INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

PROGRESS REPORT
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NEW WESTMINSTER, B. C.
CANADA
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ABSTRACT

Occasional substandard detoxification of kraft pulp mill effluent during treatment in an aerated lagoon at Kamloops Pulp and Paper prompted this study. The 8-month study encompassed a period when changes were made within the pulp mill to reduce pollution load. The in-plant changes, involving liquor recovery, contaminated water recycling, and control of black liquor spills reduced pollution load as measured by BOD and acute toxicity.

Treatment performance by the aerated lagoon was compared with a laboratory treatment unit and indicated that both responded similarly to kraft mill effluent. Spills of black liquor were responsible for substandard detoxification on some occasions, but they were not the only cause since this also occurred when no spills were evident. Effluents resulting from pulping green (not aged) Douglas fir or spruce chips were sometimes associated with substandard detoxification, but not always. Whatever their source, there was evidence that, when present, residual toxic materials might be highly resistant to biological oxidation.

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INTRODUCTION

Kamloops Pulp and Paper Co. Ltd. (Weyerhaeuser Canada Ltd. as of October 1971) commenced operation of a nominal 250 air dry ton per day (ADT, tpd) bleached kraft pulp mill at Kamloops, B.C. in December 1965. Recent production has been about 290 tpd and expansion to 1,250 tpd was planned for 1972. The mill is located along the Thompson River, 3 miles upstream of 17 mile long Kamloops Lake. The Thompson River serves as the migration route for salmon, including more than a million sockeye salmon (*Oncorhynchus nerka*) headed upstream in autumn to their native spawning grounds. Millions of sockeye smolts move downstream in spring during their journey to the ocean. In addition, young sockeye fry move downstream past the mill to Kamloops Lake where they live for one year before departing for the ocean. The Thompson River downstream of Kamloops Lake supports a variety of salmonids, and serves as the spawning ground for hundreds of thousands of pink salmon (*O. gorbuscha*).

In order to protect water quality and the valuable fisheries resources of the Thompson River system, mill effluent was required by the Canada Department of the Environment, Fisheries Service to meet certain standards including minimum BOD reductions of 60%. In addition, standards required that young salmon survive an acute toxicity test consisting of four days exposure to a mixture of 65 parts treated effluent and 35 parts river water (i.e. 65% v/v treated effluent).

In order to meet standards of effluent quality all mill effluents received 12 hr of sedimentation followed by biological oxidation in an aerated lagoon (surface aerators, 390 total hp) calculated to have about a 4-day filling time at the mean effluent discharge of 12 million U.S. gallons per day (12 MUSGD). Since considerable mixing occurred in the aerated lagoon (Bailey, 1967), plug flow did not occur and detention time was not considered precisely equal to filling time. However, the terminology "detention time" will be used herein with the understanding that it is not precise.

The treatment scheme was successful, removing 80% or more of the BOD and discharging an effluent which satisfied monthly tests for acute toxicity, as described above. However, following two years of successful treatment, effluents periodically failed to meet the detoxification standard even though BOD reduction was normal. There were no obvious reasons for substandard detoxification but the mill staff found an apparent correlation with pulping of "green" (less than two weeks between chipping and pulping) Douglas fir (Pseudotsuga taxifolia) chips. Green Engelmann spruce (Picea engelmanni) chips were not excluded as possible contributors to problems of substandard detoxification but Lodgepole pine (Pinus contorta latifolia) chips were not implicated. However, aberrant function of the aerated lagoon was not ruled out as a contributing factor.

In hope of determining the cause of substandard detoxification, a joint study including Kamloops Pulp and Paper Co. Ltd., the Western Forest Products Laboratory (Canada Department of the Environment) and the International Pacific Salmon Fisheries Commission (I.P.S.F.C.) was started in January and concluded in August 1971.

METHODS

The primary role of Kamloops Pulp and Paper (KPP) was to supply samples of raw (pH neutralized) and treated effluent to the Cultus Lake laboratory of the I.P.S.F.C. on a 4-day per week basis (later expanded to five days per week) via overnight freight shipment. A total of 127 and 137 samples of raw and treated effluent, respectively, were processed. Samples of effluent arrived at the Cultus laboratory in 5-gal plastic containers about 19 hr after collection at which time measurements of pH, 5-day BOD and toxicity were started. Initially raw effluent was collected at the mill following pH neutralization and 12 hr of sedimentation. However, during the Interim System period, to be described later, raw effluent was composited automatically following pH neutralization. The samples were filtered through fiberglass wool to remove suspended matter prior to shipment.

The mill staff also measured BOD of raw and treated effluents at KPP and recorded spills or other upsets. For the purpose of calculating BOD reduction at Kamloops the BOD of a composite sample of raw effluent collected prior to sedimentation was compared with the BOD of treated effluent. Samples of treated effluent were grab samples from the aerated lagoon outfall zones. The grab samples were considered representative since surface aerators mixed effluent during treatment.

Since substandard detoxification may have been related to some characteristic of the aerated lagoon, a bench scale aerated lagoon (4-day detention) was operated at Cultus Lake laboratory. Thus, the object of the laboratory unit was to determine whether substandard detoxification was peculiar only to the aerated lagoon or whether it would also occur in the laboratory unit when BOD reduction was normal. Samples of raw effluent were added to the laboratory unit on a continuous flow basis at 5 gal per day. Since raw effluent was collected and shipped only four or five days per week sufficient extra effluent was shipped to provide effluent for those days on which collections were not made. Therefore, the laboratory unit did not treat raw effluent samples from every day of mill operation. The laboratory treatment unit was 6.7 ft long by 0.85 ft wide with a liquid depth of 5.6 inches. The unit was divided into four sections connected by 1.5 x 0.75 inch rectangular parts. Each section was further divided into four sub-sections by baffles.

Biological solids were started in the laboratory unit using seed from the aerated lagoon at Kamloops. A metered flow of oil-free compressed air was used to maintain dissolved oxygen in the 1.4 to 5.5 mg/l range and in the 7 to 10 mg/l range in the first and last sections of the laboratory unit, respectively. This air flow was just enough to slowly mix the contents in each sub-section of the laboratory unit. By comparison surface aerators were used in the aerated lagoon at KPP to maintain dissolved oxygen between 1 and 5 mg/l in the central portion and between 5 and 8 mg/l in the outlet region. Mean temperature in the laboratory unit ranged from 58^{o}F in January to 67^{o}F in August while mean temperature in the central portion of the aerated lagoon ranged from 72^{o}F in January to 81^{o}F in August. A foam blanket on the aerated lagoon insulated it against excessive heat loss in winter and maintained temperatures in a favorable range for biological oxidation. Since temperatures in the laboratory unit could not be adjusted to coincide with those in the aerated lagoon it was believed best to err on the low side to avoid the possibility that higher temperatures in the laboratory unit would cause exceptionally good treatment. Nitrogen and phosphorous were added to both the laboratory unit and aerated lagoon at rates of BOD/N and BOD/P of 250 and 1,000, respectively. The BOD and toxicity of effluent from the laboratory unit were measured daily and compared with BOD and toxicity of raw effluents fed to the unit.

Bioassays of pulp mill effluent to measure acute toxicity were of the static type, employing effluent-water mixtures of 100, 65, 45, 25, 10 and 0% v/v (control). Five sockeye fry (O. nerka) were exposed for four days to each of the effluent-water mixtures in 5-qt plastic buckets. The mean weight of sockeye fry during the study was 0.66 gm, ranging from 0.20 gm in January to one group used for eight days in mid-July which averaged 1.60 gm. It was possible to use fry throughout the study by rearing successive groups in cool water between 41 and 45°F. Fish densities in bioassays were less than 1 gm/l from January to July 15 and between 1 and 2 gm/l the remainder of the time, except for eight days in July when density was 2.7 gm/l. (The National Council for Air and Stream Improvement (1970) now recommends density not exceed 2 gm/l and the desirable density is about 1 gm/l.) Effluent-water mixtures were aerated with oil-free compressed air to keep dissolved oxygen near saturation at the bioassay temperature which ranged from 41 to 45°F.

Biochemical Oxygen Demand was measured according to Standard Methods (1965). In order to measure soluble BOD, samples of treated effluent from the aerated lagoon and laboratory unit were filtered (Whatman No. 40 paper) to remove biological solids. Dissolved oxygen was measured with a Model 54 Oxygen Meter (Yellow Springs Instrument Co.). Selected samples of raw and treated effluent were forwarded to the Forest Products Laboratory for fractionation and identification of toxic compounds and fractions were returned to Cultus Lake laboratory for bioassay. Treated effluents which were insufficiently detoxified were preferred for analysis at the Forest Products Laboratory but raw effluents were fractionated as well. The foregoing sampling and testing scheme is depicted diagrammatically in FIGURE 1.

Since a variety of "additives" were used in the mill at Kamloops Pulp and Paper, samples of these were bioassayed at concentrations up to and, in some cases, exceeding 10 times those expected in the mill effluent. These were static bioassays of 4-day duration similar to those conducted for pulp mill effluents.

During this study construction was under way at Kamloops Pulp and Paper to increase the mill to 1,250 tpd capacity from 250 tpd. The mill was shut down starting April 3 for most of the month for maintenance and some of the in-plant alterations associated with expansion. The last samples of

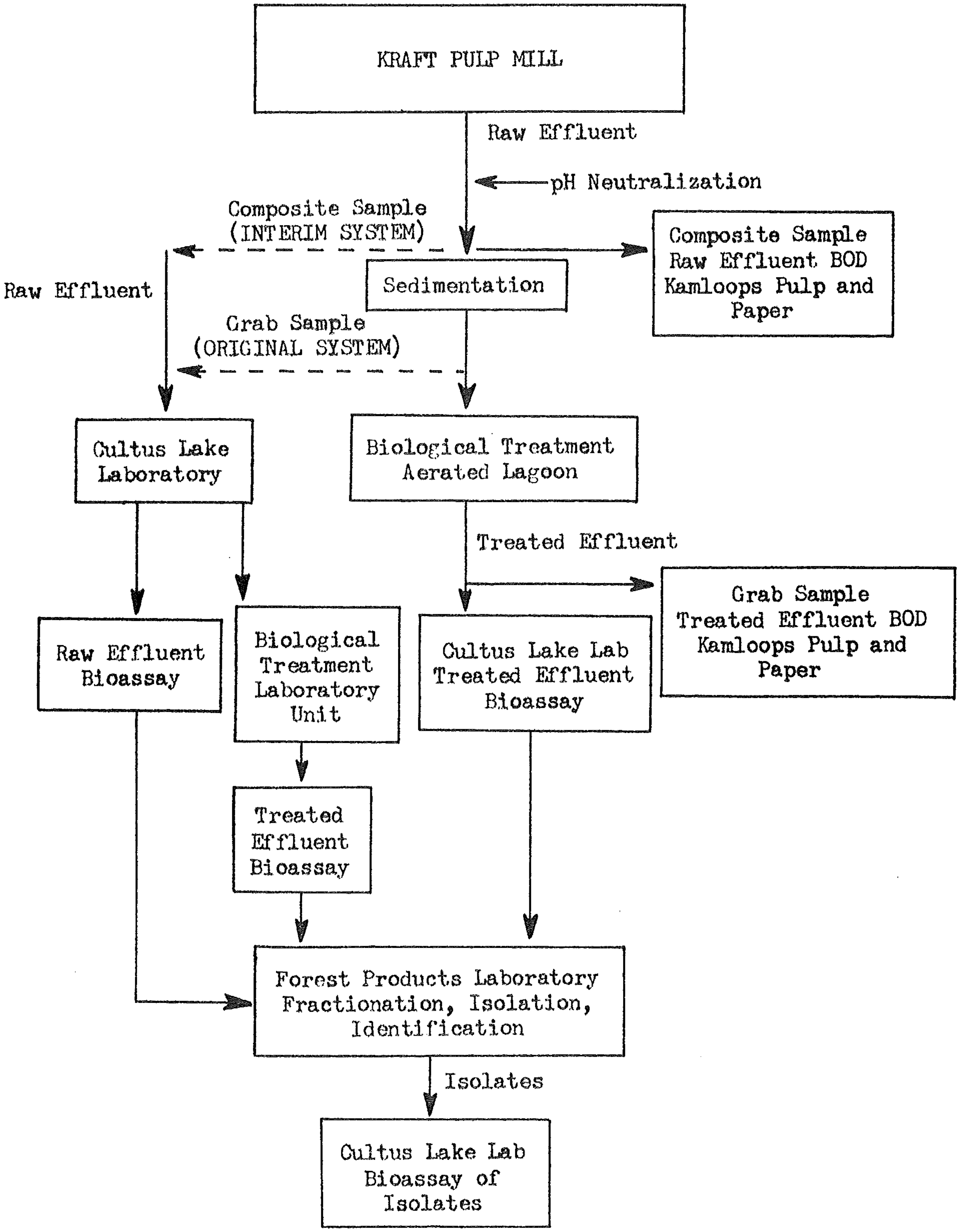

FIGURE 1 - Collection and distribution of effluent samples.

treated effluent collected from the aerated lagoon during the Original System period corresponded to raw effluent of March 30. In order to keep the laboratory treatment unit operating, raw effluent was collected on March 30 and April 1 in 5-gal plastic cans and stored in an unheated shed at the mill until shipped to Cultus Lake laboratory.

Although pulp production was not scheduled to increase until 1972, the capacities of the aerated lagoon and the sedimentation systems were increased during the mill shutdown in April 1971 giving five days aeration preceded by two days sedimentation for a total calculated detention of seven days. It would have been preferable to maintain the treatment system at four days aeration and 12 hr sedimentation since this is the treatment planned for effluent from the expanded mill. However, there wasn't any method of controlling detention time at this point in the expansion of the treatment system. This was called the Interim System because it was not identical in aeration and sedimentation design to the final system to be used when expansion was complete. Total aeration horsepower was increased to 615 hp during the Interim System period but mechanical problems reduced it to 415 hp at times. Approximately a month passed before the Interim System aerated lagoon began discharging effluent, thus it was studied from April 28 to August 27, 1971.

Several in-plant changes were made during and following the April shutdown and included installations of a press roll on No. 3 Brown stock washer and a Kinney strainer on the contaminated hot water accumulator heat exchanger system. The press roll permitted additional recovery of black liquor from the pulp. The Kinney strainer removed fibers and permitted reuse of contaminated hot water in the heat exchanger system instead of discharging it to sewer. A conductivity alarm was added to the second effect of the evaporators and an orifice plate was enlarged to permit better flow control. Overflow from the oxidized weak black liquor storage tank was directed to an oxidation tower for recycle to evaporators rather than to sewer as was done formerly. During midsummer, approximately 1 MUSGD of cooling water from the chlorine dioxide water chiller was sewered, raising raw effluent discharge to about 13 MUSGD.

In addition to the physical changes noted above, there was an increased effort to improve housekeeping by a mill Environmental Committee.

RESULTS

BOD Reduction by Biological Treatment

The BOD of raw effluent entering both the aerated lagoon and the laboratory unit varied widely from less than 100 mg/l to more than 400 mg/l (FIGURES 2 and 3). Treated effluent BOD varied from less than 10 mg/l to peaks near 140 mg/l but in every instance treatment reduced BOD. The graph of treated effluent BOD has been offset in both FIGURES 2 and 3 to account for detention time in the respective treatment systems. Thus corresponding raw and treated effluents should appear directly above one another.

Raw effluent BOD's at Kamloops and for the laboratory unit were not necessarily equal on given days. This occurred because, during the Original System period, raw effluent BOD was measured at Kamloops on a composite sample prior to primary sedimentation, whereas raw effluent BOD for the laboratory unit was measured on a grab sample collected following sedimentation and transport to Cultus Lake laboratory. During the Interim System period, BOD's of raw effluent were measured on composite samples collected prior to sedimentation (both at Kamloops and at the laboratory), but those reported for the laboratory unit were measured following transport to Cultus Lake. In addition, samples of raw effluent used in the laboratory unit were collected only four or five days per week as described earlier.

The inequalities in sampling discussed above do not detract from the fact that the two treatment systems showed considerable capacity to absorb large fluctuations in BOD load without excessive change in treated effluent BOD. However, this was not always the case as seen in early March when a black liquor spill raised raw effluent BOD to more than 400 mg/l and caused a rise in treated effluent BOD (FIGURE 2). The rise in treated effluent BOD appeared to occur in less than four days following addition of high BOD load which agrees with Bailey (1967) that considerable mixing occurred in the aerated lagoon. Unfortunately, a sample of this raw effluent was not forwarded to Cultus Lake and is therefore not represented in FIGURE 3.

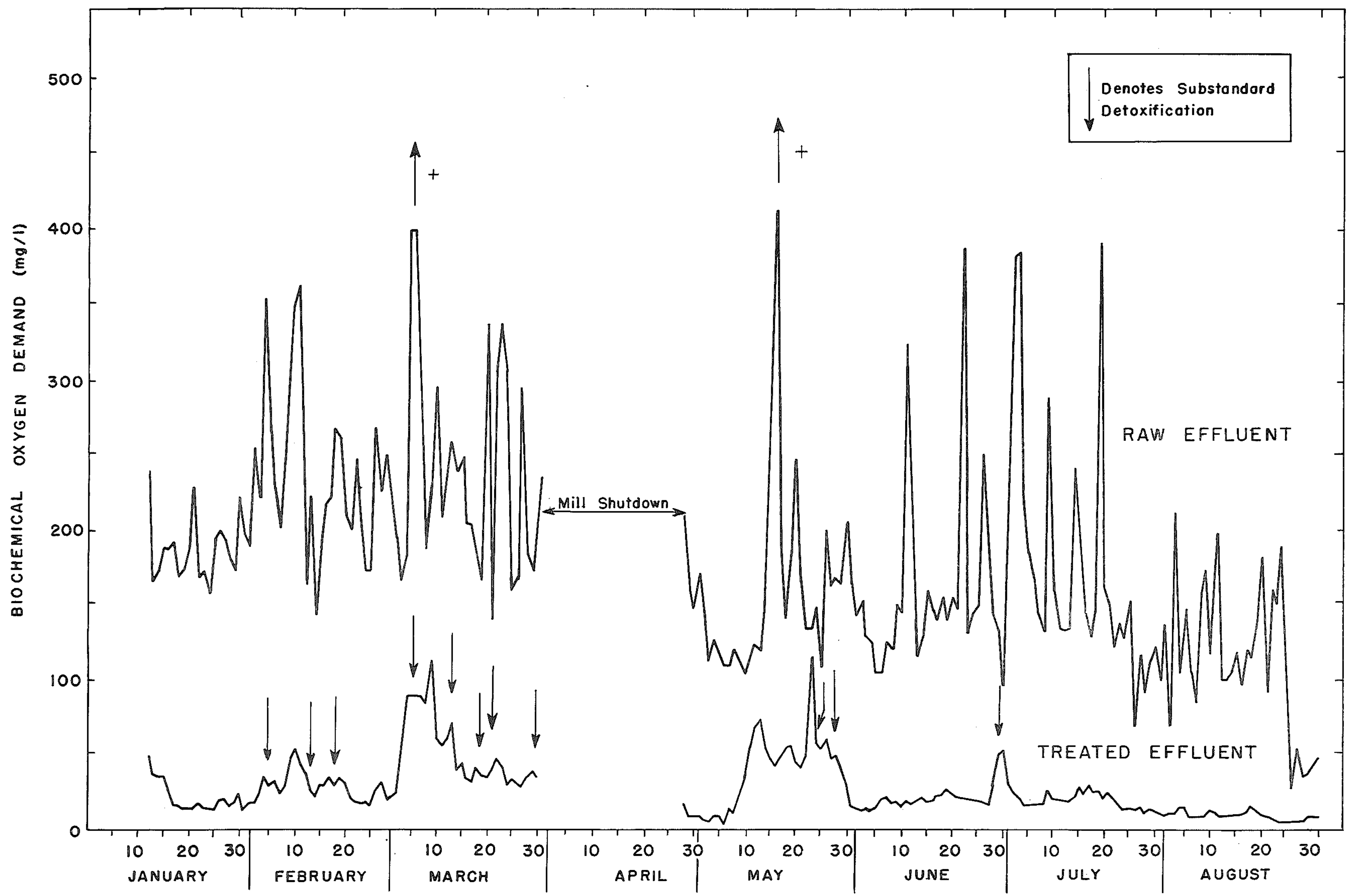

FIGURE 2 - Effect on BOD of biological treatment in aerated lagoons at Kamloops Pulp and Paper.

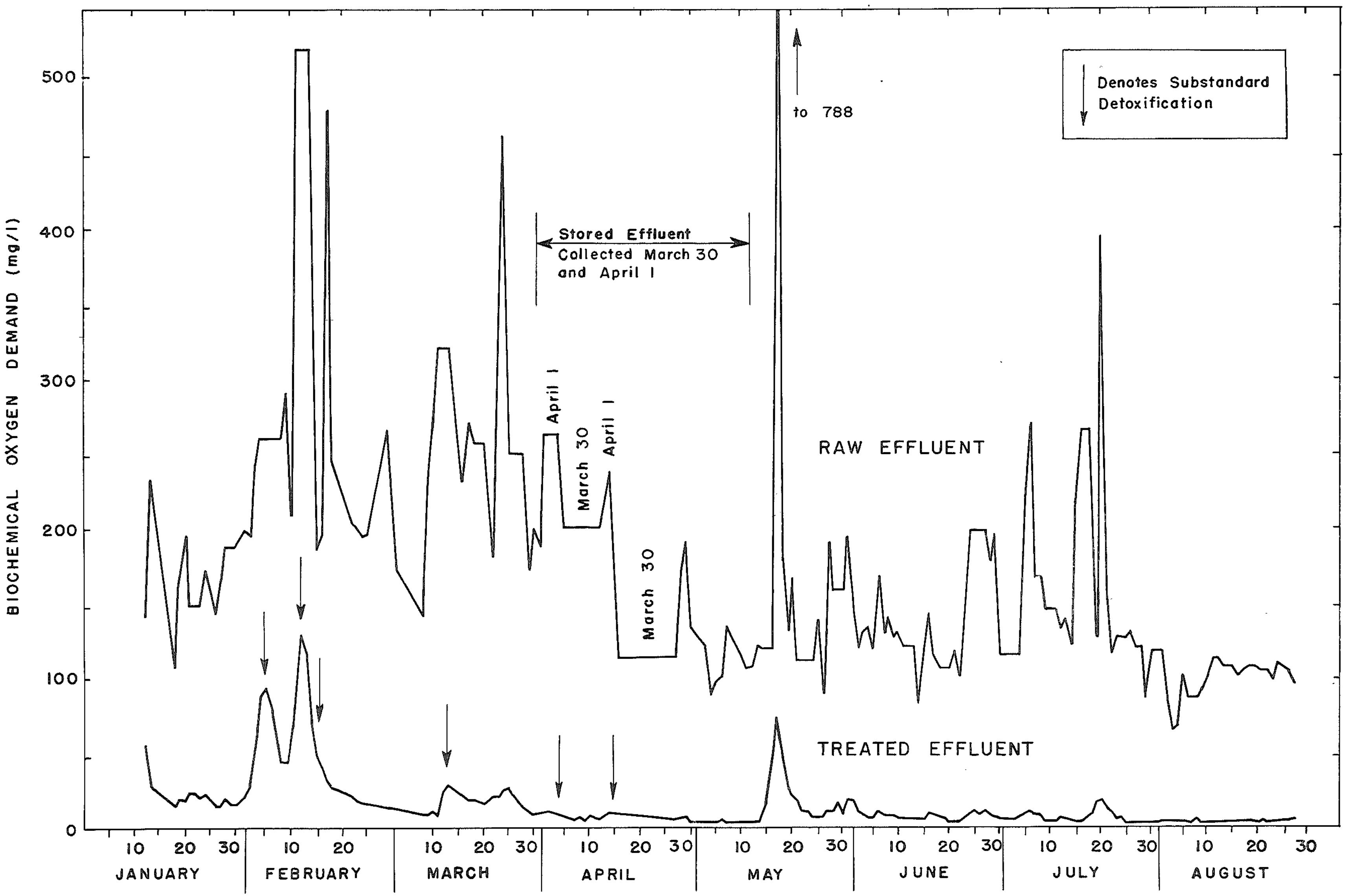

FIGURE 3 - Effect of BOD of biological treatment in Laboratory Treatment Unit at Cultus Lake Laboratory.

The BOD of effluent from the aerated lagoon increased in May and appeared correlated with a spill of black liquor on May 17. The aerated lagoon recovered by the end of May and treated effluent BOD remained low except at the end of June when black liquor was sewered to the aerated lagoon as the result of interruption in electrical power supply to the mill.

Treated and raw effluent BOD's correlated better for the laboratory unit than for the aerated lagoon since baffling in the former created more of a plug flow condition. Two peaks in treated effluent BOD occurred in February and coincided with high BOD loads. The second peak was associated with a spill of black liquor. Treated effluent BOD rose slightly from mid-March to mid-April when raw BOD was high. Another peak in treated effluent BOD occurred in May and coincided with a very high raw effluent BOD caused by a black liquor spill.

It is apparent that major peaks in treated effluent BOD from the aerated lagoon and laboratory unit were correlated primarily with spills of black liquor. Mean monthly BOD reduction exceeded 80% for the aerated lagoon except in March and May when reduction was 78 and 75%, respectively. Judging from FIGURE 2, black liquor spills during these two months were probably responsible for lower BOD reduction.

Monthly mean BOD's of raw and treated effluents for the aerated lagoon and laboratory units were almost identical during the Original System period but the laboratory unit removed about 12% more BOD on the average during the Interim System period (TABLES 1 and 2). The more uniform nature of the raw BOD load to the laboratory unit (FIGURE 3) when compared to the aerated lagoon (FIGURE 2) may have been partly responsible for greater BOD reduction in the former, but it is not uncommon for laboratory units to perform somewhat better than their prototypes. When the Interim and Original Systems at Kamloops are compared with each other, and with the laboratory unit, no advantage in BOD removal was indicated by using five days detention in the aerated lagoon preceded by two days of sedimentation, in place of 12 hr sedimentation and four days aeration. Therefore, the plan to maintain four days aeration preceded by 12 hr sedimentation for effluent from the fully expanded mill appears justified.

TABLE 1 - Biochemical Oxygen Demand of raw and treated effluents, Kamloops Pulp and Paper, 1971.

	Mean BOD (mg/l)		Mean BOD Removal
	Raw	Treated	%
Original System Period			
Jan. (12-30)	188	22	88
Feb.	237	30	87
Mar.	238	51	78
Mean	225	36	84
Interim System Period			
April[a]-May	158	38	75
June	160	22	84
July	173	20	86
Aug.	116	10	89
Mean	151	23	84

[a]last three days of April

TABLE 2 - Biochemical Oxygen Demand of raw and treated effluents, Laboratory Treatment Unit, 1971.

	Mean BOD (mg/l)		Mean BOD Removal
	Raw	Treated	%
Original System Period			
Jan. (12-30)	167	23	86
Feb.	294	57	81
Mar.	251	17	93
Mean	246	33	87
Original (stored effluent)			
April (1-27)	192	8	96
Interim System Period			
April[a]-May	156	15	91
June	138	8	94
July	162	7	95
Aug.	101	4	95
Mean	140	9	94

[a]last three days of April

Comparison of results has shown that the aerated lagoon and laboratory unit reacted similarly to daily fluctuations in BOD load, suggesting that as far as this measure of performance was concerned the aerated lagoon was not responding abnormally to kraft pulp effluent, and detoxification should have occurred as is usually the case during biological oxidation of such effluents (Betts, MacKenzie and Kerr, 1971; Bailey, 1967; Servizi, Stone and Gordon, 1966; Sprague and McLeese, 1968).

Comparison of raw effluent BOD concentration during the Original and Interim System periods indicates a decrease of about 33% during the latter period (TABLES 1 and 2). Total raw BOD discharge per day and BOD per unit of production were also lower for the Interim System (TABLE 3). These results indicate that in-plant changes made in connection with the expansion program and described earlier were evidently effective in reducing raw BOD discharge. As further evidence of a reduction in chemical loss, mill personnel reported soda loss declined from about 60 lb/ADT to about 36 lb/ADT as the mill passed from the Original to the Interim System.

TABLE 3 - Biochemical Oxygen Demand in raw effluent, Kamloops Pulp and Paper, 1971.

	Mean BOD in Raw Effluent		Mean Pulp Production
	lb/day	lb/ADT	ADT/day
Original System Period			
Jan.	20,681	83	250
Feb.	23,044	80	289
Mar.	22,445	70	320
Mean	22,057	78	286
Interim System Period			
May	17,296	62	278
June	18,476	65	285
July	19,058	69	276
Aug.	13,940	53	263
Mean	17,193	62	276

Toxicity Reduction by Biological Treatment

One of the primary objectives of biological treatment of kraft pulp mill effluent is detoxification, and the major purpose of this study was to examine performance of the KPP treatment system in this regard and compare it with the laboratory treatment unit. Treatment in the aerated lagoon at Kamloops and the laboratory unit always reduced toxicity of the effluent to some degree. Results have been summarized to show for each month the percentage of juvenile salmon which died during bioassays conducted at each concentration (TABLE 4). Results are not summarized for control bioassays since no mortalities occurred.

Several items in TABLE 4 are worthy of mention. The laboratory unit was generally slightly more successful in detoxifying raw effluent except in February when the aerated lagoon was slightly better. In four instances there were no mortalities during the month at bioassays of 100% treated effluent and on two occasions mortality was 1%. Five of these occasions were associated with the laboratory unit and one with the aerated lagoon.

Raw effluent collected on March 30 and April 1 was kept in storage and fed to the laboratory unit during April. The monthly mean mortality for this raw effluent was greater than for any other month. The laboratory unit reduced toxicity of this effluent but not to the extent attained when less toxic raw effluents were treated.

A summary of mean mortality data shows that toxicity of both raw and treated effluents was lowest during the Interim System period (TABLE 5). The occurrence of a bloom of zooplankton (Cladocerons) in July in the aerated lagoon and sedimentation basin is believed to be an additional sign of lower toxicity. Such an event had not been observed previously by personnel at the pulp mill. Lower toxicity during the Interim System period may have been related to the fact that fewer spills occurred, and the waste load and chemical losses were lower as described earlier.

TABLE 4 - Toxicity of raw and treated effluents, Kamloops Pulp and Paper aerated lagoon and Cultus Lake Laboratory Treatment Unit.

Mean Mortality - % Fish Dead in 4-Day Bioassays												
	Original System Period									Original (stored effluent)		
Effluent Conc. % v/v	January (12-30)			February			March			April (1-27)		
		Treated			Treated			Treated			Treated	
	Raw	KPP	Lab	Raw	KPP	Lab	Raw	KPP	Lab	Raw	KPP	Lab
100	100	6	0	99	36	42	95	70	24	100	-[a]	39
65	100	0	0	87	20	23	94	38	4	100	-	21
45	87	0	0	76	8	14	84	11	1	100	-	12
25	53	0	0	20	6	4	58	2	0	100	-	1
10	9	0	0	1	6	0	22	0	0	80	-	0
	Interim System Period											
Effluent Conc. % v/v	April[b]-May			June			July			August		
		Treated			Treated			Treated			Treated	
	Raw	KPP	Lab	Raw	KPP	Lab	Raw	KPP	Lab	Raw	KPP	Lab
100	77	15	1	87	17	0	87	5	1	56	0	0
65	50	7	0	58	7	0	61	0	0	7	0	0
45	39	4	0	33	5	0	50	0	0	1	0	0
25	30	1	0	27	1	0	36	0	0	0	0	0
10	6	0	0	5	0	0	11	0	0	0	0	0

[a] mill shutdown

[b] last three days of April

TABLE 5 - Comparison of effluent toxicity, Original and Interim Systems.

Mean Mortality - % Fish Dead in 4-Day Bioassays						
Effluent Conc. % v/v	Original System Period			Interim System Period		
		Treated			Treated	
	Raw	KPP	Lab	Raw	KPP	Lab
100	98	42	25	77	9	0.7
65	93	22	10	44	3	0
45	81	7	6	31	2	0
25	43	3	1	24	0.5	0
10	12	2	0	5	0	0

The standard of detoxification set by the Canada Department of Fisheries (now Department of the Environment, Fisheries Service) required that juvenile salmon survive four days without mortality at 65% v/v of treated effluent and clean water. Mortalities occurred in some bioassays of treated effluent at 65% v/v (TABLE 4) but the frequency of this occurrence is not apparent from mean mortality data. Therefore, the data have been summarized as mean monthly "No Mortality" rates. The "No Mortality" rate represents the per cent of samples at each concentration of effluent and water in which no mortalities occurred (TABLE 6). Each sample of treated effluent from the aerated lagoon at Kamloops met the detoxification standard in January, July and August and came close to doing so in May and June. On the other hand, the detoxification standard was met by only 56% and 62% of samples in February and March, respectively. The record for the laboratory unit was similar, indicating the parallel behavior of the aerated lagoon and laboratory unit. Detoxification standards were met most often during the Interim System period when raw effluent was less toxic, on the average, than during the Original System period.

In order to determine whether substandard detoxification was related to factors associated with mill operation, close liaison was maintained with pulp mill personnel who were alerted at the first indication that treated effluent did not meet standards. They kept a record of such events as spills of black liquor, and circumstances associated with substandard detoxification can be examined in greater detail using this information. Each occasion that detoxification standards were not met by treated effluents (sometimes more than one day in duration) is marked by an arrow in FIGURES 2 and 3 and pertinent information is presented in TABLE 7 where it may be seen that substandard detoxification was often related to spills of black liquor.

In some cases, such as in February, the dates of black liquor spills and substandard detoxification were closely correlated. However, in other cases, such as March 12 to 14, May 24 and 27 and June 29 and 30, dates of substandard detoxification followed black liquor spills by several days but occurred during periods when the aerated lagoon had not yet recovered from effects of the spill, judging from the elevated level of treated effluent BOD (FIGURE 2). Recovery during the March 12 to 14 period was

TABLE 6 - "No Mortality" rate of raw and treated effluents, Kamloops Pulp and Paper aerated lagoon and Laboratory Treatment Unit.

"No Mortality" Rate - % of Samples Causing No Mortality in 4-Day Bioassays

Effluent Conc. % v/v	Original System Period									Original (stored effluent)		
	January (12-30)			February			March			April (1-27)		
		Treated			Treated			Treated			Treated	
	Raw	KPP	Lab	Raw	KPP	Lab	Raw	KPP	Lab	Raw	KPP	Lab
100	0	82	100	0	31	23	0	17	48	0	-[a]	44
65	0	100	100	0	56	62	0	44	96	0	-	62
45	0	100	100	0	88	77	6	78	96	0	-	77
25	11	100	100	60	94	88	18	89	100	0	-	94
10	90	100	100	93	94	100	53	100	100	20	-	100

Effluent Conc. % v/v	Interim System Period											
	April[b]-May			June			July			August		
		Treated			Treated			Treated			Treated	
	Raw	KPP	Lab	Raw	KPP	Lab	Raw	KPP	Lab	Raw	KPP	Lab
100	4	75	94	5	75	100	5	86	94	30	100	100
65	35	88	100	29	90	100	20	100	100	85	100	100
45	52	96	100	57	95	100	35	100	100	95	100	100
25	65	96	100	71	95	100	60	100	100	100	100	100
10	87	100	100	95	100	100	85	100	100	100	100	100

[a] mill shutdown

[b] last three days of April

TABLE 7 - Conditions prevailing when mortalities occurred in bioassays of 65% v/v of treated effluent.

Raw Effluent Date	Days of Substd. Trtmnt.	Effluent BOD Raw mg/l	Effluent BOD Treated mg/l	% BOD Removal	Chip Furnish Species	Chip Furnish Age	Spills, etc.
Aerated Lagoon, Kamloops Pulp and Paper							
Feb. 5	2	265	31	84	Spruce	Green	None
6		228	33	86	Spruce	Green	None
Feb. 12	2	163	37	77	Spruce	Green	Black liquor spills
13		222	28	87	Spruce	Green	
Feb. 17	3	222	35	84	Fir	Green	Black liquor spills
18		268	31	88	Fir	Green	
19		262	35	87	Fir	Green	
Mar. 4	4	185	>90	<51	Spruce	Unkwn	Black liquor spills
5		>400	>90	-	Spruce	Unkwn	
6		>400	>90	-	Spruce	Unkwn	
7		300	89	70	Spruce	Unkwn	
Mar. 12	3	242	62	74	Fir	Old	Combined condensates plus aerated lagoon not recovered from earlier black liquor spills
13		258	71	72	Fir	Old	
14		240	40	83	Fir	Old	
Mar. 19	1	168	38	77	Spruce	Unkwn	None
Mar. 21	1	140	40	71	Fir	Unkwn	Black liquor spill
Mar. 30	1	200	35	83	Fir	Green	None
May 24	1	148	59	60	Spruce	Green	Aerated lagoon not recovered from black liquor spill of May 17
May 27	1	163	47	71	Spruce	Green	
June 29	2	133	50	62	Fir	Green	Black liquor spills three days previous
30		98	54	45	Fir	Green	
Laboratory Unit, Cultus Lake							
Feb. 4	2	261	85	64	Spruce	Green	None
4		261	95	70			
Feb. 10	4	209	70	67	Fir	Old	Black liquor spills
11		520	110	79	Fir	Old	
11		520[a]	135	74	Fir	Old	
11		520[a]	119	77	Fir	Old	
Feb. 18	1	247	28	89	Fir	Green	Black liquor spill
Mar. 11	1	321	29	91	Fir	Old	Combined condensates
April 1 (Stored Effluent)	4	263	11	95	Fir	Green	None
		263[a]	12	95	Fir	Green	None
		263[a]	9	97	Fir	Green	None
		263[a]	8	97	Fir	Green	None
April 1 (Stored Effluent)	1	239	10	96	Fir	Green	None

[a]Approximate, based upon BOD measured on first day effluent submitted to treatment.

undoubtedly disturbed by spills of combined condensates. Thus, substandard detoxification in the March, May and June periods noted above may have been caused by combinations of an overstressed aerated lagoon and raw effluents particularly difficult to detoxify.

Raw effluent dates associated with substandard detoxification by the laboratory unit do not correlate precisely with raw effluent dates for the aerated lagoon, being about one day out of phase (TABLE 7). This difference was probably related to sampling and flow within the aerated lagoon, as discussed previously. Samples of raw effluent were not collected every day for transfer to Cultus Lake laboratory and as a consequence raw effluents correlated with black liquor spills of March 4 and 21 were not available for treatment in the laboratory unit. In addition, raw effluent from the black liquor spill which apparently led to substandard detoxification in the aerated lagoon on June 29 and 30 was not collected for treatment in the laboratory unit. However, a sample of raw effluent coinciding with the black liquor spill of May 17 was treated in the laboratory unit without evidence of subsequent substandard detoxification, which was contrary to performance of the aerated lagoon.

Although some cases of substandard detoxification appeared correlated with spills of black liquor and upsets in treatment performance following spills, there were instances when substandard detoxification occurred and the pulp mill was apparently operating normally. These cases occurred when green Douglas fir or spruce chips were pulped but Lodgepole pine chips were not implicated. Although mill personnel did not exclude green spruce chips from correlation with substandard detoxification in their original assessment of the problem, results indicate that it can occur. An event of this nature involving green spruce chips occurred during the first week of February in both the aerated lagoon and laboratory unit. Spruce chips of unknown age were also correlated with substandard detoxification of raw effluent of March 19. Unfortunately, because of sampling schedule, this raw effluent was not available for treatment in the laboratory unit.

However, there were times, not itemized herein, when green fir or spruce chips were pulped and corresponding treated effluents met detoxification standards. For example, raw effluent of March 29 through April 1 originated from pulping green Douglas fir chips, but substandard detoxification in the aerated lagoon occurred for only the March 30 sample. Since the mill shut down on April 1, treated effluent was not discharged from the aerated lagoon corresponding to that date. Thus, if substandard detoxification is related to chip species or age, the relationship does not appear to be consistent.

The laboratory unit was operated during April using raw effluent collected on March 30 and April 1 from pulping of green Douglas fir chips and stored. Raw effluent from the former date was satisfactorily detoxified in the laboratory unit whereas the aerated lagoon failed to meet detoxification standards for this effluent. The difference in detoxification was probably caused by the fact that grab samples of raw effluent were collected March 30 for the laboratory unit and may have missed substances resistant to detoxification. However, toxicity of raw effluent collected April 1 was reduced by treatment in the laboratory unit, but not sufficiently to meet standards, in spite of 95 to 97% BOD reductions. This raw effluent was held in storage and an additional sample was treated in the laboratory unit when it was again insufficiently detoxified in spite of 96% BOD reduction. Treated effluent BOD's were low in these cases, ranging from 8 to 12 mg/l. It is evident from BOD data that the residual toxic compounds in the treated effluent must have been quite resistant to biological treatment. Samples of this particular effluent are being studied at the Western Forest Products Laboratory to identify toxic compounds.

Acute Toxicity of Additives

A variety of additives are used in pulp mills, and samples of those used at Kamloops Pulp and Paper were bioassayed to determine whether they might play a role in toxicity of effluents. All additives were bioassayed at concentrations up to and exceeding 10 times that expected in mill effluent. No mortalities occurred (TABLE 8) which indicates that these additives were not likely to be part of the toxicity problem. In addition, mill personnel found no correlation between use of additives and substandard detoxification.

TABLE 8 - Bioassay of mill additives, Kamloops Pulp and Paper.

Additive	Estimated Maximum Concentration in Raw Effluent mg/l	Bioassay Concentration mg/l	Mortality After Six Days
Du More 77	1.2	0.6	0
		1.2	0
		12.0	0
		32.0	0
Alchem Hi Philm	0.3	0.16	0
		0.30	0
		3.0	0
		12.0	0
Nalchelate 763	0.4	0.16	0
		0.40	0
		4.0	0
Alchem 19	0.4	0.22	0
		0.40	0
		4.0	0
Alchem 353	0.3	0.13	0
		0.30	0
		3.0	0
Hartex 1005	18.0	180.0	0
Hercules 30-H	6.0	180.0	0
Nopco 130 L	5.4	160.0	0

DISCUSSION

Various investigators have observed that BOD and toxicity of raw effluent are not correlated (Servizi, Stone and Gordon, 1966; Howard and Walden, 1971) and it was not the intent of this study to pursue this topic. However, in comparing the BOD and toxicity of raw effluent during the Original and Interim System periods it was evident that mean values of both of these characteristics had decreased. It is believed that in-plant changes associated with mill expansion played an important role in reducing these indicators of pollution load. One of the major in-plant changes was installation of a press roll on No. 3 Brown stock washer which increased recovery of cooking liquor; the fact that soda loss decreased following use of this press roll indicated chemical recovery had increased. Installation of a Kinney strainer on the contaminated hot water system permitted more dependable recycle of this stream rather than discharge to sewer. The other in-plant changes were made to assure better control of evaporator condensates and black liquor, thereby reducing the occurrence of spills to sewer. Black liquor was apparently better controlled after these changes were made since the treatment system was not subjected to upsets from this source as had previously occurred.

Both the aerated lagoon at Kamloops and the laboratory unit at Cultus Lake demonstrated that biological treatment usually detoxified kraft mill effluent sufficiently to meet standards then in force. However, performance was not acceptable at all times and black liquor spills were believed one of the primary reasons. Although not under perfect control, relatively small volumes of evaporator condensates were sewered from time to time and may have aggravated treatment problems caused by black liquor spills. However, evaporator condensates might have greater impact upon detoxification at mills where they are sewered in large volume.

Biological treatment did not cease when black liquor spills occurred but apparently the large amount of toxic material added exceeded the detoxification capacity of the treatment systems. The treatment systems undoubtedly had some capacity to absorb small black liquor spills without loss of treatment efficiency but this capacity was not determined. Knowledge of such capacity might prove of value when selecting treatment systems (activated sludge, aerated lagoon, etc.) and designing in-plant controls to prevent discharge of black liquor. However, it would appear that the best practice, from a pollution control standpoint, is to provide adequate tankage and safeguards within the mill, and spill ponds outside the mill to retain black liquor and condensates for recycle or slow release to the treatment system. The benefits of in-plant control of black liquor and condensates at Kamloops Pulp and Paper were evident during the Interim System period when the effluent treatment system performed more dependably than it had in the initial period of the study.

The possible relationship of chip species and age to substandard detoxification was not confirmed. On the one hand there were times when green fir and spruce chips were pulped and detoxification standards were met. The converse was also true, especially in one experiment with the laboratory unit when detoxification of raw effluent from pulping green chips was substandard even though BOD reduction was 95 to 96% and treated effluent BOD's were 8 to 12 mg/l. Apparently the residual toxic material was quite resistant to biological oxidation. Thus the laboratory unit demonstrated that substandard detoxification was not a peculiarity of the aerated lagoon, but occurred in the laboratory as well.

If analysis of effluents at the Forest Products Laboratory identifies materials responsible for toxicity, specific discharge standards could be set, in addition to effluent standards already in use.

CONCLUSIONS

1. Biological treatment in an aerated lagoon was generally capable of detoxifying kraft pulp mill effluent to meet standards, but there were exceptions.

2. Diversion of black liquor spills to the aerated lagoon often caused substandard detoxification. Spills of black liquor should be retained within the mill or in spill ponds for recycle or slow release to the treatment system.

3. Effluents resulting from pulping of green Douglas fir or spruce chips were sometimes associated with substandard detoxification, but not always, and reasons were not apparent. There was evidence that the residual toxicants might be highly resistant to biological treatment.

4. Kraft pulp mill pollution load, as described by BOD and acute toxicity, was lowered by improving chemical recovery, recycling contaminated water, and controlling spills of black liquor.

RECOMMENDATIONS FOR FURTHER WORK

In-plant changes reduced pollution load at Kamloops Pulp and Paper but it remains to be seen how successful they will be when the mill reaches full production of 1,250 tpd. In order to evaluate this factor an intensive sampling program should be conducted somewhat along the lines reported herein. There is considerable scope at several other pulp mills for further work of the type reported herein.

In addition, further research to identify residual toxic materials in treated effluents should be conducted and their biological effects evaluated. Further research is also required to describe and improve detoxification processes, with special attention to means of detoxifying the resistant toxicants.

In the interest of obtaining background information for setting effluent standards, it would be desirable to apply fractionation procedures being developed at the Western Forest Products Laboratory to several mills in order to quantify the discharge of toxic materials on a pulp production basis.

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