ANAEROBIC TREATMENT OF TMP/CTMP WASTEWATER

WTC-BIO-02-1988

REVIEW NOTICE

ANAEROBIC TREATMENT OF TMP/CTMP WASTEWATER

A Report For

Environment Canada
Conservation and Protection
Wastewater Technology Centre

by

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September 1986

Report WTC-BIO-02-88

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ANAEROBIC TREATMENT OF
TMP/CTMP WASTEWATER

ENVIRONMENT CANADA
WASTEWATER TECHNOLOGY CENTRE
BURLINGTON, ONTARIO

PROJECT: 4069.1

DATE: SEPTEMBER 1986

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1.0 SUMMARY

This report examines conceptual anaerobic/aerobic treatment processes to meet the specific needs of Quesnel River Pulp Ltd.'s TMP/CTMP pulp mill at Quesnel River, B.C. The designs were evolved bearing in mind the existing effluent treatment facilitites and recognizing the need for three basic components as follows:

- pretreatment for fiber removal and detoxification,
- anaerobic treatment for COD/BOD_5 removal, and
- aerated polishing for odour and toxicity removal.

Two treatment processes are shown in Drawing D-100 in Section 4 of the report and differ only in the approach to the pretreatment and the aerated polishing steps. Details of "anybrid" anaerobic reactors are discussed in Section 6.

It was concluded that one or both of the treatment systems would be able to achieve the federal and provincial standards for BOD_5, suspended solids and toxicity although a comprehensive bench and pilot scale development program would be necessary to select design parameters. Among the most important issues requiring further investigation are the following.

- pretreatment requirements to avoid toxic effects caused by hydrogen peroxide and sulfite in the wastewater,
- determining the quantity/cost of caustic soda for buffering the anaerobic process,
- methane yield and feasibility of use in the flash drier to displace natural gas,
- stability of the anaerobic process under varying loadings caused by biweekly production changes from TMP to CTMP,
- the ability of the TMP/CTMP wastewater to develop granular sludge required in UASB operating mode,
- toxicity removal in the aerobic polishing step.

The total estimated capital costs of the conceptual processes were $7.3 million for Process A (ASB for polishing step) and $8.7 million for Process B (activated sludge for polishing step). These estimates include direct and indirect costs plus all development costs escalated to an assumed project completion in 1988/89. Annual operating costs are expected to be equal to or lower than present operating costs because of a reduction in the power required in the aerated basins.

A comparison was made between the capital costs of Process A and costs estimated for 5 commercially available anaerobic systems. The results are presented in Section 7 and show that the anhybrid concept would be competitive with other processes.

An outline for a 15 to 19 month development program for anaerobic/aerobic treatment at Quesnel River Pulp is presented in Section 6. It is recommended that such a program evaluate two different anaerobic technologies. Fifteen months, including 9 months of pilot trials, would be adequate if only commercially available anaerobic processes are tested. An additional four months would be required to examine "anhybrid" treatment. The cost of this program was estimated to be approximately $500,000.

2.0 INTRODUCTION

2.1 Background

Quesnel River Pulp Co. (QRP) is a joint venture between West Fraser Timber Co. Ltd. and Daishowa Canada Co. Ltd. producing nominally 500 ADtPD of thermomechanical (TMP) or chemithermomechanical (CTMP) pulp. The mill started production of TMP in 1981. Modifications were subsequently made in 1983 to allow mill production to alternate between TMP and CTMP production on a bi-weekly basis.

Effluent treatment at the mill consists of primary clarification for the fiber bearing effluents followed by a 5 to 7 day aerated stabilization basin (ASB) for the total mill flow. This system has been unable to meet the Level A objectives for effluent discharges for mechanical pulp mills as established by the British Columbia Ministry of Environment. These objectives are presented in Table 2.1.

TABLE 2.1 B.C. LEVEL A OBJECTIVES FOR MECHANICAL PULP MILLS

Parameter	Effluent Objective	
5-Day Biochemical Oxygen Demand	7.5	kg/ADt
	3750	kg/d
Total Suspended Solids	10.0	kg/ADt
	5000	kg/d
Toxicity	100	% LC_{50}

Note: Calculated on the basis of 500 tPD production

Alternating the production between TMP and CTMP has been part of the problem as the organic load in the untreated wastewater more than doubles during CTMP production.

Improving the ASB process to meet the objectives is probably possible but this would mean adding to the aeration power, expanding basin volumes and possibly allowing for dewatering and disposal of excess biosolids. This would increase further the already high annual operating cost.

A combination of anaerobic pretreatment with an aerobic polishing step is a logical alternative to consider for QRP. The concentration of BOD_5 in the wastewater is relatively high (1500 - 3000 mg/l) which is favourable for anaerobic processes; anaerobic pretreatment would reduce the amount of aeration power required in the ASB system; and production of excess biosolids would be minimized.

Energy, Mines and Resources have an interest in and a mandate to promote new energy saving technology with Canadian content. In view of the unique situation at QRP, the federal Departments of the Environment and Energy, Mines and Resources sponsored the present study to determine the technical, schedule and financial implications of developing anaerobic/aerobic treatment to meet the mill's needs.

There exist three different anaerobic technologies which have been developed or partially developed through research and development efforts in Canada. These are:

- the Downflow Fixed Film (DSFF) process,
- the Bulk Volume Fermenter (BVF) process, and
- the "anhybrid" process.

Downflow fixed film anaerobic treatment has received considerable support during the last ten years in Canada, particularly within the National Research Council (NRC). To date, only one large full-scale plant has been constructed based on the NRC work. A two-year performance evaluation of this system demonstrated that the process was failing due to solids accumulation in the media (BEAK, 1985). The reactor has since been converted to an upflow sludge blanket system. In view of this experience, it would seem inappropriate to fund a major R&D program for this technology before practical methods are proposed to control plugging. Furthermore, there are at least two non-Canadian companies which are currently marketing successful DSFF processes. A Canadian demonstration project for this technology would be more to the advantage of these companies in marketing their systems in Canada.

The BVF process is a "low rate" anaerobic process developed and marketed by ADI Ltd. of Fredericton. There are several BVF or similar systems operating in Canada and other countries, and Environment Canada considers this to be a proven process. For this reason, it would not be eligible for development support by the federal government, even though the process has not been specifically demonstrated as a suitable process at QRP.

The "anhybrid" process consists of a reactor vessel with the upper portion filled with packing media. There is particular interest in assessing this type of process, as there are two Canadian developed installations incorporating features of "anhybrid" treatment (e.g., HYAN and SYDLO). Widespread utilization of these systems in Canada is unlikely until more design and performance data are available.

2.2 Scope of Work

Successful implementation of anaerobic/aerobic treatment at QRP depends on the following:

- Phase 1: Preliminary technical and economic evaluation,
- Phase 2: Pilot scale development program, and
- Phase 3: Design, construction and start-up.

This Phase 1 study has, as its principle objective, to develop a rational program of pilot testing and development to generate the data necessary for final design. Comparison of commercially available anaerobic processes to a potential "anhybrid" system is a fundamental requirement as it is not predetermined that "anhybrid" treatment is necessarily the most appropriate. Following is a list of the specific tasks which were completed in accomplishing the Phase 1 study objectives.

- summarize results of bench tests completed at the Wastewater Technology Centre (WTC) in Burlington, Ontario using effluent samples from QRP,

- evaluate the treatability of TMP/CTMP effluents,

- provide a conceptual design of an anaerobic/aerobic system that would meet the federal and provincial effluent objectives,

- outline the requirements and estimate the costs and schedule for the necessary pilot testing program,

- compare the costs of developing and constructing an "anhybrid" based treatment system with other anaerobic processes which are available commercially, and

- present recommendations in a final report.

3.0 DESCRIPTION OF MILL

3.1 Mill Operations

Quesnel River Pulp is located at Quesnel, B.C., situated between the Quesnel and Fraser Rivers. Chips are delivered to the mill by truck and stored outside awaiting delivery by conveyor to the pulping process. Production of both types of pulp follows the standard sequence of chip screening, steaming, two stage refining, pulp washing and cleaning. Sodium sulfite liquor is used in the chip steaming/impregnation step during CTMP production whereas this step is not used for TMP pulp.

CTMP pulp is bleached using a MoDo-Chemetics medium consistency hydrogen peroxide system which has the result of leaving 50-100 mg/l of residual peroxide in the mill's whitewater system. The TMP pulp is brightened using the Borol sodium hydrosulfite process which leaves some residual sulfite in the wastewater.

Thune presses are used to dewater the bleached pulp ahead of a gas fired flash-dryer. The dried pulp is then pressed and bailed in preparation for shipment.

The mill normally operates 24 hours per day, 7 days per week subject to market demand for pulp. As mentioned earlier, the standard production schedule calls for two weeks of TMP production followed by two weeks of CTMP production.

3.2 Design Wastewater Characteristics

Table 3.1 presents a summary of the design wastewater characteristics selected for the purpose of this study. Data for flow, BOD_5, and TSS were derived from mill records for 1985 which was a typical year for production. Actual figures for production are not included. The 1985 losses appear to be a reasonable basis for design as there are no immediate plans for process changes or production increases.

Limited data were available for effluent COD concentrations and some interpretive judgement was necessary. Selection of COD concentrations is important as reactor sizing for anaerobic treatment is usually based on a loading expressed as kg of COD per cubic meter of liquid volume per day. Analytical data from the samples used in the bench tests at the WTC gave an average ratio of 3.3:1 and 2.8:1 COD/BOD_5 for TMP and

CTMP respectively. It is recognized that the WTC data were not derived from fresh composite samples. Information from the mill representing a few analyses suggested a lower ratio of 2.4:1 for both processes. Table 3.2 summarizes these results as well as data from several other TMP and CTMP mills. The design COD values presented in Table 3.1 were chosen based on a presumed ratio of 2.8:1 in both cases.

TABLE 3.1 WASTEWATER CHARACTERISTICS

OPERATION	BASIS		UNITS	TMP	CTMP
PRODUCTION	Nominal		ADtPD	500	500
FLOW	Average	- White Water	m^3/d	6480	6480
		- Clarifier Sewer	m^3/d	1520	3620
		- Total to Anaerobic	m^3/d	8000	10100
			m^3/t	16	20
BOD_5	Average		mg/L	1550	2920
			kg/t	25	59
			kg/d	12400	29500
	Max Month		kg/d	15000	36000
COD	Average		mg/L	4300	8180
			kg/t	70	165
			kg/d	34700	82600
	Max Month		kg/d	42000	100000
TSS	Average		kg/d	2400	2200
			mg/L	300	220
	Max Month		kg/d	3600	3500
Volatile Acids			mg/L	200-400	400-800
Hydrogen Peroxide			mg/L	0	50-100
Sulfate-S			mg/L	0	300
Sulfite-S			mg/L	200	0
TKN			mg/L	minimal	
Phosphorus - total			mg/L	5	5
Temperature (controlled to suit)			°C	35	35
pH				6	8

TABLE 3.2 COD:BOD_5 RATIOS FOR TMP AND CTMP PULPING

Source of Data	TMP	CTMP
Quesnel River Data	2.4:1	2.4:1
WTC Analyses of QRP Samples	3.3:1	2.8:1
Mill A (bleached CTMP) **	—	2.9:1
Mill B (bleached CTMP COD/BOD_7) **	--	2.3:1
Jurgensen <u>et. al.</u> (1985) *	2.6:1	--
Select for Design Purposes	2.8:1	2.8:1

* Average of 6 mills

** Confidential BEAK reference

3.3 Existing Effluent Treatment Facilities

The present wastewater treatment system at Quesnel consists of a primary clarifier for fiber bearing effluents followed by an aerated stabilization basin (ASB) with 5 to 7 days of hydraulic retention for the total process flow. Approximately 20 to 35 percent of the process effluents are contaminated with high concentrations of fiber and are directed to the clarifier by gravity. This component of the flow originates from chip washing, pressates from presteaming and impregnation, cleaner rejects and intermittent spills. The remainder of the contaminated process flow is excess clear whitewater from pulp thickening and dewatering operations. This is pumped directly to the ASB as the suspended solids content is less than 150 mg/L.

The treatment system is located about 200 meters to the northeast of the mill and is approximately 80 meters from the Cariboo Highway at its closest point. Terrain at the treatment site is flat with soils consisting of 1.2 to 4.7 m of loose sand and silt overlying a 2.5 to 17 m thick layer of dense gravel. Vegetative screening exists at the site, some of which could be removed on the mill side for new treatment facilities if needed. Treated effluent discharged from the ASB flows under the highway in a gravity pipeline to the Fraser River. The primary clarifier is 20 m in diameter with a side wall depth of 4.5 m. Rise rates are 0.2 and 0.5 m/h during TMP and CTMP production respectively which is a very conservative loading.

Primary sludge is dewatered using a Komline belt filter press at a rate averaging between 1.5 and 2.5 t/d based on differences between influent and effluent suspended solids data. The press is located in a small control building beside the clarifier.

The aerated basin has a liquid depth of 7 m and is divided into two cells in series each with a hydraulic volume of 27,000 m^3. A baffle wall constructed from steel piles and 150 mm by 300 mm timbers separates the two cells. Phosphoric acid and ammonia are added to the ASB in a BOD_5:N:P ratio of 100:1.4:0.5 as the mill effluent is deficient in nitrogen and phosphorus nutrients. Caustic soda and sulfuric acid are added to the wastewater to maintain a pH of 7 entering the first cell of the ASB. Caustic is used to bring TMP effluent from pH 6 to pH 7. Acid is used for CTMP effluent which is slightly alkaline. Neutralization of TMP or CTMP effluent before biological treatment is not a common procedure and is used at Quesnel mainly to avoid temporary shifts in the pH of Cell 1 during the change from one pulping sequence to the other. The mill does not keep records of the caustic soda and acid consumed.

Oxygen transfer is provided by a compressed air system comprising roughly 1200 kW of compressor capacity and 636 bottom mounted static aerators. Total air flow is 620 Nm^3/min (22,000 SCFM) to the basin with 450 static aerator units in Cell 1 and the remaining 186 units in Cell 2.

The compressors, headers and static aerators are separated into two systems which can be operated independently. This situation developed as the original aeration capacity was more than doubled when CTMP pulping was introduced. The nominal BOD_5 load at full power during CTMP production is 25 kg BOD_5/kW · d (39 lb/HP · d) which would generally be considered as somewhat high for this type of aeration equipment (e.g., more power required).

In its present form, the treatment system has been unable to provide the effluent quality required by the B.C. Level A guidelines as demonstrated by the average final effluent quality for 1985 shown in Table 3.3.

TABLE 3.3 TREATED EFFLUENT CHARACTERISTICS FOR 1985

Parameter	Units	TMP	CTMP	Combined	Limit*
BOD_5 Discharge	kg/d	4800	11900	8300	3750
TSS Discharge	kg/d	8800	12100	10500	5000
Toxicity		lethal	lethal	lethal	non-lethal

* Assumes 500 tPD production and BC Level A Guidelines

4.0 TREATABILITY OF CTMP/TMP WASTEWATER

4.1 Basic Considerations

There are many factors associated with the wastewater characteristics at Quesnel River which could have a significant bearing on the ultimate design and cost of an anaerobic treatment system. This is irrespective of whether the anaerobic process is an anhybrid system or some other process. Following is a partial listing of the many issues which are considered in Sections 4 and 5 and for which preliminary design assumptions are made.

- degree of COD/BOD_5 removal possible,
- effluent toxicity to anaerobic organisms,
- anticipated gas production and composition,
- alkalinity requirements,
- sulfide toxicity,
- sulfite toxicity,
- hydrogen peroxide toxicity and degradation,
- micronutrient requirements and the effect of DTPA or other chelating agents present in the wastewater,
- nitrogen and phosphorus requirements,
- the effects of fiber spills on reactor operations, and
- the effect of large variations in organic loadings.

Serum bottle tests and other bench scale testing such as those conducted at the WTC are generally able to address the first three items in the above list (e.g., COD reduction, acute toxicity, and gas production). Other sources of information such as full scale experience, published results from relevant pilot plant or bench scale tests, or specific knowledge of mill operations are needed to address the remaining issues.

4.2 Bench Testing at WTC

In November 1985, a small scale continuous flow treatability study was initiated by Environment Canada at the Wastewater Technology Centre using samples of CTMP and

TMP effluents obtained from QRP. Results from previous serum bottle tests presented in Appendix 1 had shown little or no toxic effects of the wastewater to anaerobic biomass.

Two anhybrid reactors were employed for the study. As indicated in Figure 4.1, the reactors consisted of a lower section 3.8 cm in diameter and approximately 0.9 L in volume devoid of packing. The upper section was 9.5 cm in diameter with an approximate volume of 1.8 L and was packed with cylindrical random packing (2.5 cm diameter). Provision was made for effluent recycle.

The plan for reactor operation was as follows:

Reactor 1:	Continuous treatment of CTMP effluent.
Reactor 2:	Alternate treatment of CTMP and TMP every 14 days.

The reactors were seeded from an anhybrid pilot plant which had been treating a starch waste for approximately 6 months. Reactor 2 was seeded on 26 November. Reactor 1 was seeded on 10 December. Reactor 1 was fed CTMP on a continuous basis, except for three periods of shut down; 24 December to 8 January, 21 January to 28 January and 11 February to 19 February. Feed to Reactor 2 was continuous, alternating between CTMP and TMP. Temperature in both reactor systems was maintained at 35° C except for the first two periods of flow interruption to Reactor 1 when the contents cooled to room temperature.

The CTMP and TMP effluent was shipped in 200 L batches. These were stored at the WTC at 4° C. Two to three days supply of feed for each reactor was taken from storage, augmented with nutrients and placed in a feed bucket. Waste characteristics of the reactor feed are given in Table 4.1. Probability plots for feed and effluent are given in Appendix 1.

The average waste characteristics of CTMP feed to Reactor 1 and 2 were similar with the exception of TSS as noted on Table 4.1. Most of the higher feed TSS to Reactor 1 occurred after day 70 and would not affect the pseudo steady state comparison of Reactor 1 and Reactor 2.

FIGURE 4.1

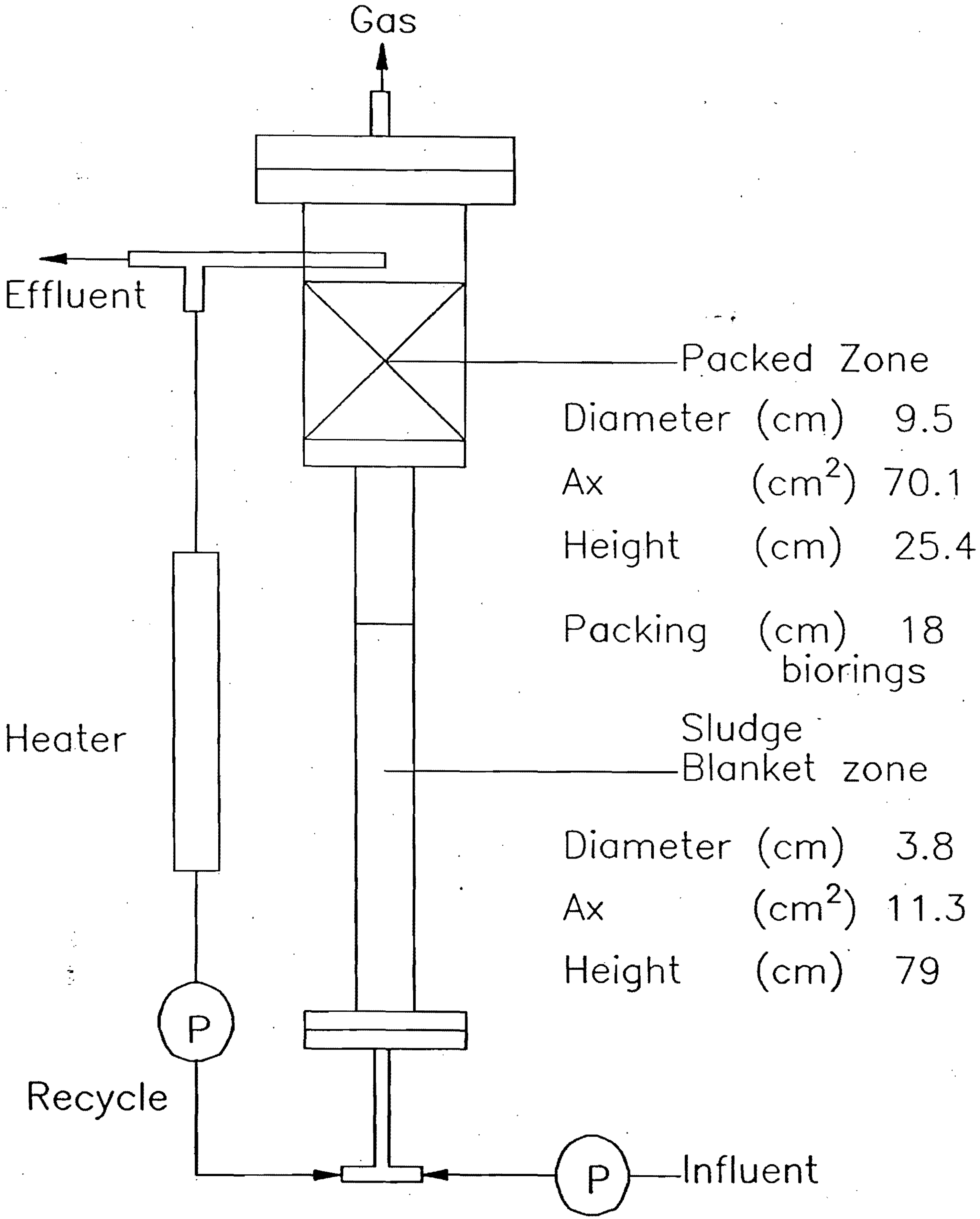

Gas
Effluent
Packed Zone
Diameter (cm) 9.5
Ax (cm^2) 70.1
Height (cm) 25.4
Packing (cm) 18 biorings
Heater
Sludge Blanket zone
Diameter (cm) 3.8
Ax (cm^2) 11.3
Height (cm) 79
P
Recycle
P
Influent

TABLE 4.1 FEED CHARACTERIZATION

Parameter		TMP (mg/L)	CTMP (mg/L)
COD	Tot	3570	6450
	Filt	2530	4620
BOD_5	Tot	1150	2420
	Filt	850	1720
TSS		460	772 *
TKN	Tot	50	65
	Filt	31	41
NH_4		19	22
P	Tot	19	16
	Filt	12	12
TVA		360	760

* TSS to Reactor 1 averaged 980 mg/l
Reactor 2 averaged 460 mg/l

Table 4.2 summarizes the average hydraulic and organic loadings for the reactors for the period of interest.

TABLE 4.2 PSEUDO-STEADY STATE REACTOR OPERATION
(Average Conditions)

	UNITS	REACTOR 1	REACTOR 2
Empty Void Volume	L	2.9	2.5
Feed Rate	L/d	2.8	2.5
Test Period	d	0-70	0-129
Hydraulic Residence *	h	25	24
Recycle	--	75:1	64:1
COD Load			
- CTMP Feed	$kg/m^3.d$	5.6	6.2
- TMP Feed	$kg/m^3.d$	--	3.6

* Based on empty reactor void volume

Problems with the nutrient concentrations in the wastewaters were noted by WTC staff. The COD:N:P ratios in Table 4.3 would indicate that nitrogen feed to the reactors was low. Experimental data for carbohydrate waste indicate that 1.0 to 1.5 mg of N are required for every 100 mg of COD removed to provide for biomass synthesis. The ammonia nitrogen in the TMP and CTMP effluents fed to the reactor was theoretically just sufficient based on the COD removal obtained. In contrast, only minor removals of NH_4^+ nitrogen or filtered total P were observed and significant residual concentrations of both N and P were present in the treated effluent.

Median effluent filtered ammonia-N concentrations for reactor 1 and 2 were between 15 and 23 mg/l and filtered total phosphorus values were between 8 and 10 mg/L. Less than 10% of the time did effluent ammonia values fall below 7 mg/l or phosphorus values fall below 1 mg/l for either reactor. This appears to indicate that nitrogen and phosphorus was available if required for additional COD removal in the reactors.

TABLE 4.3 NUTRIENT ANALYSIS OF AVERAGE REACTOR FEED

	Reactor 1	Reactor 2	
	CTMP	CTMP	TMP
COD (mg/l)	6640	6250	3570
BOD (mg/l)	2460	2380	1150
Filt NH_4 (mg/l)	22	22	19
Filt Tot P (mg/l)	13	12	12
COD:N:P	500:1.5:1	500:2:1	300:1.5:1
	100:0.3:0.2	100:0.4:0.2	100:0.5:0.3
BOD:N:P	100:0.9:0.5	100:0.9:0.5	100:1.6:1

Reactor #1 Operation

During the first 70 days of operation, Reactor 1 was loaded at 5.6 kg COD/m^3.d and averaged 47 percent COD removal. Feed pH during this period was maintained between pH 7.0 and 8.5. Approximately 0.13 L of methane were recovered in the biogas for each gram of COD removed. Operational difficulties developed during the first shutdown period while the reactor was on recycle. On day 20, the recycle line plugged causing the fluidized sludge bed to collapse. The biosolids had to be drained and then pumped back into the reactor to refluidize the bed. On day 23, the bed collapsed again. On day 42, when the feed to the reactor was stopped for the second time, biosolids were still granular in appearance and gas was averaging 1.6 L/d.

After restarting on day 49, fluidization again was lost on day 51. The two attempts which were made to refluidize the biosolids broke up a large proportion of biosolid granules allowing biomass to escape from the reactor. On day 59, the recycle line broke. On day 63, the reactor was again placed on recycle for 8 days. The granular appearance of biosolids continued to deteriorate and by day 70, COD and BOD removal, gas production and percent methane had decreased substantially (Figure 4.2). From day 71 to day 141, COD removal averaged 33 percent. Gas production decreased to 0.4 L/d while effluent volatile acids averaged 1144 mg/l. Total COD loadings were 25 to 35 percent higher during this period (e.g., 7.5 and 5.4 kg/m^3.d respectively).

It is evident that operational difficulties contributed substantially to the poor performance of Reactor 1. The reactor was only fed CTMP waste for 30 of the first 60 days of the operating period. The problems with biomass fluidization caused degradation of the biosolid granules with resultant loss of biomass. This in turn resulted in atypical results after day 70.

As previous serum bottle testing had not demonstrated the CTMP waste to be toxic (Appendix 1) and as the waste proved to be amenable to treatment in Reactor 2 (when alternated with TMP), the poor results are attributed to the operational difficulties associated with intermittent feeding. This hypothesis definitely requires confirmation in future pilot trials.

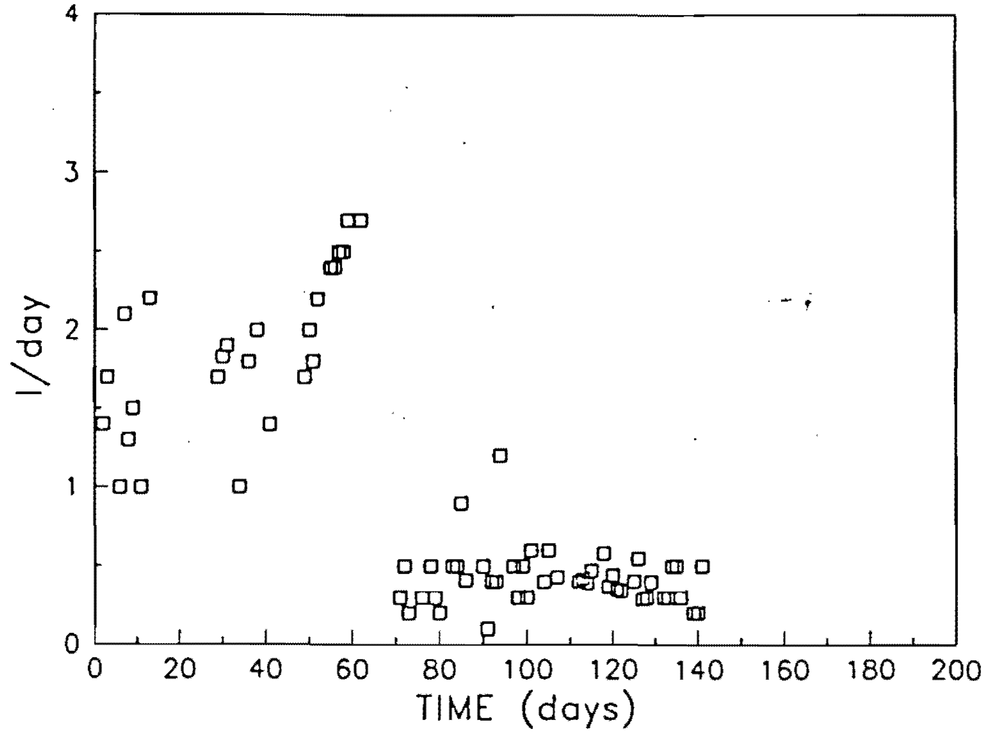
Reactor #2 Operation

Feed to Reactor 2 alternated between CTMP and TMP on a two week cycle. Loading of CTMP up to day 129 averaged 6.2 kg COD/m^3.d with the average for TMP at 3.6 kg/m^3.d. Overall COD removal for the period averaged 45 percent. Graphical data presented in Appendix 1 show that median BOD_5 removals were 65-69 percent for both TMP and CTMP for total and filtered samples. Reactor pH varied with the type of feed but remained within a relatively safe range between 6.5 and 8.5.

Figure 4.3 shows that the cyclic nature of the influent loading was evident in the measured rate of gas production and in the effluent BOD concentration. The figure also shows that performance was relatively stable during each two week period and that the treatment system appeared to adjust rapidly to the loading changes without difficulty.

REACTOR 1
GAS PRODUCTION

FIG. 4.2a



REACTOR 1
% BOD REMOVAL

FIG. 4.2b

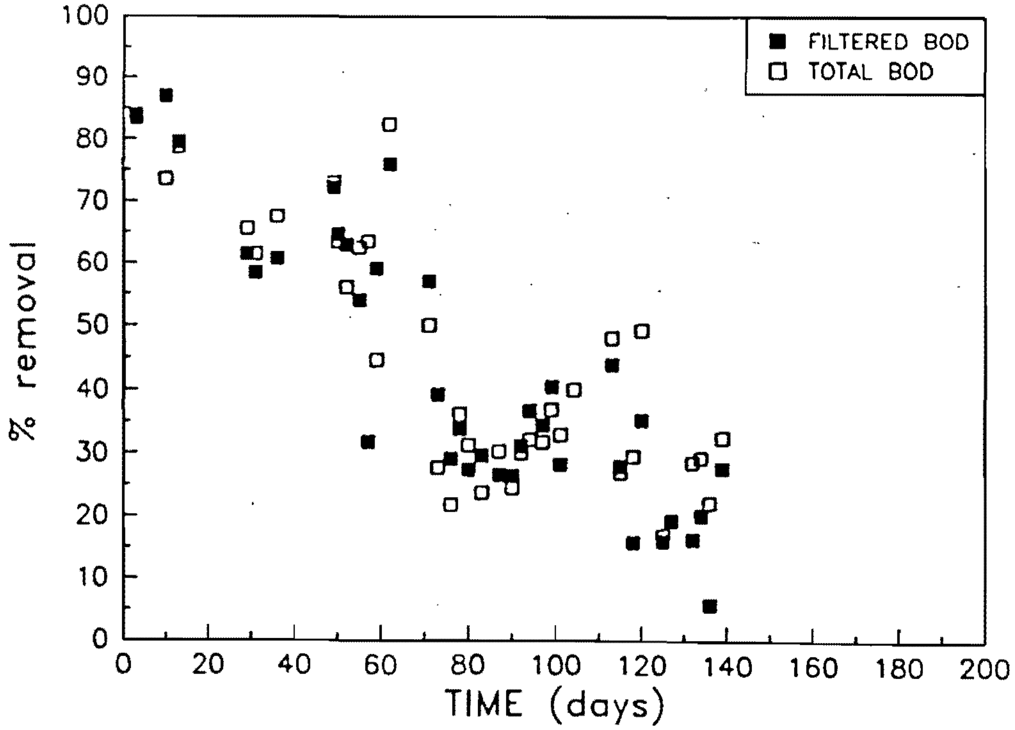
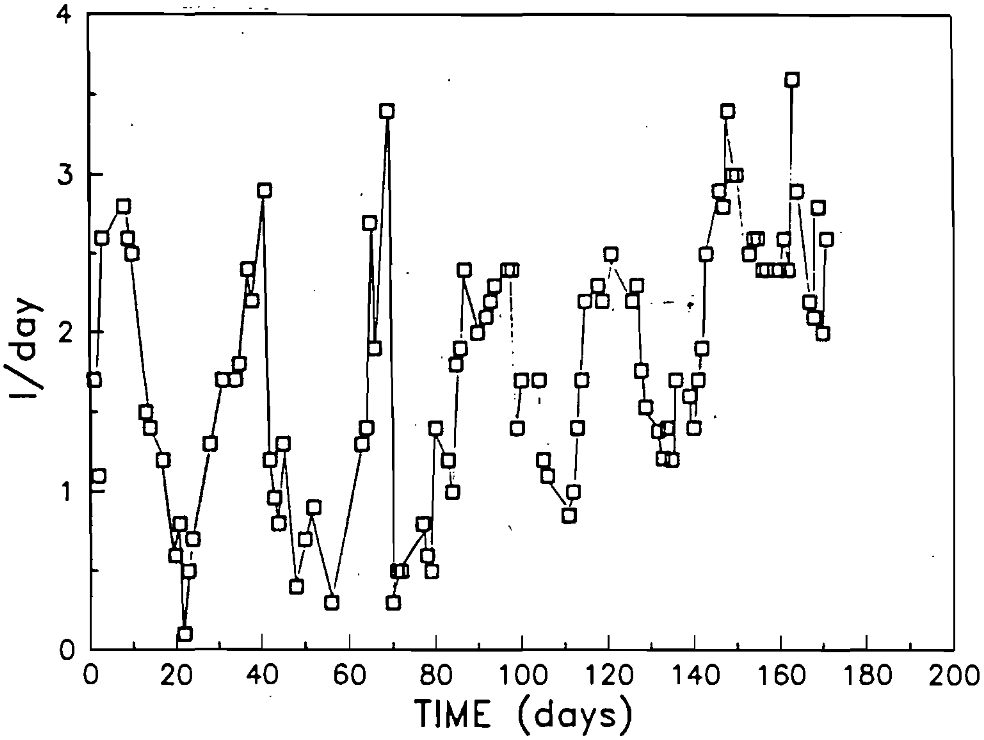
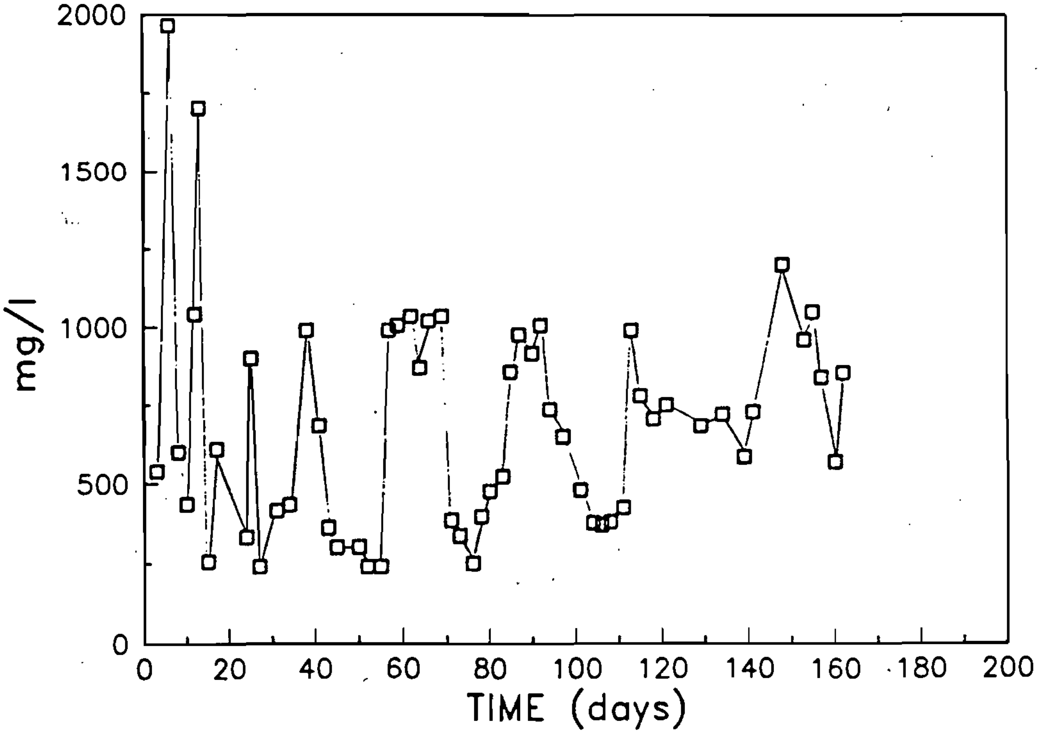


FIG. 4.3



REACTOR 2
GAS PRODUCTION



REACTOR 2
EFFLUENT BOD

BOD_5 concentrations in the treated effluent were generally between 200 and 400 mg/L at the lower loading range when TMP effluent was treated. They increased to maximums in the range of 900 to 1100 mg/L at the higher loading with CTMP effluent.

Starting on day 130, flow rates were increased gradually to an average of 5.2 L/d between day 160 and day 170 giving a COD loading of 6.4 $kg/m^3.d$. No difference in COD removal was observed compared to the prior period. This is demonstrated in Figure 4.4 which is a plot of cumulative influent and effluent COD loads during the test program. The figure shows that percent COD removed in the reactor was relatively constant despite differences in loading.

Methane content in the biogas varied considerably during the 170 days of reactor operation with values as low as 40-45 percent and as high as 80 percent methane. The median was approximately 65 percent methane which is within the anticipated range. Methane yield measured as cubic meters of methane gas per kilogram of total COD removed generally varied between 0.1 and 0.3 compared to a theoretical value close to 0.35 m^3/kg. It is suspected that some of the gas may have evaded measurement (e.g., dissolved gas in treated effluent and leaks) creating the greater than expected variability and a general underestimate of yield. COD conversion by sulphur reducing bacteria could also have depressed methane yield.

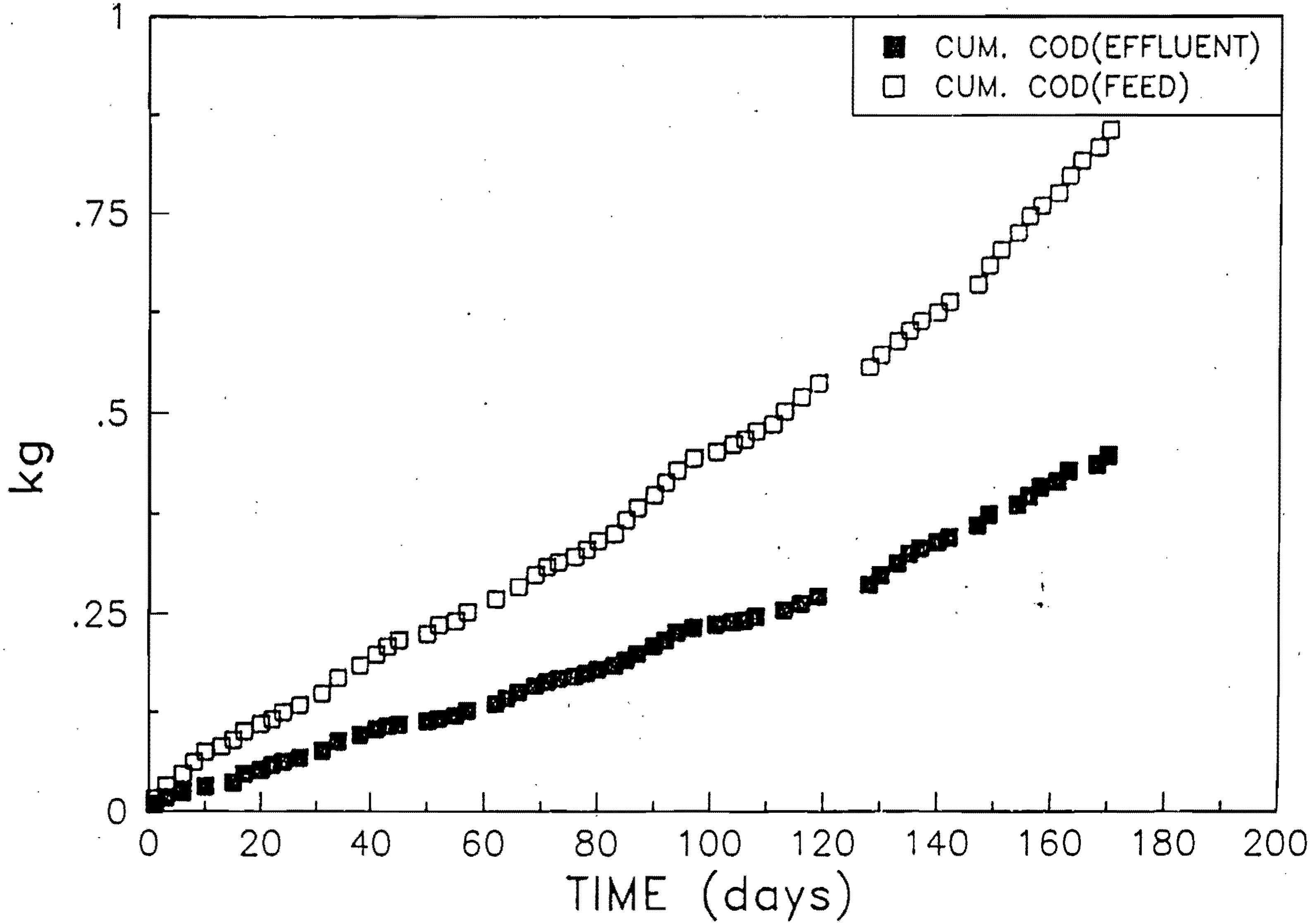
Operational problems did not appear to affect Reactor 2 performance to the extent they impacted Reactor 1. Unlike Reactor 1, feeding was continuous without periods of recycle only. A failure in the recycle line allowed the fluidized bed to collapse on day 7. After converting to TMP feed on day 14, the sludge bed subsided again, indicating a reduction in buoyancy possibly due to lower gas production. The biosolids gradually lost their granular appearance and acquired the appearance of a grey loose fibrous floc. Microscopic examination indicated the presence of wood fibres. By day 51, wall growth on the reactor had developed sufficiently to obscure visual observation of the fluidized bed. After day 120, it was noted that the colour of the biosolids was becoming darker.

Summary

Two anhybrid reactors were operated on QRP effluent at the Wastewater Technology Centre. Reactor 1 received only CTMP while Reactor 2 received CTMP and TMP on a two week cycle. Operating difficulties apparently led to the failure of Reactor 1 after

REACTOR 2
CUMULATIVE COD

FIG.4.4



70 days of operation. Reactor 2 appeared to operate successfully for the entire 170 days it was monitored.

A comparison of Reactor 1 (day 0 to day 70) and Reactor 2 (day 0 to day 129) in Figure 4.5 indicates no difference in effluent COD or percent removal. Cycling of the feed bi-weekly apparently did not affect performance. It should be noted from Figure 4.5 that the different feed stocks did not affect the percentage removal of COD obtained. Similarly, the BOD_5 removal in Reactor 2 averaged 65-69 percent regardless of effluent feed (e.g., CTMP vs TMP). This would appear to indicate no difference in treatability between CTMP and TMP.

Methane yield for both Reactors 1 and 2 was considerably lower than theoretical averaging 0.14 $m^3/kg\ COD_r$-d and 0.17 $m^3/kg\ COD_r$-d respectively. No difference in methane yield was observed for Reactor 2 with the different feed stocks.

4.3 Relevant Design Experience

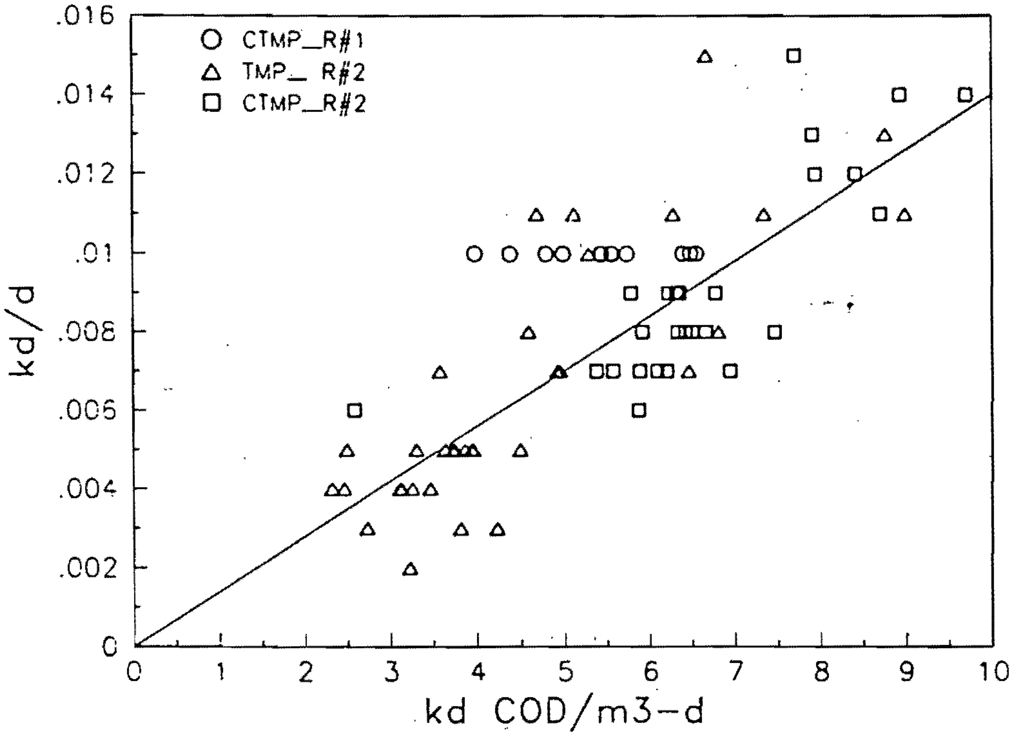
Introduction

There are very few full scale anaerobic treatment systems at TMP or CTMP mills worldwide and most of these were still under construction at the time this study was undertaken. Table 4.4 identifies several of the most relevant examples. In most cases, only partial design information is available for the treatment systems referred to in the table as some processes are proprietory. However, sufficient data are available to develop some guidelines for conceptual design at Quesnel.

Hydrogen Peroxide Toxicity: Hydrogen peroxide is known to be toxic to anaerobic biological processes suggesting that pretreatment ahead of the anaerobic system must be considered. Bench scale testing completed by SCA using a small continuous flow anaerobic reactor with CTMP effluent showed that influent concentrations of H_2O_2 up to 200 mg/L were removed without disrupting the process (Welander et. al. 1984). There was no measurable peroxide in the reactor effluent (e.g., ORP in the reactor remained at -300 to -400 mv Ec when 200 mg/L of peroxide was added to the feed). Increasing the dose to 500 mg/L caused a rapid increase in reactor ORP which stabilized at high positive values (e.g., approximately +350 mv Ec) indicative of high H_2O_2 residuals and causing reactor failure.

FIGURE 4.5

EFFLUENT COD vs COD LOADING



%COD REMOVAL vs COD LOADING

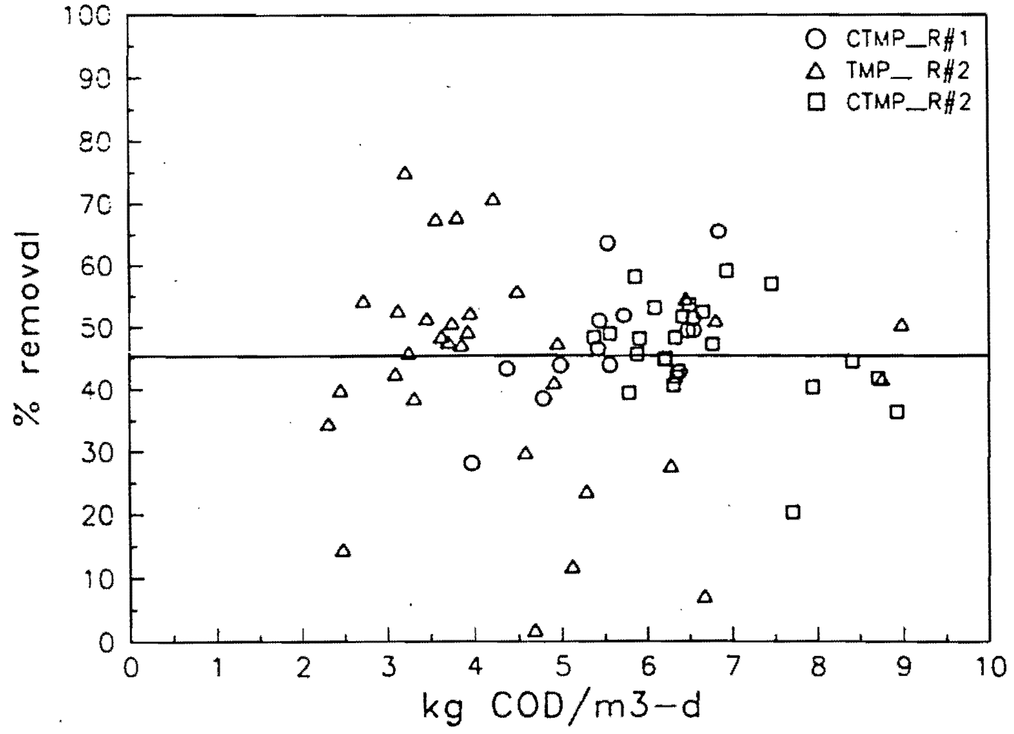


TABLE 4.4 RELEVANT FULL SCALE ANAEROBIC EXPERIENCE

1. SCA, Ostrand Mills, Sweden

   Production: 240 tPD CTMP with H_2O_2 bleach and 860 tPD bleach kraft pulp.

   Treatment: Separate anaerobic/aerobic treatment system for CTMP effluent. The process comprises pretreatment for H_2O_2 removal, sludge bed anaerobic treatment, a lamella clarifier and activated sludge post-treatment.

   Status: Under construction summer 1986.

2. Tampella Ltd., Anjala Paper Mill, Finland

   Production: 890 tPD newsprint and specialty grades from Pressure Groundwood/TMP. The paper mill uses H_2O_2 and/or dithionite bleach.

   Treatment: TAMAN anaerobic/aerobic effluent treatment process for woodroom, groundwood/TMP, and paper mill effluent. The system includes H_2O_2 removal, primary clarification, an anhybrid type two-stage anaerobic process and aerobic polishing in an aerated basin.

   Status: Scheduled start-up 1986.

3. MoDo Papper AB, Domsjo Sulfite Mill, Sweden

   Production: 700 tPD bleached sulfite pulp and 190 tPD bleached CTMP.

   Treatment: ANAMET anaerobic treatment process without the activated sludge post-treatment component. The system has no significant equalization step and only a short retention post-aeration unit.

   Status: The system has been undergoing start-up since early 1985 and will shortly start to treat CTMP effluent when the new mill start-up occurs.

4. Caxton Paper, New Zealand

   Production: CTMP pulp and tissue.

   Treatment: BIOTIM-A two stage treatment with CSTR in first stage for detoxification and anhybrid type sludge blanket methanogenic second stage.

   Status: Reported to start up is 1987.

5. Niagara Paper, Niagara, Wisconsin

   Production: 440 tPD coated specialties including 190 tPD H_2O_2 bleached stone groundwood.

   Treatment: Anaerobic contact process for pretreatment of bleach plant filtrate, excess machine whitewater and waste activated sludge from the existing Attisholz activated sludge process. Equalization for H_2O_2 removal.

   Status: Construction and start-up in 1986.

Hydrogen peroxide is a highly reactive oxidizing agent and will degrade spontaneously in the wastewater given sufficient time. The degradation process can be accelerated under the proper environmental conditions such as the following:

- in the presence aerobic biological sludges,
- in the presence of reducing agents such as sulfides and sulfites, or
- in the presence of catalysts such as manganous oxide.

The process developed by SCA will have a pretreatment stage, essentially two tanks in series, with a combined hydraulic retention of 9-10 hours (Anderson et. al. 1985). A controlled flow of activated sludge will be recycled to the first tank which is mixed but not aerated. Some aerobic and facultative organisms in the return sludge produce the enzyme catalase which enables the breakdown of H_2O_2 into molecular oxygen and water. All of the peroxide is removed in the first tank but the redox potential will be relatively high because of the evolution of oxygen from the wastewater. The second tank is provided to allow sufficient time for the acid forming organisms to return the wastewater to a suitable negative ORP before the wastewater is pumped to the anaerobic reactors. It is reported that 100 to 500 mg/L of peroxide is expected in the SCA wastewater under normal conditions. This form of effluent pretreatment is possible only if the treatment process includes an activated sludge step to provide a source of thickened aerobic sludge.

Niagara Paper has apparently elected a pretreatment method relying on natural degradation to reduce peroxide concentrations ahead of anaerobic treatment (Ref. 11). The bleach plant effluent containing several hundred mg/L of H_2O_2 will be blended with the other feed flows and stored in an equalizing basin for several hours before the anaerobic step. This method of peroxide control was successful during the pilot plant testing program. The design hydraulic residence of the full scale equalizing basin is not known but it is probably somewhere between 4 and 12 hours based on communications with mill staff.

Tampella's Anjala mill has a stirred equalization tank of unknown hydraulic retention to remove the 200 to 300 mg/L residuals of peroxide emanating from the pressure groundwood and TMP mill (Rekunen 1985). The tank is upstream of the primary clarifier and it appears that provision has been made to recirculate some primary sludge to this tank to assist the degradation process. This presumably is done to maximize contact/reaction opportunity between the peroxide and the bark and fiber which originate in the woodroom.

MoDo Domsjo has made no allowance for a specific pretreatment stage for peroxide removal when its new CTMP mill commences operation in 1986 (Ref. 11). The wastewater presently being treated in the single stage ANAMET process has a relatively high concentration of sulfites and company representatives feel that the chemical oxidation/reduction reaction between the peroxide and the sulfite will be adequate protection against peroxide entering the anaerobic process in significant concentrations. CTMP liquor in the pressates contains sulfite at significant concentrations which MoDo personnel believe will be sufficient to react with any peroxide residuals in the main flow of excess CTMP white water, even if the sulfite mill is not running.

There is obviously a wide diversity of approach to removing hydrogen peroxide ranging from no pretreatment (e.g., MoDo) to very complex pretreatment (e.g., SCA). It does seem, however, that hydrogen peroxide containing effluent can be pretreated successfully. The differences in approach may relate to the expected H_2O_2 residual concentrations in the combined effluents which are very little after reaction with residual sulfite at MoDo versus 100-500 mg/L at SCA. The design range of 50-100 mg/L of H_2O_2 remaining in the effluent at Quesnel River during CTMP production (Table 3.1) is an estimate only. The concentration discharged in the white water could be much higher on occasion during upsets in the bleach plant. For example, a concentration of 500 mg/L could be possible during an upset (assume only 60 percent H_2O_2 utilization on pulp) based on typical peroxide charges of 2.0 to 2.5 percent on unbleached fiber. This does not consider the reducing power of sulfites or other substances present in the high liquor/fiber streams entering the clarifier. It is anticipated that the present clarifier effluent has reducing potential to offset the effects of a considerable H_2O_2 load. Exactly how much potential exists and the rate of reaction is unknown. This must be explored by direct testing of fresh effluents.

Hydrolysis Step: TMP/CTMP wastewaters are generally poorly hydrolyzed. This is to say that the majority of the degradable organic material is present as carbohydrate as opposed to acetic acid and related short chain organic acids. For example, Jurgensen and coworkers (1985) presented data from sampling programs at 9 mills using TMP type pulping processes. On average, the volatile fatty acids accounted for only 12 percent of the BOD_5 and 4 percent of the COD in samples of fresh untreated wastewater.

Designers and vendors of anaerobic processes often talk about the need for a hydrolysis reactor ahead of the main anaerobic process in such cases. This is to ensure that the highest possible proportion of the degradable organic substances entering the anaerobic phase are immediately available for conversion to methane. There is little hard evidence that a separate hydrolysis step has proven to be important in treating pulp and paper effluents. Some commercial anaerobic systems such as the BIOTHANE process include a hydrolysis/recycle reactor as part of the basic system. Other vendors do not have hydrolysis reactors in their standard designs (e.g., ANAMET) and rarely if ever consider them. The SCA process described in Table 4.4 incorporates hydrolysis as part of the H_2O_2 detoxification step but the designers admit that the basis for design was to eliminate the peroxide and other toxic materials and that hydrolysis was a lesser concern. BIOTIM are also promoters of a pretreatment stage when the effluent is poorly acidified or when it is likely to be toxic to anaerobic biomass; both of which could apply at Quesnel.

COD/BOD_5 Removal: Table 4.5 summarizes COD and BOD_5 removal data from two pilot studies, the design objectives for SCA's and Tampella's full scale anaerobic/aerobic treatment systems and bench scale testing results used in the design for the treatment system at Caxton Papers in New Zealand. The WTC bench test data are generally within the range of removals shown in the table. Most of the BOD_5 removals cited are in the 70 to 80 percent range or higher. COD removals are much lower in the 45 to 60 percent range in most cases. This is understandable as lignin and lignin derivatives account for a significant percentage of the total COD in TMP/CTMP effluents. Lignin is generally considered to be non-biodegradable anaerobically.

The data in the table give a clear indication that TMP and CTMP type pulp and paper effluents are generally amenable to anaerobic treatment based on BOD removal. The design removals selected by SCA and Tampella were the products of extended bench scale and pilot scale testing in each case.

TABLE 4.5 BOD$_5$ AND COD REMOVALS FOR TMP/CTMP EFFLUENTS (%)

Mill	Type	Data	Anaerobic Reactor COD	Anaerobic Reactor BOD$_5$	Ref.
SCA, Sweden	CTMP	Design for Full Scale	60-70	80-90	1, 13
Tampella, Finland	TMP/ Grdwd.	Design for Full Scale	55-60	75	13, 15
Con. Bath., New Bruns.	CTMP/ NSSC	Pilot - An. Basin	50	76	19
		- An. Filter	29	63	
Mac Bloe., Ontario	TMP/ * NSSC	Pilot - Hybrid	54	75	6
		- UASB	56-59	85-91	
		- Fluid Bed	54-58	81-90	
Caxton, New Zealand	CTMP/ Tissue	Bench	33-37	73-81	3

* Hardboard production which uses pulping process similar to TMP

Inhibition and Toxicity: It is possible that there will be some problems with inhibition or toxicity in an anaerobic treatment process at Quesnel. These, however, should be resolvable. At Tampella it is claimed that no special steps are necessary to ensure a non-toxic effluent beyond the hydrogen peroxide removal process discussed previously. SCA claim to have developed a special chemical mixture to counteract inhibition/ toxicity that remains a problem even after the peroxide is removed. This may be related partly to DTPA, a chelating agent used in CTMP process. The availability of micronutrients in the anaerobic system may be affected if they are tied up by DTPA.

The presence of sulfides in the anaerobic reactor is an item which merits study at Quesnel River. Sulfide concentrations in the reactor could easily stabilize at 100 to 200 mg/L during CTMP production if most of the sulfate in the influent wastewater is reduced. This is in a range that many researchers feel may lead to sulfide toxicity (Puhakka et. al., 1984; Speece, 1983). On the other hand, many successful pilot and full scale systems have been reported with sulfate-S concentrations at or above the concentration in the CTMP effluent (e.g., 300 mg/L) including recent pilot studies at a waste-paper board mill in Scotland (Newns, 1986), a gypsum board mill (Habets, 1986), and with the ANAMET system at Saica in Spain (Ref. 13). This may be due in part to incomplete reduction of sulfur during treatment thus limiting sulfide concentration. Eis and coworkers (1983) reported that only 10 to 60 percent of influent sulphate is accounted for as sulfide in anaerobic processes. This is not always the case as 90 percent or higher conversions of sulfate have been reported for pulp and paper effluents (Eekhaut et. al., 1986); Jopson et. al., 1986).

Some reports show that sulfites are not reduced to sulfide in anaerobic treatment systems and that sulfite can be toxic to anaerobic organisms at concentrations as low as 40 mg/L SO_3-S (Puhakka et. al., 1984; Pipyn et. al., 1985). Sulfite may or may not be present in the CTMP effluent depending on the balance between SO_3-S and H_2O_2 losses. Sulfite and peroxide will not co-exist for long. Sulfite may be a problem with the TMP effluent as the Borol bleaching system leaves significant sulfite residuals in the excess whitewater as shown in Table 3.1.

Alkalinity: Some wastewaters are low in bicarbonate alkalinity and require a supplement to maintain the proper pH range in the anaerobic reactor. The amount of alkalinity required can make a major difference in the economic feasibility of a proposed treatment process.

The caustic soda and sodium sulfite used in the CTMP cooking liquor produces an effluent at Quesnel which is neutral to slightly alkaline containing a small amount of bicarbonate alkalinity. There is at least one procedure available that would predict a substantial requirement for additional alkalinity for anaerobic treatment of this effluent (Li et. al., 1983). It is BEAK's experience that the procedure can overpredict the need for alkalinity in at least some cases. The Papierfabriek mill at Roermond in Holland (PAQUES UASB process) has a wastewater with pH of 6.8 with a few hundred mg/L of bicarbonate alkalinity and does not require extra chemicals. At Tampella, the groundwood, TMP and woodroom effluents are reported to have an initial pH of 5.5, yet the expected alkalinity requirement for full scale is only 50 mg/L of NaOH (Ref. 11). This is considerably lower than an estimate using the theoretical procedure. SCA claim that their CTMP anaerobic system will need some extra alkalinity (combination of lime and NaOH) but they were not prepared to say how much.

TMP effluent is more acid than CTMP effluent. This suggests a higher probability for supplementary alkalinity. Untreated effluent pH at Quesnel decreases from 8 to approximately 6 when mill production changes to TMP when there is no pH adjustment.

5.0 TREATMENT STRATEGY

5.1 Process Overview

This section describes a conceptual anaerobic/aerobic treatment process developed to meet the specific needs at Quesnel River Pulp. The design was evolved bearing in mind the existing effluent treatment facilities and recognizing the need for three basic components as follows:

- pretreatment for fiber removal and detoxification,
- anaerobic treatment for COD/BOD removal, and
- aerated polishing for odour and toxicity removal.

Discussions in Section 4 have shown that there is considerable uncertainty regarding the degree of detoxification necessary at Quesnel to prevent sulfite or hydrogen peroxide toxicity. Preliminary calculations of solids yields and removals in the post aeration step also indicated some uncertainty regarding the control measures required to meet the TSS limits of 10 kg/ADt. Therefore, two different conceptual designs were developed instead of one. The anaerobic component is common to both processes while the variations exist in the approach to pre and post treatment. Drawing D-100 following presents schematic flowsheets of the two processes.

5.2 Anhybrid Treatment Process A

Pretreatment: Process A in Drawing D-100 starts with a 12 hour agitated equalizing basin where both effluent flows are combined ahead of solids removal in the clarifier. This will provide time for residual concentrations of hydrogen peroxide and reducing agents such as sulfite to neutralize one another before the effluent reaches the anaerobic reactors. The flowsheet shows two submerged mixers and the potential for recirculating sludge from the clarifier. Recirculation is provided for flexibility as this pretreatment arrangement is similar to the system for the TAMAN process in Anjala.

The flowsheet indicates that the pretreatment basin is for peroxide control. The same facility may be useful in partially controlling sulfite toxicity during TMP production by introducing some pre-aeration.

Combined pretreated effluent would flow by gravity to the existing primary clarifier. Hydraulic loading to the clarifier at present is very low and it is thought that the unit could treat the combined whitewater and fiber bearing streams. This has apparently been done in the past. Residence time of the combined effluent flow in the clarifier would allow the effluent to stabilize at a low oxidation/reduction potential (ORP) before anaerobic treatment. This would act as a safeguard against upsets in the anaerobic reactor caused by dissolved oxygen or peroxide residuals. Provision could be made to bypass the entire anaerobic process during extreme upset conditions in the mill to prevent irreversible toxic effects to the anaerobic sludge. Severe disruption of the biomass could require months for recovery.

Anaerobic Treatment: Anaerobic treatment in Process A is based on two parallel anhybrid reactors, each 4650 m^3 in volume. The design COD load is 10 kg COD/m^3-d. Preliminary estimates of reactor costs were based on two circular concrete tanks 9 m high by 28 m in diameter. Total liquid volume in each tank would be 4130 m^3 including a 1060 m^3 section (e.g., 2 m deep) near the top of the reactors which would contain a rigid plastic media. Feed from the clarifier would be pumped into the bottom of the reactors through a plastic header system containing an array of nozzles with a aerial density of 0.5 nozzle/m^2 of floor area.

Anhybrid reactors are designed for upflow operation. Biomass accumulates in the lower void zone and the media act to retain the biomass in the reactor and for initial gas/liquid separation. Final gas/liquid separation would be accomplished using a submerged weir system designed to provide a liquid seal between the outside atmosphere and the gas space at the top of the reactor. A further function of the rigid media is to accelerate the start-up process by providing a zone in the reactor where anaerobic biomass can become physically attached and accumulate rapidly.

A recycle pumping system would be provided so that a portion of the treated effluent could be returned to the reactors. This allows a constant upflow rate to be maintained to promote proper sludge development and reduces concentration gradients that might otherwise form in a plug flow system.

Auxilliary facilities associated with the anaerobic process would include a gas collection, metering and emergency flare system; a control building to house the pumps and control area; and a tank for preparing, storing and metering of caustic soda for alkalinity control in the reactors. The flowsheet shows that the biogas would normally be burned in the flash drier in the mill. The predicted gas flows of 7800 Nm^3/d and 18600 Nm^3/d for TMP and CTMP respectively represent considerable fuel value. Nevertheless, a careful evaluation of the feasibility and costs for dual fuel firing in the drier is a must. The cost estimates presented in Section 6 exclude the cost of gas re-utilization.

The current mill practice of adding sulfuric acid to the CTMP effluent at the mill to lower pH to 7 should not be required with anaerobic treatment. Addition of 50 percent sodium hydroxide to TMP effluent to increase pH would likely continue to some degree. Notwithstanding the caustic addition capability at the mill, the conceptual design shown on the flowsheet has allowed for a 10 percent caustic tank at the reactors for fine tuning of pH/alkalinity in the reactors directly.

The mill's current practice of controlling the temperature of the mill effluent to prevent excessive temperatures in the first cell of the aerated basin would continue. This would be to maintain a steady operating temperature of 35 to 38 degrees C in the anaerobic reactors. It has been assumed that no changes to the existing heat exchange facility would be required. Existing nutrient addition systems for aqua ammonia and phosphoric acid would also be retained for anaerobic/aerobic treatment with the clarifier outfall as the point of addition.

Aerated Polishing: The existing aeration basin system would be retained as an aerobic polishing step to oxidize sulfides and residual biodegradable organics in the effluent from the anaerobic reactors. Oxygen transfer requirements would be much lower than at present such that the original blower system could be shut down under normal conditions (e.g., reduction of 630 kW of aeration power). Most of the air distribution would be to the first cell in the 5-day polishing system.

5.3 Anhybrid Treatment Process B

The major difference between Process A and Process B is that in Process B the existing 2 cell aerated basin would be converted into a low rate activated sludge polishing step following anaerobic treatment. Effluent from the first cell would flow by gravity to a new 23 m diameter secondary clarifier with clarifier effluent flowing to the second aeration cell. A differential head of 25 to 35 cm of water would be maintained at the existing baffle wall to permit gravity flow through the process. It was assumed that the baffle is sufficiently robust to withstand this head once existing holes or gates are sealed.

Table 5.1 presents the operating conditions for the activated sludge portion of the system assuming 75 percent BOD_5 through the anaerobic process. This is a low BOD_5 load but is within conventional limits for extended aeration processes.

TABLE 5.1 PROCESS B - ACTIVATED SLUDGE POLISHING

	UNITS	CTMP	TMP
Flow	m^3/d	10100	8000
BOD_5 Load	kg/d	7400	3100
Basin - Volume	m^3	27000	27000
- Residence	d	2.7	3.4
Mixed Liquor (MLVSS)	mg/L	2500	2500
F:M Ratio	kg BOD_5/kg VSS.d	0.11	0.05

Treatment efficiencies should remain consistent year round as the relatively short retention will prevent excessive declines in operating temperatures in winter.

The conversion to activated sludge would allow direct control on solids discharge in the final effluent and also would permit recycle of aerobic, catalase producing sludge to a peroxide destruction step ahead of anaerobic treatment. This is in line with the approach used by SCA at their CTMP mill in Ostrand, Sweden (Table 4.4). Aeration power required for the activated sludge and polishing system would be roughly the same as for aerobic polishing in Process A.

The pretreatment system in this design would combine the existing clarifier effluent and the excess whitewater flow in a 4-5 hour retention detoxification basin. The detox basin would be completely mixed using submerged mixers and would include an overflow/ underflow baffle arrangement to create two compartments. Return activated sludge and the two process streams would be mixed in the first compartment to promote H_2O_2 destruction by reaction with sulfite and other reducing agents in the clarifier effluent. Hydrogen peroxide decomposition to water and molecular oxygen would also be catalyzed by the presence of the bacterial enzyme catalase present in the aerobic biological sludge (Anderson et. al., 1985; Welander et. al., 1984). The ORP of the effluent in the first compartment could be high until all of the hydrogen peroxide is removed. The second part of the baffled basin is intended to provide enough time following the peroxide removal for a stable negative ORP to re-establish. This would provide a suitable monitoring control on the efficiency of H_2O_2 removal.

Flowsheet D-100 shows a small quantity (1100 kg/d) of excess biological sludge returned to the primary clarifier for removal and dewatering. Normal wasting of sludge would be to the anaerobic reactors. This could represent a 50 percent increase in the present sludge load to the twin wire belt press used for dewatering and would affect sludge dewaterability. An allowance was made in preparing cost estimates to replace the belt press for Process B as the present unit is in poor condition even though the total sludge load would remain relatively low based on most 1.0 - 1.2 m wide machines.

5.4 Predicted Effluent Quality

Table 5.2 is a summary of the performance predicted for the two processes shown in Drawing D-100. BOD_5 and toxicity are expected to meet the regulatory guidelines routinely for both processes. It is understood that toxicity removal by aerobic treatment alone was found to be difficult during recent pilot studies at Quesnel River (Servizi et. al., 1985). The only additional published information relevant to this issue showed that 5 days of aerobic polishing following anaerobic treatment of a mixed NSSC/CTMP effluent was adequate to produce a non-lethal effluent (Wilson et. al., 1985).

TABLE 5.2 PREDICTED TREATED EFFLUENT QUALITY

	Units	TMP	CTMP	Limit
Process A				
Flow	m^3/d	8000	10100	--
BOD_5	kg/d	820	1500	3750
TSS	kg/d	4200	6500	5000
Toxicity		N.L.	N.L.	N.L.
Process B				
Flow	m^3/d	8000	10100	--
BOD_5	kg/d	250	590	3750
TSS	kg/d	4200	4200	5000
Toxicity		N.L.	N.L.	N.L.

N.L. = non-lethal

Predicted suspended solids discharges in the final effluent from Process A would exceed the limit during CTMP production. The predictions were made using conventional yield values for anaerobic treatment and a yield for the aerobic polishing step calculated using pilot data from QRP presented by Servizi et al. (1985). There is some uncertainty about the ability of Process A to meet the Level A standards for TSS. It was partly for this reason that the option for activated sludge was included in Process B. Solids wasting could be controlled to more or less guarantee compliance with solids in this case.

6.0 DEVELOPMENT PROGRAM

6.1 Overview

CTMP/TMP effluents in general, including the effluents at Quesnel River Pulp, appear to be amenable to anaerobic biological treatment. At least three CTMP mills in Sweden and New Zealand have already committed to full scale anaerobic/aerobic treatment and several other mills have reported success treating effluents which are at least partially thermomechanical in origin. On this basis, combined anaerobic/aerobic treatment appears to be a reasonable technology with a high probability of success for Quesnel River.

Rigorous pilot scale testing at the mill using a continuous source of fresh effluent must precede final process selection, design and construction as there are several aspects of the wastewater characteristics and mill operation which are unusual and which probably will affect the ultimate design. Furthermore, there are little or no full scale data from the other CTMP mills employing anaerobic technology as these systems were under construction or just beginning start-up at the time of this study.

The recommended program would incorporate the following components:

- o Preliminary Evaluations
  - Bench testing to examine the need for pretreatment (SO_3-S or H_2O_2 control)

- o Pilot Plant Testing
  - Process start-up/acclimatization
  - "Steady state" operation to select design data for:
    COD load,
    alkalinity requirements,
    nitrogen and phosphorus requirements,
    micro-nutrient requirements, and
    methane yield.
  - Transient Conditions
  - Pretreatment Performance Evaluation
  - Aerated Polishing Performance Evaluation

- Related Studies
  - Feasibility review of biogas use in flash drier.

6.2 Preliminary Evaluation

6.2.1 Bench Testing

A two to three month period of bench scale testing involving anaerobic toxicity assays (ATA's), biochemical methane potential (BMP) tests, and chemical degradation studies will be necessary to examine the potential presence and toxicity of residual concentrations of hydrogen peroxide and sulfite in the combined effluent. This work must be done at the mill using fresh samples of effluent. The test results will be used to determine the following:

1. mean and maximum H_2O_2 concentration in CTMP effluent immediately after mixing the clarifier effluent and the whitewater,
2. same as above for SO_3-S during TMP production,
3. natural decay rate for residual H_2O_2,
4. relative toxicity of residual SO_3-S and H_2O_2 containing effluents (by ATA), and
5. preliminary design for pretreatment system for the pilot trials.

6.3 Pilot Plant Testing

6.3.1 Process Start-Up/Acclimatization

An initial source of anaerobic seed sludge will be necessary regardless of the type of anaerobic reactor tested. Sludge from a healthy municipal anaerobic digester would be adequate for starting a contact or a packed reactor system. This may also be adequate for a sludge bed, an anhybrid or a fluidized bed process although a direct source of "granular" sludge or "acclimated sand media" would be much better to avoid unacceptably long start-ups.

A start-up period of 12 to 16 weeks should be planned. This length of time is necessary to allow biomass inventory in the reactor and the organic loading to increase to design operating levels and it provides time for a reasonable "turn-over" of the seed. Performance at "design loading" should be evaluated after it is reasonably certain that a majority of the biomass in the reactor is "new" (e.g., developed from the mill effluent) rather than original seed sludge.

Start-up is completed when the anaerobic reactor is physically stable, has demonstrated an ability to increase biomass inventory, and is biochemically stable. Biochemical stability is assessed by regular monitoring of volatile acids, COD removal, BOD_5 removal, system alkalinity and gas production.

The question of load variation caused by the biweekly production cycle is an important issue in selecting a start-up sequence. The approach recommended would be to proceed through the start-up period avoiding biweekly variations in loading by adjusting feed rates to maintain a steady COD load. This would be increased slowly as sludge inventories increase. Testing the effects of biweekly load variation caused by the change from TMP to CTMP would be a component of the "Steady State" phase.

6.3.2 "Steady State" Operation

Steady Loading: An 8 to 12 week period would be assigned to testing the performance of the anaerobic reactor at different "steady state" COD loads. The main objective would be to select a design COD load for the full scale process. Some pilot operation above the selected design value is necessary to develop a basis for estimating the inherent safety factor.

Design values for COD/BOD_5 removal, alkalinity requirements and gas yield/quality separately for CTMP and for TMP treatment would be determined from reactor operation/performance during this period. These are the most important process data next to the COD load as they have a significant influence on system economics.

Nutrient additions (e.g., nitrogen, phosphorus and micro-nutrients) would not be optimized during the pilot program. Dosages would be selected to ensure that the nutrient supply is adequate and within reason for anaerobic treatment. Uptake in the biomass and residual concentrations in the anaerobic effluent would be carefully monitored. Some special care would be necessary in selecting nitrogen dosages as excess ammonia in anaerobic effluent could influence the evaluation of toxicity removal in the aerated polishing step.

Biweekly Variation: The flow and COD load to the system would be controlled to simulate the biweekly variation that would occur in a full scale system once the system loading parameters have been selected. An 8 to 12 week period should be allocated for this purpose.

6.3.3 Transient Conditions

Mill operations and layout would be reviewed to identify the type of transient upset conditions which occur from time to time and which may affect the treatment process. It is best to design containments or diversion/collection systems to eliminate the risk of upset in the anaerobic reactor in cases where leaks or spills at chemical tanks could enter the wastewater. Maximum concentrations of suspended solids due to stock spills or bleaching chemicals due to bleach process upsets are important to identify. Short periods of 1 to 2 weeks may be required to simulate the major types of upsets to determine how the treatment process responds.

6.3.4 Pretreatment Performance Evaluation

The purpose of the pretreatment system would be to ensure that hydrogen peroxide or sulfite concentrations entering the anaerobic reactor are sufficiently low to avoid toxic effects in the biomass. It may be desirable to operate two pretreatment systems in parallel for at least part of the program. One system would be operated conservatively and would provide the effluent source for the anaerobic reactor(s). The second system would be used to develop design data by varying the operating parameters such as peroxide or sulfite concentration, pretreatment HRT, or mixing conditions. In this manner, the design evaluations of pretreatment and the methanogenic processes can proceed simultaneously.

6.3.5 Aerated Polishing

Anaerobically treated effluent would be polished aerobically in a continuous feed pilot system to permit an evaluation of toxicity removal and total solids production. Two different aerobic polishing configurations are presented in Drawing D-100. It is recommended that only one of these be tested during the pilot program. The selection of the appropriate process should be made once it is determined whether aerobic sludge is needed in the pretreatment step. The choice can then be made based on the Consultant's recommendation in discussion with mill staff and B.C. Environment officials.

3.71 to 4.72

The design HRT's which would be those of the existing aeration facility, 2.5 to 3.5 days each. There is little need to investigate other conditions if toxicity removal is successful as these values reflect the volumes and flows to the existing treatment facility which would become the polishing process. Effluent toxicity (LC_{50}) would be monitored following the first aeration cell/basin, as well as in the final treated effluent after the second cell. The data from the first cell will be an important measure of the safety margin in the system if the final effluent proves to be non-lethal.

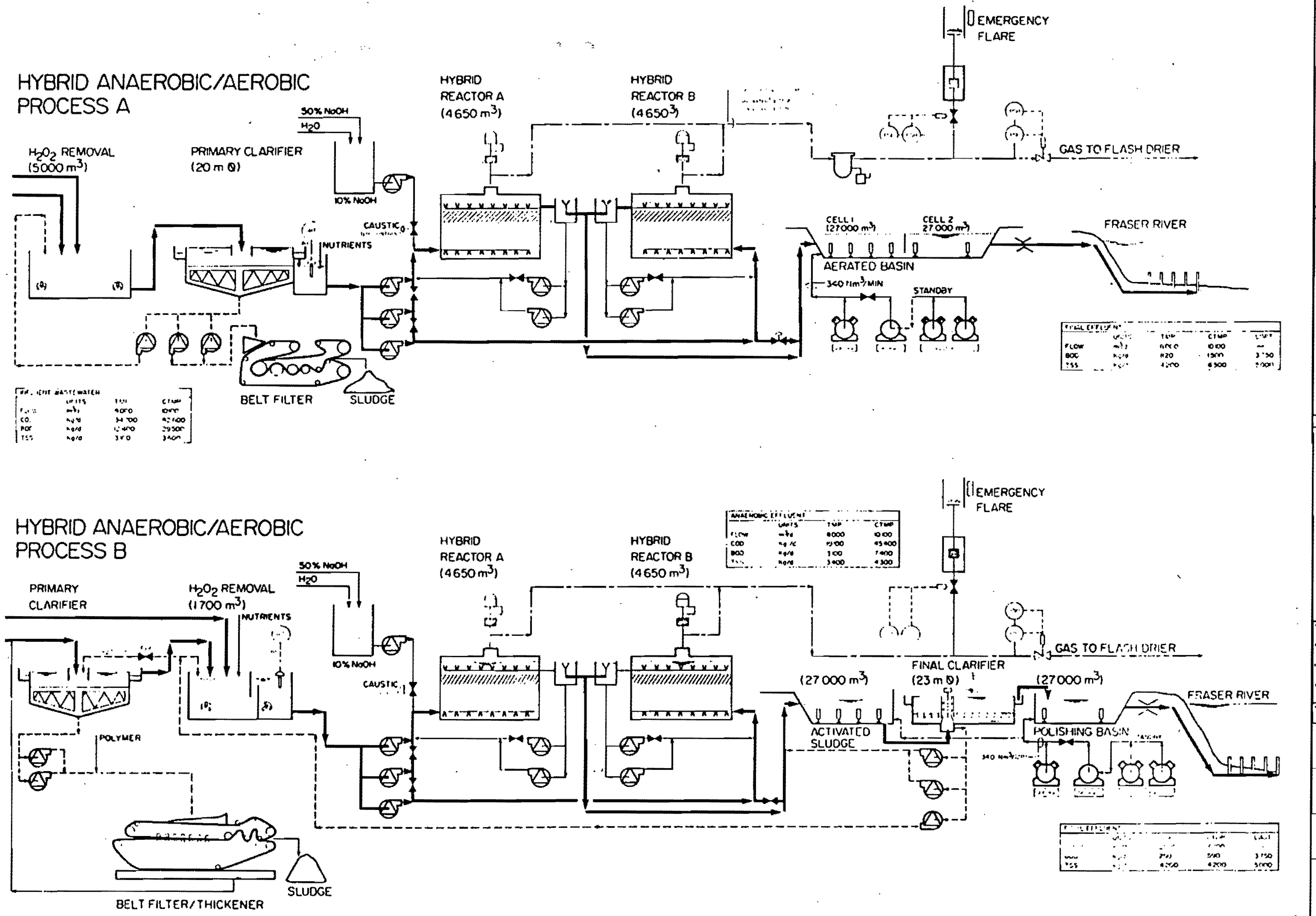
6.4 Related Studies

A feasibility evaluation of biogas utilization in the flash drier should be completed during the course of the pilot trials. No final decision regarding a full scale system would be possible before this issue is resolved as the ultimate use of the gas will have a significant influence on the total financial analysis.

6.5 Development of an Anhybrid Process

6.5.1 Overview of Anhybrid Design Experience

The general development outline presented in Section 6.2 through 6.4 is recommended regardless of the anaerobic process selected for testing. Consideration must now be given to additional development work that would be required if an anhybrid system were to be tested.



INFLUENT WASTEWATER

	UNITS	TMP	CTMP
FLOW	m³/d	8000	10100
COD	kg/d	34 700	42 400
BOD	kg/d	12 400	29500
TSS	kg/d	3 [illegible] 0	3400

FINAL EFFLUENT

	UNITS	TMP	CTMP	LIMIT
FLOW	m³/d	8000	10100	—
BOD	kg/d	820	1500	3750
TSS	kg/d	4200	6500	5000

ANAEROBIC EFFLUENT

	UNITS	TMP	CTMP
FLOW	m³/d	8000	10100
COD	kg/d	[illegible]	45400
BOD	kg/d	3100	7400
TSS	kg/d	3400	4300

FINAL EFFLUENT

	UNITS	TMP	CTMP	LIMIT
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BOD	[illegible]	[illegible]	590	3750
TSS	[illegible]	4250	4200	5000

An anhybrid process consists of an upflow anaerobic reactor with two zones, an "empty" or "void" zone at the bottom and a zone containing random or rigid packing media near the top. Most of the anaerobic treatment occurs in the lower zone where anaerobic biomass is accumulated. The upper zone is for gas/liquid/solids separation and keeps the biomass from washing out of the reactor. This is a generic process and there are at least several different reactor designs with anhybrid features which are operating or under construction. The two main issues which have lead to individualism in anhybrid design to date are:

1. Media selection, and
2. Operating Mode.

Media: The focus on media selection is on cost and potential for plugging. Media plugging in fixed film anaerobic reactors is a long-term phenomenon (at least 1 to 2 years) which cannot be tested easily in pilot trials. It is well known that plugging can have disastrous effects on treatment efficiency in fixed film processes. However, there is little or no information available on the effects of plugging in an anhybrid design where most of the treatment occurs in the lower zone of the reactor. Severe short circuiting in the media zone of an anhybrid reactor will have little or no effect on performance if the function of liquid/solids separation is unaffected.

The anhybrid system treating heat treated liquor at the Lakeview Water Pollution Control Plant in Mississauga, Ontario (e.g., HYAN process) uses a random plastic packing. It has been operating since the spring of 1985 and has achieved sustained loadings of 5-6 kg COD/m^3.d. Performance has been reasonably good to date but this is the first HYAN system and it is too early for final conclusions regarding media plugging and biomass washout.

Several of the anaerobic reactors operating and under construction for pulp and paper effluent treatment sited in Table 4.1 have characteristics of the anhybrid design. The TAMAN process at Anjala apparently contains a media zone as well as some form of submerged gas hood. The BIOTIM-A process under construction in New Zealand will have an upper zone containing a proprietary media design of polyurethane foam. Although there is some uncertainty, SCA's anaerobic methane reactor design may include some form of media zone in the upper portion. This was certainly tested during the development work (Rosen et al, 1986) but details on the internal arrangement in the full scale system have been difficult to obtain.

The full scale anaerobic processes sited above were not due to start up until late 1986 or 1987. Therefore, there is no operating experience and the design details are considered proprietary. A small full scale TAMAN process has been operating on dairy effluent since early 1985. Early reports on performance were encouraging (Rekunen, 1985).

Operating Mode: Anhybrid designs to date have included sludge bed designs (e.g., granular sludge), as well as contact design (e.g., flocculated sludge). The Lakeview HYAN system operates as a contact system whereas the TAMAN system at Anjala is reportedly a UASB process. The SCA system is described as operating primarily as a contact process but with some graduation in sludge characteristics with bed height as expected in sludge bed systems.

The intended operating mode is important to specify in advance of designing a pilot reactor. Sludge bed processes must be designed with even distribution of flow at the bottom of the reactor. This generally requires a complex header and nozzle arrangement, plus a recycle system designed to maintain constant upflow velocities. A much simpler and less expensive distribution system is adequate if contact operation is the design objective (e.g., HYAN process at Lakeview). The appeal of a sludge bed operating mode is the probability of developing a greater sludge inventory (e.g., mass) per reactor volume allowing higher COD unit loadings and a smaller total reactor volume.

6.5.2 Development Outline for Quesnel River

Process: The design basis for an anhybrid pilot reactor for Quesnel River should include provision to operate in a UASB mode. The characteristics of the mill effluent will ultimately determine whether a granular sludge can be developed. If granulation cannot be achieved during the pilot trials then the design development would work toward a contact system. The system should be seeded initially with a granular seed sludge. It would be known by the end of the start-up/acclimatization phase whether the effluent is condusive to granular sludge development. This may require a somewhat longer schedule allowance than the 10 to 12 weeks mentioned earlier for start-up. Some thought should be given initially to a potential source and cost of seed sludge that would be available for a full scale start-up. It could require an unacceptably long start-up at full scale if it were intended to develop a granular sludge starting with municipal digester sludge.

The information available to date cannot fully answer the important question regarding media selection. It may be that the media type is relatively unimportant at least for reactor performance in the short term judging from the diversity of media types that are apparently in use or about to be commissioned in full scale plants. Without further information on the effects of plugged media on solids retention in the reactor, it would be prudent to select an open media that would take a relatively long time to develop severe short circuiting. This favours rigid media as opposed to a random media.

Some allowance should be made in an anhybrid test schedule to compare reactor performance and solids retention under conditions of severe short circuiting and plugging in the media zones. There are several methods that could be used to accelerate or simulate fouling that might otherwise occur only after several years of operation.

Mechanical: Independent development of a Canadian designed anhybrid process carries risks which one would expect to avoid if purchasing a commercially available anaerobic process. Most of the extra risk pertains to the mechanical design. For example, the design of the effluent distribution header for a sludge blanket system must consider even flow distribution and nozzle plugging, scaling and erosion. Header systems are not easily accessible when an anaerobic process is operating and a reactor shutdown would be necessary for major overhauls.

Media design/selection is another area of risk as already discussed. In this case, however, the existing design, testing and operating experience of commercially available anhybrid type systems also appears to be limited.

Proven design procedures are readily available for most of the remaining mechanical design requirements for an anhybrid reactor system.

6.6 Schedule

Approximately 19 months would be required for a thorough development and testing program for a treatment system at Quesnel River incorporating an anhybrid anaerobic reactor. This includes the 6 month initial period for design, fabrication, delivery and set-up of the reactor and equipment, 11 months of start-up and testing and 3 months at the end to complete the design reports. Bench testing for the pretreatment process would be carried out during the initial six months. A proposed schedule is presented in Figure 6.1.

A second schedule was developed on the basis that a commercially available pilot plant(s) would be rented from a process vendor as an alternate to developing an anhybrid system. Overall it is estimated that the program would be completed in 15 months instead of 19 months. The start-up and pilot testing phase would require 8.5 months. Most vendors would agree that this is a suitable test duration for their respective processes.

Detailed design, construction and start-up of a full scale facility could commence immediately following the test program. The total elapsed time between start of detailed design and process start-up would probably be 15 to 18 months regardless of which treatment system were selected.

6.7 Facilities and Estimated Costs

Table 6.1 summarizes the estimated costs for a pilot plant program at the mill. The cost for evaluating two different anaerobic processes (e.g., an anhybrid system and one other) was estimated to be $520,000. Costs for testing only one system are also presented and would be in the range of $370,000.

An attempt was made to allow for all costs associated with such a program including equipment rentals and purchases, building enclosures and services for the test area, laboratory equipment and supplies, operating staff, and the services of a process consultant. Following is a summary of the major assumptions made:

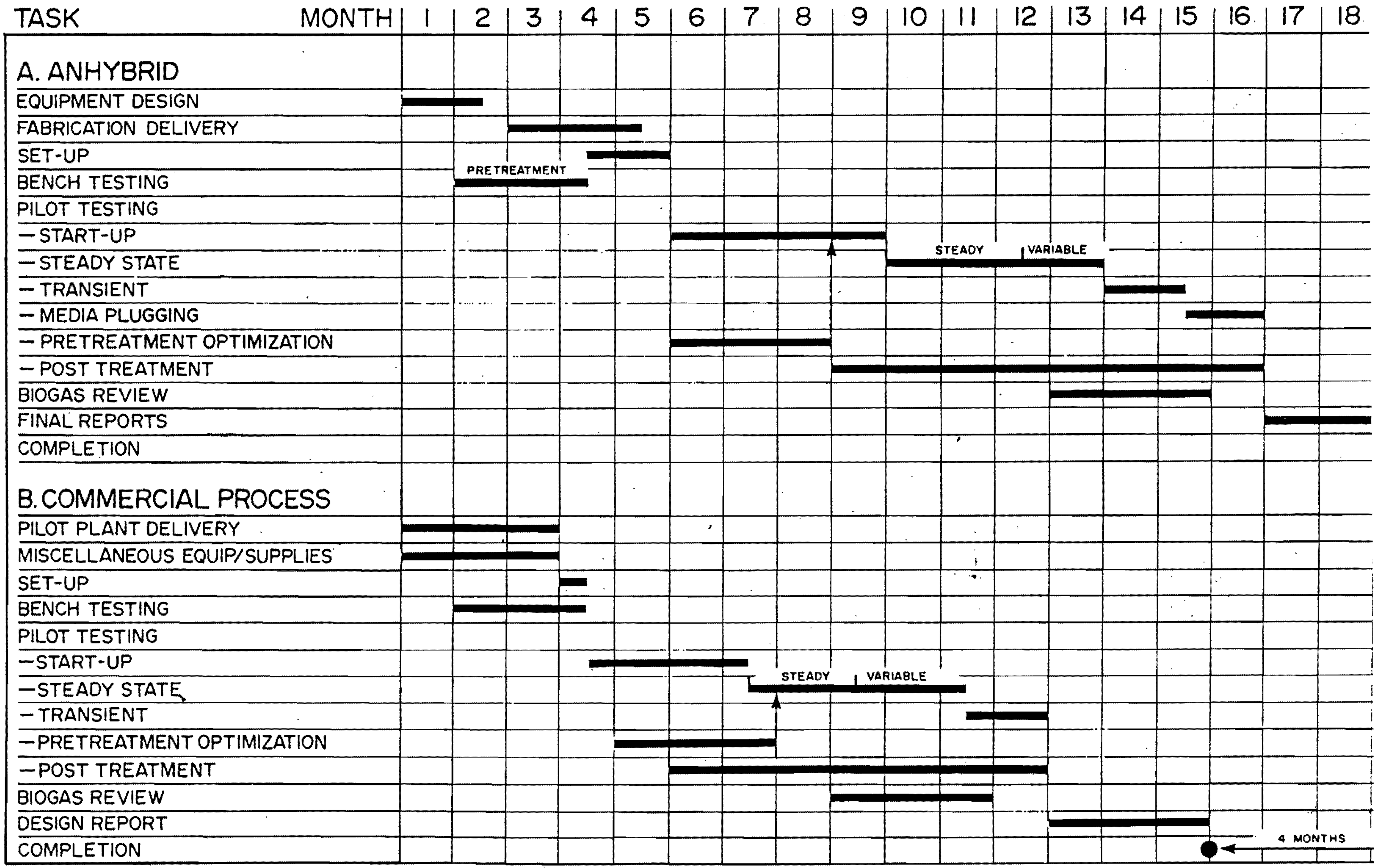


FIGURE 6.1 Schedule for Anaerobic Process Development

TABLE 6.1 ESTIMATED COSTS FOR PILOT SCALE DEVELOPMENT

Item	Anhybrid [1] Pilot Unit (1 system) $	Commercial [2] Pilot Unit (1 system) $	Anhybrid [1] and Commercial (2 systems) $
Pilot Equipment			
- Rentals/Freight	0	120,000	120,000
- Anhybrid Process	75,000	0	75,000
- Miscellaneous	15,000	15,000	15,000
Sub-Total	90,000	135,000	210,000
Site Preparation	20,000	20,000	24,000
Laboratory Facilities/Testing			
- Equipment Purchases	6,000	6,000	6,000
- Consumables	5,000	5,000	5,000
- Outside Lab Allowance	8,000	8,000	14,000
- Bioassay Allowance	4,000	4,000	6,000
Sub-Total	23,000	23,000	31,000
Pilot Plant Operator	50,000	43,000	55,000
Process Consultant	190,000	150,000	200,000
Estimate of Total Costs	373,000	371,000	520,000

[1] Pilot Operation: 11 months for anhybrid

[2] Pilot Operation: 9 months for commercial system

Pilot Plants: The anhybrid reactor would be designed for an operating volume of 5-6 m^3 which is consistent with the sizes generally offered for testing by the vendors of proprietory processes (e.g., 2 m^3 to 20 m^3). This would be adequate for scale-up purposes. Preliminary costs sited by four different firms offering pilot equipment ranged from approximately $70,000 to $130,000 for a 9 month test program including allowances for freight and an engineer on site for a 4-8 week training period and vendor technical support during the program.

Pilot Equipment Set-Up: An enclosure would be built for the pilot facilities at the existing treatment plant close to the effluent source. The area required for 2 pilot systems would be roughly 8 m x 9 m x 5 m high and it was assumed that this would consist of a temporary frame structure on a gravel base erected by mill labour. The trailer used for the previous test program for aerobic treatment could be useful as part of the facility but it would be much too small for housing the pilot equipment.

An effluent supply system would be provided to pump fresh mill effluent continuously to an overflow tank in the pilot area. Feed to the pretreatment system ahead of the anaerobic processes would be taken directly from this tank. It is assumed that the mill can control the temperature at or below 36-38 degrees C to avoid the requirement for a cooling system.

Laboratory Facilities and Testing: All routine analyses would be completed by the pilot plant operator if only one pilot system is tested. There would still be only one operator in the event that two plants are tested although part-time support for routine analyses would probably be required in this case. The mill has indicated that existing bench space would be made available in the laboratory and that basic equipment for completing BOD_5 and suspended solids analyses is already available. Some dedicated equipment for COD, ORP, methane, hydrogen sulfide and D.O. analyses would be needed. Allowances have been made for purchasing new equipment in these cases.

Estimated costs for the laboratory and analysis costs include allowances for some outside laboratory support for special sampling programs (e.g., sulfur balances, individual volatile acid identification, etc.). Similarly, an allowance was made for a limited number of LC_{50} bioassays in conjunction with the testing of the aerated polishing step.

Pilot Plant Operator: A full time pilot plant operator would be hired to work at the mill for 14 months exclusively on the pilot plant program. He would be needed on site at least two months ahead of the scheduled pilot start-up to co-ordinate the set-up activities and to carry out the bench testing program for the pretreatment process. Allowance has been made for operator salary, overheads and some allowance for overtime. It is expected that the operator would be a graduate engineer with knowledge of wastewater treatment and/or a strong background in analytical work.

Process Consultant: It is expected that a process consultant would be hired for the duration of the project to assume responsibility for the following tasks:

- design/procurement of pilot equipment,
- developing the detailed bench testing and pilot testing programs and schedules,
- supervising the pilot plant operator,
- tabulating and interpreting all of the test data,
- completing the feasibility review of gas burning,
- organizing progress review meetings with the mill staff and other project sponsors, and
- completing a final design report at the end of the program.

Organized in this fashion, the program will minimize extra work loads and responsibilities for mill staff.

7.0 ESTIMATED FULL SCALE COSTS

7.1 Anhybrid System

7.1.1 Capital Costs

Estimates were prepared of the total capital cost for the two anhybrid process options described in Section 4. These were \$7.3 million for Process A (e.g., ASB polishing) and \$8.7 million for Process B (e.g., activated sludge polishing). Dollar values were scaled to allow for an assumed start-up date in 1988 or 1989 and the estimates include allowances for direct costs as well as indirect costs.

A general breakdown of each estimate is presented in Table 7.1. Most of the cost is associated with the anaerobic process and its related facilities, accounting for 70 to 80 percent of the total direct cost. Siting the anaerobic process adjacent to the existing clarifier and sludge dewatering building was assumed for the purpose of the estimates. This accounts for the small component in the estimate associated with yard piping.

Costs for running pilot development trials were included as part of the overhead estimates. It was assumed that these trials would include two pilot processes as a final decision to proceed with anhybrid or any other treatment must await the results of a successful pilot demonstration.

7.1.2 Operating Costs

Estimated annual operating costs for the anhybrid treatment options are summarized in Table 7.2. The combined costs for chemicals, power and labour are estimated at \$574,000 to \$600,000 per annum. This excludes costs for equipment maintenance and for disposal of dewatered sludge. The annual allowance of \$32,000 for caustic soda was based on the assumption that no caustic would be needed for alkalinity control with the CTMP effluent and that dosing during TMP operation would average 100 mg/L alkalinity as $CaCO_3$. This was an arbitrary estimate for TMP especially which would have to be confirmed during pilot testing. Nutrient requirements would be relatively close to the existing dosing rates at the mill.

TABLE 7.1 ESTIMATED CAPITAL COSTS FOR ANHYBRID ANAEROBIC SYSTEMS

Process	Process A ($ x 1000)	Process B ($ x 1000)
Direct Costs		
Effluent Pumping	150	150
Pretreatment (Detoxification)	440	240
Anaerobic Reactors and Recycle	3,650	3,680
Gas Handling and Flare	190	190
Yard Piping	160	170
Aerated Basin Modification	20	80
Final Clarifier and Sludge Return	—	530
Sludge Dewatering and Polymer	—	450
Sub-Total Direct Costs	4,610	5,590
Indirect Costs		
Process Development/Pilot Testing	520	520
Engineering (EPC)	550	670
Start-Up Program/Training	80	80
Owners Costs (5% TDC)	230	280
Contingency (10% TDC)	460	560
Sub-Total Indirect Costs	1,840	2,110
Total Cost	6,450	7,700
Escalation to 1988/89 (5%/y)	800	960
Estimated Total Cost	7,250	8,660

TABLE 7.2 ESTIMATED OPERATING COSTS (ANHYBRID TREATMENT)

Item		Process A ($ x 1000)	Process B ($ x 1000)
Chemicals	- Nitrogen	115	115
	- Phosphorus	37	37
	- Caustic	32	32
	- Polymer	0	19
		184	203
Power	- Aeration	208	208
	- Other	55	62
		263	270
Labour	- Operators	68	68
	- Testing	45	45
	- Supervision/Administration	14	14
		127	127
Sub-Total		574	600
Potential Gas Value (assumes no pretreatment cost)		190	190

Total power consumption by the complete anaerobic/aerobic process would be less by 400 - 450 kW than the present connected aeration horsepower. Estimated annual costs of $270,000 were based on an average power cost of $0.04/kWh.

The treatment process should be capable of operating with 1 shift supervision for the entire system, including sludge dewatering. Therefore, estimates of operator costs were made assuming 1 shift times 7 days per week. Effluent testing would be a separate requirement as indicated in the table.

Table 7.2 shows $190,000 per year as the potential value of the biogas. This assumes the biogas displaces an equivalent thermal value of natural gas in the flash drier and that there is no operating cost associated with cleaning or pretreating the biogas. A methane yield of 0.3 $m^3 CH_4$/kg COD removed was used in estimating gas value. This assumes that COD reduction by sulfate reducing organisms does not have a major influence on COD removal.

7.2 Cost of Alternate Anaerobic Processes

7.2.1 Alternate Processes

Five vendors of proprietory anaerobic processes were contacted to provide budget estimates for turn-key supply of their treatment systems at QRP. The purpose was to determine whether the cost of anhybrid treatment could be competitive with existing processes. A specific cost comparison of the various proprietory processes was not intended and care should be taken in comparing the results. Following is a list of the vendors contacted and a summary of the respective processes and specified loadings.

Each of these vendors have commissioned one or more large full scale treatment processes and some have systems operating in the pulp and paper industry. The COD loadings for the budget estimates were specified in advance to ensure some intersystem comparability.

Loadings for the UASB and the Celrobic systems were set at 10 kg COD/m^3.d, similar to the design value selected for evaluating the anhybrid process. This ensures that similar reactor volumes were used in developing costs.

Vendor	Process	Description	Specified Loading (kg COD/m^3.d)
A.C. Biotechnics	ANAMET	- Stirred tank "Contact" Process - external clarifier - usually includes activated sludge polishing (excluded in this case)	4
Biothane Corp.	BIOTHANE	- UASB process - includes equalization/ recycle tank	10
Paques Lavalin	BIOPAQ	- UASB process - includes equalization/ recycle tank	10
Badger	CELROBIC	- Fixed Film process - includes equalization tank	10
Dorr Oliver	ANITRON	- Two stage fluidized bed - no equalization	20

Contact processes are traditionally "lower rate" systems and the design value of 4 kg COD/m^3.d is representative of typical loadings at several full scale installations.

There is growing recognition that fluid bed anaerobic systems are able to treat higher loadings than other anaerobic processes even though there is limited full scale demonstration of this technology (Mueller et al., 1984; Hall et al., 1986). The loading of 20 kg COD/m^3.d was selected on this basis.

7.2.2 Estimated Costs

Table 7.3 shows the results of the cost comparisons escalated to 1988/89, similar to the previous estimates in Table 7.1. The estimated capital cost of the anhybrid process at $7.25 million is well within the range of $6.2 to 9.7 million estimated for the proprietory systems. The costs in the table represent the total estimated costs for the anaerobic

TABLE 7.3 COST COMPARISONS WITH ALTERNATE ANAEROBIC SYSTEMS

	ESTIMATED COST *					
SYSTEM	ANAMET	BIOTHANE	ANITRON	CELROBIC	BIOPAQ	ANHYBRI
Type	Contact	UASB	Fluid Bed	Fixed Media	UASB	Process A
Loading (kg COD/m^3.d)	4	10	20	10	10	10
Anaerobic Vendor Supply (\$ x 10^6)	4.2	4.1	5.7	7.6	6.1	0
Supply by Others (\$ x 10^6)	2.1	2.1	2.1	2.1	2.1	7.2
Total Estimated Cost (\$ x 10^6)	6.3	6.2	7.8	9.7	8.1	7.2

* Costs escalated to allow 1988/89 completion

systems, as well as the pretreatment and post treatment facilities. The value of $2.1 million shown as "Supply by Others" includes items not included in the scope of supply by the anaerobic vendors. This includes the following:

- pretreatment for H_2O_2/SO_3 detoxification,
- pumping the effluent into the equalizing basin or anaerobic reactor systems,
- modifications and additions to the ASB system,
- underground piping and other services,
- the cost of the pilot plant development program, and
- engineering and owner costs associated with the facilities not provided by the anaerobic vendors.

The table suggests a broad range in costs among the proprietory processes. It must be kept in mind, however, that these were quick budget estimates and there may have been different levels of effort within the various organizations in developing the estimates. More importantly, there were significant differences in some key areas such as presence/absence and size of equalization tanks. Minor adjustments were made in some of the vendor estimates to account for these differences and for escalation.

8.0 CONCLUSIONS AND RECOMMENDATIONS

1. There is a high probability that a combined anaerobic/aerobic treatment process at Quesnel River Pulp would be successful in meeting the B.C. Environment effluent standards. This is based on the strength of the limited bench testing at WTC and also on the apparent degree to which anaerobic treatment is being or will shortly be adopted for CTMP and TMP effluents in Canada and other countries.

2. Thorough bench scale and pilot plant testing is recommended before a final anaerobic process is selected. At present there is insufficient full scale operating experience with CTMP or TMP effluent to answer important design questions such as:

- pretreatment requirements for H_2O_2 or sulfite control,
- alkalinity requirements,
- effectiveness of post aeration for toxicity removal,
- methane yield and BOD_5 removal,
- anaerobic reactor stability during biweekly production changes, and
- the ability of the effluent to form a granular sludge for operation in a UASB mode.

3. The development process would require approximately 19 months for an anhybrid process or 15 months if only proven commercial anaerobic processes are considered.

4. The anhybrid anaerobic process is attractive technically and economically. Several full scale anaerobic treatment plants have anhybrid features in their design which is a sign of confidence for the process. Furthermore, it was estimated that an anhybrid/aerobic system at QRP would cost in the order of $7.3 to 8.7 million including all development work (1988/89 basis). The $7.3 million estimate was compared to the probable costs for existing proprietory anaerobic processes. These estimates ranged between $6.2 and 8.6 million.

5. It is recommended that further development work on anaerobic treatment at QRP proceed on the basis of testing two different pilot systems. This is recommended regardless of whether a decision is made to develop an anhybrid process. This would be a

safeguard in the event that one system were tested and found to be unsatisfactory, probably causing a 12 to 15 month delay. Furthermore, selecting a specific process or process vendor before confirming feasibility through pilot testing can lead to problems in objectivity and cost competetiveness.

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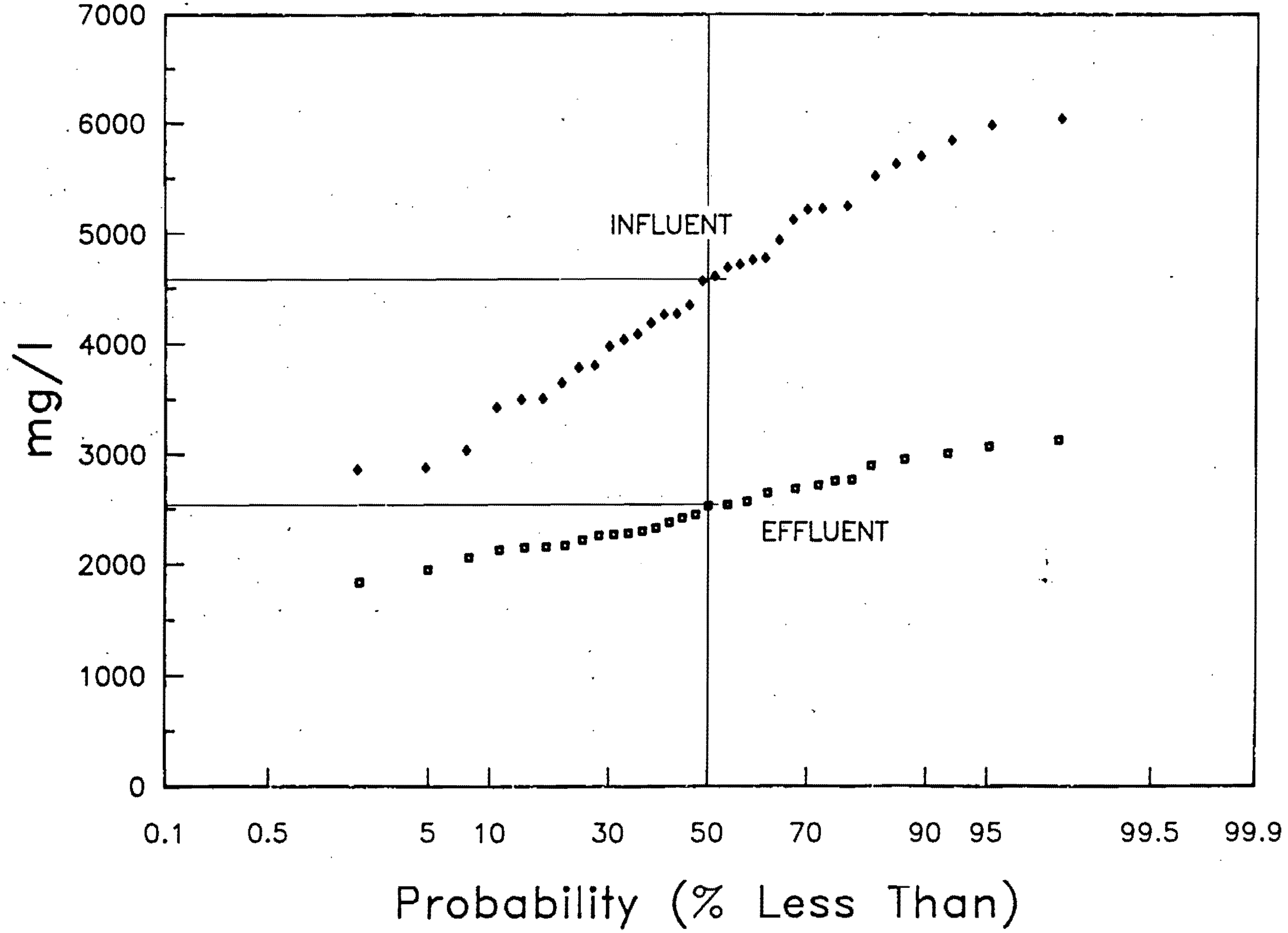
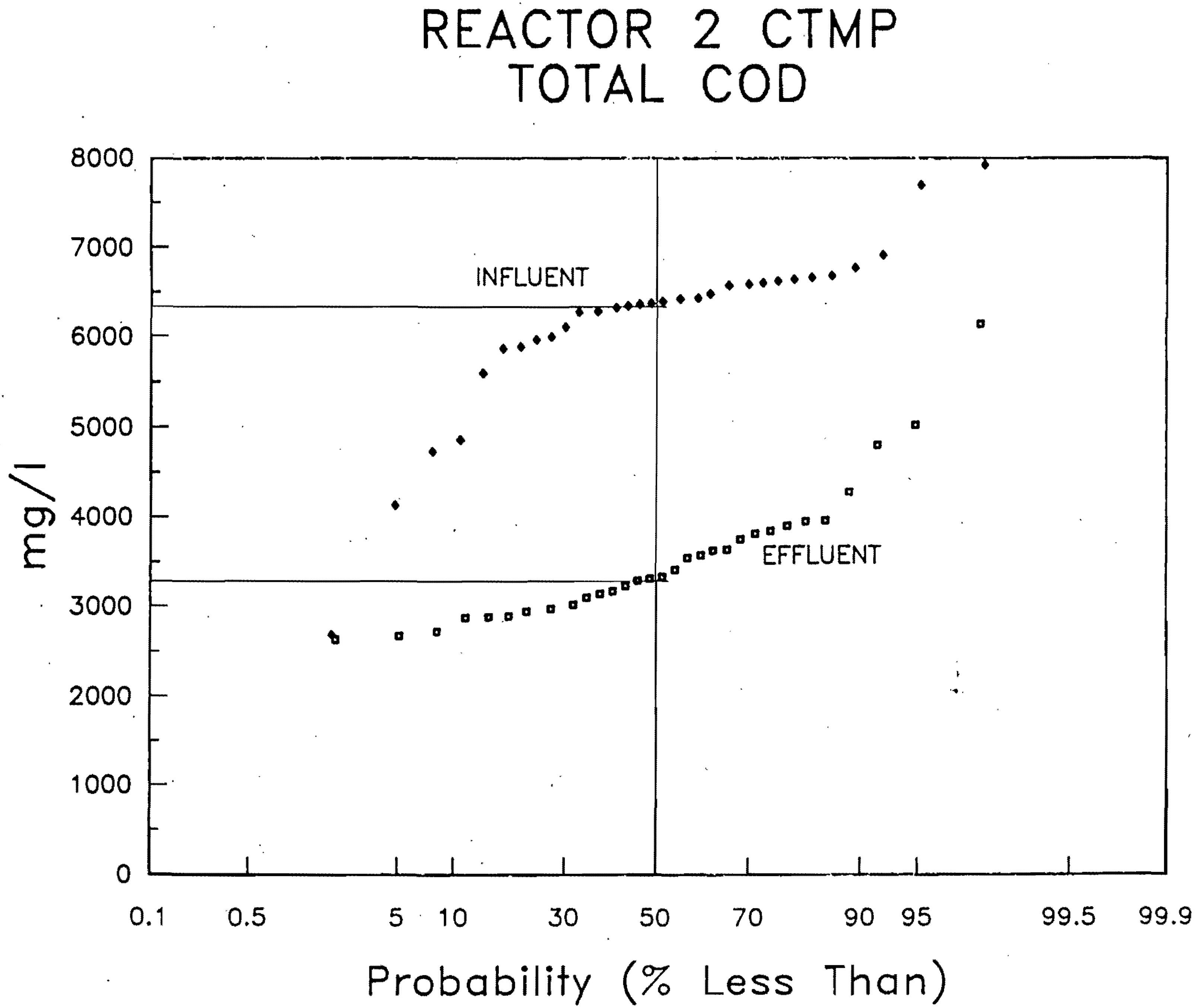
ABBREVIATIONS

BOD_5	5-day biochemical oxygen demand
QRP	Quesnel River Pulp
ASB	aerated stabilization basin
TMP	thermomechanical pulp
CTMP	chemithermomechanical pulp
ADtPD	air dry metric tonnes per day
kg	kilogram
LC_{50}	median lethal concentration (percent effluent concentration in which 50 percent of test organisms will die during the exposure period, usually 96 hours)
d	day
t	metric tonne
WTC	Wastewater Technology Centre
TSS	total suspended solids
COD	chemical oxygen demand
m, m^2, m^3	meter, square meter, cubic meter
mg	milligram
L	litre

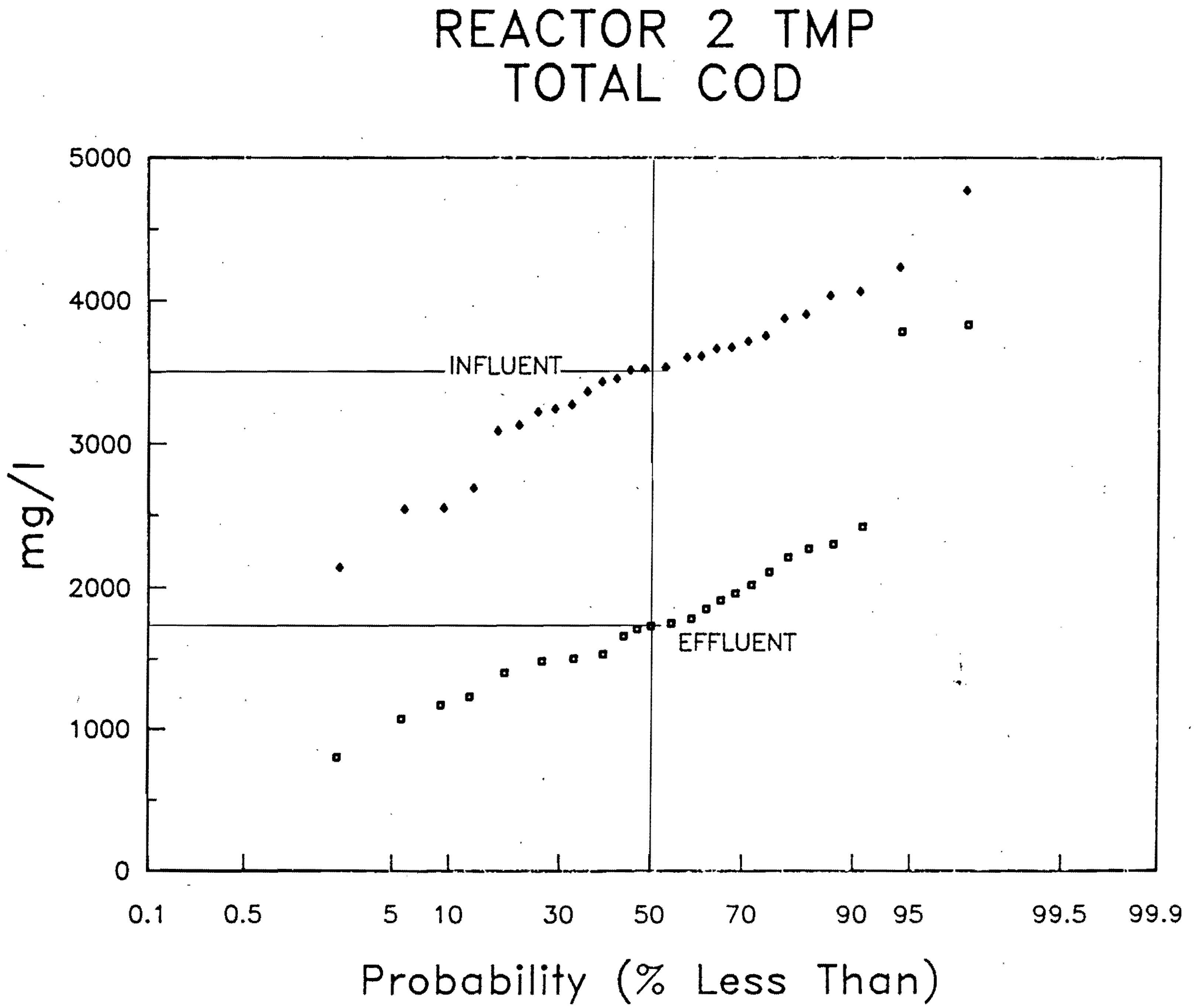
°C	degrees Celcius
TKN	total Kjeldahl nitrogen
SCFM	standard cubic feet per minute
kW	kilowatt
Nm^3/min	normal cubic meters per minute
HP	horsepower
lb	pound
h	hour
cm	centimeter
N	nitrogen
P	phosphorus
CSTR	completely stirred tank reactor
ORP	oxidation/reduction potential
mv	millivolts
UASB	upflow anaerobic sludge blanket
ATA	anaerobic toxicity assay
BMP	biochemical methane potential
D.O.	dissolved oxygen

REACTOR 2 CTMP
FILTERED COD

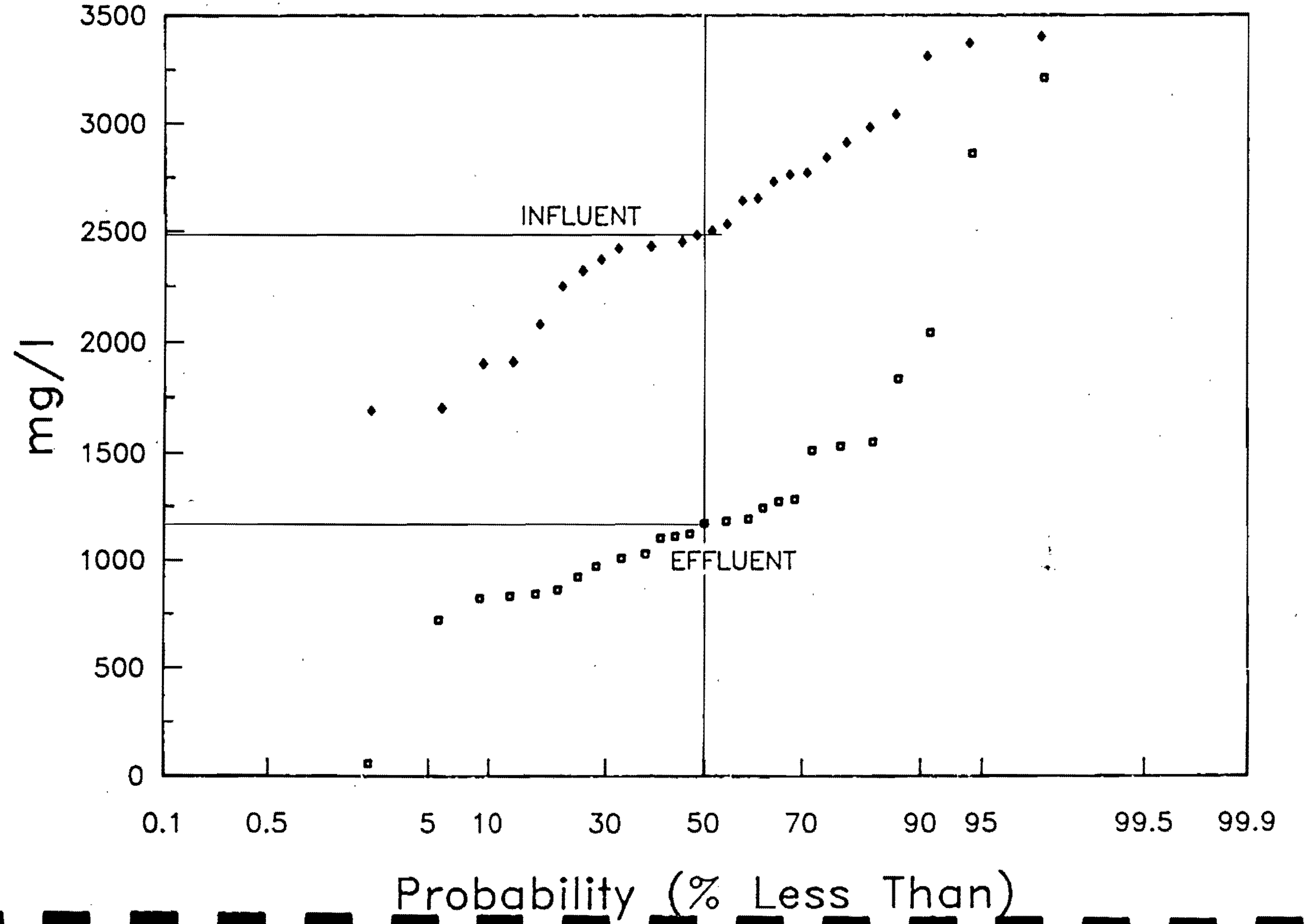




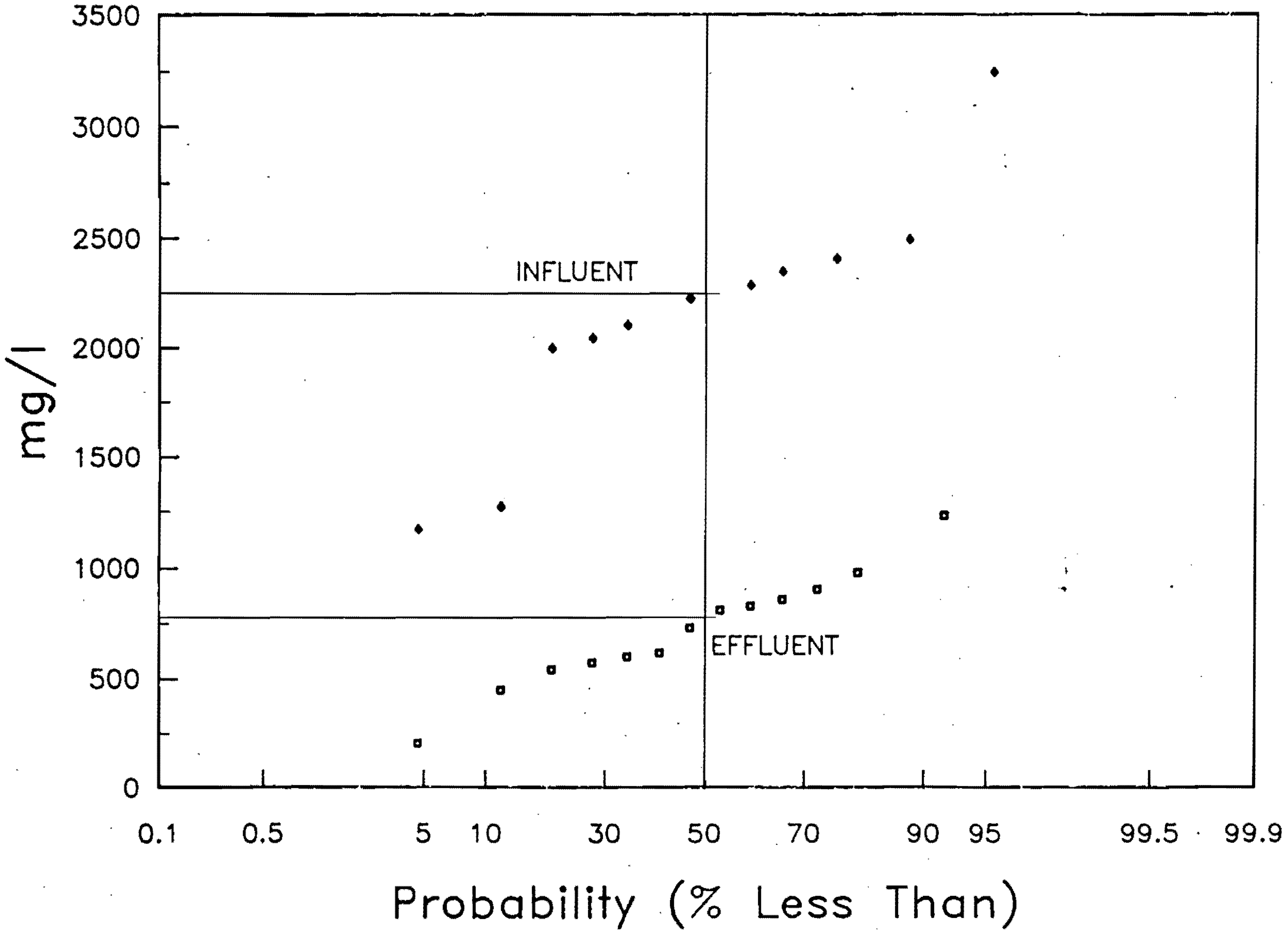
REACTOR 2 CTMP
TOTAL COD


REACTOR 2 TMP
TOTAL COD
5000
4000
3000
2000
1000
0
mg/l
INFLUENT
EFFLUENT
0.1
0.5
5
10
30
50
70
90
95
99.5
99.9
Probability (% Less Than)

REACTOR 2 TMP
FILTERED COD



REACTOR 1
TOTAL BOD



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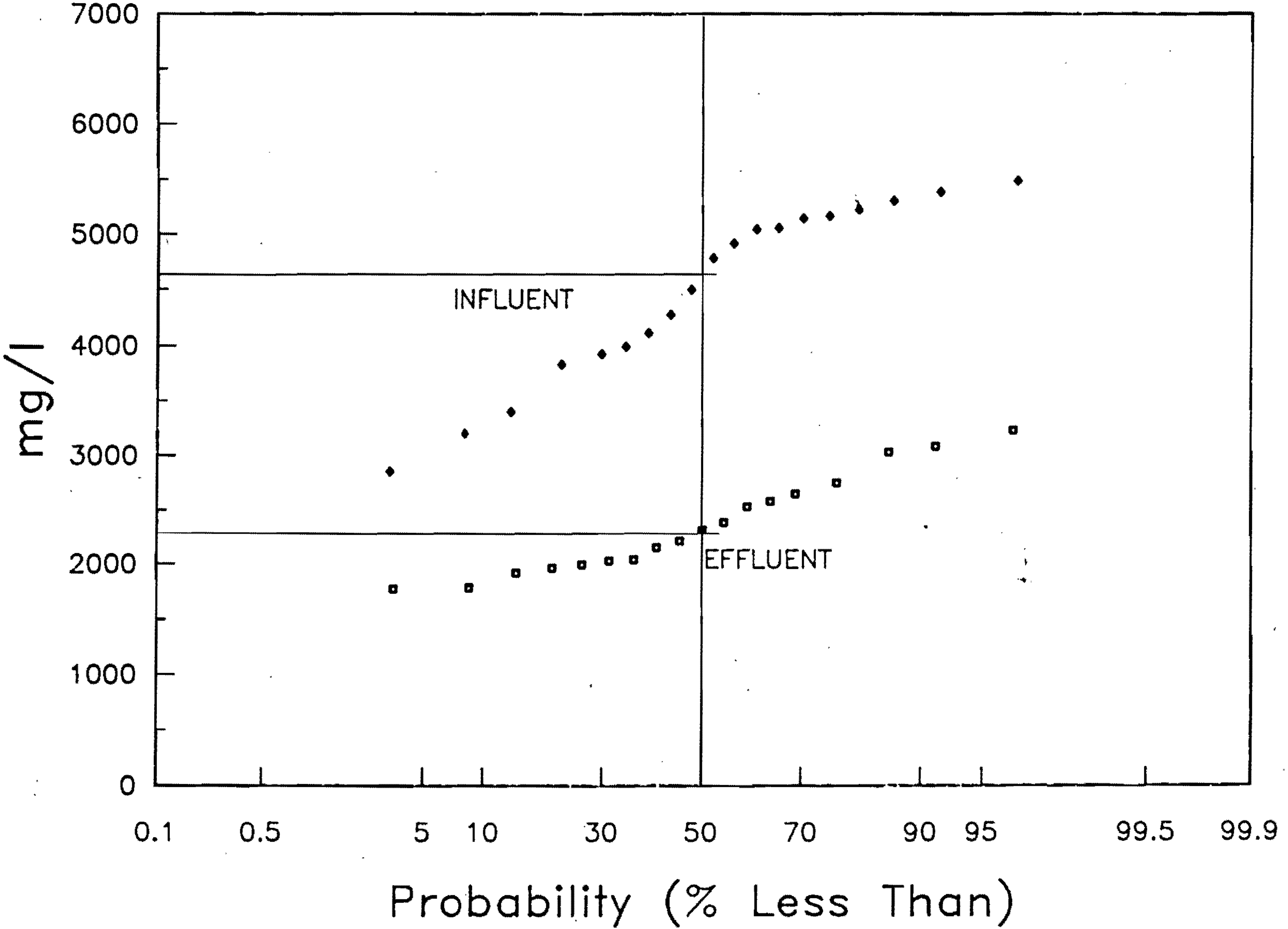

REACTOR 2 CTMP
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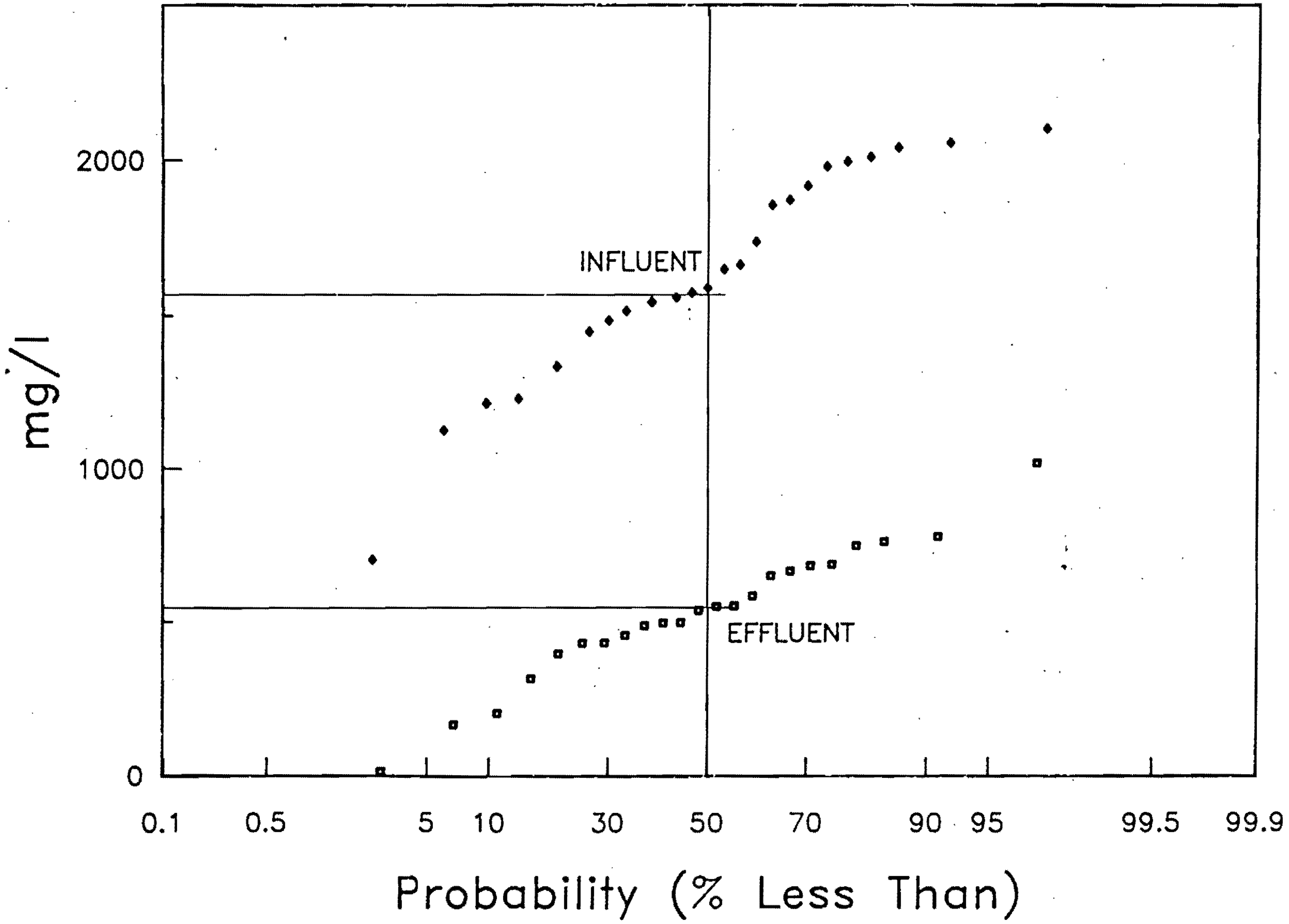
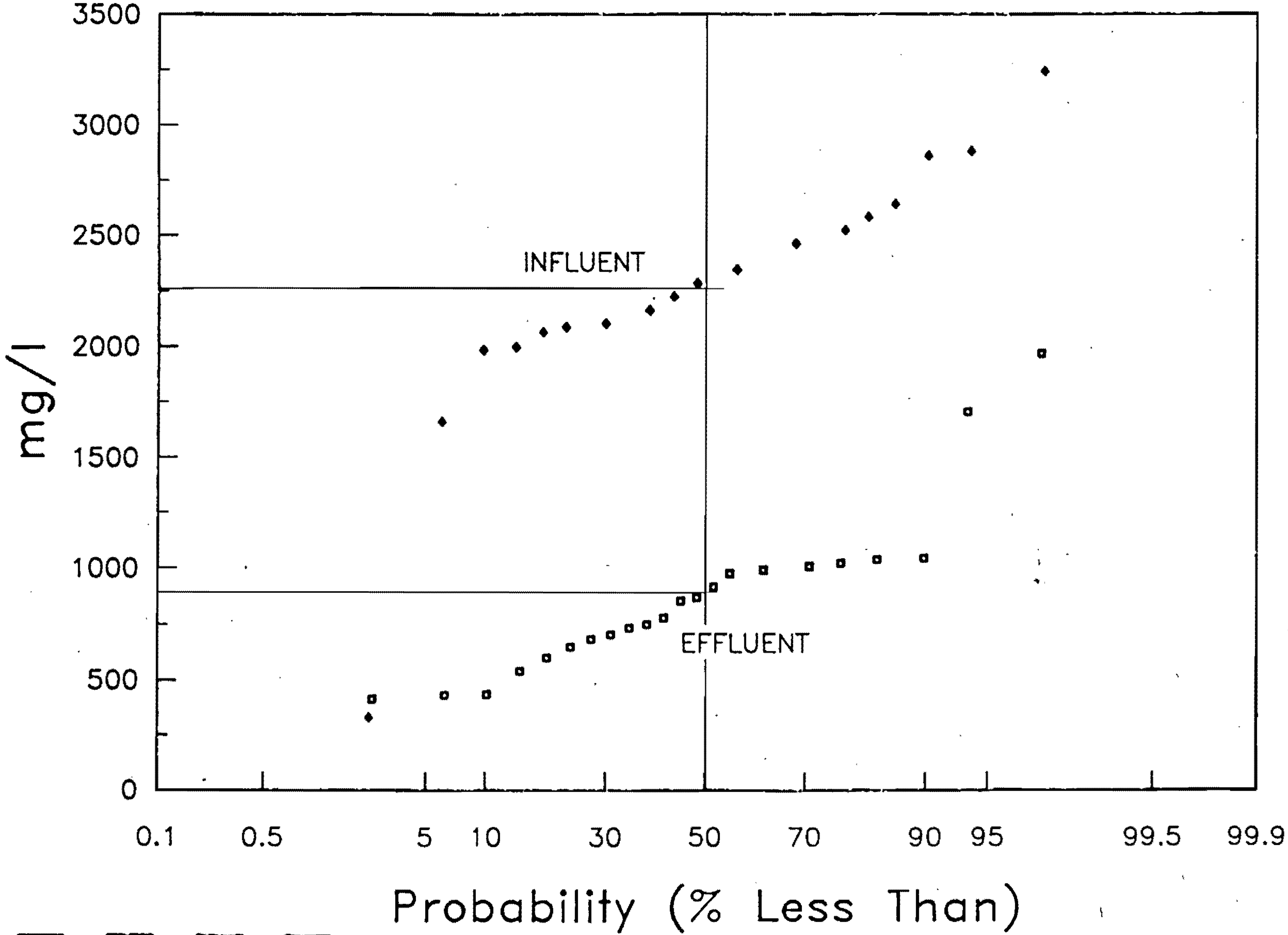
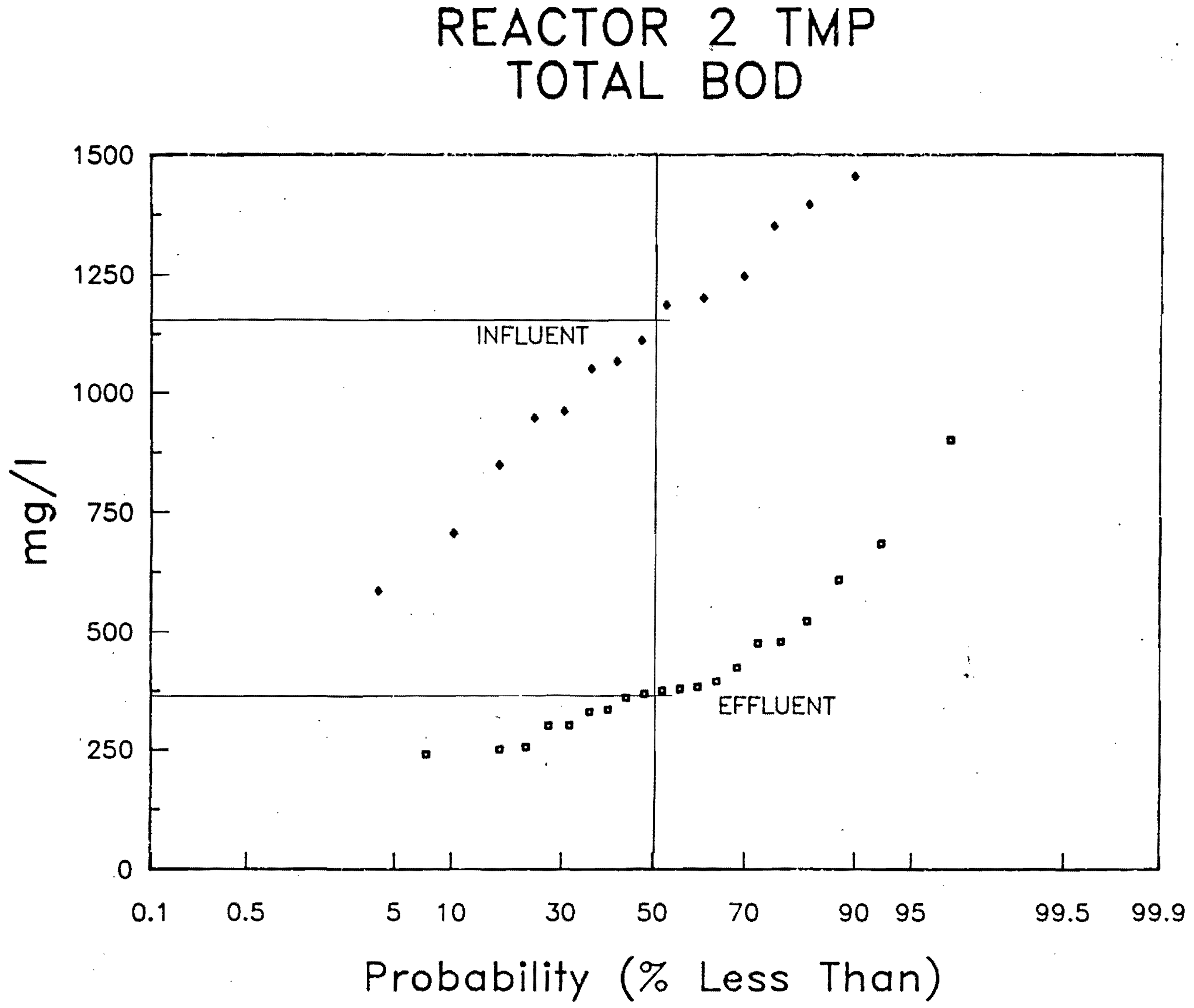
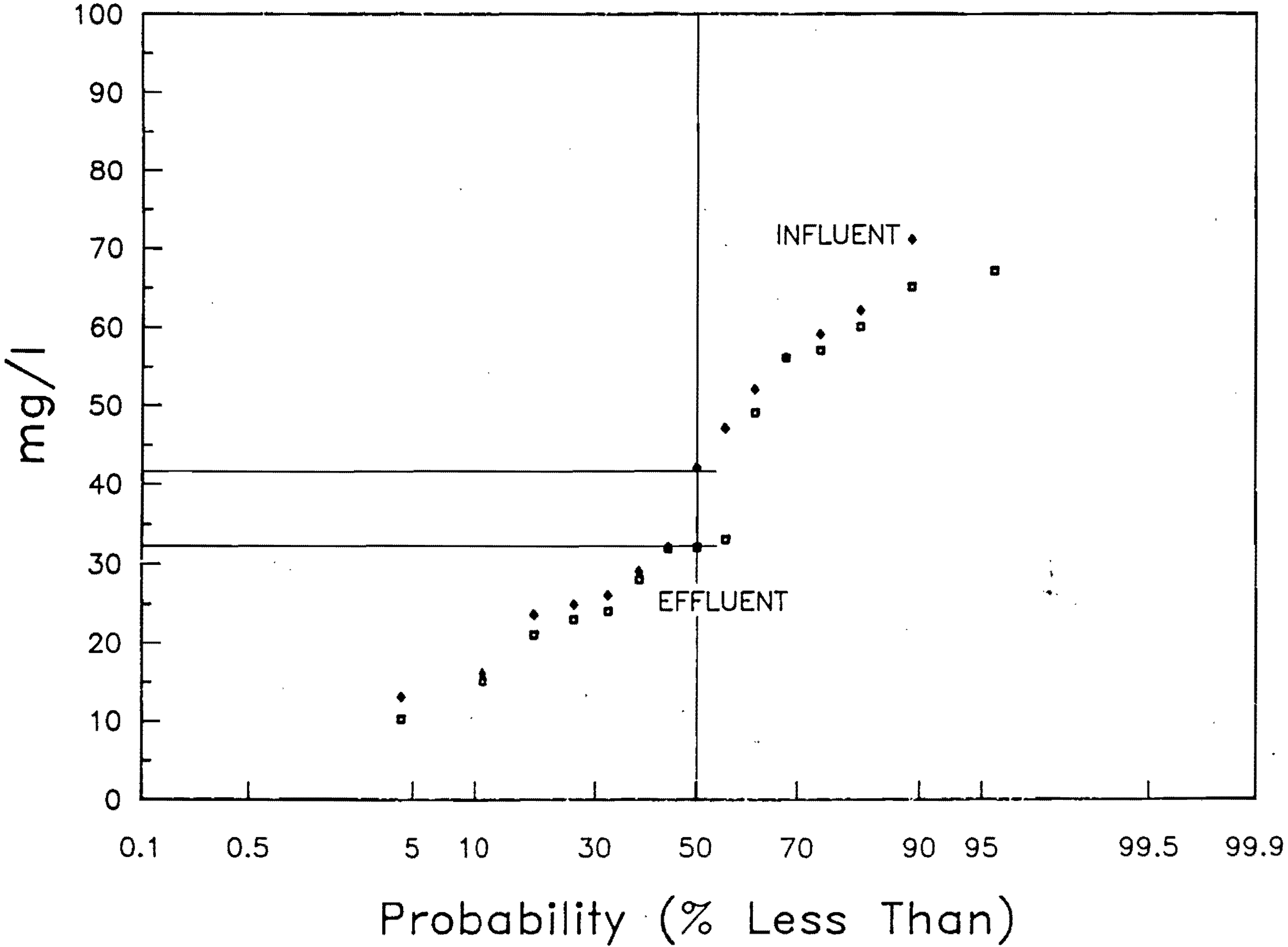




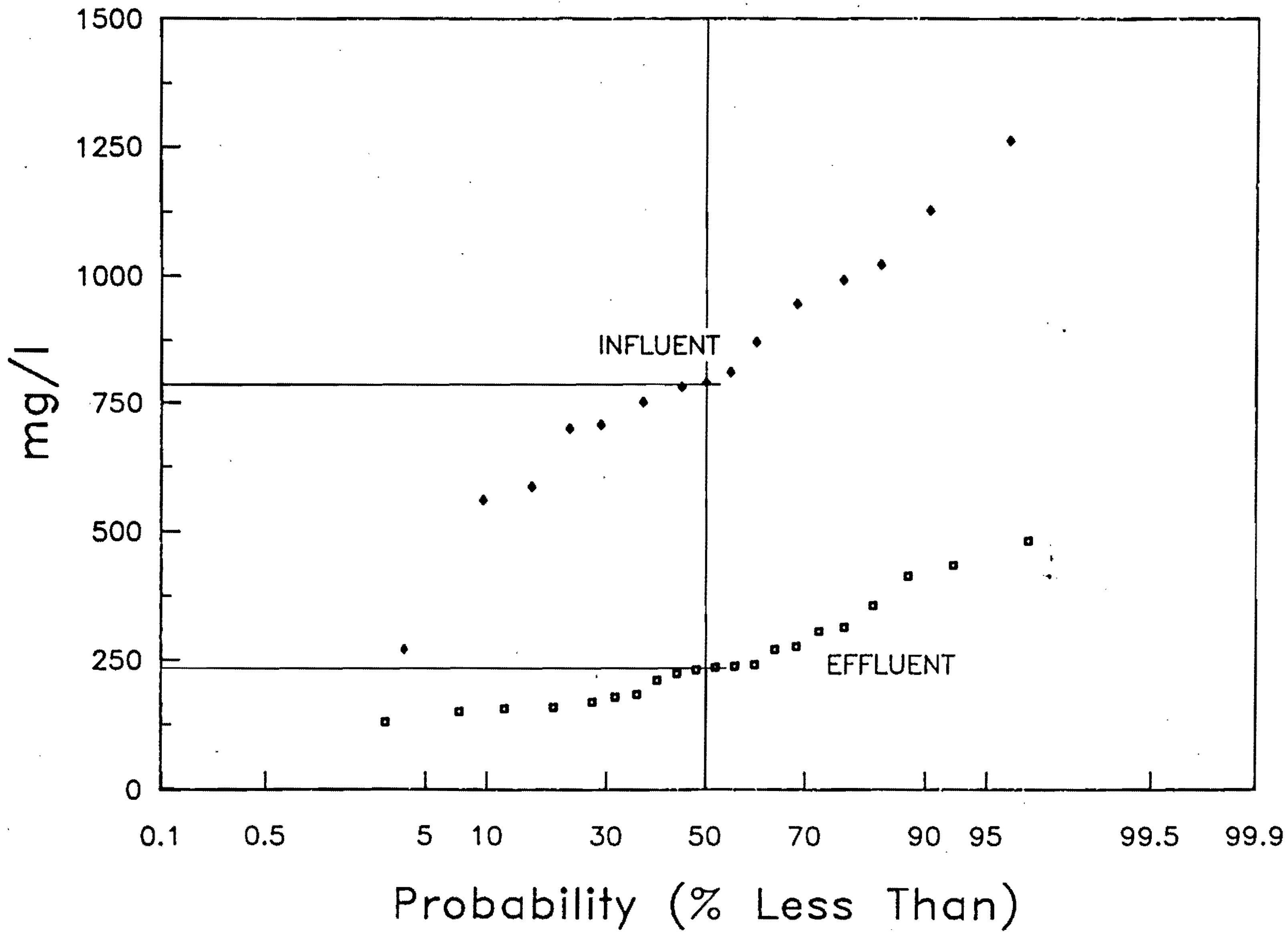
REACTOR 2 CTMP
TOTAL BOD

REACTOR 2 TMP
TOTAL BOD
mg/l
1500
1250
1000
750
500
250
0
INFLUENT
EFFLUENT
0.1
0.5
5
10
30
50
70
90
95
99.5
99.9
Probability (% Less Than)

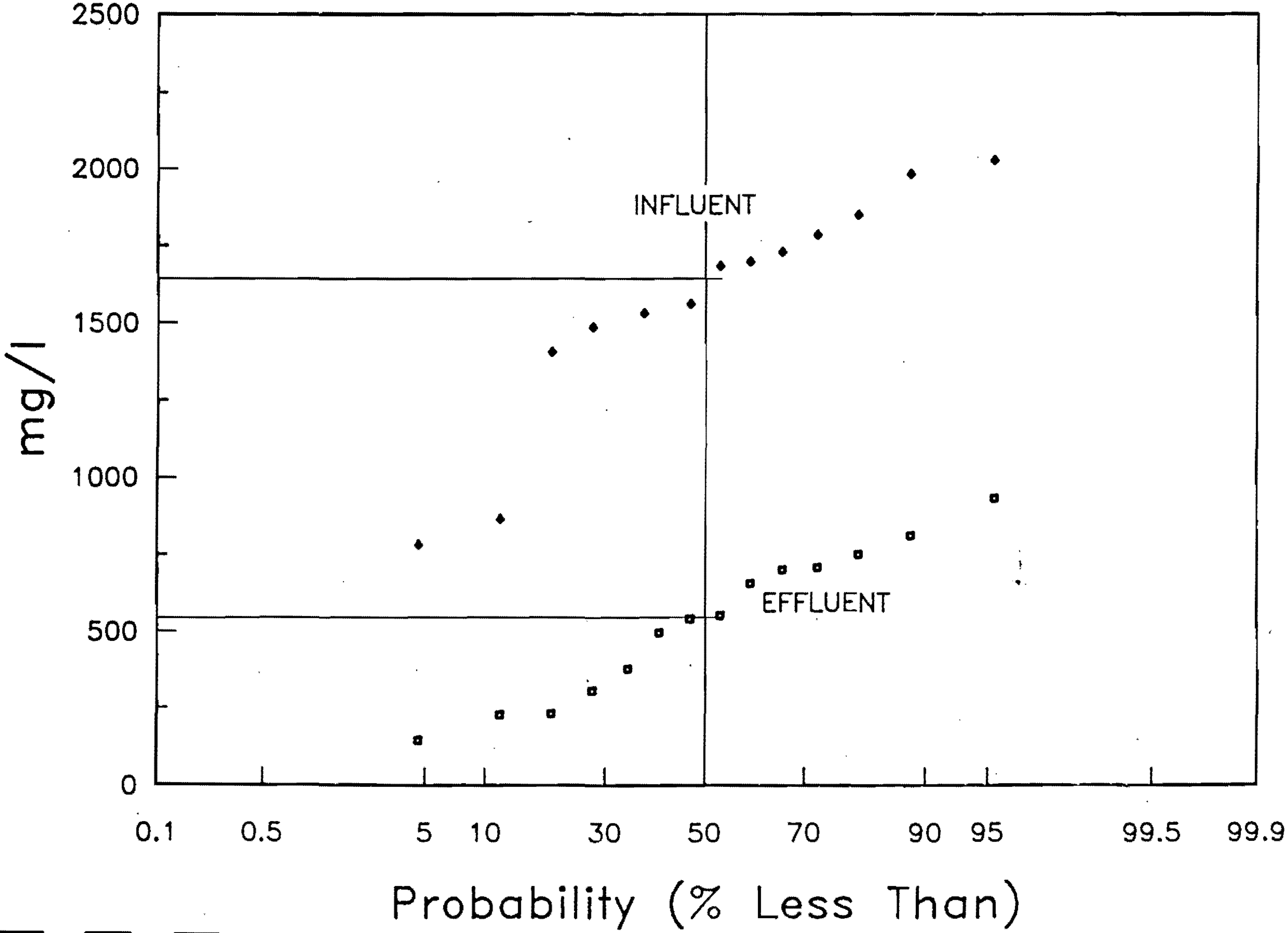
REACTOR 1
FILTERED TKN



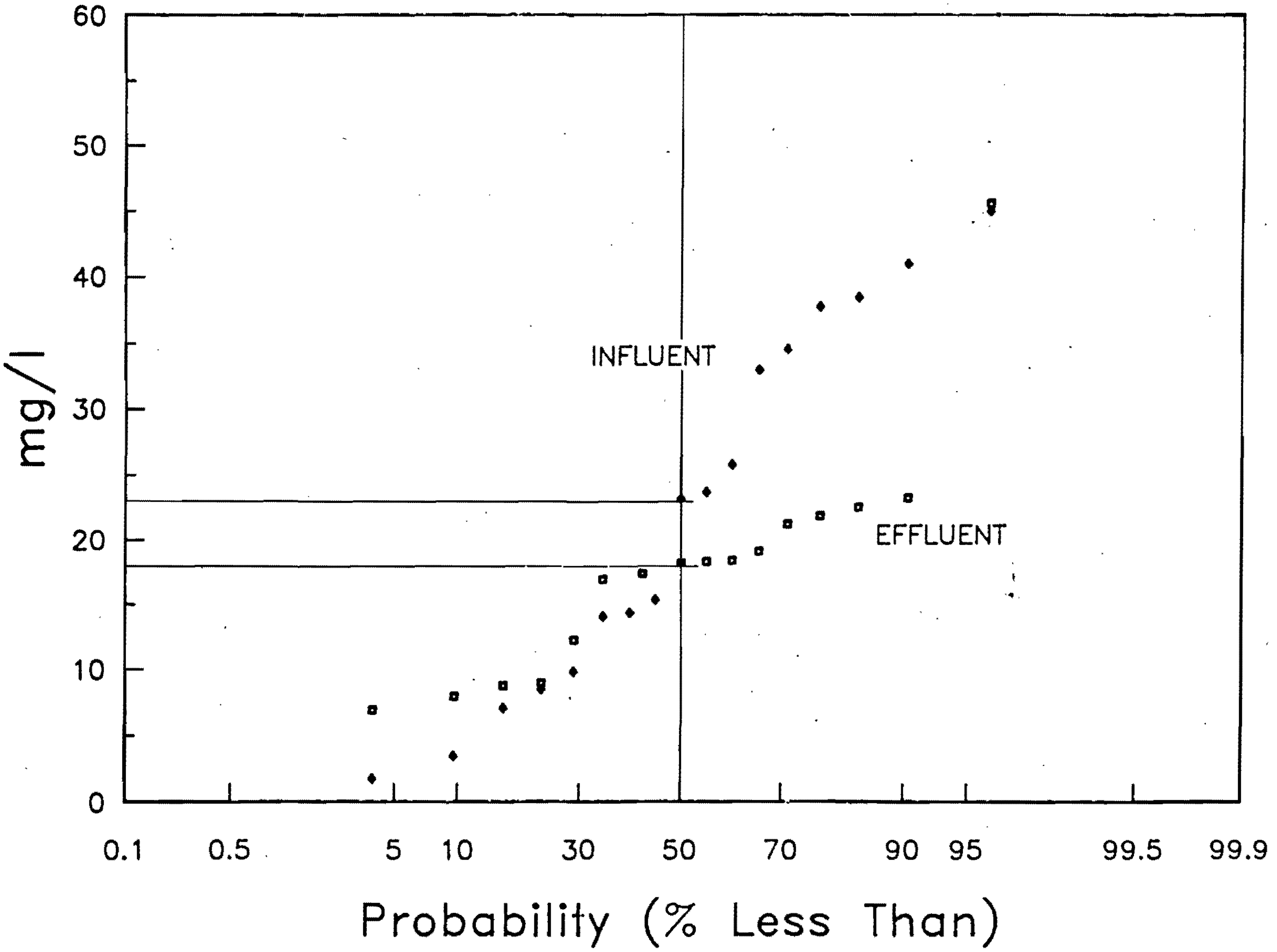
REACTOR 2 TMP
FILTERED BOD



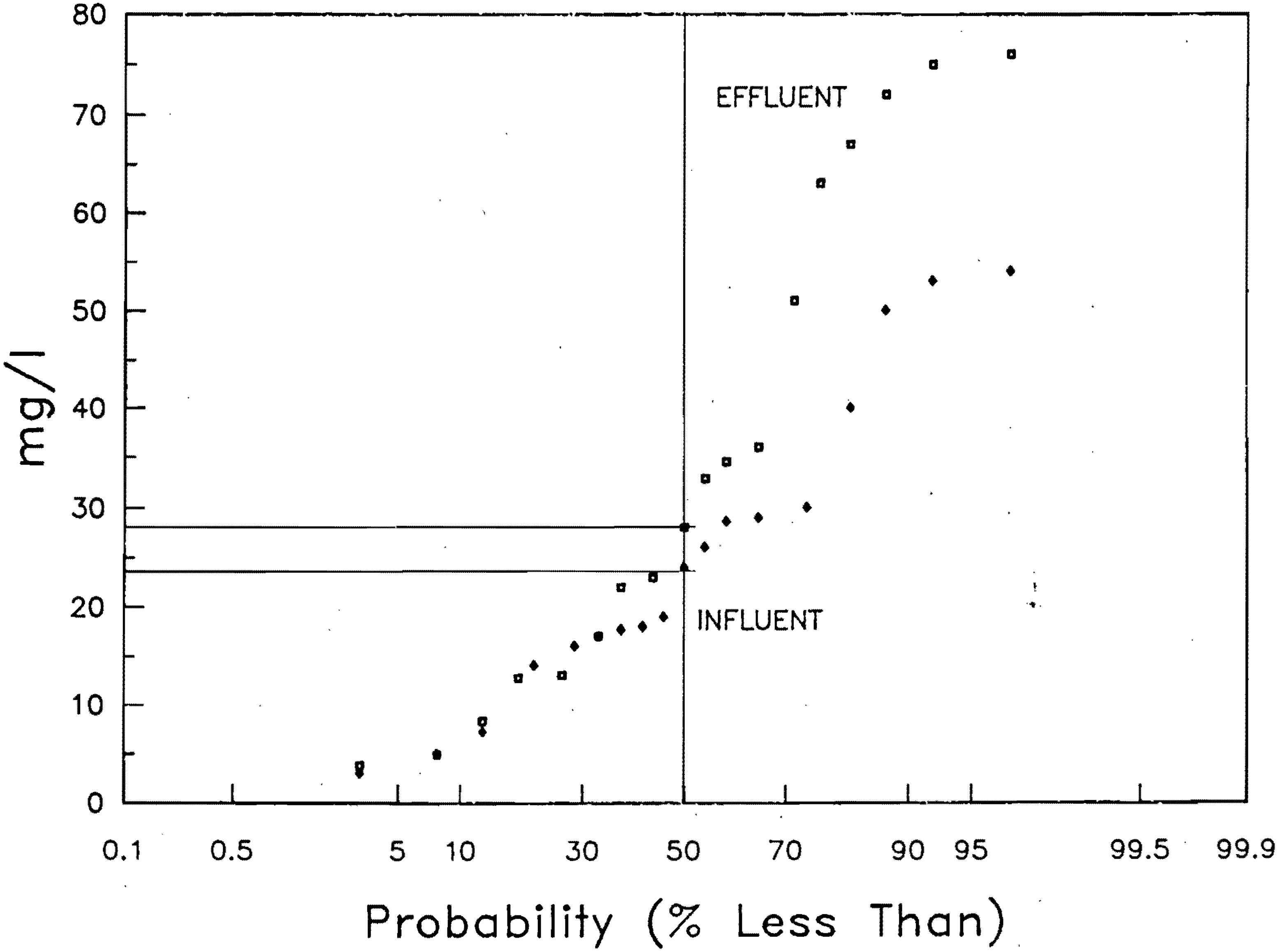
REACTOR 1
FILTERED BOD



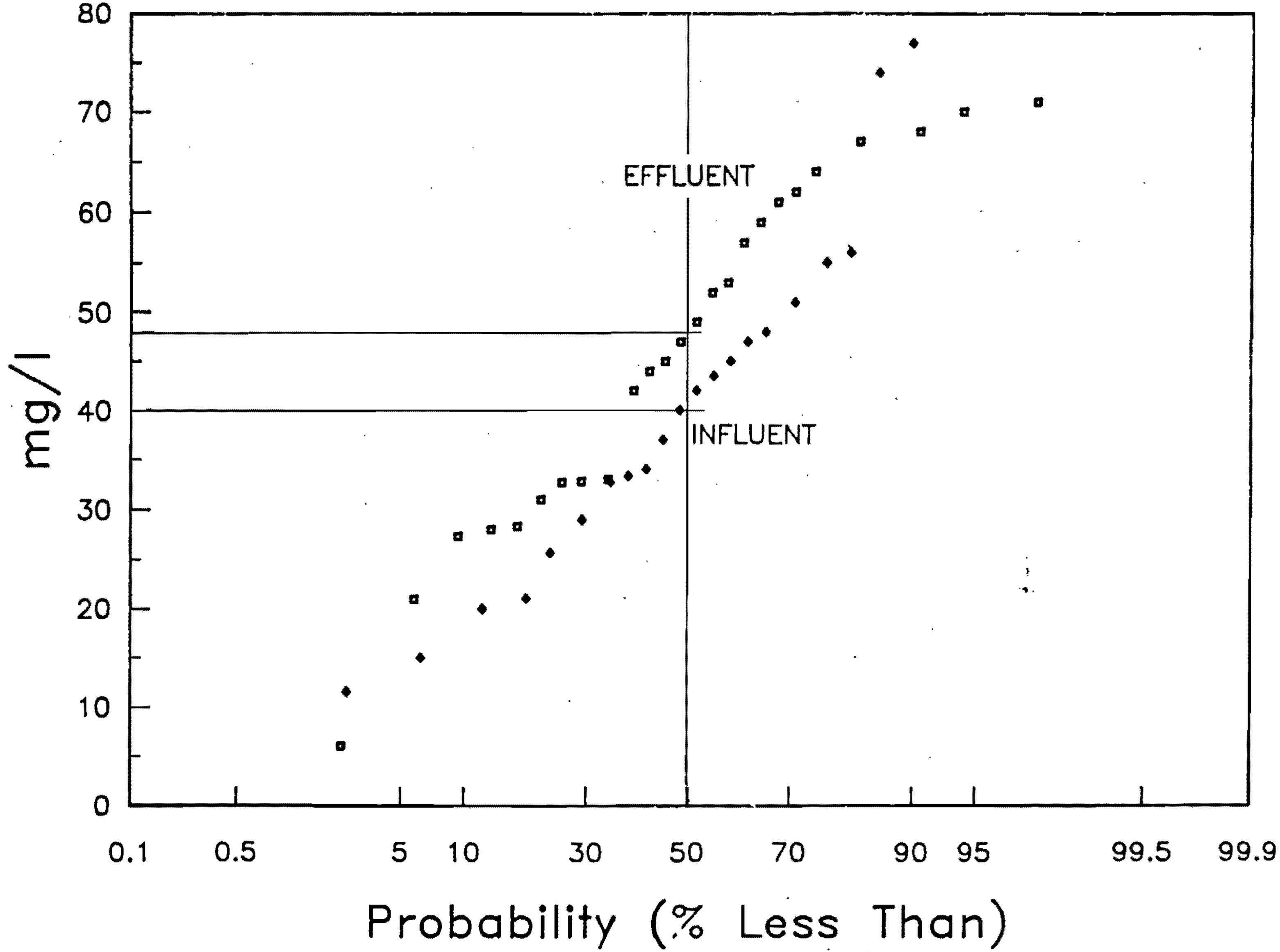
REACTOR 1
FILTERED NH_4



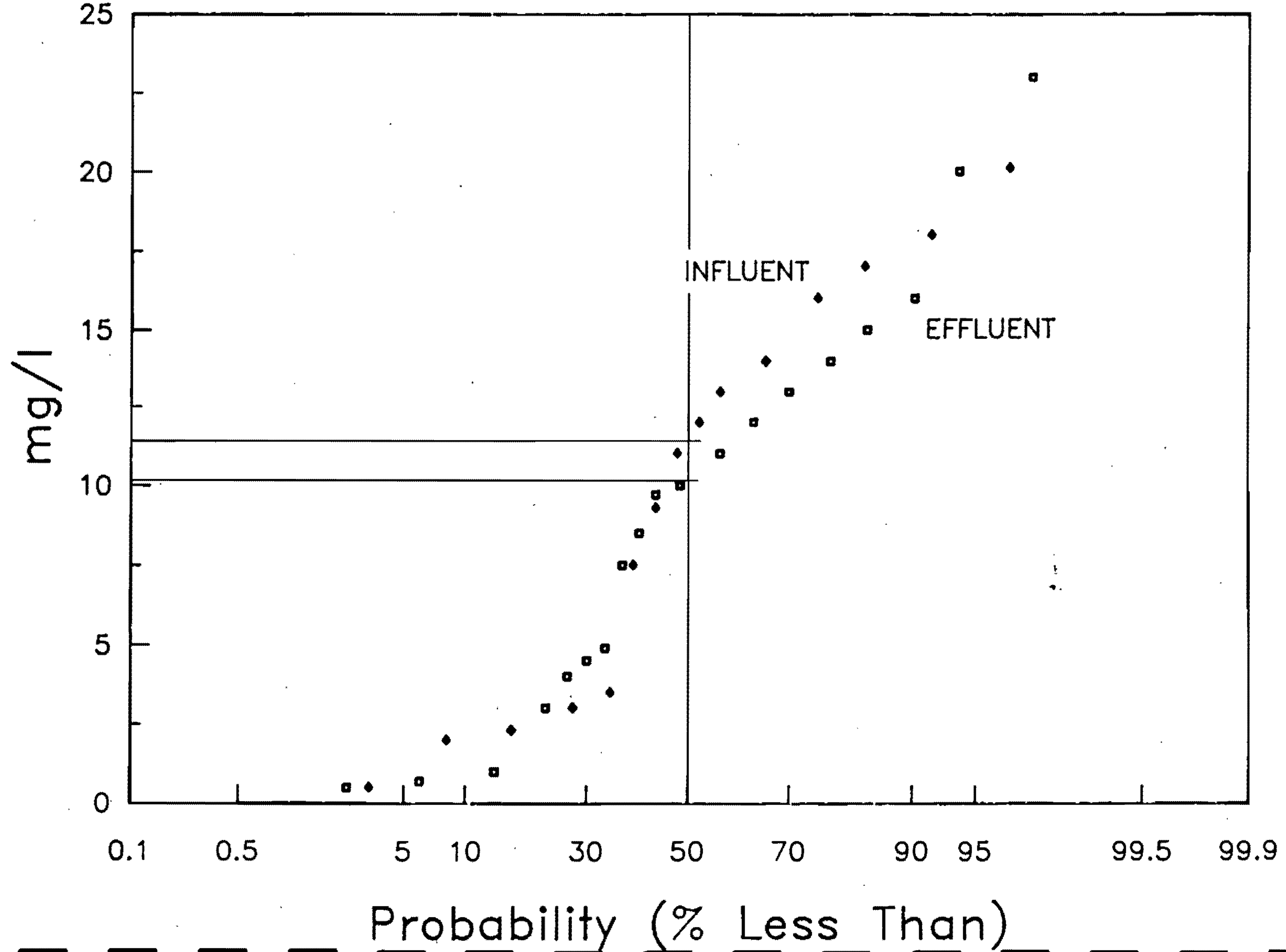
REACTOR 2 TMP
FILTERED TKN



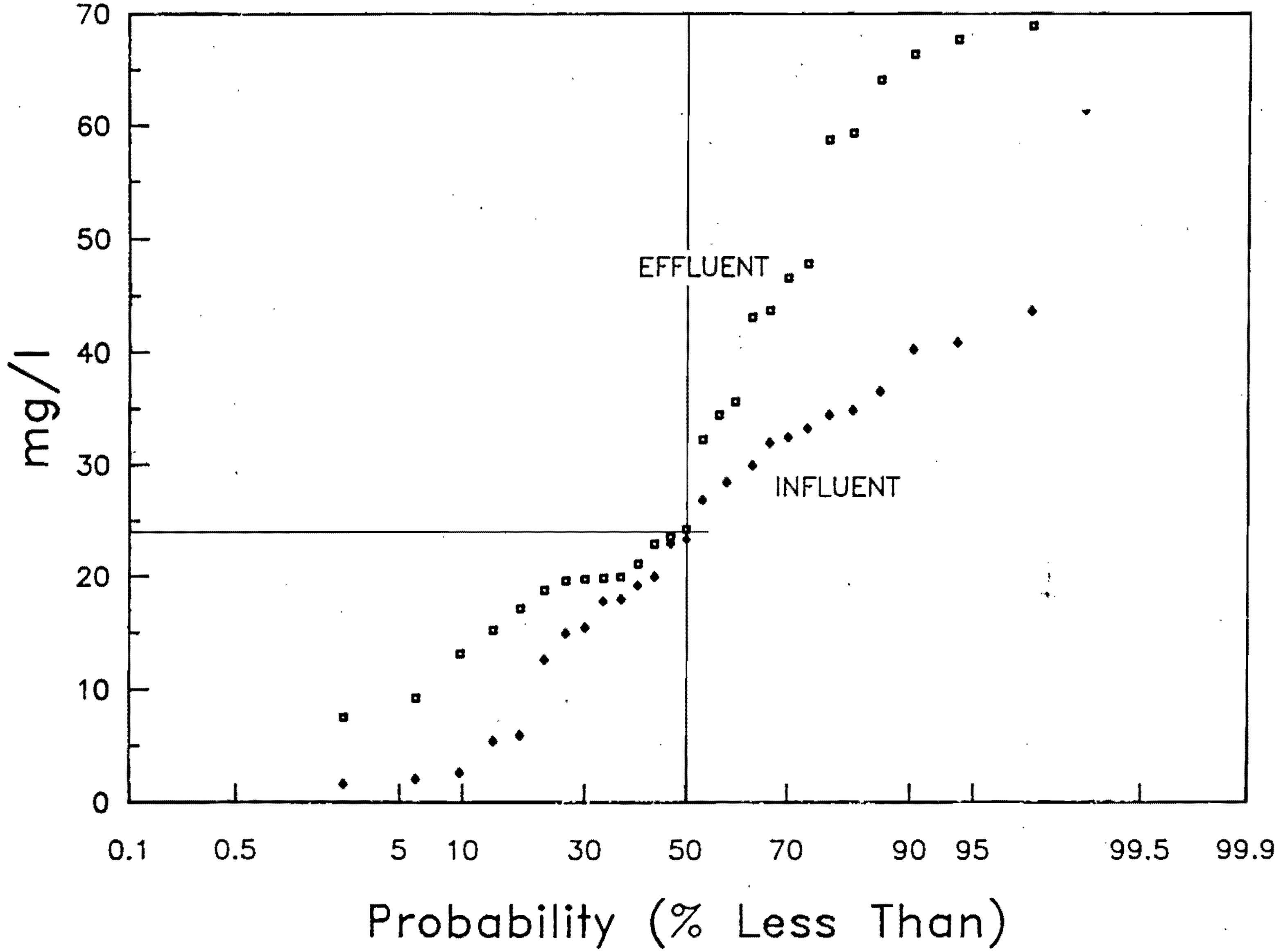
REACTOR 2 CTMP
FILTERED TKN



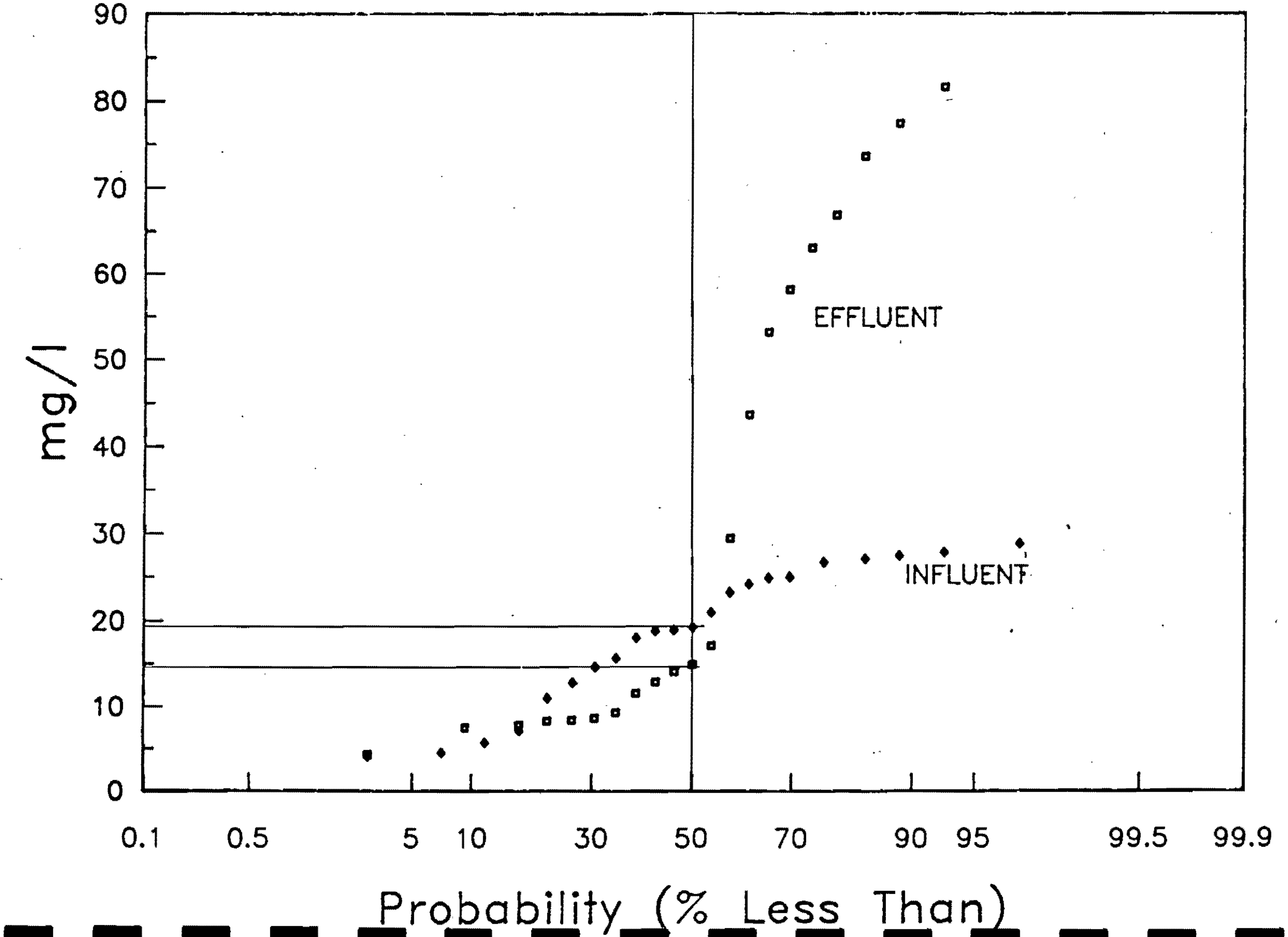
REACTOR 2 CTMP
FILTERED TP



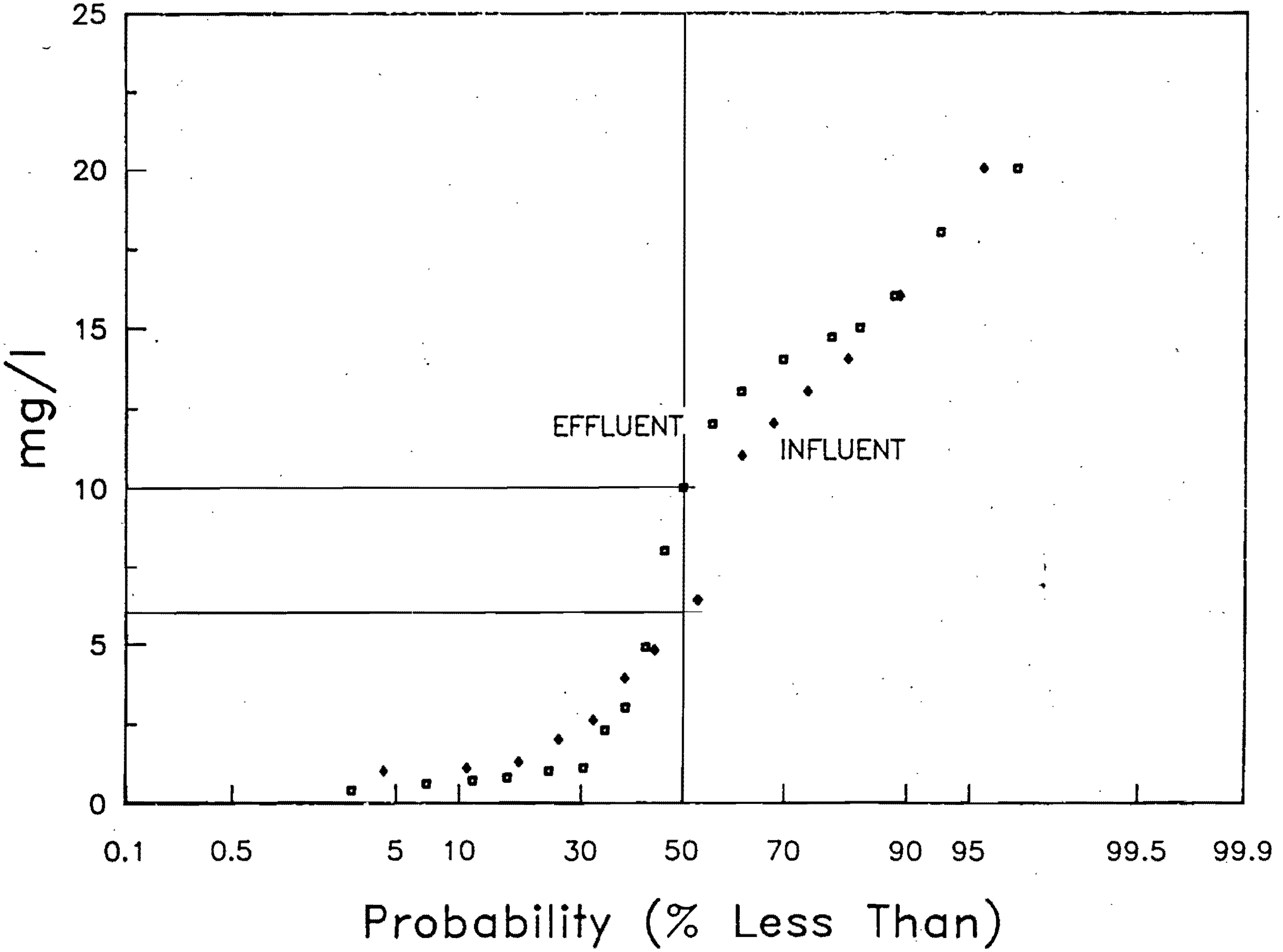
REACTOR 2 CTMP
FILTERED NH_4

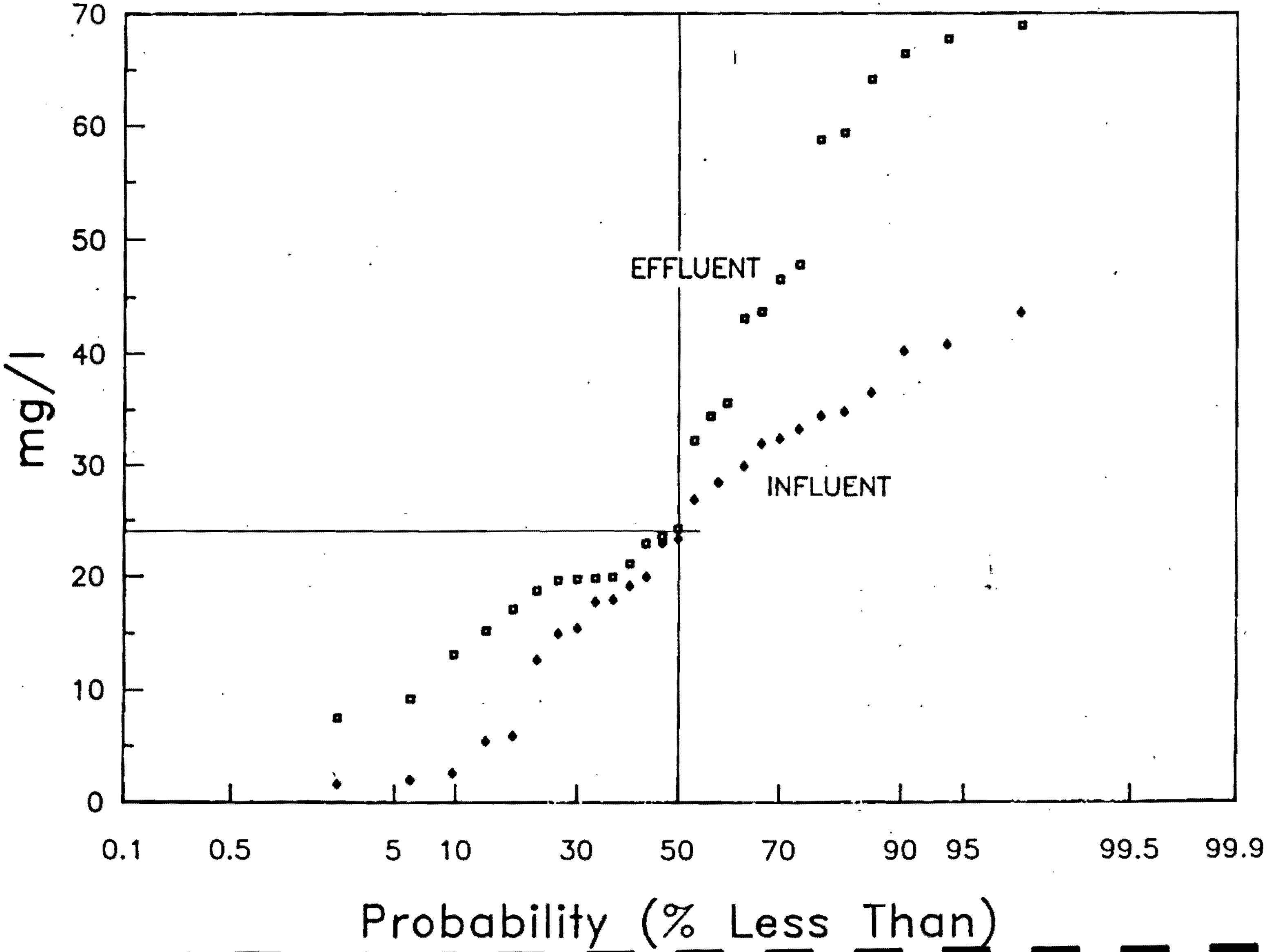


REACTOR 2 TMP
FILTERED NH_4



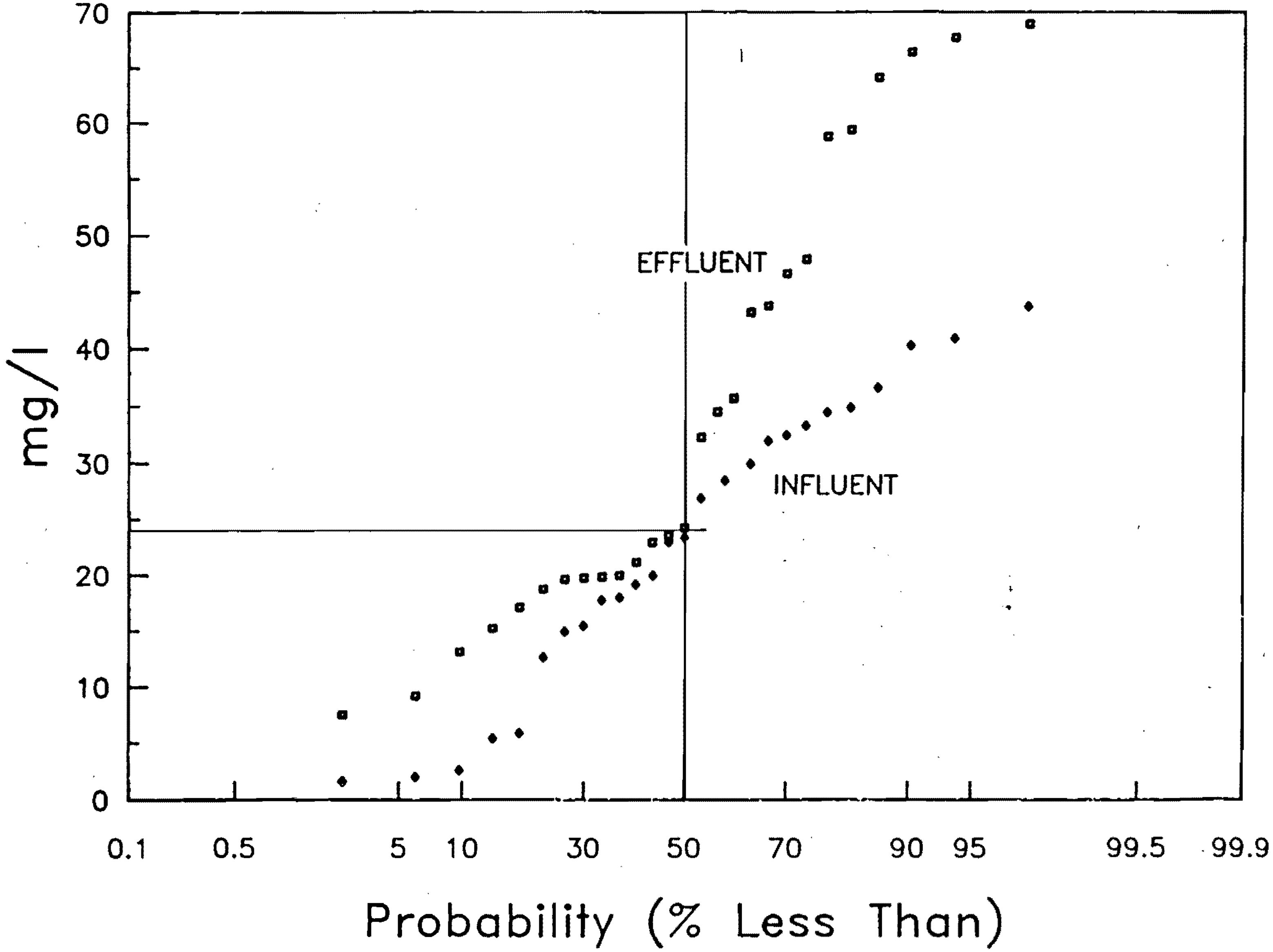
REACTOR 2 TMP
FILTERED TP



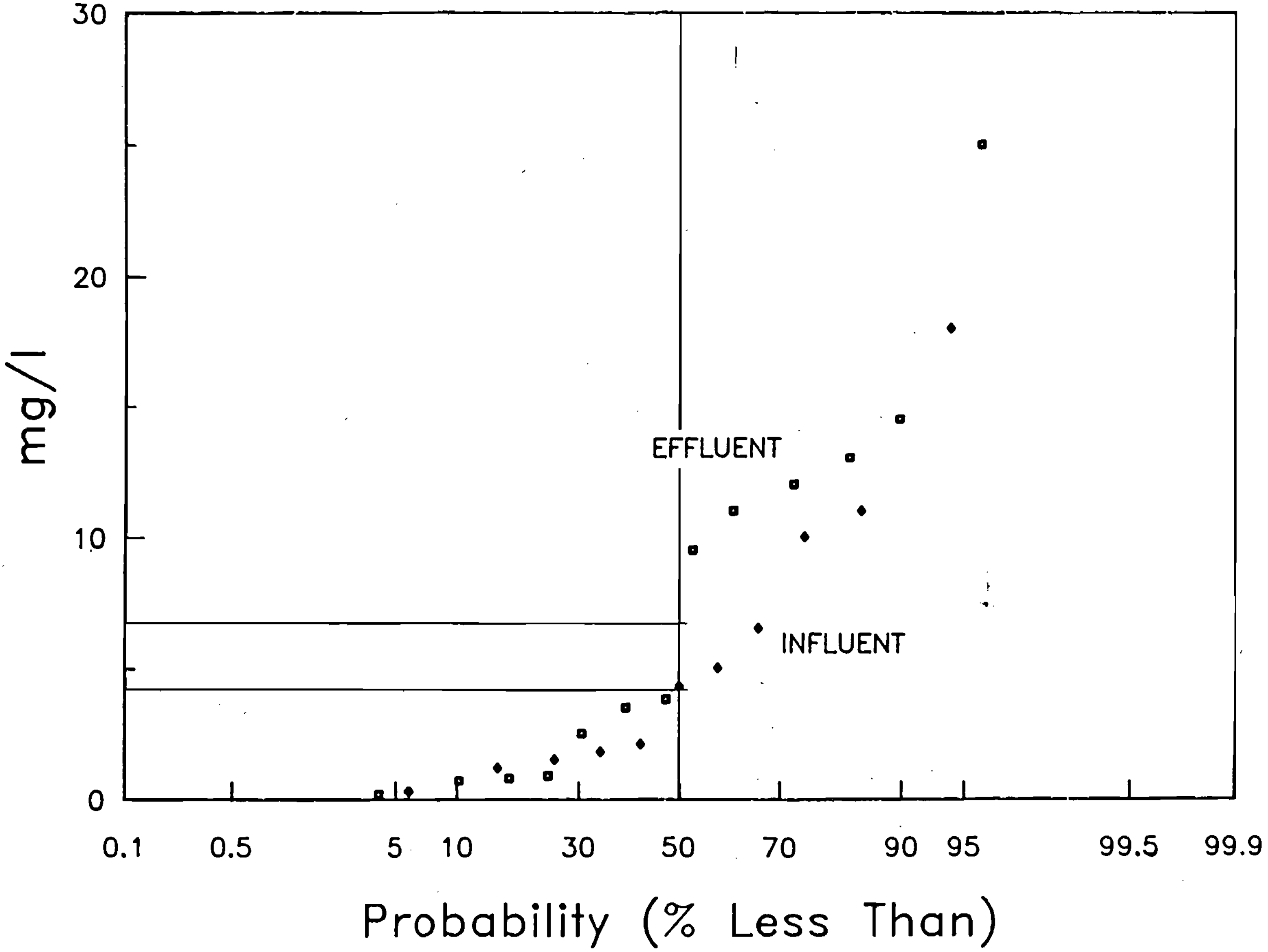


REACTOR 2 CTMP
FILTERED NH_4

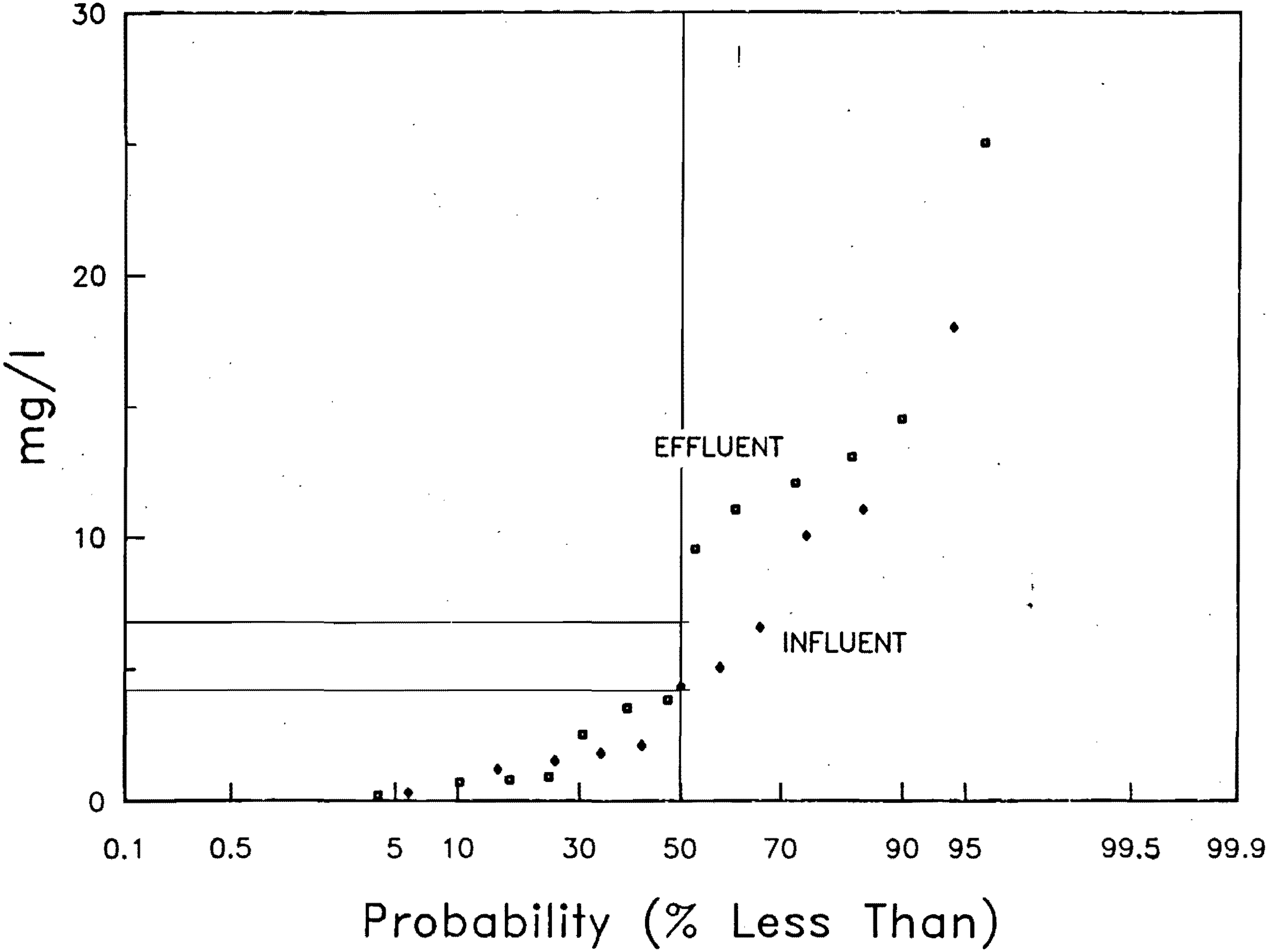
REACTOR 2 CTMP
FILTERED NH_4



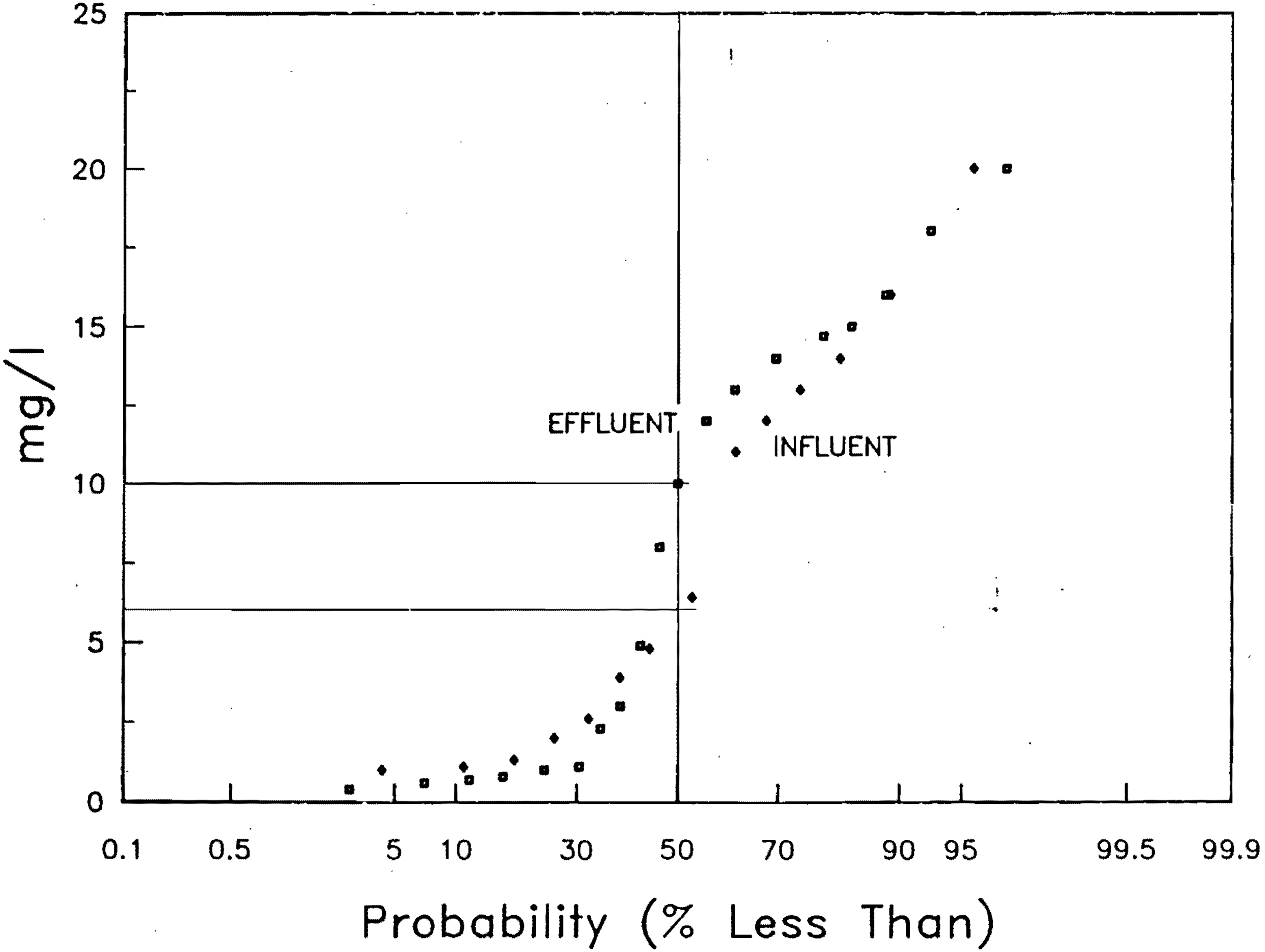
REACTOR 1
FILTERED TP



REACTOR 1
FILTERED TP



REACTOR 2 TMP
FILTERED TP



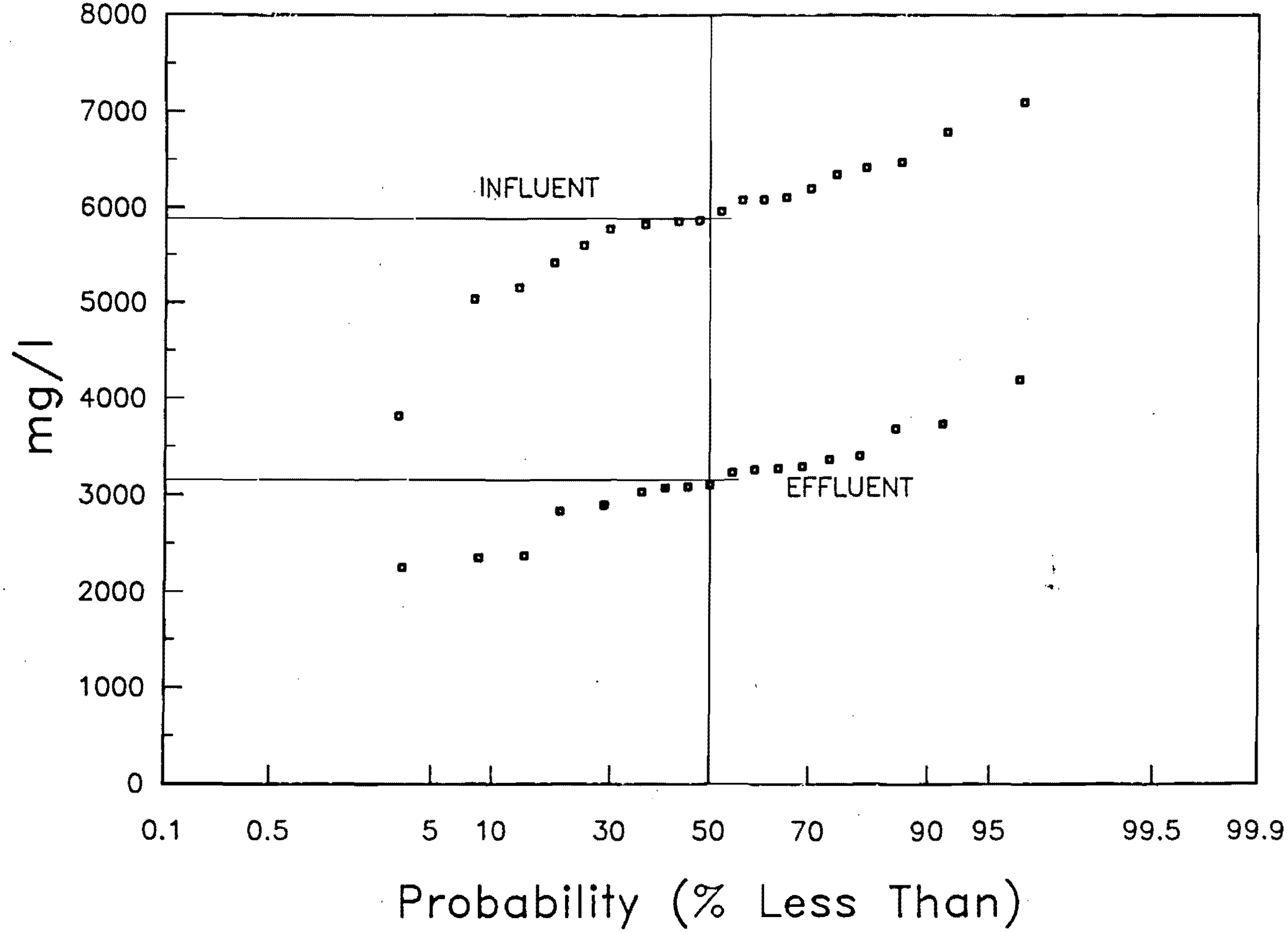
APPENDIX 1

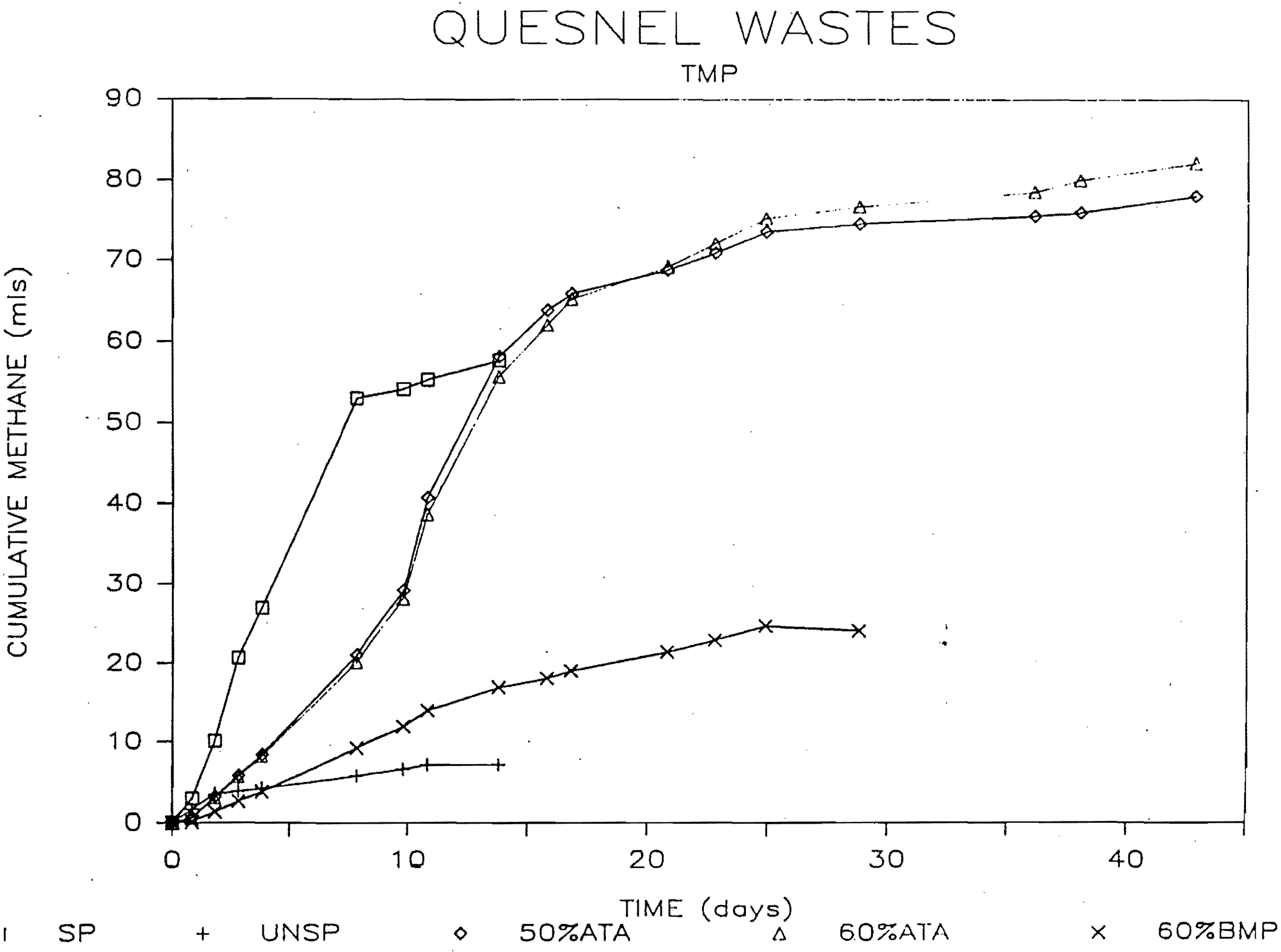
BENCH TEST RESULTS

SERUM BOTTLE TESTING AT WTC
QUESNEL RIVER PULP
INITIAL WASTE CHARACTERISTICS

Value Parameter	Concentration (mg/l) CTMP	 TMP
COD Unfiltered	6080	3400
COD Filtered	4110	2340
BOD_5 Unfiltered	1935	1054
BOD_5 Filtered	1545	866
Total Volatile Acids		
Total Organic Carbon	1610	861
Volatile Suspended Solids		
TKN Unfiltered	72	7.7
TKN Filtered		
Ammonium-N	51	0.5
Total Phosphorus Unfiltered	3.2	2.2
Total Phosphorus Filtered		
Nitrate	0.1	0.1
Nitrite	0.1	0.1
pH	6.85	7.3

REACTOR 1
TOTAL COD




QUESNEL WASTES
TMP
CUMULATIVE METHANE (mls)
0
10
20
30
40
50
60
70
80
90
0
10
20
30
40
TIME (days)
I SP
+ UNSP
◇ 50%ATA
△ 60%ATA
× 60%BMP