method, consequently reagents, glassware and other sample processing hardware must be of highest purity and cleanliness. Activated carbon must have minimal exposure time to the laboratory atmosphere and under no circumstances should it be used in, or adjacent to, laboratories that employ halogenated organic solvents.

Particles will cause the carbon column to choke, therfore samples with particulates must either be diluted or filtered prior to adsorption.

Filtering and mixing will cause losses of volatile organic halogens and should therefore be executed with this in mind.

Apparatus and Materials

- Adsorption Module - Dohrmann or equivalent pressurized unit
- Granular Activated Carbon - Xertex 100/200 mesh or equivalent with background Cl^- value of <1 ng/mg and satisfactory adsorption efficiencies of molecular weight species of <500 through >10 000.
- Cerafelt - (Available from Johns-Manville or Dohrmann), or equivalent.
- Combustion/microcoulometric-titration unit - Dohrmann or equivalent system.
- Data acquisition system.

Reagents

- Distilled/deionized water.
- Sodium Sulfite (0.1 m) - dissolve 12.6 g reagent grade Na_2SO_3 in 1 litre of water.
- Potassium Nitrate - (5×10^3 mg NO_3^-/L) - dissolve 8.2 g reagent grade KNO_3 in 1 litre of water.
- Nitric Acid - concentrated reagent grade.
- Acetic Acid - 70% aq.
- Trichlorophenol standard - dissolve 0.1855 g reagent grade $Cl_3C_6H_2OH$ in 50 mL glass distilled methanol and dilute up to 100 mL with water. 1 mL = 1×10^3 µg Cl^-
- Carbon dioxide - 99.9% pure gas.
- Oxygen - 99.9% pure gas.
- Nitrogen - pre-purified.

Sample Collection and Preservation:

A minimum of 100 mL of sample should be collected as this will allow at least duplicate analyses to be performed on a sample. After collection in an amber bottle fitted with teflon lined caps, 0.5 mL of 0.1 m Na_2SO_3 is added to neutralize any residual chlorine; NB: greater doses of $Na_2S_2O_3$ may be required depending on the stream being sampled. Add HNO_3 to reduce the pH to 2.0. Cap headspace free and refrigerate at 4°C or lower until analyses. No statistically significant changes have been observed in AOX concentration over a six-week period under these conditions.

Procedure

Place two cerafelt plugged, pyrex, carbon packed columns in the respective column holders. Attach the two plastic holders together in series and thread them onto the bottom of the sample reservoir on the adsorption unit, taking care to include the rubber 'O' rings at the top and bottom of each column.

Transfer up to 80 mL of sample to the reservoir, cap tightly and pressurize the system. Regulate the pressure so as to give a flow of 3-4 mL per minute. When the sample flow terminates, rinse the reservoir with 10-20 mL H_2O followed by a second rinse of 10-20 mL KNO_3 solution (5×10^3 ppm NO_3^-). Transfer the columns and holders to the nitrate rinse reservoir. Rinse with 4-5 mL of KNO_3 wash solution. The contents of the columns are then ejected into a quartz "solids combustion boat" and immediately transferred to the combustion/microcoulometric AOX analyser. Once a stable baseline is established, the instrument is started and the contents of the boat are pyrolyzed.

Calculations

$$\frac{C_s - C_b}{V} = \mu g/L \text{ adsorbable organic halide}$$

Where

C_s = μg Cl^- found in sample

C_b = μg Cl^- found in blank

V = volume of sample analysed.

Quality Control

Blanks should be run every five samples while standards should be run every ten samples in order to verify calibration.

Samples should be run in duplicate with one spike for every five samples.

Method Performance

Working with the maximum volume of sample (i.e. 80 mL), the detection limit of this method is 8 $\mu g/L$. Analyses (20) run on an industrial wastewater with a mean value of 11.05 $\mu g/mL$ produced a std. deviation = 0.32, variance = 0.099 and coefficient of variation = 2.85%. Spike recovries on several different matrices generated in the pulp and paper industry have rendered values of 85-100%.

J. Fraser
1988

ADSORBABLE ORGANIC CHLORINE, BROMINE, IODINE BY NEUTRON ACTIVATION

Scope and Application

This method may be used for the analysis of specific organic halogens with the exception of fluorine. This method is recommended for dealing with samples which contain suspended solids.

Summary of Method

An appropriate aliquot of a well mixed, properly preserved sample (up to 30 mL) is poured into a pyrex culture tube containing 80 mg granular activated carbon. The tube is capped and placed on a shaker for one hour after which the contents are filtered, washed, and placed in a scintillation vial for analysis.

Interferences

Contamination is the main source of interference upon this method, consequently reagents, glassware and other sample processing hardware must be of highest purity and cleanliness. Activated carbon must have minimal exposure time to the laboratory atmosphere and under no circumstances should it be used in, or adjacent to, laboratories that employ halogenated organic solvents.

Filtering and mixing will cause losses of volatile organic halogens and should therefore be executed with this in mind.

Apparatus and Materials

- 50 mL culture tubes with screw caps.
- Wrist arm shaker.
- Filter apparatus including 0.45 μm membrane filters, vacuum pump, vacuum flask and membrane filter holder.
- Scintillation vials - polyethylene snap cap containers.
- Granular activated carbon - Xertex 100/200 or equivalent.
- Access to a slow poke reactor.
- Gamma ray detector and data handling system.
- Potassium nitrate solution (5×10^3 ppm NO_3^-).

- Distilled/Deionized water.

- Sodium Sulphite (0.1 m) - 12.6 g of reagent grade Na_2SO_3 in 1 litre of H_2O.

- Reagent grade HNO_3.

- Trichlorophenol (1000 ppm) - dissolve 0.1856 g of reagent grade fresh trichlorophenol in 50 ml of glass distilled methanol and dilute to 100 mL with water.

Sample Collection and Preservation:

A minimum of 100 mL of sample should be collected as this will allow at least duplicate analyses to be performed on a sample. After collection in an amber bottle fitted with teflon lined caps, 0.5 mL of 0.1 m Na_2SO_3 is added to neutralize any residual chlorine; NB: greater doses of $Na_2S_2O_3$ may be required depending on the stream being sampled. Add HNO_3 to reduce the pH to 2.0. Cap headspace free and refrigerate at 4°C or lower until analyses. No statistically significant changes have been observed in AOX concentration over a six-week period under these conditions.

Procedure:

Transfer up to 30 mL of preserved sample to a 50 mL culture tube containing 80 mg GAC. Cap tightly and place the tubes on a Burell wrist arm shaker. Start the shaker and make sure that complete mixing is in effect; allow the contents to shake for one hour. Vacuum filter the mixture through a 0.45 µm membrane filter and wash the solute with 10-20 mL of 5×10^3 ppm NO_3^- solution. Carefully fold the membrane filter and place it in a scintillation vial, cap tightly, code it and submit it for neutron activation analysis. The method used for this is irradiation using the rabbit method with a slowpoke reactor having a neutron flux of 5×10^{12} neutrons/cm^2/sec. Chlorine is then analysed using the 1642-KeV gamma ray produced by 37.1-min ^{38}Cl; Bromine uses the 616-KeV gamma ray from 17.7-min ^{80}Br; Iodine is analysed using the 442-KeV gamma ray from 25-min ^{128}I.

Quality Control:

Blanks should be run every five samples while standards should be run every ten samples in order to verify calibration.

Samples should be run in duplicate with one spike for every five samples.

Method Performance:

Working with the maximum volume of sample (30 mL), the detection limit of this method is 1 µg/mL. With larger culture tubes and mixing apparatii, this detection limit may be reduced accordingly. Analyses (20)

run on an industrial wastewater with a mean value of 359 µg/mL produced a std. deviation = 26.6 with a coefficient of variation of 7.40%, while analyses (20) run on a wastewater with a mean of 77 µg/mL produced a std. deviation = 3.33 and a coefficient of variation of 4.31%. Spike recoveries on several different matrices generated in the pulp and paper industry have shown values of 80-100%.

J. Fraser
1988

DATA REPORT

Microbiological Toxicity and Mutagenicity Testing of Pulp and Paper Mill Wastewaters

Materials and Methods

Wastewater Collection and Preparation

Six to eight-hour composite wastewater samples were collected from various process streams from three kraft and one neutral sulphite semi-chemical mill (Table 1). They were transported to the Wastewater Technology Centre (WTC) in Burlington, Ontario within 24 hours of collection. The pH was adjusted to between 6.5 and 7.0 on all the wastewaters, except for one set of Sturgeon Falls wastewaters which were submitted for Daphnia bioassays at Beak Consultants. Both pH-adjusted and non-adjusted results are reported for those samples. The insoluble component of all the wastewaters was removed by centrifugation at 15,000 rpm for about 20 minutes. In a duplicate set of Sturgeon Falls wastewaters, glass fibre filtration was used for solids removal.

Analytical Methods

Toxicological type analyses included Daphnia magna, microtox, algal assays, the ATP-TOX system toxicity test, and Spirillum toxicity test. Daphnia bioassay results are reported as LC_{50} values which correspond to the concentration of the wastewater that is lethal to fifty percent of the Daphnia magna over a 96 hour incubation period.

The microtox toxicity analyzer developed by Beckman employs a bioluminescent strain of marine bacteria (Photobacterium phosphoreum). The principal of the microtox test is that the bioluminescence diminishes in response to exposure to toxicants. This reduction in light emittance is reported in terms of an effective concentration (EC_{50}). The EC_{50} denotes the concentration of toxicant required to inhibit 50% of the luminescence in P. phosphoreum.

In the algal-ATP assay, the ATP production in Selenastrum capricornutum is compared both in the presence and absence of possible toxicants. ATP-content is measured indirectly using light emission from the ATP-dependent luciferin-luciferease reaction. Results are given as percent inhibition of the algae in the presence of 100% wastewater concentration.

ATP-TOX system also uses the measurement of ATP as an indication of growth inhibition. It, however uses bacterial cells, not algae.

A toxic response in the Spirillum volutans test is indicated by a disruption in the co-ordinated movement of the flagellated bacterium, Spirillum volutans after 2 hours exposure to a toxicant. Results are given as a positive, which indicates a toxic effect, or a negative, if 90% of the bacteria are still mobile after the 2 hours exposure time. These were changed from a negative to a 1 and from a positive to a 0 for the purposes of graphical analysis.

The S.O.S. chromotest is used to detect a genotoxic response. An unrelated enzyme gene, B-galactosidase was introduced to the gene responsible for induction of the S.O.S. repair mechanism in the micro-organism provided in the S.O.S. kit. S.O.S. repair is induced by the bacteria in an attempt to repair DNA that is damaged by exposure to genotoxic agents. Since the B-galactosidase enzyme gene is incorporated into the S.O.S. repair operon, the B-galactosidase activity can be used as an indicator of S.O.S. repair hence exposure to a genotoxic agent. B-galactosidase activity is indicated by a color change. Results are provided in terms of an induction factor. Values greater than one indicate genotoxicity in the test sample relative to a control.

APPENDIX B

DETAILED LISTINGS OF CHEMICAL ANALYTICAL DATA

LEGEND

BOD	5-day biochemical oxygen demand
(UF)	unfiltered sample
(F)	filtered sample
COD(UF & F)	chemical oxygen demand
TKN(UF & F)	total Kjeldahl nitrogen
TP(UF & F)	total phosphorus
NH_4-N	ammonia as nitrogen
NO_2	nitrite
NO_3	nitrate
TOC	total organic carbon
H_2S-S	hydrogen sulphide as sulphur
SO_3	sulphite
SO_4	sulphate
S_2O_3	thiosulphate
AOX	adsorbable organic halide or total organic chlorine
ClO_3	chlorate

Metals

Al	aluminum
Ca	calcium
Cd	cadmium
Cr	chromium
Cu	copper
Fe	iron
Mn	manganese
Ni	nickel
Pb	lead
Zn	zinc

Na	sodium
Co	cobalt
Mg	magnesium

Resin Fatty Acids (RFA)

DHA	dehydroabietic acid
C-23:0	percent recovery of fatty acid spike
T.S.S.	total suspended solids
V.S.S.	volatile suspended solids

Purgeable Organic Halides

CCl_4	carbontetrachloride
$CHCl_3$	chloroform

Other Abbreviations

NA	not available
N.L.	non lethal
ND	non detectable

BLEACH PLANT "A" (results in mg/L unless otherwise indicated)

	BOD(UF)	BOD(F)	COD(UF)	TKN(UF)	TP(UF)	COD(F)	TKN(F)	TP(F)
BROWN STOCK	NA	NA	NA	NA	NA	NA	NA	NA
C-STAGE SEAL TANK	450	330	1120	2.8	2.2	960	2	2.6
COMB. ALKALINE FILTRATE	405	360	1320	1.1	0.4	1280	1.1	0.4
Eo STAGE SEAL TANK	585	540	2200	2	0.7	2280	2.1	0.7
H-STAGE SEAL TANK	30	30	80	0.3	<0.1	<1	0.2	<0.1
E2-STAGE SEAL TANK	40	40	120	0.8	0.2	80	0.3	<0.1
D-STAGE SEAL TANK	109	107	320	0.8	<0.1	180	0.8	0.2
#1 EVAPORATOR CONDENSATE	118	115	440	1.4	<0.1	220	1.4	<0.1
#2 EVAPORATOR CONDENSATE	164	142	460	1.2	<0.1	240	1.3	<0.1
COMBINED FOUL WATER	660	650	1220	15.1	0.2	1080	15.1	<0.1
BLEACHED PULP	NA	NA	NA	NA	NA	NA	NA	NA
Field blank	NA	NA	NA	NA	NA	NA	NA	NA

	VOLATILE ORGANIC ACIDS							
	ACETIC	PROP.	BUTYRIC	ISO-BUTYR	pH	AL	CA	CD
C-STAGE SEAL TANK	23	0	0	0	2.0	1.25	98	<.010
COMB. ALKALINE FILTRATE	27	0	0	0	10.0	0.275	13.8	<.010
Eo STAGE SEAL TANK	17	0	0	0	10.0	0.56	15.4	<.010
H-STAGE SEAL TANK	0	0	0	0	8.9	0.137	7.9	<.010
E2-STAGE SEAL TANK	0	0	0	0	10.8	0.52	22.5	<.010
D-STAGE SEAL TANK	0	0	0	2	2.8	0.42	31	<.010
#1 EVAPORATOR CONDENSATE	0	0	0	0	9.1	0.21	1	<.010
#2 EVAPORATOR CONDENSATE	3	0	0	0	8.7	0.2	0.4	<.010
COMBINED FOUL WATER	0	0	2	0	8.0	0.21	0.65	<.010

	RESIN FATTY ACIDS							
	linoleic	oleic	pimaric	sandaracopimaric	isopimaric	palustric	DHA	abietic
C-STAGE SEAL TANK	ND	ND	ND	ND	ND	ND	ND	ND
COMB. ALKALINE FILTRATE	ND	ND	ND	ND	ND	5.68	ND	ND
Eo STAGE SEAL TANK	ND	ND	ND	ND	ND	11.2	ND	ND
H-STAGE SEAL TANK	ND	ND	ND	ND	ND	ND	ND	ND
E2-STAGE SEAL TANK	ND	ND	ND	ND	ND	ND	ND	ND
D-STAGE SEAL TANK	ND	ND	ND	ND	ND	ND	ND	ND
#1 EVAPORATOR CONDENSATE	ND	9.96	0.527	ND	1.12	ND	ND	0.524
#2 EVAPORATOR CONDENSATE	ND	12.9	0.702	ND	1.63	1.63	ND	0.956
COMBINED FOUL WATER	ND	0.568	ND	ND	0.292	1.09	ND	0.454

	NH4+	NO2-	NO3-	TOC	H2S	SO3	SO4	S2O3
BROWN STOCK	NA	NA	NA	NA	NA	NA	NA	NA
C STAGE SEAL TANK	0.3	<0.1	0.3	560	0.1	NA	42	<10
COMB. ALKALINE FILTRATE	1.4	0.2	<0.1	652	3	NA	34	186
Eo STAGE SEAL TANK	2.2	0.3	<0.1	992	0.4	NA	60	105
H-STAGE SEAL TANK	<0.1	<0.1	0.3	64	0.1	NA	<10	<10
E2-STAGE SEAL TANK	0.2	<0.1	0.3	83	NA	NA	<10	<10
D-STAGE SEAL TANK	0.3	<0.1	0.4	156	0.3	NA	30	198
#1 EVAPORATOR CONDENSATE	0.8	<0.1	<0.1	89	5.9	NA	18	117
#2 EVAPORATOR CONDENSATE	0.7	<0.1	<0.1	112	8.4	NA	16	126
COMBINED FOUL WATER	10.5	<0.1	<0.1	350	24.7	NA	<10	NA
BLEACHED PULP	NA	NA	NA	NA	NA	NA	NA	NA
field blank	NA	NA	NA	NA	NA	NA	NA	NA

	METALS							
	CR	CU	FE	MN	NI	PB	ZN	NA
C-STAGE SEAL TANK	0.091	0.028	1.01	3.99	0.052	<.020	0.474	224
COMB. ALKALINE FILTRATE	0.027	0.029	0.407	0.235	0.042	<.020	0.069	780
Eo STAGE SEAL TANK	0.057	<.010	0.507	0.3	0.041	<.020	0.073	978
H-STAGE SEAL TANK	0.037	<.010	0.3	0.035	0.043	<.020	0.047	160
E2-STAGE SEAL TANK	0.025	<.010	0.223	0.037	0.019	0.268	0.051	429
D-STAGE SEAL TANK	0.047	0.02	0.525	0.216	0.016	<.020	0.136	170
#1 EVAPORATOR CONDENSATE	0.049	<.010	0.267	0.014	<.010	<.020	0.05	12.8
#2 EVAPORATOR CONDENSATE	0.018	0.012	0.14	0.013	<.010	<.020	0.053	18.5
COMBINED FOUL WATER	0.018	0.043	0.176	0.016	<.010	<.020	0.053	14.5

	neo-abietic	chloro-DHA	dichloro-DHA	TOTAL RFA	C-23:0 (% rec)	T.S.S.	V.S.S.
C-STAGE SEAL TANK	ND	ND	ND	ND	94.4	23	25
COMB. ALKALINE FILTRATE	ND	0.546	0.27	6.496	97.1	58	48
Eo STAGE SEAL TANK	0.521	1.01	0.46	13.191	109	53	45
H-STAGE SEAL TANK	ND	ND	ND	ND	79.8	57	57
E2-STAGE SEAL TANK	ND	ND	ND	ND	93.6	23	27
D-STAGE SEAL TANK	ND	ND	ND	ND	97.7	7	13
#1 EVAPORATOR CONDENSATE	ND	ND	ND	12.131	96.1	23	18
#2 EVAPORATOR CONDENSATE	ND	1.1	ND	18.918	94.9	13	23
COMBINED FOUL WATER	ND	ND	ND	2.404	89.4	10	17

	TOTAL SULPHUR	AOX	WOOD SUGAR	METHANOL	ACID SOL. LIGNIN	ACID INS. LIGNIN	CL	CLO3
BROWNSTOCK	NA	24.3 ug/g	NA	NA	NA	NA	NA	NA
C-STAGE SEAL TANK	102	209	305	305	1400	916	2886	157
COMB. ALKALINE FILTRATE	108	117	213	213	440	392	616	10
Eo STAGE SEAL TANK	114	145	312	312	920	660	846	4
H-STAGE SEAL TANK	138	22.4	25	<10	840	312	231	4
E2 STAGE SEAL TANK	168	12	53	<10	320	288	168	<1
D STAGE SEAL TANK	156	12.3	155	<10	1040	352	350	287
#1 EVAPORATOR CONDENSATE	140	0.3	10	52	440	252	<10	NA
#2 EVAPORATOR CONDENSATE	132	0.2	14	56	280	112	<10	NA
COMBINED FOUL WATER	200	0.2	14	587	440	152	<10	NA
BLEACHED PULP	NA	76.9 ug/g	NA	NA	NA	NA	NA	NA
Field blank	NA	3.1	NA	NA	NA	NA	NA	NA

	CO	MG
C-STAGE SEAL TANK	<.010	16
COMB. ALKALINE FILTRATE	<.010	3.6
Eo STAGE SEAL TANK	<.010	3.38
H-STAGE SEAL TANK	<.010	2.96
E2-STAGE SEAL TANK	<.010	5.53
D-STAGE SEAL TANK	<.010	7.7
#1 EVAPORATOR CONDENSATE	<.010	0.24
#2 EVAPORATOR CONDENSATE	<.010	0.24
COMBINED FOUL WATER	<.010	0.28

C STAGE SEAL TANK
COMB. ALKALINE FILTRATE
Eo STAGE SEAL TANK
H-STAGE SEAL TANK
E2-STAGE SEAL TANK
D-STAGE SEAL TANK
#1 EVAPORATOR CONDENSATE
#2 EVAPORATOR CONDENSATE
COMBINED FOUL WATER

	COD	EXTRACT.	PHENOL	TOXICITY LC50 (% vol/vol)
BROWN,TMCI	NA	NA	NA	NA
C-STAGE SEAL TANK	<1	7.4	0.11	6.34
COMB. ALKALINE FILTRATE	<1	7.8	0.19	20.09
Eo STAGE SEAL TANK	<1	9.2	0.27	17.86
H-STAGE SEAL TANK	<1	1.8	0.04	3.75
E2-STAGE SEAL TANK	<1	1.5	0.02	59.78
D-STAGE SEAL TANK	<1	1.4	<0.1	12.4
#1 EVAPORATOR CONDENSATE	<1	50.2	14.2	0.88
#2 EVAPORATOR CONDENSATE	<1	33.5	17.6	4.02
COMBINED FOUL WATER	<1	35.5	8.56	6.76
BLEACHED PULP	NA	NA	NA	NA
Field blank	NA	NA	NA	NA

C-STAGE SEAL TANK
COMB. ALKALINE FILTRATE
Eo STAGE SEAL TANK
H-STAGE SEAL TANK
E2-STAGE SEAL TANK
D-STAGE SEAL TANK
#1 EVAPORATOR CONDENSATE
#2 EVAPORATOR CONDENSATE
COMBINED FOUL WATER

C-STAGE SEAL TANK
COMB. ALKALINE FILTRATE
Eo STAGE SEAL TANK
H-STAGE SEAL TANK
E2-STAGE SEAL TANK
D-STAGE SEAL TANK
#1 EVAPORATOR CONDENSATE
#2 EVAPORATOR CONDENSATE
COMBINED FOUL WATER

CCl4	CHCl3
0.0013	10
0.01	1.6
0.0058	0.78
0.0084	7.8
0.0009	0.23
ND	0.024
NA	NA
NA	NA
NA	NA

BLEACH PLANT "B"

(All results given in mg/l unless otherwise noted)

	BOD(UF)	BOD(F)	COD(UF)	TKN(UF)	TP(UF)	COD(F)	TKN(F)	TP(F)	NH4-N
BARRAFLOOR WATER	NA	NA	NA	NA	NA	NA	NA	NA	NA
"A" HOT WATER	302	267	1050	3.3	<0.1	780	3.1	<0.1	2.6
D/C SEAL TANK	450	420	3800	0.9	3.9	2200	0.8	4.2	0.3
Eo SEAL TANK	975	940	8000	5.5	3.3	7200	5.1	3.8	4.2
D1 SEAL TANK	420	391	2400	1.5	1	2020	1.6	1.1	0.5
"B" WHITE WATER	111	78	1350	1.4	0.3	1100	0.5	0.2	0.6
FIELD BLANK	NA	NA	NA	NA	NA	NA	NA	NA	NA
BLEACHED PULP	NA	NA	NA	NA	NA	NA	NA	NA	NA

	--VOLATILE ORGANIC ACIDS--								
	ACETIC	PROPIONIC	BUTYRIC	ISOBUTYRIC	pH	Al	Ca	Cd	Cr
"A" HOT WATER	0	0	0	0	6.5	0.24	7.33	<.010	<.010
D/C SEAL TANK	0	0	0	0	1.9	3	162	<.010	0.472
Eo SEAL TANK	18	0	0	0	10.2	0.5	23.5	<.010	0.67
D1 SEAL TANK	0	0	0	0	2.9	2.1	70	<.010	1.22
"B" WHITE WATER	0	0	0	0	4.1	0.5	8.4	<.010	0.04

	RESIN FATTY ACIDS								
	LINOLEIC	OLEIC	PIMARIC	SANDARA-COPIMARIC	ISO-PIMARIC	PALUSTRIC	DHA	ABIETIC	NEO-ABIETIC
"A" HOT WATER	ND	0.384	0.315	ND	0.7	ND	ND	ND	ND
D/C SEAL TANK	ND	ND	ND	ND	ND	ND	ND	ND	ND
Eo SEAL TANK	ND	ND	ND	ND	ND	2.02	1.38	ND	0.408
D1 SEAL TANK	ND	ND	ND	ND	ND	ND	ND	ND	ND
"B" WHITE WATER	ND	ND	ND	ND	ND	ND	ND	ND	ND

	CHCl3 (mg/L)	CCl4 (mg/mL)
"A" HOT WATER	NA	NA
D/C SEAL TANK	1.2	0.41
Eo SEAL TANK	0.18	0.42
D1 SEAL TANK	0.1	0.04
"B" WHITE WATER	NA	NA

	NO2	NO3	TOC	H2S S	Cl-	SO4	S2O3	TOTAL SULPHUR	ROX
BROWN STOCK WATER	NA	NA	NA	NA	NA	NA	NA	NA	5.7 ug/g
"A" HOT WATER	<0.1	<0.1	161	4.8	8	13	43	78	0.3
D/C SEAL TANK	<0.1	0.3	876	0.4	2711	88	<10	84	184.5
Eo SEAL TANK	0.7	0.4	.0002	<0.1	2446	113	NA	270	139
D1 SEAL TANK	<0.1	0.5	816	0.4	1918	189	45	190	70.8
"B" WHITE WATER	<0.1	0.2	125	0.4	52	46	<10	79	7
FIELD BLANK	NA	NA	NA	0.2	NA	NA	NA	NA	NA
BLEACHED PULP	NA	NA	NA	NA	NA	NA	NA	NA	51.9 ug/g

METALS

	Cu	Fe	Mn	Ni	Pb	Zn	Na	Co	Mg
"A" HOT WATER	0.045	0.163	0.016	<.010	<.020	0.041	22	<.010	2
D/C SEAL TANK	0.051	1.43	5.49	0.025	<.020	0.792	685	<.010	30
Eo SEAL TANK	0.086	2.1	8.4	0.01	<.020	0.336	2655	<.010	10.5
D1 SEAL TANK	0.066	2.11	2.34	0.053	<.020	0.442	1327	<.010	19.2
"B" WHITE WATER	0.04	0.324	0.053	<.010	<.020	0.096	95.5	<.010	4.75

	CHLORO-DHA	DICHLORO-DHA	TOTAL RFA	C-23:0 (% RECO)
"A" HOT WATER	ND	ND	1.399	95.9
D/C SEAL TANK	0.283	ND	0.283	111
Eo SEAL TANK	11.3	0.443	15.551	113
D1 SEAL TANK	1.56	ND	1.56	115
"B" WHITE WATER	2.15	ND	2.15	112

"A" HOT WATER
D/C SEAL TANK
Eo SEAL TANK
D1 SEAL TANK
"B" WHITE WATER

	WOOD SUGAR	METHANOL	ACID SOL. LIGNIN	ACID INS. LIGNIN	C103	C102	EXTRACT.	TOXICITY LC50
BROWNSTOCK WATER	NA	NA	NA	NA	NA	NA	NA	NA
"A" HOT WATER	8	252	1520	92	NA	NA	NA	7.49
D/C SEAL TANK	201	374	1080	88	251	<1	9.1	17.63
Eo SEAL TANK	621	365	880	1596	501	<1	32.5	16.59
D1 SEAL TANK	158	73	1960	100	837	<1	18.3	40.84
"B" WHITE WATER	22	<10	840	192	NA	NA	151.4	48.34
FIELD BLANK	NA	NA	NA	NA	NA	NA	NA	NA
BLEACHED PULP	NA	NA	NA	NA	NA	NA	NA	NA

"A" HOT WATER
D/C SEAL TANK
Eo SEAL TANK
D1 SEAL TANK
"B" WHITE WATER

"A" HOT WATER
D/C SEAL TANK
Eo SEAL TANK
D1 SEAL TANK
"B" WHITE WATER

"A" HOT WATER
D/C SEAL TANK
Eo SEAL TANK
D1 SEAL TANK
"B" WHITE WATER

[illegible] PLANT: "C" (softwood) & "H" (hardwood)
results in mg/L unless otherwise indicated

	BOD(UF)	BOD(F)	COD(UF)	TKN(UF)	TP(UF)	COD(F)	TKN(F)
SOFT, BROWNSTOCK	NA	NA	NA	NA	NA	NA	NA
SOFT, C-STAGE SEAL TANK	180	240	1450	2.3	3.1	1410	2.1
SOFT, E-STAGE SHOWER WATER	3	3	11	1.6	0.2	<10	0.3
SOFT, E-STAGE SEAL TANK	230	291	2330	1.4	0.8	2180	1.6
SOFT, H-STAGE SEAL TANK	90	101	605	1	0.4	560	0.6
SOFT, D-STAGE SHOWER WATER	30	17	250	2.2	<0.1	120	0.3
SOFT, D-STAGE SEAL TANK	66	36	214	1.5	<0.1	210	0.5
BLEACHED PULP	NA	NA	NA	NA	NA	NA	NA
HARD, BROWNSTOCK	NA	NA	NA	NA	NA	NA	NA
HARD, C-STAGE SEAL TANK	84	63	740	1.5	6.9	630	0.7
HARD, E-STAGE SEAL TANK	336	210	1160	3	3.4	1040	1.1
HARD, H-STAGE SEAL TANK	60	40	302	3.1	2.0	260	0.4
HARD, D-STAGE SHOWER TANK	45	30	312	3.1	0.9	270	<0.1
HARD, D-STAGE SEAL TANK	9	4	138	1.7	2.8	70	<0.1
BLEACHED PULP	NA	NA	NA	NA	NA	NA	NA
STRIPPER FEED	1560	1080	6140	777	0.5	4110	80.5
INFLUENT, BIOPLANT	362	293	1450	9.2	1.6	1280	3.9
EFFLUENT, BIOPLANT	NA	11	415	11.7	2.1	370	1.5
Fieldblank	NA	NA	18	1.6	<0.1	NA	NA

	VOLATILE ORGANIC ACIDS						
	ACETIC	PROP.	BUTYRIC	ISO-BUTYR	TOTAL	AL	CA
SOFT, C-STAGE SEAL TANK	0	0	0	0	<2	1	121
SOFT, E-STAGE SHOWER WATER	0	0	0	0	<2	0.074	9.12
SOFT, E-STAGE SEAL TANK	0	0	0	0	<2	0.585	62
SOFT, H-STAGE SEAL TANK	0	0	0	0	<2	0.2	22.3
SOFT, D-STAGE SHOWER WATER	0	0	0	0	<2	0.144	9.02
SOFT, D-STAGE SEAL TANK	0	0	0	0	<2	0.45	28.2
HARD, C-STAGE SEAL TANK	0	0	0	0	<2	1.29	295
HARD, E-STAGE SEAL TANK	0	0	0	0	<2	0.417	57
HARD, H-STAGE SEAL TANK	0	0	0	0	<2	0.175	106
HARD, D-STAGE SHOWER TANK	0	0	0	0	<2	0.164	27.5
HARD, D-STAGE SEAL TANK	0	0	0	0	<2	0.175	149
STRIPPER FEED	32	0	0	21	53	0.15	4.22
INFLUENT, BIOPLANT	23	0	0	0	23	1.38	92
EFFLUENT, BIOPLANT	0	0	0	0	<2	0.99	84.5
Fieldblank	NA	NA	NA	NA	NA	0.457	0.935

	TP(F)	NH4+	NO2	NO3	TOC	H2S	SO3
SOFT, BROWNSTOCK	NA	NA	NA	NA	NA	NA	NA
SOFT, C-STAGE SEAL TANK	1.8	0.4	<0.1	0.1	559	0.2	NA
SOFT, E-STAGE SHOWER WATER	0.1	0.2	<0.1	0.1	7.6	<0.1	NA
SOFT, E-STAGE SEAL TANK	0.5	1.2	<0.1	<0.1	776	0.4	NA
SOFT, H-STAGE SEAL TANK	0.4	0.3	<0.1	0.1	271	0.4	NA
SOFT, D-STAGE SHOWER WATER	0.3	0.3	<0.1	<0.1	54	0.3	NA
SOFT, D-STAGE SEAL TANK	0.1	0.4	<0.1	0.2	104	0.2	NA
BLEACHED PULP	NA	NA	NA	NA	NA	NA	NA
HARD, BROWNSTOCK	NA	NA	NA	NA	NA	NA	NA
HARD, C-STAGE SEAL TANK	3.8	0.2	<0.1	0.2	323	0.4	NA
HARD, E-STAGE SEAL TANK	1	0.4	<0.1	0.1	435	0.3	NA
HARD, H-STAGE SEAL TANK	0.9	0.2	<0.1	0.1	113	0.3	NA
HARD, D-STAGE SHOWER TANK	0.5	0.2	<0.1	<0.1	38	0.4	NA
HARD, D-STAGE SEAL TANK	1.2	0.2	<0.1	<0.1	42	0.8	NA
BLEACHED PULP	NA	NA	NA	NA	NA	NA	NA
STRIPPER FEED	0.1	58.2	<0.1	<0.1	1021	199	NA
INFLUENT, BIOPLANT	0.6	1	<0.1	<0.1	452	1.8	NA
EFFLUENT, BIOPLANT	0.2	2.42	<0.1	<0.1	128	1.2	NA
fieldblank	NA	NA	NA	NA	NA	NA	NA

	METALS						
	CD	CR	CU	FE	MN	NI	PB
SOFT, C-STAGE SEAL TANK	<.020	0.074	0.054	1.96	4.62	0.164	0.1
SOFT, E-STAGE SHOWER WATER	<.020	<.020	<.020	0.225	0.032	<.020	<.020
SOFT, E-STAGE SEAL TANK	<.020	0.025	0.032	0.842	3.17	0.05	<.020
SOFT, H-STAGE SEAL TANK	<.020	0.025	0.032	0.717	0.85	0.087	<.020
SOFT, D-STAGE SHOWER WATER	<.020	<.020	<.020	0.3	0.015	<.020	<.020
SOFT, D-STAGE SEAL TANK	<.020	0.22	0.035	1.22	1.05	0.125	0.5
HARD, C-STAGE SEAL TANK	<.020	0.06	0.05	3.62	3.97	0.167	0.15
HARD, E-STAGE SEAL TANK	<.020	<.020	0.022	0.73	1.36	0.03	<.020
HARD, H-STAGE SEAL TANK	<.020	<.020	0.055	0.605	1	0.052	<.020
HARD, D-STAGE SHOWER TANK	<.020	<.020	0.025	0.525	0.178	0.032	<.020
HARD, D-STAGE SEAL TANK	<.020	0.03	0.025	0.75	1.32	0.065	<.020
STRIPPER FEED	<.020	<.020	<.020	0.182	0.027	0.02	<.020
INFLUENT, BIOPLANT	<.020	0.02	0.025	1.42	1.82	0.045	<.020
EFFLUENT, BIOPLANT	<.020	<.020	0.025	0.825	2.65	0.04	<.020
fieldblank	<.020	<.020	0.022	0.05	<.020	<.020	<.020

	VH4	S2O3	TOTAL SULPHUR	AOX	WOOD SUGAR	METHANOL	ACID SOL. LIGNIN
SOFT, BROWNSTOCK	NA	NA	NA	4.8	NA	NA	NA
SOFT, O-STAGE SEAL TANK	428	<10	NA	198	235	185	2080
SOFT, E-STAGE SHOWER WATER	37	<10	116	10.5	<1	30	2120
SOFT, E-STAGE SEAL TANK	164	<10	53	176	166	89	1680
SOFT, H-STAGE SEAL TANK	54	<10	95	42	64	21	2040
SOFT, D-STAGE SHOWER WATER	112	<10	63	5.6	34	<10	5440
SOFT, D-STAGE SEAL TANK	238	<10	137	8.9	80	115	3560
BLEACHED PULP	NA	NA	NA	57.6	NA	NA	NA
HARD, BROWNSTOCK	NA	NA	NA	1.9	NA	NA	NA
HARD, O-STAGE SEAL TANK	82	<10	74	108	281	72	1520
HARD, E-STAGE SEAL TANK	132	<10	63	48	83	62	2120
HARD, H-STAGE SEAL TANK	247	<10	158	16	43	<10	440
HARD, D-STAGE SHOWER TANK	141	<10	116	5.6	20	<10	1240
HARD, D-STAGE SEAL TANK	309	<10	200	4.3	19	<10	520
BLEACHED PULP	NA	NA	NA	112.9	NA	NA	NA
STRIPPER FEED	13	1110	179	1	<1	NA	800
INFLUENT, BIOPLANT	164	87	105	24	66	85	1200
EFFLUENT, BIOPLANT	156	<10	169	14	20	<10	1400
Fieldblank	NA	NA	NA	NA	<1	NA	680

	ZN	NA	CO
SOFT, O-STAGE SEAL TANK	0.875	325	<.020
SOFT, E-STAGE SHOWER WATER	0.042	4.75	<.020
SOFT, E-STAGE SEAL TANK	0.325	1550	<.020
SOFT, H-STAGE SEAL TANK	0.125	465	<.020
SOFT, D-STAGE SHOWER WATER	0.05	134	<.020
SOFT, D-STAGE SEAL TANK	0.151	168	<.020
HARD, O-STAGE SEAL TANK	1.6	158	<.020
HARD, E-STAGE SEAL TANK	0.592	1290	<.020
HARD, H-STAGE SEAL TANK	0.25	258	<.020
HARD, D-STAGE SHOWER TANK	0.094	101	<.020
HARD, D-STAGE SEAL TANK	0.637	60.2	<.020
STRIPPER FEED	0.05	15.8	<.020
INFLUENT, BIOPLANT	0.372	409	<.020
EFFLUENT, BIOPLANT	0.188	285	<.020
Fieldblank	0.042	0.472	<.020

	ACID INS. LIGNIN	CL-	CLO3	CLO2	EXTRACT.	PHENOL	TOXICITY LC50 (% VOL/VOL)
SOFT, BROWNSTOCK	NA	NA	NA	NA	NA	NA	NA
SOFT, C-STAGE SEAL TANK	268	2505	97	<1	18.89	0.09	8.73
SOFT, E-STAGE SHOWER WATER	240	5	<1	<1	2.35	0.02	<100
SOFT, E-STAGE SEAL TANK	204	1621	95	<1	7.03	0.30	99.99
SOFT, H-STAGE SEAL TANK	308	648	29	<1	5.10	0.12	N.L.
SOFT, D-STAGE SHOWER WATER	116	124	63	<1	7.47	0.01	82.13
SOFT, D-STAGE SEAL TANK	208	289	163	<1	1.62	<0.01	N.L.
BLEACHED PULP	NA	NA	NA	NA	NA	NA	NA
HARD, BROWNSTOCK	NA	NA	NA	NA	NA	NA	NA
HARD, C-STAGE SEAL TANK	148	1468	125	<1	4.39	0.05	43.61
HARD, E-STAGE SEAL TANK	252	1373	120	<1	13.74	0.10	21.21
HARD, H-STAGE SEAL TANK	176	420	87	<1	6.90	0.06	54.77
HARD, D-STAGE SHOWER TANK	152	72	70	<1	23.42	0.11	100
HARD, D-STAGE SEAL TANK	128	184	162	<1	7.13	0.02	N.L.
BLEACHED PULP	NA	NA	NA	NA	NA	NA	NA
STRIPPER FEED	104	<1	85	<1	233.00	41.67	1.67
INFLUENT, BIOPLANT	216	510	55	<1	15.47	0.95	97.93
EFFLUENT, BIOPLANT	248	509	12	<1	3.59	0.06	N.L.
fieldblank	72	<1	<1	<1	1.20	<0.01	NA

SOFT, C-STAGE SEAL TANK
SOFT, E-STAGE SHOWER WATER
SOFT, E-STAGE SEAL TANK
SOFT, H-STAGE SEAL TANK
SOFT, D-STAGE SHOWER WATER
SOFT, D-STAGE SEAL TANK
HARD, C-STAGE SEAL TANK
HARD, E-STAGE SEAL TANK
HARD, H-STAGE SEAL TANK
HARD, D-STAGE SHOWER TANK
HARD, D-STAGE SEAL TANK
STRIPPER FEED
INFLUENT, BIOPLANT
EFFLUENT, BIOPLANT
fieldblank

BLEACH PLANTS "C" (softwood) & "D" (hardwood)
results in mg/L unless otherwise indicated

	pH	linoleic	oleic	pimaric	sandaracopimaric	isopimaric
SOFT, C-STAGE SEAL TANK	2.2	ND	ND	ND	ND	ND
SOFT, E-STAGE SHOWER WATER	7.6	ND	ND	ND	ND	ND
SOFT, E-STAGE SEAL TANK	11.0	ND	ND	ND	ND	0.922
SOFT, H-STAGE SEAL TANK	9.5	ND	ND	ND	ND	0.305
SOFT, D-STAGE SHOWER WATER	6.0	ND	ND	ND	ND	ND
SOFT, D-STAGE SEAL TANK	2.6	ND	ND	ND	ND	ND
HARD, C-STAGE SEAL TANK	2.6	ND	ND	ND	ND	ND
HARD, E-STAGE SEAL TANK	11.6	ND	ND	ND	ND	1.23
HARD, H-STAGE SEAL TANK	6.9	ND	ND	ND	ND	3.47
HARD, D-STAGE SHOWER TANK	7.1	ND	ND	ND	ND	ND
HARD, D-STAGE SEAL TANK	3.1	ND	ND	ND	ND	ND
SIPIPPER FEED	8.9	0.943	0.48	0.114	0.28	0.357
INFLUENT, BIOPLANT	8.6	13.3	0.964	ND	ND	0.403
EFFLUENT, BIOPLANT	7.9	ND	ND	ND	ND	ND
Fieldblank	NA	ND	ND	ND	ND	ND

	Resin Fatty Acids						
	palustric	DHA	abietic	neo-abietic	chloro-DHA	dichloro-DHA	TOTAL RFA
SOFT, C-STAGE SEAL TANK	ND	ND	ND	ND	ND	ND	ND
SOFT, E-STAGE SHOWER WATER	ND	ND	ND	ND	ND	ND	ND
SOFT, E-STAGE SEAL TANK	ND	ND	ND	0.202	0.458	0.706	2.288
SOFT, H-STAGE SEAL TANK	ND	ND	ND	ND	0.378	0.278	0.961
SOFT, D-STAGE SHOWER WATER	ND	ND	ND	ND	ND	ND	ND
SOFT, D-STAGE SEAL TANK	ND	ND	ND	ND	ND	ND	ND
HARD, C-STAGE SEAL TANK	ND	ND	ND	ND	ND	ND	ND
HARD, E-STAGE SEAL TANK	ND	ND	1.63	3.37	0.296	0.195	6.721
HARD, H-STAGE SEAL TANK	ND	3.03	ND	ND	2.23	ND	8.73
HARD, D-STAGE SHOWER TANK	ND	ND	ND	ND	ND	ND	ND
HARD, D-STAGE SEAL TANK	ND	ND	ND	ND	ND	ND	ND
STRIPPER FEED	1.04	ND	0.583	0.341	ND	ND	4.138
INFLUENT, BIOPLANT	2.14	0.736	1.13	ND	ND	ND	18.673
EFFLUENT, BIOPLANT	ND	ND	ND	ND	ND	ND	ND
fieldblank	ND	ND	ND	ND	ND	ND	ND

	D-23:0 (% rec.)	T.S.S.	V.S.S.
SOFT, C-STAGE SEAL TANK	114	505	490
SOFT, E-STAGE SHOWER WATER	108	10	45
SOFT, E-STAGE SEAL TANK	130	0	0
SOFT, H-STAGE SEAL TANK	108	65	135
SOFT, D-STAGE SHOWER WATER	83.2	80	245
SOFT, D-STAGE SEAL TANK	81.1	0	0
HARD, C-STAGE SEAL TANK	116	455	475
HARD, E-STAGE SEAL TANK	NA	115	45
HARD, H-STAGE SEAL TANK	96.5	50	80
HARD, D-STAGE SHOWER TANK	111	180	160
HARD, D-STAGE SEAL TANK	111	0	0
STRIPPER FEED	107	0	0
INFLUENT, BIOPLANT	NA	65	65
EFFLUENT, BIOPLANT	100	65	30
Fieldblank	109	NA	NA