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The Brunei Bay as an Effluent Receiving Waterbody: Observations during the Start-up Period of a Kraft Pulp and Paper Mill

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ABSTRAK

Kualiti air Teluk Brunei, Malaysia, selepas menerima efluen dari satu kilang pulpa dan kertas, telah dimonitor. Beberapa parameter kualiti air yang konvensional seperti oksigen terlarut, pepejal terampai dan permintaan oksigen biokimia, telah digunakan sebagai penunjuk untuk membandingkan kualiti air di teluk tersebut masa kini dengan kualiti garis dasarnya. Pada keseluruhannya, data yang terkumpul dalam masa 16 bulan pertama kilang tersebut beroperasi tidak menunjukkan berlakunya perubahan yang ketara pada kualiti air Teluk Brunei. Paras pepejal terampai, karbon organik total, serta sebatian 1,1-diklorodimetil sulfon di dalam air teluk telah digunakan sebagai penunjuk untuk menentukan corak penyerakan efluen di perairan pantai teluk tersebut.

ABSTRACT

The water quality of Brunei Bay, Malaysia, subsequent to receiving effluent from a pulp and paper mill, was monitored. Conventional water quality parameters such as dissolved oxygen, suspended solids, and biochemical oxygen demand were used as indicators to compare the present status of the bay water quality with that of the baseline. Generally, data gathered during the first 16 months of the mill operation did not indicate marked changes in the bay water quality. Levels of suspended solids, total organic carbons, and 1,1-dichlorodimethyl sulfone in the bay water were used as indicators in the determination of dispersion pattern of the effluent in the coastal areas of the bay.

INTRODUCTION

Wastewater from an integrated pulp and paper milling operation generally includes effluents from wood preparation, chemical recovery, bleachery, and paper making processes. Thus, two major polluting substances present in the combined effluent are dissolved organics and suspended solids. Apart from imparting biochemical oxygen demand (BOD) and colour to the receiving water, a number of dissolved organics occurring in the effluent is known to be toxic, mutagenic, bioaccumulating, and resistant to biodegradation (Kringstad and Lindstrom 1984; Murtedza 1987). Thus, discharge of pulp mill effluent, especially untreated effluent into receiving waters, is generally considered environmentally hazardous due to the potential negative impacts on aquatic lives.

One of the earlier studies showed that concentration of bleached kraft mill effluent in excess of 2-3 parts per thousand had a significantly depressive effect on metabolic activity in oysters (Galstoff *et al.* 1947). Experiments using untreated bleached kraft mill effluent indicated that the 96 h LC_{50} of the effluent solution is 15-50 °C for rainbow trout (Leach and Thakore 1975). Apart from the direct toxicity problems, there are also indirect, non-lethal effects such as avoidance reactions in migrating fish coming into waters contaminated with pulp and paper mill effluent (Livingston 1975). Organoleptic (taste and odour)

effects have also been reported (Gordon *et al.* 1980; Shumway and Chadwick 1971). Use of chlorine dioxide in the pulp bleaching process results in the formation of chlorate; chlorate in bleached pulp mill effluent has been shown to be capable of causing damage to brown algae, *Fucus versiculosus,* even at concentrations as low as 20 ug/L (IPK, 1985).

There are suggestions that effects of pulp mill effluents actually observed in receiving waters were few in number and limited to receiving waters with poor water exchange or to areas close to the effluent outlet. The IPK (1982) study for example, concluded that sublethal effects of the effluents on fish disappeared after a dilution of 70-100 times. A more recent study, however, indicated that some mild effects were still detectable after a 2000-time dilution (IPK, 1985). Leach *et al.* (1978) and Mueller *et al.* (1977) reported that the toxicity of pulp mill effluents is almost totally removed after a 6-day treatment in an aerated system. Mills equipped with well-operated effluent treatment facilities are claimed to discharge effluents which even improve the productivity of receiving waters (Byrd and Eysenbach 1986; Cook and Chandrasekaran 1985). It is thus apparent that organic enrichment of receiving water with pulp mill effluent may be beneficial if toxicity is absent and a correct level of nutrient input is maintained. In this respect, it is therefore important that receiving water quality be regularly monitored to determine if the prevailing condition is favourable or otherwise.

This report presents results of water quality monitoring carried out in the Brunei Bay, Malaysia. The bay has been receiving effluent from the Sabah Forest Industries (SFI) Pulp and Paper Mill (the only pulp mill in Malaysia) since April 1987. The monitoring was performed primarily to determine (i) possible changes in the general water quality of the bay, by comparison with that of the baseline (Murtedza *et al.* 1987), and (ii) the dispersion pattern of the effluent in the bay. For the dispersion study, a tracer intrinsic in the effluent, *viz.* 1,1-dichlorodimethyl sulfone (DDS) was used.

The SFI mill is an integrated kraft pulp and paper mill; pulp is obtained from mixed tropical hardwoods. The maximum annual production capacity of the mill is 94 000 tonnes of bleached kraft pulp. When operating at maximum capacity, the volume of effluent discharged daily is approximately 43 000 m^3. The combined effluent is treated in a high purity oxygen activated sludge effluent treatment plant prior to discharge into the bay (via a telescopic diffuser pipe, 200 m in length). The pulp bleaching at SFI utilises a (C + D).Eo.D.D. sequence, comprising pre-bleaching stages using a mixture of chlorine (C) and chlorine dioxide (D), followed by oxidative extraction (Eo), and subsequent brightening stages using chlorine dioxide.

MATERIALS AND METHODS

Sample Source and Sampling

Samplings of seawater were carried out during September 1987 - December 1988 at sites denoted by 10, 11, 12, and 14 in *Figure 1.* Description for the sampling sites is presented in Table 1. Water temperature, salinity, and dissolved oxygen (DO) were measured *in-situ* for the entire water column at 2 m intervals, using an *in-situ* water quality probe (Hydrolab Surveyor MK 2). For the determination of suspended solids (SS), BOD, and

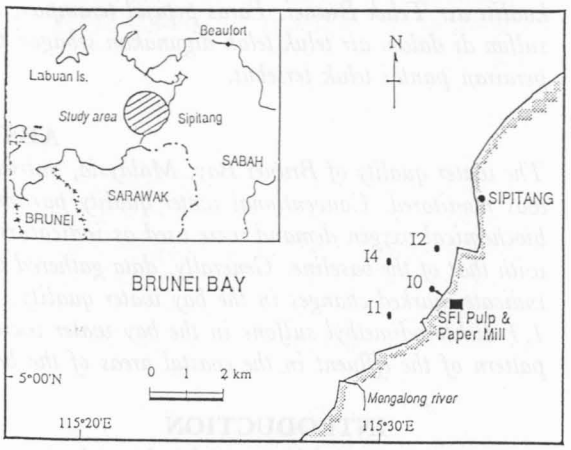


Fig. 1: Map of the study area showing points of sampling, 10-14.

TABLE 1
Description of the sampling site

Site	Latitude north	Longitude east	Depth (m)	Distance from effluent discharge point (km)
IO	5°2.65'	115°30.60'	16	0
I1	5°2.20'	115°29.60'	20	2.7
I2	5°3.60'	115°31.00'	16	2.7
I4	5°3.20'	115°30.00'	22	2.5

DDS, water samples were collected from 5 m depth using an automatic grab sampler. Samples were immediately transported back to UKMS Laboratory and/or stored at 4 °C if not immediately analysed. The sampling sites and methods for the determination of *in-situ* parameters, SS, and BOD were identical to those of the baseline study described elsewhere (Murtedza et al. 1987).

Sample Analysis

Suspended solids. 500 ml sample was filtered on a preweighted Whatman GFC filter paper, followed by rinsing with excess distilled water to completely remove solubles such as sodium chloride. The paper was reweighted after drying to a constant weight at 105 °C and the difference in weight recorded and standardised to mg/l unit.

BOD_3(30 °C). 3-Day biochemical oxygen demand (BOD_3) was determined by a method similar to that of the Standard Method for BOD_5 determination (APHA 1981). Samples for BOD_3 determination were incubated at 30 °C over a 3-day period prior to determination of final dissolved oxygen levels by the Winkler titration method.

Total Organic Carbon (TOC) was determined with a TOC-TC analyser (Astro Model 1850 TOC-TC Analyser).

1,1-Dichlorodimethyl sulfone. 40 uL of a 62.8 ug/mL solution of 1,6-dibromo-benzene in diethyl ether (internal standard) was introduced into a 500 mL sample and the pH of the solution adjusted to 12. The solution was extracted with 25 mL diethyl ether; the ether layer was then separated, dried (Na_2SO_4), evaporated to about 1 mL and analysed on GC. Gas chromatographic analyses were carried out using a Hitachi Model 163 Gas Chromatograph with a ^{63}Ni electron capture detector (ECD) and a fused silica capillary column (25 m x 0.25 mm i.d., BP1 methyl silicon). The oven and injector temperatures were maintained at 90 °C and 300 °C, respectively. Nitrogen was used both as the carrier gas (0.6 mL/min) and the make-up gas (30 mL/min). The injector split ratio was 1:20. Compound identification was based on retention time comparison, and subsequent confirmation by sample spiking/addition method using authentic DDS supplied by Helix Biotech, B.C., Canada. Quantification was based upon the internal standard method.

RESULTS AND DISCUSSION

Values for five conventional water quality parameters for samples obtained from the four sampling sites are shown in Table 2. Also presented in the same table are the baseline values, obtained during a three-year monitoring programme prior to the SFI Mill operation. As apparent, the two sets of values are comparable, except probably for a slight dilution effect, as reflected in the salinity readings.

TABLE 2
Values of selected water quality parameters for the study area; the baseline values *versus* values obtained during the present study[1]

Parameters	Baseline (Mac'84-Jan'87)	Present[2] (Sept'87-Aug'88)
Temperature (°C)	24.0 - 30.8 (n = 185)	27.1 - 31.0 n = 185)
Salinity (10^3)	27.0 - 33.6 (n = 185)	17.9 - 33.3 (n = 185)
Suspended solids (mg/L)	1.6 - 41.8 (n = 20)	1.0 - 43.4 (n = 20)
Dissolved oxygen (mg/L)	2.7 - 6.5 (n = 185)	1.4 - 6.9 (n = 185)
BOD_3(mg/L)	0.8 - 3.3 (n = 20)	0.3 - 1.2 (n = 20)

n represents number of data

[1]Values for temperature, salinity, and dissolved oxygen represent the minimum and maximum values for entire water column, measured at 2m intervals, whereas those of suspended solids and biochemical oxygen demand represent the minimum and maximum values for samples obtained at 5m depth.

[2]Pollutants' level in the effluent during the period of sampling were: suspended solids 32-197 mg/L, BOD_3 23 - 85 mg/L.

Depletion of oxygen in water column is normally obvious in the case of waterbodies receiving pulp and paper mill effluent, primarily due to the active bacterial degradation of wood fibres settled at the bottom. For the coastal areas of Brunei Bay, however, oxygen depletion at the bottom layers was noted even during the baseline study period (see the representative DO profiles for Sites 10 and 14 in *Figure 2).* As indicated in Table 3, this condition remained obvious during the present study. Nevertheless, there was no obvious evidence of further deterioration in

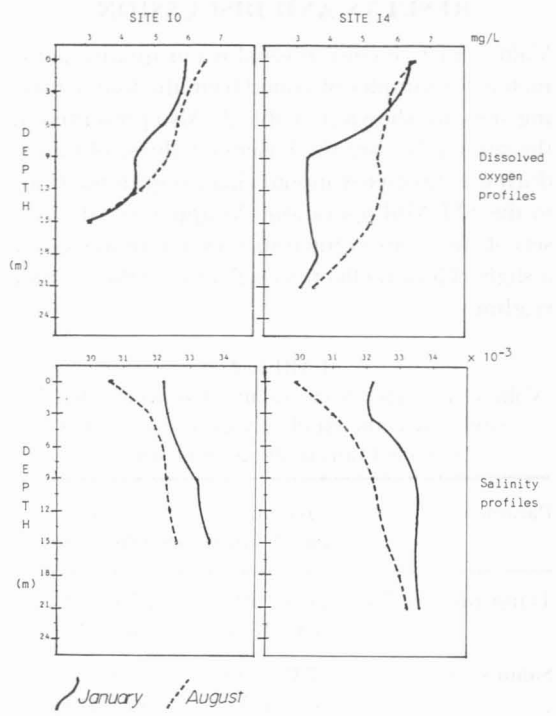


Fig. 2: Representative dissolved oxygen and salinity profiles at Site 10 and 14, for the months of January and August. Data was obtained during the 1984-1987 samplings, prior to the mill operation.

oxygen status in the water column following the mill operation. *Figure 3* presents comparison of DO readings for the four study sites, against those of the baseline. Readings presented are both for the same season (for the month of January), so as to avoid misinterpretation due to seasonal variations. The previous study did indicate a certain degree of variation in the DO readings during the N-E and S-W monsoons *(Figure 2)*.

BOD_3(30 °C), instead of BOD_5(20 °C) was used in this study to assess biodegradable organics in the receiving water. Comparative theoretical and experimental studies for BOD_3(30 °C) and BOD_5(20 °C) showed that BOD determined under the two different conditions were comparable in values (Murtedza, unpublished data). As in the case of DO, analysis of the Brunei Bay

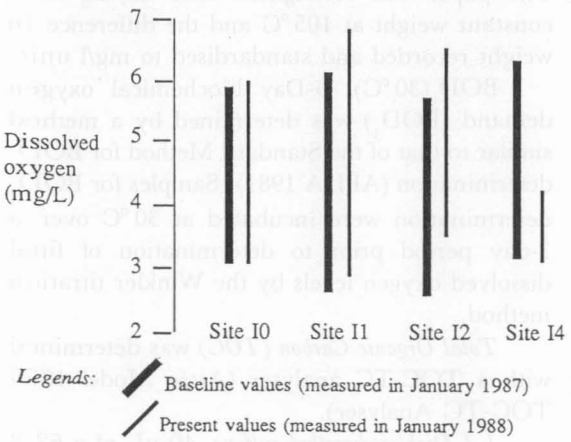
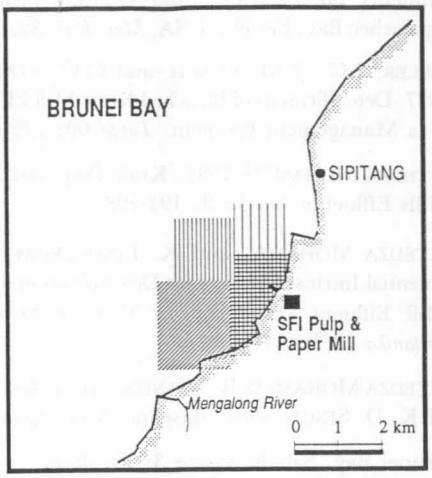


Fig. 3: Levels of dissolved oxygen at the four sites as measured in Jan 1987 (prior to pulp mill operation) compared to the levels measured in Jan 1988).

TABLE 3
Dissolved oxygen readings taken during five occasions at the four sampling sites. Values are in mg/L

Sampling site	month	Sept '87	Nov '87	Jan '88	Oct '88	Dec '88
Site 10	surface	5.77	6.26	5.93	6.59	5.40
	mid-depth	4.73	5.54	3.27	5.37	5.21
	bottom	2.97	5.06	3.17	4.54	2.72
Site II	surface	6.00	6.62	6.84	6.82	6.60
	mid-depth	5.01	5.63	3.98	6.55	5.70
	bottom	2.44	4.12	3.48	4.45	4.55
Site 12	surface	5.96	6.06	6.45	6.75	5.12
	mid-depth	4.63	5.43	3.62	4.48	3.09
	bottom	1.78	3.71	3.48	4.20	3.57
Site 14	surface	5.98	6.40	4.00	6.91	5.68
	mid-depth	4.53	5.28	3.42	4.90	5.65
	bottom	1.36	3.19	3.32	3.53	5.00



Legends:

	SS (mg/L)	TOC (mg/L)	DDS (ng/L)
			10	3	28
			21	8	27
			19	7	32
			19	14	33

Fig. 4: Map showing a simplified dispersion pattern of SFI Mill effluent in areas near the discharge point. Abbreviations: SS - suspended solids; TOC - total organic carbon; DDS-1,1-dichlorodimethyl sulfone. Their average values (for the five samplings) are given in the legends. Level of DDS in the effluent during the sampling period was 86 - 232 mg/L.

water for BOD_3 gave values similar to that of the baseline. The values were within the normal range expected for tropical seawater (Riley and Chester 1979; Beer 1983).

Use of DDS as a tracer for determination of pulp mill effluent dispersion in tropical seawater has been suggested by Murtedza and Lindstrom (1987). This particular compound was suggested primarily due to its presence in a sufficiently high concentration in the effluent to match excessive dilution of effluent in receiving waters. Also, DDS does not require derivatisation prior to gas chromatographic analysis, enabling rapid sample work-up and analysis. In the present study, it was confirmed that DDS was absent in samples collected from the middle of Brunei Bay. Also, to account for the differences in solubility and density of the various effluent components, TOC and suspended solids (SS) were used complementary to DDS in the effluent tracing. As reflected in the tabulated legends to *Fig. 4,* concentrations of the three indicators generally indicated that the movement of effluent was west - southwesterly, i.e. away from the Sipitang coasts.

CONCLUSION

The period during which this study was carried out may be considered as a 'start-up' period for the SFI Mill. During such a period, significant fluctuations in the process parameters occurred, and loading of pollutants in the effluent fluctuated accordingly. Nevertheless, under the conditions prevailing during this period, it was found that the Brunei Bay water quality in areas within *ca.* 10 km^2 around the effluent discharge point remained within the normal range expected for tropical seawater (BOD $<$ 4 mg/L, TOC $<$ 30 mg/L, SS $<$ 50 mg/L) (Riley and Chester 1979; Beer 1983). Use of DDS, TOC and SS as tracers indicate that the dominant effluent movement was towards west - southwest, away from the Sipitang coasts.

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