B-033-OKLA

Technical Completion Report
on
Biological Evaluation of Best Practicable and Best Available Treatment Control Technology for Petroleum Refinery Wastewaters

from
S.L. BURKS
RESERVOIR RESEARCH CENTER
OKLAHOMA STATE UNIVERSITY

and
J.L. WILHM
DEPT. OF ECOLOGY, FISHERIES, AND
WILDLIFE
OKLAHOMA STATE UNIVERSITY

to
USDI, OFFICE OF WATER RESOURCES TECHNOLOGY

and

OKLAHOMA OIL REFINERS' WASTE CONTROL COUNCIL

The work upon which this report is based was supported in part by funds provided by the United States Department of the Interior, Office of Water Research and Technology, as authorized under the Water Resources Research Act of 1964.

Table of Contents

ACKNOWLEDGEMENTS

This project would not have been possible without the financial support of the U.S. Department of Interior, Office of Water Resources Technology, Grant B-033 Okla.; the financial support and cooperation of the Oklahoma Oil Refiners' Waste Control Council. Sincere appreciation is expressed to the management and personnel of those oil refineries where evaluations were performed. They willingly contributed both material and technical assistance.

I gratefully acknowledge the efforts of the staff of the Reservoir Research Center; Conrad Kleinholz, Maria Mottola, Geoffrey Russell, Sarah Schatz, Elaine Stebler, David Parrish, Jenny Harbaugh, Lurinda Burge, Jim Reidy, Mike Clover, Jan Nicholson, Randy Staggs, and Barbara Mays. Without their diligent efforts and personal initiative this project could not have been accomplished.

ABSTRACT

A biological evaluation of conventional secondary biological treatment, Best Practicable Treatment Control Technology, and Best Available Technology Economically Achievable was performed to determine the effectiveness of the treatment systems for producing non-toxic effluents from petroleum refining wastewaters. On-site continuous-flow Fathead Minnow and Benthic Macroinvertebrate bioassays were used to measure the toxic effects of the test effluents. BATEA, sequential biological treatment-dual media filtration-activated carbon adsorption, improved final effluents by adsorbing slugs of chemicals which had upset the conventional biological treatment systems and thus protected the bioassay organisms from lethal doses of chemicals. A waste stabilization lagoon system produced a final effluent of comparable quality as that of BATEA as measured by changes in species diversity, number of taxa and mean density of benthic macroinvertebrates. BPTCT, sequential biological treatment-dual media filtration, did not significantly improve final effluent quality as measured by Fathead Minnow and Benthic Macroinvertebrate bioassays. The technique of using benthic macroinvertebrate colonized artificial substrate samplers as a bioassay tool was developed and successfully demonstrated in this evaluation of wastewater treatment methods used in the petroleum refining industry.

List of Figures

List of Tables

Technical Completion Report

Biological Evaluation of Best Practicable Treatment and Best Available Treatment Control Technology for Petroleum Refinery Wastewaters.

By mid-1977, all industries must attain a level of wastewater treatment equivalent to Best Practicable Treatment Control Technology (BPTCT) and Best Available Treatment Economically Achievable (BATEA) by mid-1983. For the petroleum refining industry, BPTCT has been defined as the equivalent of sequential treatment with activated sludge followed by dual media filtration. The BATEA level of treatment was defined as the equivalent of sequential treatment with activated sludge, dual media filtration, followed by adsorption on activated carbon.

Based upon reduction of specific chemical contaminants, these levels of treatment will probably meet effluent criteria recommended by the regulatory agencies responsible for attaining goals established by the 1972 amendments to the Federal Clean Water Act. However, effluent criteria based upon maximum allowable concentrations of chemical contaminants were developed by scientists attempting to predict the effect of pollutants upon aquatic organisms. The ultimate test of the acceptibility of a treatment method must be the long-term effect of continuous wastewater discharge upon the biological organisms within the receiving environment. The concept of using biological organisms to determine the effectiveness of a treatment method is in accord with the intent of the 1972 amendments, since the 1985 goal was defined as "zero pollutant discharge". Pollutants were defined as "any substance which directly or indirectly, through the food chain, causes a deleterious effect upon any organism in the aquatic environment".

Water pollution ecologists have developed many tests using the response of biological organisms as an index of the quality of water. Probably the most commonly used test is the measurement of survival of individuals of a single species of aquatic organism to a range of concentrations of a test chemical poison. Such bioassays have provided information on maximum concentrations of chemical poisons that would not cause lethal effects upon the test species. Bioassays performed on several different species of aquatic organisms have shown that the toxic threshold concentration of some chemical poisons varied from no differences to a 300 fold difference between the tested species (Stewart, 1967). Since there are thousands of different species of aquatic organisms and of chemical poisons, it would take many years to test all of the possible combinations.

Many aquatic biologists have used the aquatic communities in the receiving bodies of water as indicators of water quality (Tarzwell, 1962; Beak, 1964; Gaufin and Tarzwell, 1956). The populations of benthic macroinvertebrates have been shown to be an important monitor of the present and past water quality conditions, since this group of organisms was relatively non-motile and long-lived (Hawkes, 1962). Quantitative mathematical indices of the diversity and complexity of the benthic macroinvertebrate assemblage have been correlated with the effects of pollutants upon the receiving waters (Wilhm & Dorris, 1968;

Weber, 1973). The major limitation of the technique has been the inability to control the experimental conditions of exposure. Aquatic biologists could only monitor the biological community above and below a point source discharge to a receiving stream and thus were limited to an evaluation of the water quality conditions of the point source discharge.

The authors have developed a technique which involves using the multi-species response of the benthic macroinvertebrates as an indicator of water quality and laboratory control over the exposure conditions. Artificial substrate samplers colonized with benthic macroinvertebrates from a natural unpolluted body of water were transferred to artificial streams for exposure to test effluents.

The fiscal year 1976 and 1977 project of the Oil Refiners' Waste Control Council - USDI Office of Water Resources Technology - OSU Reservoir Research Center was designed to use fish bioassays, diversity of benthic aquatic organisms, and periphyton as biological monitors to evaluate the effectiveness of BPTCT and BATCT for producing a non-deleterious effluent. The project was initiated in July, 1975, when matching federal funds from the USDI Office of Water Resources Technology became available. The first four months were spent on purchasing supplies and equipment, constructing artificial streams, and converting the mobile bioassay trailer to function as a dual media filter and activated carbon adsorption unit.

Materials and Methods.

The overall flow diagram of the control stream (river water), activated sludge, dual-media filter, and activated carbon effluents to the bioassay aquaria and artificial streams is shown in Figure 1.

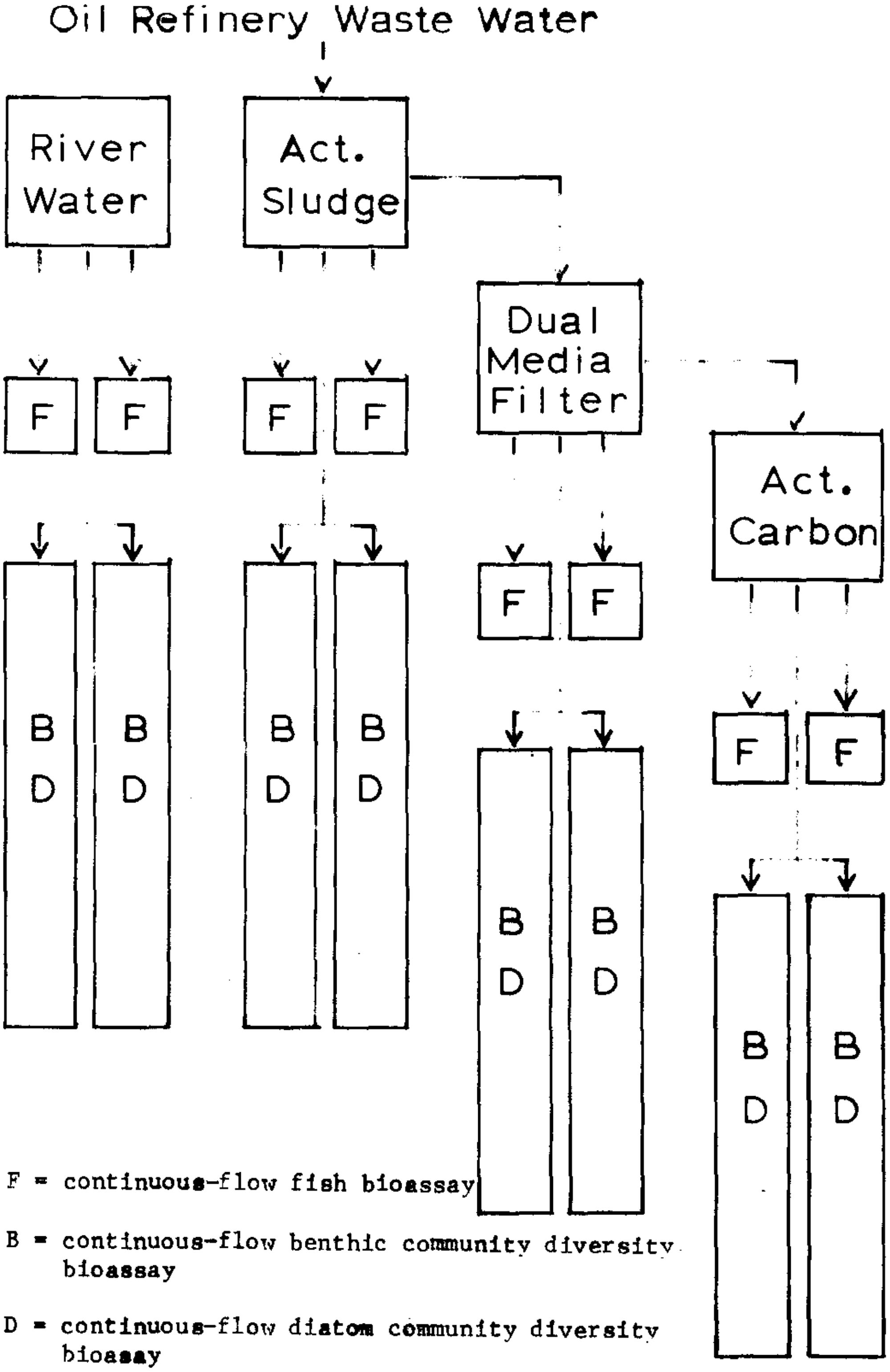
Control water had to be transported to the test site in a 5,000 gallon tank truck and then pumped to the test units. Biologically activated sludge or lagoon treated oil refinery waste water was pumped from the final clarifier to the trailer and subsequently through the dual-media and activated carbon columns. The designed flow rate through the dual-media filter was 2 liters/minute. After passing through the dual-media filter, the flow was split into 1 liter/minute for the bioassay tests and 1 liter/minute for filtration through the carbon units (Figure 2).

Dual-media filter columns were constructed of eight inch diameter polyethylene pipe with one-half inch thick walls (purchased from Ryerson, Dallas, Texas). The length of the column was set at 5 ft. 6 in. to hold 18 in. of #1220 sand and 36 in. of anthracite coal #2 (purchased from Chase & Assoc., Tulsa, Okla.). The filtration column was designed to operate as a downflow gravity flow column. The plumbing was designed to permit manual backflushing as needed.

Eight columns for activated carbon were constructed from eight inch diameter polyethylene pipe. The columns, 5 ft. 6 in. long, were filled with 5 ft. of Darco activated carbon (source; ICI United States, Wilmington, Delaware). The characteristics of this carbon are:

Mean particle size	0.9-1.1 mm
Abrasion number, max.	25 NBS test
Molasses number, min.	230
Iodine number, min.	600
Total pore volume	0.9
Particle density	1.3-1.4

Each carbon column contained 1.33 ft^3 of activated carbon or 20.0 lbs per column. The recommended loading rate for activated carbon is 0.2 to 0.3 lb of COD/lb of carbon. In order to prevent overloading, the loading rate in this project was set at 0.1 lb of COD/lb of carbon. The flow rate through the columns was set at 1 liter/minute.



F = continuous-flow fish bioassay

B = continuous-flow benthic community diversity bioassay

D = continuous-flow diatom community diversity bioassay

Figure 1. Block diagram of experimental set-up to evaluate the best practicable treatment control technology (BPTCT) and best available treatment control technology (BATCT) for producing a non-polluting effluent.

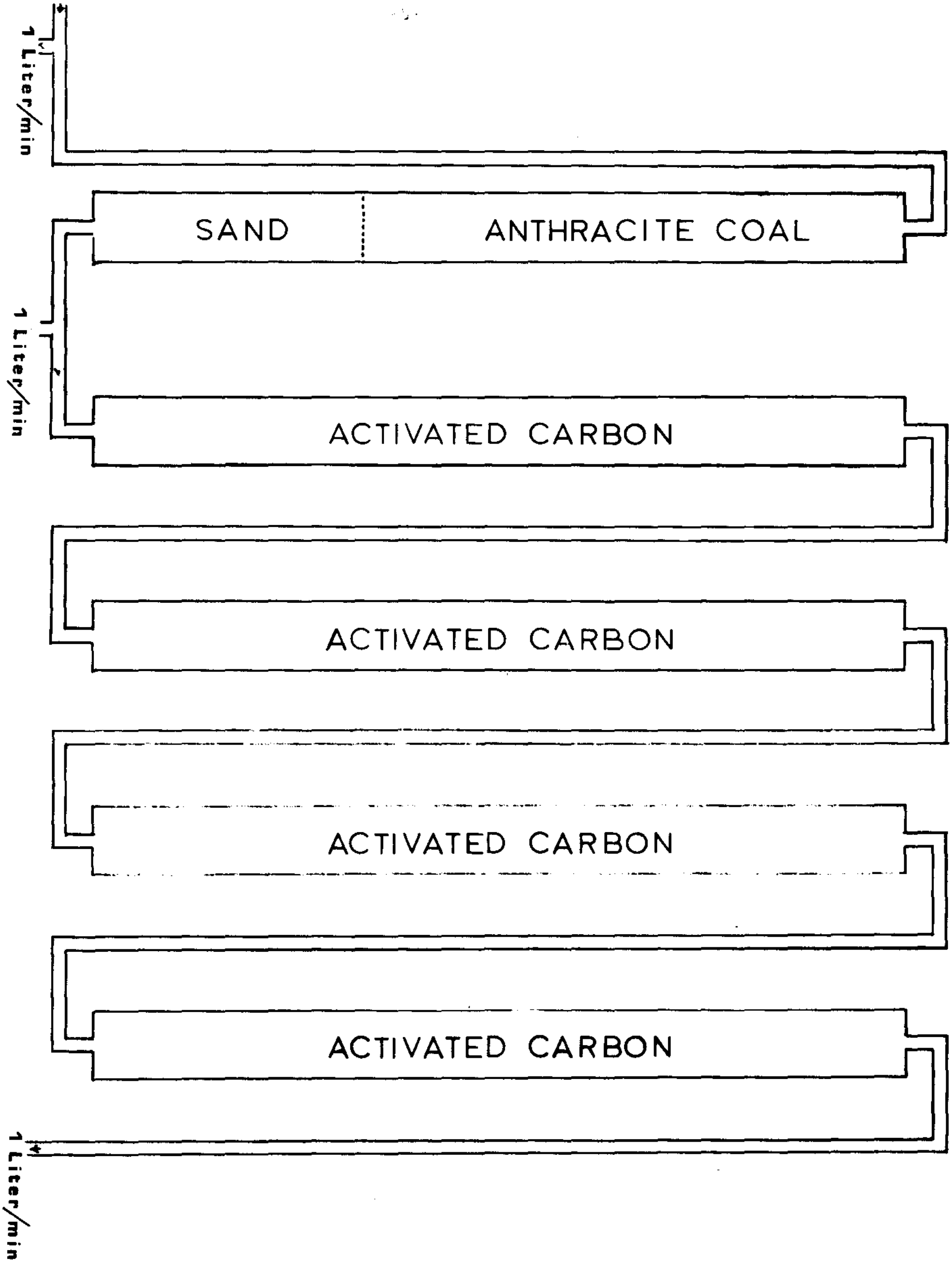


Figure 2. Block diagram and flow patterns of dual media filter and activated carbon units.

Water from each of the test units was split and passed continuously through duplicate fish bioassay aquaria (0.10 liters/min.) and through duplicate artificial streams (0.4 liters/min.). The flow rates were designed to deliver a volume of water equivalent to the total volume of fish bioassay aquaria in 5 to 6 hours and to that of the artificial streams in 10 to 12 hours. The recommended flow rate for continuous-flow bioassays is a volume equivalent to that of the test container in 6 to 8 hours (EPA, 1975).

A chemical ion probe monitoring chamber was designed and constructed for measurement of pH, temperature, dissolved oxygen, conductivity and a specific ion (probes and meter purchased from Hydrolab Corp., Austin, Texas). Each test stream was switched via an industrial timer controlled 3-way solonoid valve to flow through the chemical ion probe chamber for 15 minutes each hour (Figure 3). The data from the ion probe monitoring meter was recorded every 5 minutes on a 1/4" magnetic tape data logger. The day, hour, minutes, seconds, and an identification code for each stream were also logged at the same time as the ion probe data (data logger from Metrodata Corp., Norman, Okla.).

The bioassay aquaria were all-glass ten-gallon containers fitted with an overflow stand-pipe which could be adjusted to control the total volume of the aquaria. The concentration of dissolved oxygen in the test effluents was generally less than 2 mg/l and it was decided to gently aerate the water to prevent mortalities due to low dissolved oxygen. The artificial streams were constructed of redwood and fiberglassed interior (Figure 4). A paddlewheel was installed to create currents in the artificial streams since the flow rate of test effluents was not sufficient to cause adequate currents. The current velocity was

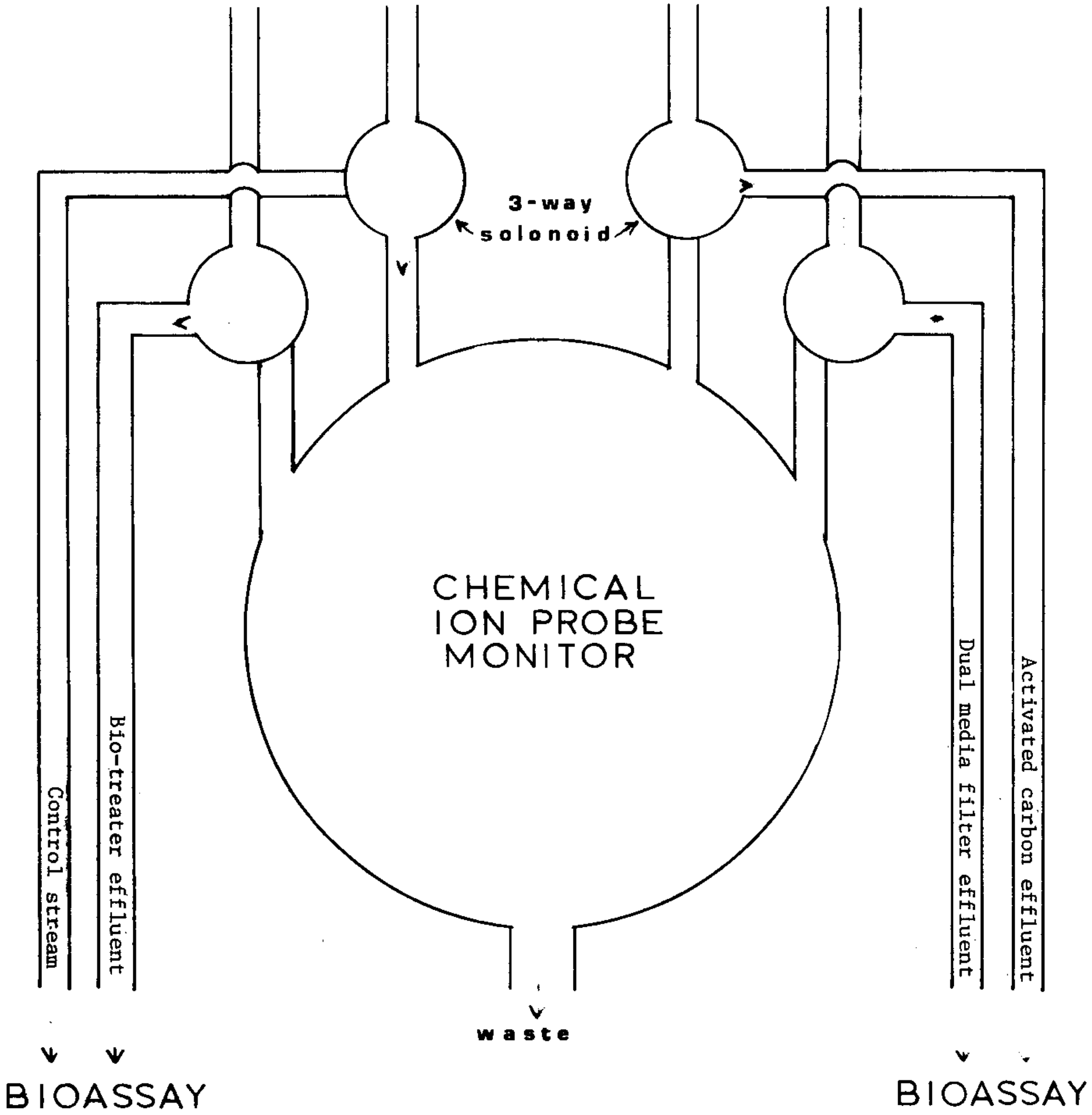


Figure 3. Diagramatic sketch of ion probe monitoring chamber

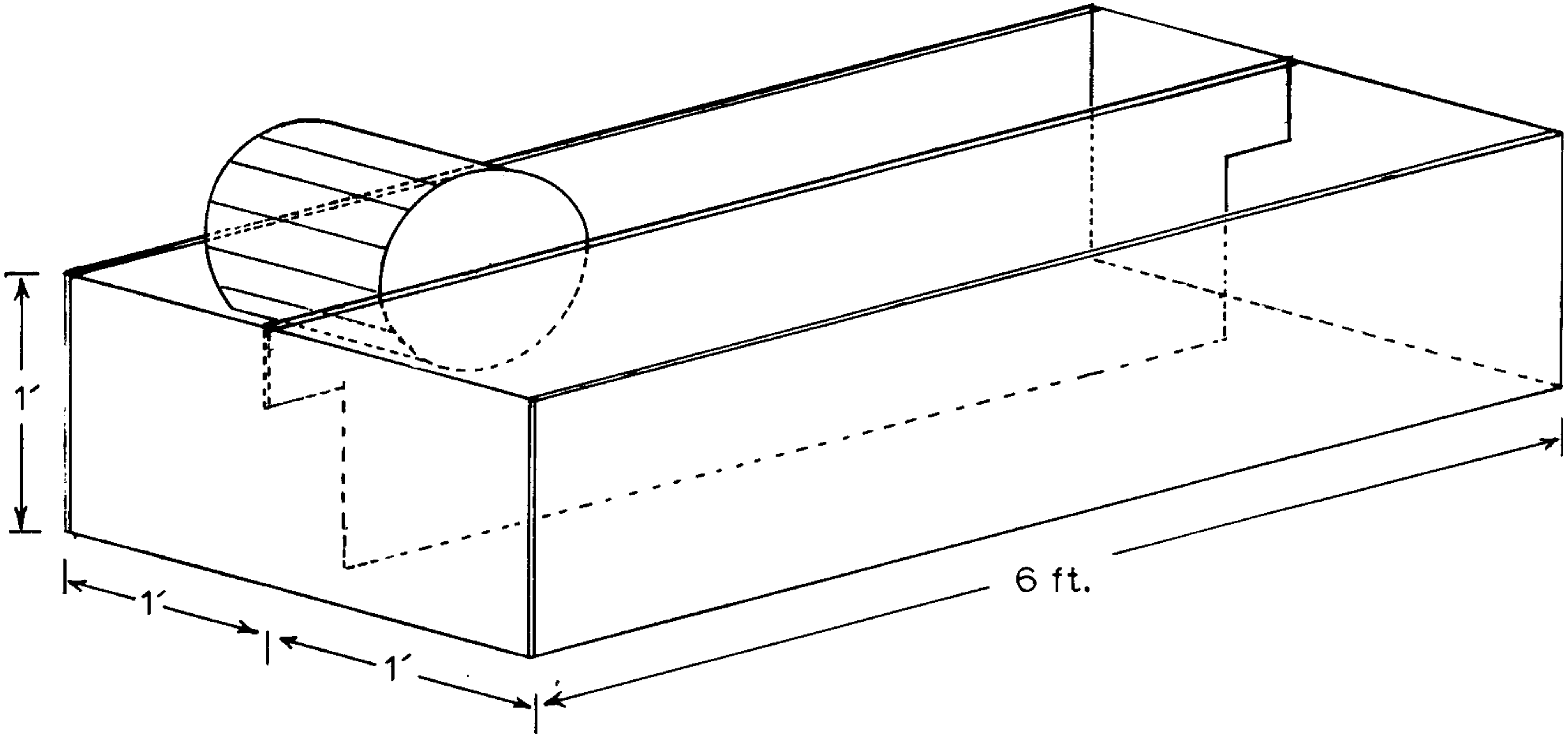


Fig. 4. Sketch of Artificial Stream

estimated to be from 2.0 to 4.0 cm/sec. All fathead minnows used in the bioassay tests were laboratory raised fish from the OSU Reservoir Research Center. Most of the fish were at least 90 days old or older since we were attempting to obtain a spawn during the exposure. Photoperiods were controlled at 16L:8D in order to stimulate spawning behavior.

Colonies of aquatic benthic invertebrates were initially established by placing polyethylene trays (33.0 cm x 22.8 cm x 10.2 cm) filled with rocks (5.1 cm to 7.6 cm in diameter) in a natural unpolluted stream approximately 20 miles (12.4 km) from the refinery location. The polyethylene trays were left in the creek for 8 weeks to permit adequate time for the organisms to colonize the trays. The colonized trays were then transported to the test location and placed in the artificial streams. Control water was passed through the artificial streams for 5 days prior to introduction of effluents to allow the organisms time to acclimate to the artificial streams.

After the first test in November - December, 1975, an alternative method of colonizing the benthic macroinvertebrates was used since the previous method proved to be too cumbersome and the colonized trays did not appear to be homogeneous. Therefore, an alternative sampler, called Hester-Dendy artificial substrate sampler, was selected.

Hester-Dendy artificial substrate samplers were constructed from 76 cm squares of masonite separated by 25 cm squares on an eyebolt (7, 8). A set of 126 samplers were placed in an unpolluted natural stream and colonized by benthic macroinvertebrates for 6 weeks (9). After colonization, six Hester-Dendy samplers were collected for determining initial species diversity, number of taxa, and mean density of benthic organisms. The remaining 120 samplers were transported to artificial streams located near the wastewater outfall of a petroleum refinery. Samplers were transferred within three h in 2-quart polyethylene containers. Fifteen samplers were placed in each of eight artificial streams, 3.6 m long by 0.3 m wide with water 22.8 cm deep.

Two streams each were exposed to control dechlorinated tap water, activated sludge treated, sequential activated sludge-dual-media filtered BPTCT and sequential activated sludge-dual-media-activated carbon treated BATEA oil refinery wastewater.

Three Hester-Dendy samplers were collected from each stream after 2, 4, 8, 16, and either 30 or 32 days of exposure. Organisms were washed from the samplers and those retained by a 30 mesh sieve were preserved in 10% formalin within 24 h after collection. The organisms were subsequently sorted from the debris and identified to the lowest taxa possible.

A pooled species diversity value ($\bar{d}$) was calculated for the organisms identified on the three samplers collected from each treatment stream by the following formula (10):

$$\bar{d} = -\sum_{i=1}^{s} n_i/n \ \log_2 \ n_i/n$$

where, n_i = number of individuals in the $\underline{i}$th taxon.

n = total number of individuals in the collection.

s = total taxa.

A mean pooled $\bar{d}$ and standard deviation was calculated from the pooled $\bar{d}$ of the two replicate streams for each treatment. Total number of taxa identified from the six Hester-Dendy samplers from the two replicate treatment streams were recorded. Mean density was calculated by dividing the total number of individuals per sampler by the area (0.144 m^2).

Sources of Benthic Macroinvertebrates

Test 1 - Refinery A.

Benthic macroinvertebrate colonies for the first test were obtained by placing polyethylene trays (3" x 9" x 12") containing 2 to 3 inch diameter rocks in a natural stream for 6 weeks. Chemical analyses of the stream indicated that it was good quality water. However, during the 6-week colonization period, the stream stopped flowing due to a lack of rainfall and subsequent surface water runoff. The samplers had been installed in a pool in the stream and remained submerged, however, the standing water conditions and hot weather in the pool were not conducive to development of a diverse population of benthic organisms on the samplers.

Test 2 - Refinery B.

The artificial substrate for colonizing the benthic macroinvertebrates was changed from the rocks in polyethylene trays to stacks of 3 in^2 of masonite spaced on an eyebolt (Hester-Dendy Samplers) for all of the latter exposures. This sampler was much easier to transport and provided sufficient numbers of taxa and individuals to obtain a good measure of the diversity of the benthic population.

The Hester-Dendy samplers were installed in a small creek east of Stillwater, Oklahoma (NW 1/4 of Section 29 - R5E - T20N).

Test 3 - Refinery C.

Hester-Dendy samplers were installed in a small creek below an earth-fill dam for six-weeks colonization. There was almost no current in the creek, therefore most of the organisms were characteristic of low velocity pool-type habitat.

Description of Refinery Wastewater Treatment Systems.

Refinery A. The first refinery evaluated was a class B refinery which processed about 50,000 barrels of crude oil per day. The wastewater treatment system consisted of an API gravity oil separator, activated sludge, sludge clarifier, and polishing lagoons. The biological evaluation was performed on the effluent from the activated sludge clarifier.

Refinery B. A class D refinery processing about 88,000 barrels of crude oil per day. The wastewater treatment system consisted of an API gravity oil separator, a dissolved air floatation unit, an activated sludge unit and a final sludge clarifier. The biological evaluation was performed on the final clarifier effluent.

Refinery C. A class D refinery processing about 120,000 barrels of crude oil per day. The wastewater treatment system consisted of API gravity separators, a small bio-oxidation treatment plant for highly concentrated hydrocarbon process effluents, followed by polishing lagoons for the combined plant wastewaters. The biological evaluation was performed on the final effluent from the polishing lagoons.

Refinery personnel at all locations assisted in recording of fish mortality and feeding of the fish. They were very cooperative and helpful, sometimes telephoning to inform us if mechanical problems developed with pumps or other apparatus.

Results and Conclusions

A thirty-day test was conducted at Refinery A from November 4 to December 4, 1975. The results of the continuous-flow fish bioassay tests show that no mortality occurred in the first six days of the exposure (Figure 5). These results indicate that in the normal 96-hour bioassay test, the response of the fish would not be sensitive enough to perform an evaluation of the waste treatment methods. After thirty-days exposure to the test effluents, there was 70% mortality in the activated sludge effluent, 20% in the combination activated sludge-dual-media filter effluent, and 15% in the combined activated sludge-dual-media activated carbon effluent. Thus on the basis of fish mortality, the additional treatment by dual-media filters or activated carbon improved the quality of the effluent.

Abnormal mortality occurred in one of the duplicate aquaria exposed to the effluent from the combined activated sludge-dual-media-activated carbon. All ten fish died on the second day of exposure to this effluent, however no fish died in the other duplicate tank. The dead fish were removed and replaced with ten new fish. Only two fish died in the remaining 28 days of exposure. It was decided to disregard this abnormal mortality when calculating the total mortality. A possible explanation for the abnormal mortality was that large quantities of fine carbon particles were washed from the carbon columns when water was initially passed through. This fine carbon could have an abrasive effect upon fish gills, causing physical damage and subsequent mortality. Another possible explanation was that the activated carbon adsorbed all of the dissolved oxygen from the water since the unwetted virgin carbon has a high surface activity when first wetted.

It was observed that from one-half to one inch of sludge accumulated in the bottom of the fish bioassay tanks receiving the activated sludge effluent. No sludge accumulated in the tanks receiving dual-media or activated carbon effluent. Fathead minnows normally rest on the bottom of the tanks, thus the presence of sludge on the bottom of the tanks which may have caused a deleterious stress to the test fish. In future tests, the accumulated sludge will be siphoned out of the test tanks to prevent possible physical effects upon the test fish. Wild fish in a receiving stream could move away from areas in a stream where sludge accumulated on the bottom and thus would probably not be subjected to acute effects. Dissolved chemical constituents, however, would bathe the fish continuously unless it could escape by moving up or downstream to clean water. Thus it appears that the major objective should be to measure the effects of dissolved chemical poisons in the effluents.

A typical representative sample of the chemical data collected by the ion probe-data logging system shows that conductivity was the parameter which varied the most (Table 1). The control stream had a mean conductivity of 5,924 micromhos, during this period, as contrasted against 4,980; 3,512; and 2,049 micromhos for the activated sludge, dual-media, and activated carbon effluent streams, respectively. It would

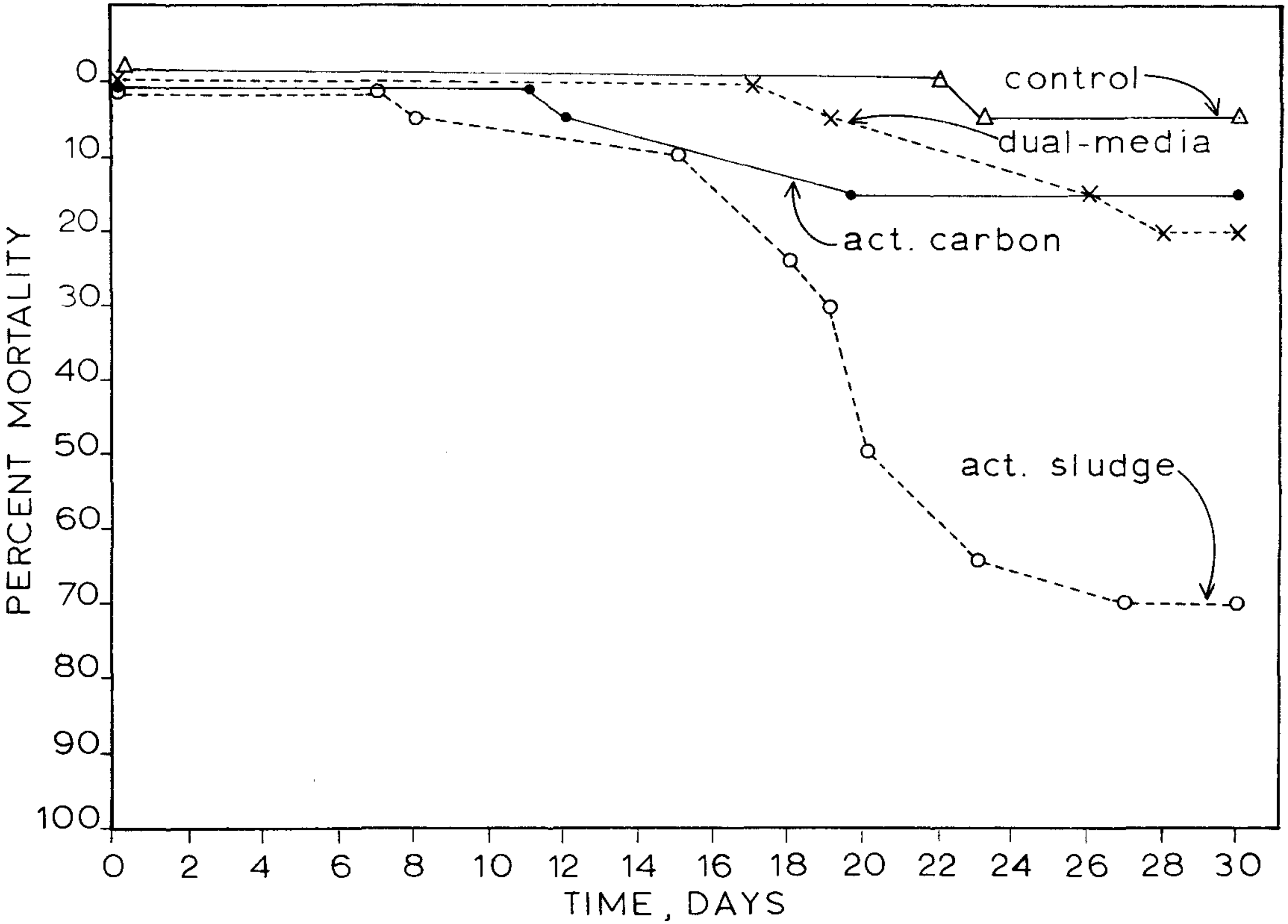


Fig. . Percent mortality of Fathead minnows exposed to oil refinery A effluent treated by activated sludge, plus dual-media filtration, plus adsorption on activated carbon.

appear that the dual-media and activated carbon units removed considerable concentrations of ionic materials.

There was a slight decrease in pH as the activated sludge stream was passed through the dual-media and activated carbon columns. The pH in the control stream was high, but it did not vary, so there was probably no effect upon the biological test organisms. The dissolved oxygen in all four streams was low, generally 2 mg/l or less, which necessitated the aeration of the fish bioassay tanks. No measurable concentrations of sulfide could be detected with the ion probe.

Analyses of species diversity values of benthic invertebrate organisms exposed to the treatment streams were used to evaluate the effectiveness of the systems. Four of the samples were collected from the natural stream, Peavine Creek, the day that the remainder were transported to the oil refinery for placement in the artificial streams. This sample of four was collected to determine the average starting diversity index prior to exposure to the test effluent streams. The starting mean diversity index of 2.75 (Table 2) is indicative of the adverse physical conditions which existed in the creek. Very little rainfall occurred in August, September, and October, as a result the creek, which had good flow when the trays of rocks were placed in it for colonization, dried-up into small pools. When the flow stopped, most of the samplers were still submerged in a pool, however some samplers had to be discarded. Water quality in the pool was affected by dead leaves and other debris in the standing pool.

The species diversity indices of the benthic macroinvertebrates exposed to the test effluent streams did not show any significant changes during the 30-day exposure (Figure 6). In this first exposure, since

Table 1. Chemical parameters of effluent streams measured by chemical ion probe-data logger.

November 21, 1975

Effluent Stream	Time Span	No. Scans	Temp. °C	Conductivity micromhos	Dissolved Oxygen mg/1	pH
Act. Sludge	15:40-15:46	4	14.0	4,559	1.9	7.5
Dual Media	15:52-15:58	4	15.2	3,504	2.2	7.0
Act. Carbon	16:08-16:14	4	17.3	2,180	2.2	7.0
Control	16:22-16:28	4	13.3	5,683	1.2	8.2
Act. Sludge	16:36-16:46	6	13.7	5,010	1.7	7.7
Dual Media	16:52-17:00	5	15.4	3,394	2.2	6.9
Act. Carbon	17:06-17:16	6	17.0	2,029	2.2	7.0
Control	17:22-17:30	5	12.8	5,853	1.1	8.3
Act. Sludge	17:36-17:46	4	13.2	5,342	1.6	7.8
Dual Media	17:52-18:00	5	15.1	3,495	2.2	7.0
Act. Carbon	18:06-18:16	6	16.9	1,939	2.3	7.0
Control	18:24-18:30	4	11.9	6,235	1.0	8.4
Act. Sludge	18:38-18:46	5	12.7	5,010	1.9	7.7
Dual Media	18:52-19:00	5	13.3	3,655	2.2	7.0

Table 2. *Species Diversity of Benthic Macroinvertebrates Exposed to an Oil Refinery Effluent Treated by Activated Sludge, BPTCT, and BATCT.

	Dates - 1975				
	10/27	11/6	11/3	11/21	12/5
Control	3.36	2.74	2.64	3.18	2.71
Activated Sludge	-	2.69	3.07	2.27	3.08
BPTCT**	-	2.98	2.89	2.80	3.43
BATCT***	-	3.36	2.49	2.74	3.60

*Each number is the species diversity index of 4 pooled samples.

**BPTCT = Sequential Activated Sludge and Dual Media filtration treatment.

***BATCT = Sequential Activated Sludge, Dual Media filtration, and Activated Carbon adsorption treatment.

no other investigators had measured a change with time in diversity of benthic organisms exposed to an industrial effluent, it was not known how long an exposure must be before a response could be anticipated.

The results of this exposure were influenced by mechancial pumping difficulties in maintaining continuous-flow of the treatment effluents through the test aquaria and artificial streams. The response of the benthic macroinvertebrates as measured by the species diversity index ($\bar{d}$) showed that the control stream had the lowest diversity and the BATEA stream had the highest at the end of the thirty-day exposure. The control stream was tap water from Lake Arbuckle. The control water was transported to the test site in the 5,000-gallon tank truck. Apparently, the control water became anaerobic sitting in the tank truck and possibly caused a deleterious effect upon the benthic macroinvertebrates, even though a paddlewheel stirrer was maintaining current in the artificial streams.

The results of this first test were not very conclusive, due to mechanical problems and possibly a non-homogeneous set of benthic macroinvertebrate samplers. However, it was implemental in identifying various problems which could be corrected prior to the next exposure.

Evaluation at Refinery B, Spring, 1976

A thirty-day exposure was conducted at Refinery B during April 7 to May 7, 1976. The results of the continuous-flow fish bioassay tests showed that activated sludge and sequential activated sludge-dual media treatments were not adequate to degrade acutely toxic substances (Table 3).

Table 3. Fathead Minnow Bioassay of Oil Refinery Wastewater Treatment Methods

Treatment	Cumulative 30-Day, Percent Mortality
Control	0%
Activated Sludge	100%
Activated Sludge-Dual Media	100%
Activated Sludge-Dual Media-Activated Carbon	65%

The degree of difference in toxicity of the different treatment effluents was even greater than the cumulative percentage mortality indicated, since there was 100% mortality of the test fish in the activated sludge and BPTCT effluents within 24 hours, whereas no mortality occurred in the BATCT effluent until the 16th day of exposure when 65% mortality of the test fish occurred. Since most of the fish mortality in the BATCT effluent occurred in a short interval of time, it was suspected that the activated carbon had been exhausted, allowing some toxic organics to pass through unabsorbed. However, the Total Organic Carbon concentration of the effluent from BATCT showed only 7.3 mg/l concentration (Table 5). The activated carbon was renewed and no additional fish mortality occurred.

The results of the Benthic Macroinvertebrate (BM) bioassay of the treatment methods showed that after eight days of exposure, the species diversity index ($\bar{d}$) of the activated sludge treated effluent was 1.5 and that of BPTCT - 1.8, contrasted with a $\bar{d}$ of 3.0 and 2.9 for the control and BATCT respectively.

The $\bar{d}$ of BM samplers exposed to the treatment effluents was not significantly different on the 16th day of exposure (Figure 6). However, $\bar{d}$ of BM samplers exposed to the activated sludge treated effluent was 0.4 by the 30th day of exposure, compared to $\bar{d}$ of 1.9, 2.1, and 2.2 for BPTCT, BATCT, and control streams. The species diversity index was not a good measure of the effects of the effluent streams upon the BM samplers. A plot of total species identified in the combined triplicated samples from each of the treatment streams indicates that there was a significant reduction in species in the activated sludge and BPTCT effluents compared to the total number of species in the BATCT and control streams (Figure 7). Similarly, a plot of the mean density (numbers of individuals/meter^2) of the BM samplers shows a significant difference in the effects of activated sludge and BPTCT compared to the control stream (Figure 8). There was no decrease in mean density of BM's exposed to the BATCT effluent stream, however, the mean density of BM's in the control stream increased nearly 100% during the exposure to 770 individuals/M^2 as contrasted to 400 individuals/M^2 for the BATCT stream. The results of the periphyton growth and species diversity evaluations of the different treatment streams showed that the chlorophyll *a* concentration was lowest in the BATCT stream (Table 4). Chlorophyll *a* concentration is used as an index of algae growth and the health and age of the algae. Pheaphyton *a* is the intermediate breakdown produce of chlorophyll *a* and a high percentage of pheaphyton *a* concentration in relation to the concentration of chlorophyll *a* indicates that the algae community

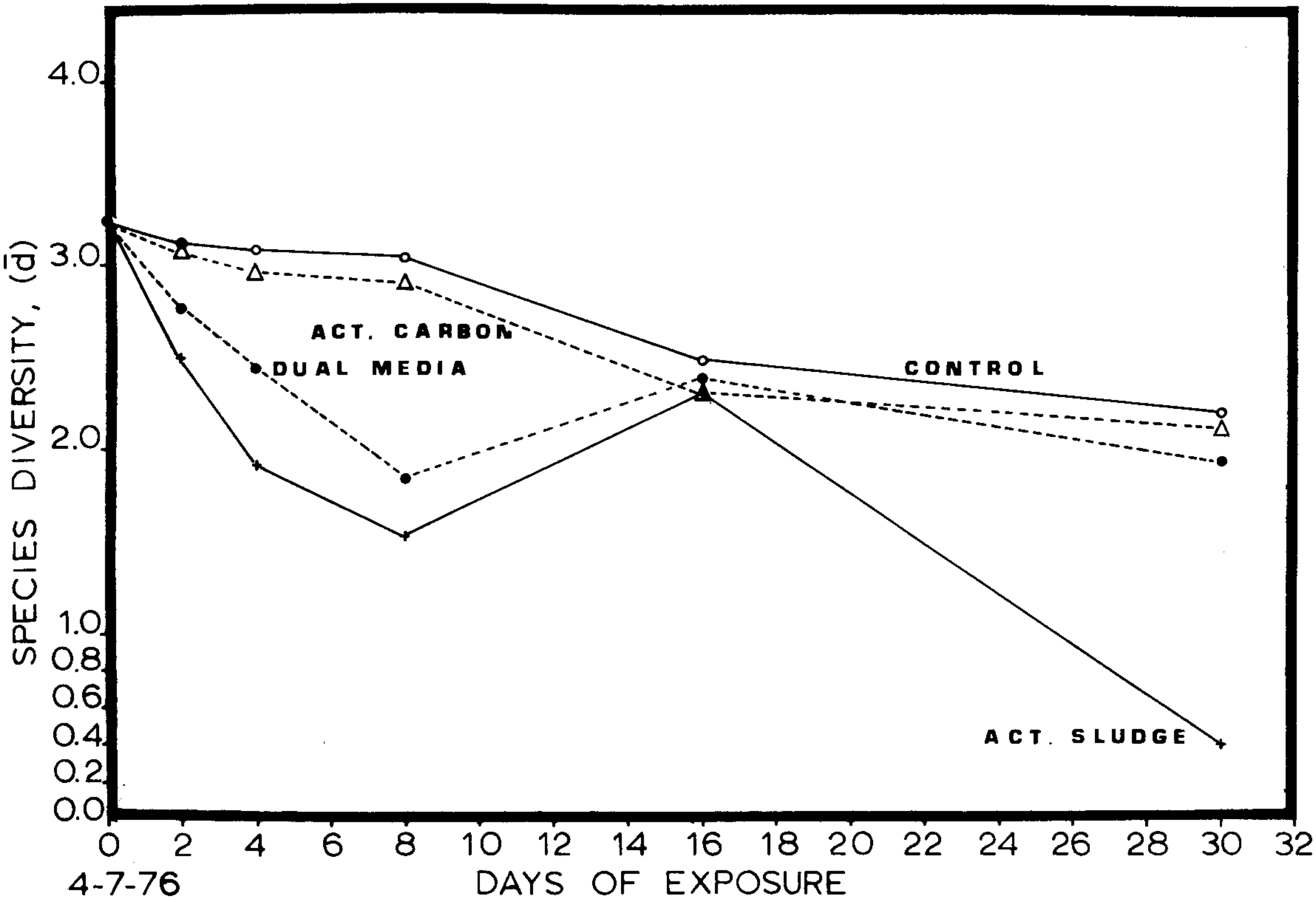


Figure 6. Species diversity of benthic macroinvertebrates exposed to oil refinery B wastewaters treated by activated sludge, BPTCT, and BATEA.

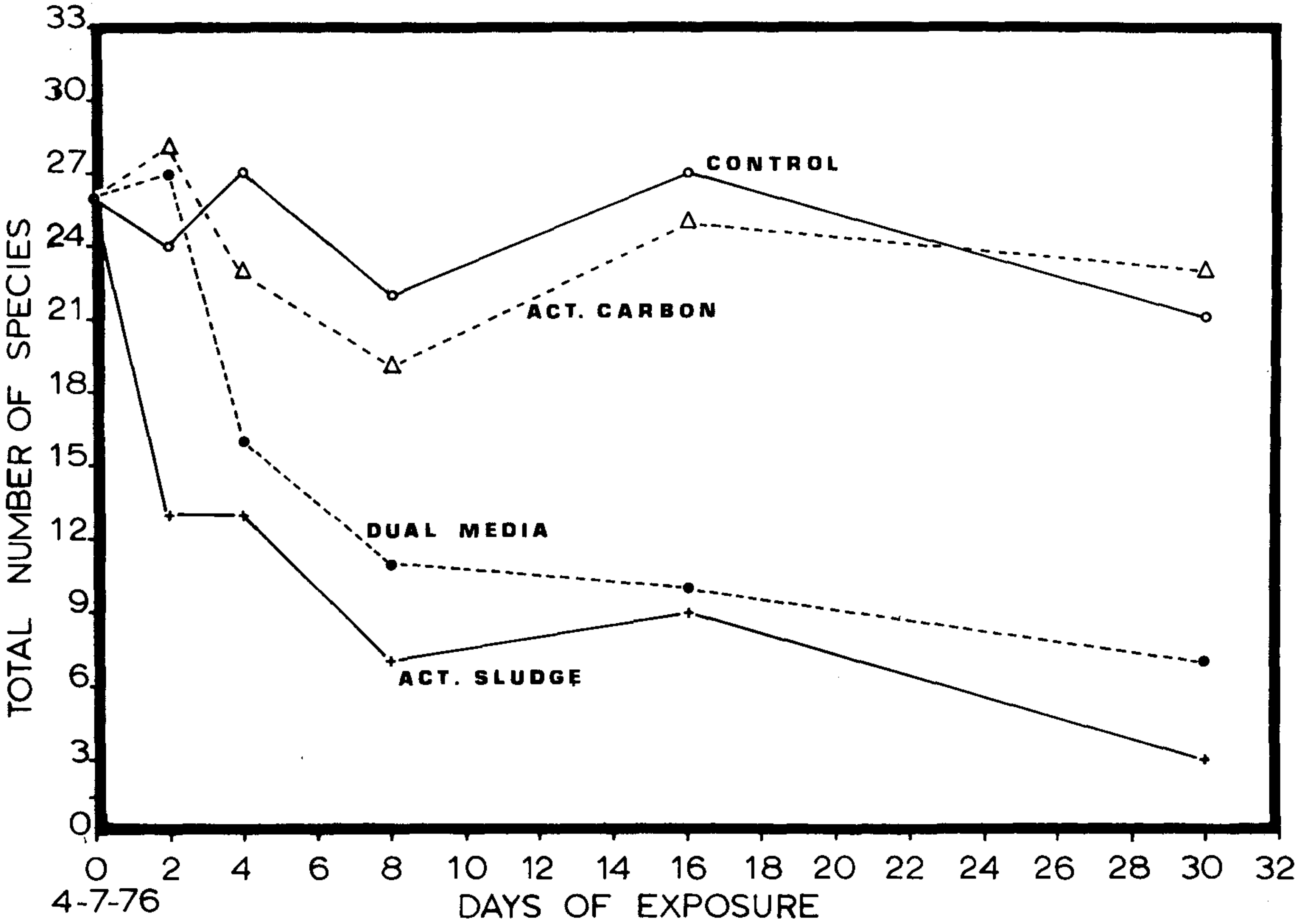


Figure 7. Total number of species of benthic macroinvertebrates exposed to oil refinery B wastewaters treated by activated sludge, BPTCT, and BATEA.

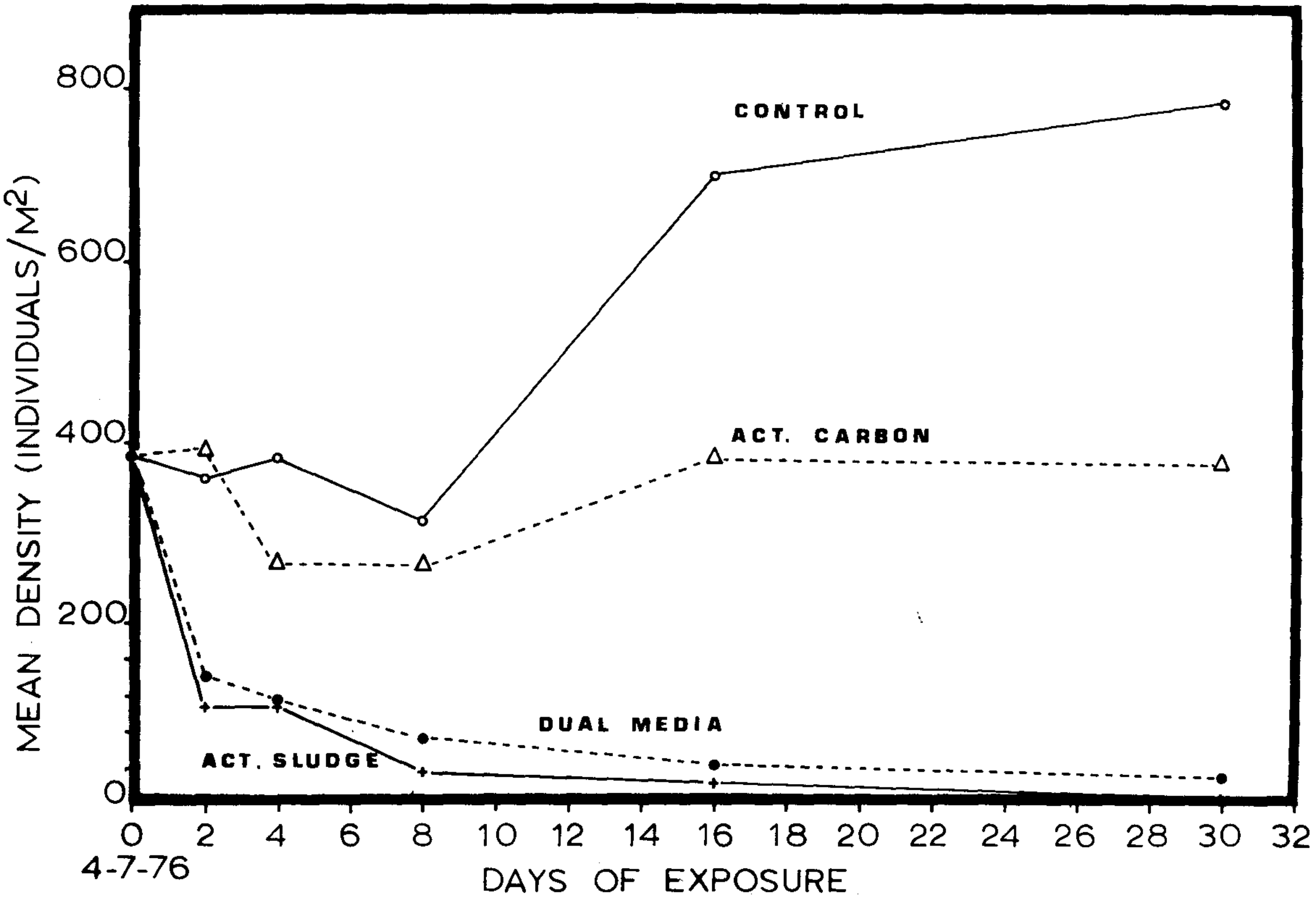


Figure 8. Mean density of benthic macroinvertebrates exposed to oil refinery B wastewaters treated by activated sludge, BPTCT, and BATEA.

Table 4. Response of Periphyton to Different Levels of Treatment of an Oil Refinery Effluent.

	CONTROL	ACT. SLUDGE	BPTCT	BATCT
Chlorophyll a	18.2 mg/m^2	129.2 mg/m^2	76.1 mg/m^2	3.2 mg/m^2
Pheaphyton a	1.9 mg/m^2	80.9 mg/m^2	27.3 mg/m^2	0.0 mg/m^2
*Production Stream-1	0.25 g/m^2/day	0.56 g/m^2/day	0.29 g/m^2/day	0.02 g/m^2/day
Stream-2	0.05 g/m^2/day	0.85 g/m^2/day	0.63 g/m^2/day	0.02 g/m^2/day
Species Diversity	1.40	1.15	1.86	2.48
Number of Species	7.50	5.80	6.20	11.30

* Productivity estimates based upon dry weights of algae. The rate of production was calculated as an instantaneous rate of change from dry weight data collected at 4, 8, 16, 24, and 32 days.

is in a senescent or declining stage of growth. The pheaphyton a concentration in the activated sludge and BPTCT streams was 62% and 35% respectively of the chlorophyll a concentration, indicating that the algal populations in these two streams were in a senescent stage of growth. The rate of production was highest in the activated sludge and BPTCT streams (Table 4) and lowest in the BATCT stream.

The results of the chemical analyses performed on the effluent streams correlate with and support the biological data (Table 5). The biological data clearly indicated that the activated sludge and BPTCT were the most deleterious to the aquatic organisms. The TOC and ammonia concentrations were most likely the parameters which would cause deleterious effects upon the aquatic organisms. However, the ammonia concentration was not significantly different in the BATCT effluent (mean of 14.6 mg/l) from that of the activated sludge (mean = 15.6 mg/l) or BPTCT (mean = 17.6 mg/l) effluent streams. Therefore, it appears that the ammonia concentration was not causing a significant acute effect upon either the fish or the benthic macroinvertebrates. The data indicates that TOC concentration showed the highest correlation with toxicity of the effluent streams. The activated sludge and BPTCT effluent streams contained a mean TOC concentration of 64.5 mg/l and 67.5 mg/l respectively as contrasted against the TOC concentration in the control and BATCT effluent streams of 3.7 mg/l and 6.8 mg/l respectively (Table 5). The test aquaria and streams were maintained at a high dissolved oxygen concentration by aerating the aquaria and by the action of the paddle-wheels in the artificial streams (Table 6). Therefore, no mortality could have been caused by low dissolved oxygen concentrations. Temperature in the test containers could not be controlled and thus fluctuated with

Table 5. Chemical Analyses of Treatment Effluent Streams at ETU.

Parameter	Treatment Stream	4/7/76	4/9/76	4/11/76	4/15/76	4/23/76	4/29/76	5/7/76	$\bar{x}$	SD
Alkalinity mg/l (Total)	CONTROL	37.	-	-	-	-	-	82.		
	ACT. SLUDGE	94.	-	-	-	-	-	296.		
	BPTCT	81.	-	-	-	-	-	259.		
	BATCT	107.	-	-	-	-	-	87.		
Hardness mg/l	CONTROL	81.6	-	-	-	-	-	91.1		
	ACT. SLUDGE	190.8	-	-	-	-	-	146.5		
	BPTCT	193.8	-	-	-	-	-	146.5		
	BATCT	138.7	-	-	-	-	-	217.8		
NH_3 mg/l	CONTROL	.3	.2	0	.06	0	0	0	0.08	0.1
	ACT. SLUDGE	8.4	21.7	30.9	25.30	1.9	10.6	10.6	15.60	10.4
	BPTCT	9.4	23.3	35.0	26.10	5.7	8.6	15.5	17.60	10.8
	BATCT	16.2	16.9	19.7	14.70	15.0	13.1	6.9	14.6	4.0
TOC	CONTROL	6.6	6.7	3.6	< 1.0	3.9	3.0	2.3	3.7	2.4
	ACT. SLUDGE	79.0	91.2	62.1	43.3	55.7	46.0	74.3	64.5	17.8
	BPTCT	62.2	83.1	57.2	46.2	58.1	97.5	68.3	67.5	17.4
	BATCT	8.5	2.6	6.9	6.0	*7.3 **5.0	10.5	5.6	6.8	2.5
COD mg/l	CONTROL	76.1	-	-	-	-	-	7.6		
	ACT. SLUDGE	296.4	-	-	-	-	-	296.4		
	BPTCT	242.3	-	-	-	-	-	208.4		
	BATCT	48.1	-	-	-	-	-	22.9		
SUS. SOLIDS mg/l	CONTROL	2.4	3.7	-	-	-	-	2.6		
	ACT. SLUDGE	57.1	16.0	-	-	-	-	165.8		
	BPTCT	35.3	18.0	-	-	-	-	5.2		
	BATCT	11.2	8.0	-	-	-	-	22.5		

* TOC concentration of effluent from activated carbon columns prior to renewing activated carbon

** TOC concentration of BATCT effluent after renewing the activated carbon

Table 6. Dissolved Oxygen Concentration in Test Aquaria & Artificial Streams.

			4/23/76	5/3/76	5/5/76
D.O. mg/l	AF-1	Control Aquaria	6.0	7.1	6.2
	AF-2		5.8	7.7	6.3
	BF-1	Act. Sludge Aq.	.4	3.3	2.3
	BF-2		2.4	7.4	6.3
	CF-1	BPTCT Aquaria	5.2	5.4	4.6
	CF-2		6.1	8.0	6.8
	DF-1	BATCT Aquaria	4.9	8.1	7.5
	DF-2		6.5	8.4	7.6
	AM-1	Control Stream	7.8	8.8	8.5
	AM-2		8.3	9.3	8.5
	BM-1	Act. Sludge Stream	7.3	9.0	8.0
	BM-2		5.9	9.9	8.2
	CM-1	BPTCT Stream	7.6	9.7	8.6
	CM-2		8.6	9.9	8.7
	DM-1	BATCT Stream	7.5	9.2	8.4
	DM-2		7.2	9.0	8.3

TABLE 7.

Temperature °C	AF-1	Control Aquaria	23.9	14.3	20.0
	AF-2		23.0	14.0	20.0
	BF-1	Act. Sludge Aquaria	23.5	15.5	21.0
	BF-2		22.5	14.0	19.5
	CF-1	BPTCT Aquaria	23.9	16.5	20.8
	CF-2		23.0	14.0	19.0
	DF-1	BATCT Aquaria	23.0	15.0	20.0
	DF-2		23.1	15.0	20.0
	AM-1	Control Streams	25.0	14.5	18.0
	AM-2		25.0	14.5	18.8
	BM-1	Act. Sludge Streams	25.0	14.0	17.5
	BM-2		25.0	13.3	17.5
	CM-1	BPTCT	25.0	13.9	17.3
	CM-2		25.0	13.5	17.3
	DM-1	BATCT Streams	25.0	13.5	17.3
	DM-2		25.0	14.3	17.5

the ambient air temperature (Table 7).

A single grab sample was collected from each treatment stream at the start and end of the exposure period. Heavy metal analyses of the sample collected at the start of the exposure period have been completed (Table 8). Zinc and Chromium were the only two toxic metals which were found in high enough concentrations to potentially have a deleterious effect. The activated carbon appears to reduce the concentration of divalent and trivalent cations and thus could improve water quality.

TABLE 8. ATOMIC ABSORPTION SPECTROPHOTOMETRIC ANALYSIS OF TREATMENT STREAMS AT REFINERY B
APRIL 7, 1976

4/7/76

	Na (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	Fe (ppm)	Pb (mg/l) cs*	Zn (ppm)	Cu (ppm)	Cr (mg/l) cs*	Ni (ppm)	Cl (ppm)	Cd (mg/l) cs*
A-CONTROL												
Suspended	.28	< 1.0	<1.0	1.09	.41	<.01	.11	<.04	.036	<.1		.003
Dissolved	3.66	27.31	4.47	1.51	<.04	<.01	.07	<.04	<.02	<.1		.001
B-EFFLUENT												
Suspended	1.26	< 1.0	<1.0	1.23	.73	.02	.64	<.04	.167	<.1		.003
Dissolved	330.00	47.37	6.48	20.01	.73	<.01	.60	<.04	.376	<.1		.007
C-SANDCOAL FILTERS												
Suspended	1.33	< 1.0	<1.0	1.23	1.04	.01	1.41	<.04	.126	<.1		.003
Dissolved	350.00	47.37	7.82	20.01	.73	<.01	.51	<.04	.070	<.1		.005
D-CARBON COL. #4												
Suspended	1.12	< 1.0	<1.0	1.23	.41	.02	.21	<.04	.064	<.1		.005
Dissolved	320.00	35.45	5.81	20.01	.10	.03	.26	<.04	<.02	<.1		.005

*Corrected for Matrix Interference by Standard Addition Method: $CS = \frac{A_s \times C_{std}}{A_{std} - A_s}$

(Table 8 cont.)

ATOMIC ABSORPTION SPECTROPHOTOMETRIC ANALYSIS OF REFINERY B - SPRING, 1976

MAY 7, 1976 5/7/76

	Na (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	Fe (ppm)	Pb (mg/l) cs*	Zn (ppm)	Cu (ppm)	Cr (mg/l) cs*	Ni (ppm)	Cl (ppm)	Cd (mg/l) cs*
A-CONTROLL												
Suspended	< 1.0	< 1.0	< 1.0	< 1.0	.46	< .01	.11	< .04	.037	<.1		.003
Dissolved	3.8	34.0	2.81	2.0	.34	.03	.04	< .04	.020	<.1		<.001
B-EFFLUENT												
Suspended	< 1.0	< 1.0	< 1.0	1.29	.58	.02	.35	< .04	.184	<.1		.004
Dissolved	170.0	26.53	5.35	18.52	1.39	.02	.80	< .04	.692	<.1		.027
C-SANDCOAL FILTER												
Suspended	< 1.0	< 1.0	< 1.0	< 1.0	.46	.01	.14	< .04	.041	<.1		.003
Dissolved	180.0	26.53	4.99	18.52	.76	.01	.14	< .04	.037	<.1		.002
D-CARBON COL.												
Suspended	< 1.0	< 1.0	< 1.0	< 1.0	.46	.01	.08	< .04	.041	<.1		.011
Dissolved	130.0	36.5	13.71	19.23	.46	< .01	.18	< .04	.004	<.1		.003

* Corrected for Matrix Interference by Standard Addition Method $CS = \frac{A_s \times C_{std}}{A_{std} - A_s}$

A second 32-day evaluation of the treatment methods at Refinery B was started June 4, 1976, and completed July 6, 1976. The results of the continuous-flow fathead minnow bioassays showed that within 96 hours there was 100% mortality in both the activated sludge and BPTCT effluent streams (Table 9). There was no mortality observed in the control or BATCT effluent streams during the 32-day exposure. Dual-media filtration after the activated sludge treatment appeared to have no effect upon reducing the acute toxicity of the effluent.

Table 9.

Fathead Minnow Bioassay of Different Treatment
Effluent Streams, June 4 to July 6, 1976

Treatment	*LT50	Cumulative 32-Day Percent Mortality
Control	Not Applicable	0%
Act. Sludge	11.5 hours	100%
BPTCT	22.5 hours	100%
BATCT	Not Applicable	0%

*LT50 = Estimated time of exposure to kill 50% of test fish.

The activated carbon treatment however, improved water quality significantly, based upon the response of the fathead minnows to the effluent streams. Visual observations of the physical conditions of the fish at the end of the 32-days exposure indicated that the fish exposed to the BATCT effluent showed no visible external signs of deleterious effects.

The results of the Benthic Macroinvertebrate (BM) bioassays clearly indicate that the effects of the activated sludge and BPTCT effluent streams were more deleterious to species diversity ($\bar{d}$) than that of the BATCT or control (Figure 9). The effects were even more obvious if

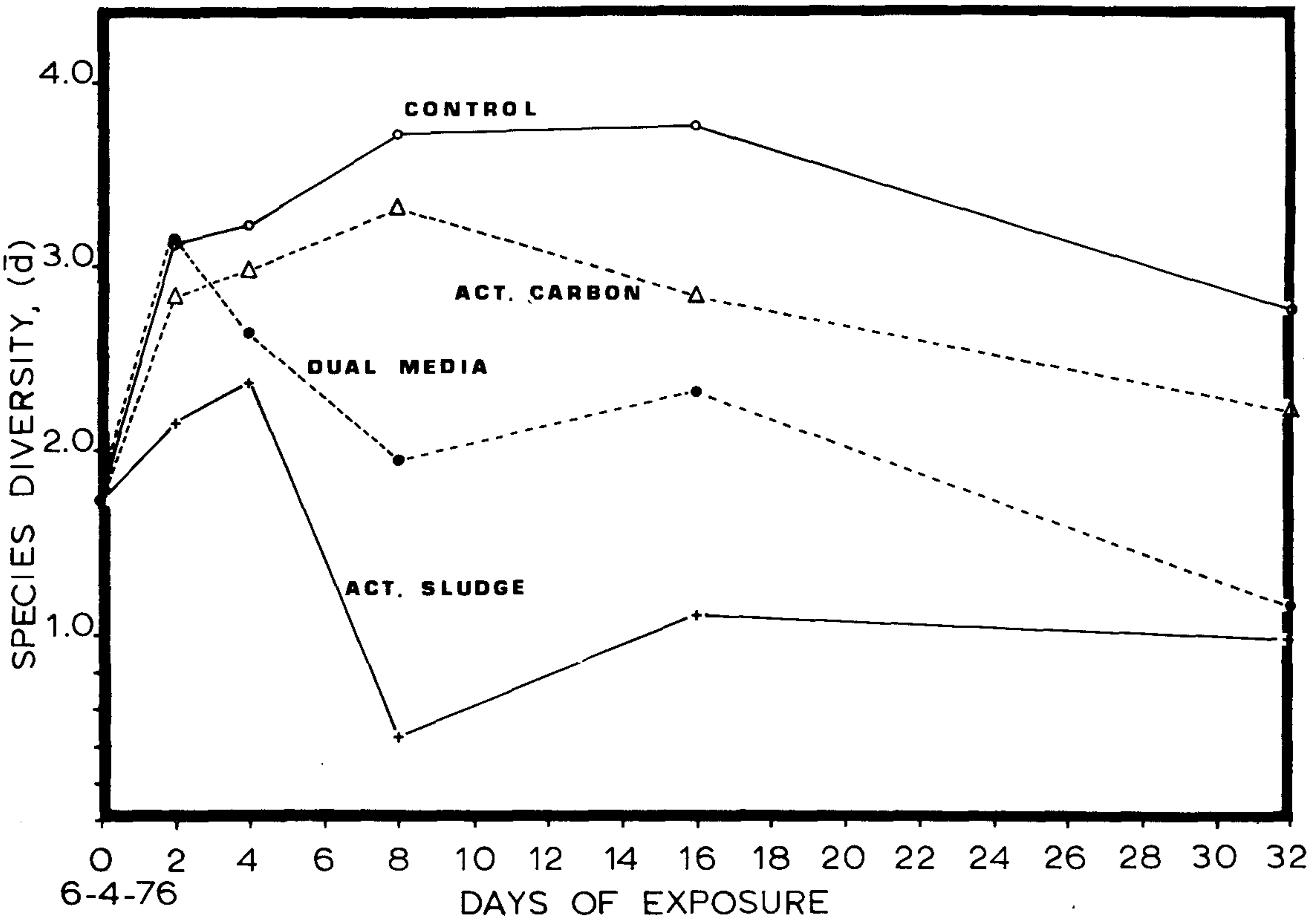


Figure 9. Effectiveness of activated sludge, BPTCT, and BATEA wastewater treatment methods at Refinery B as measured by changes in species diversity of benthic macroinvertebrates, June 4 to July 6, 1976.

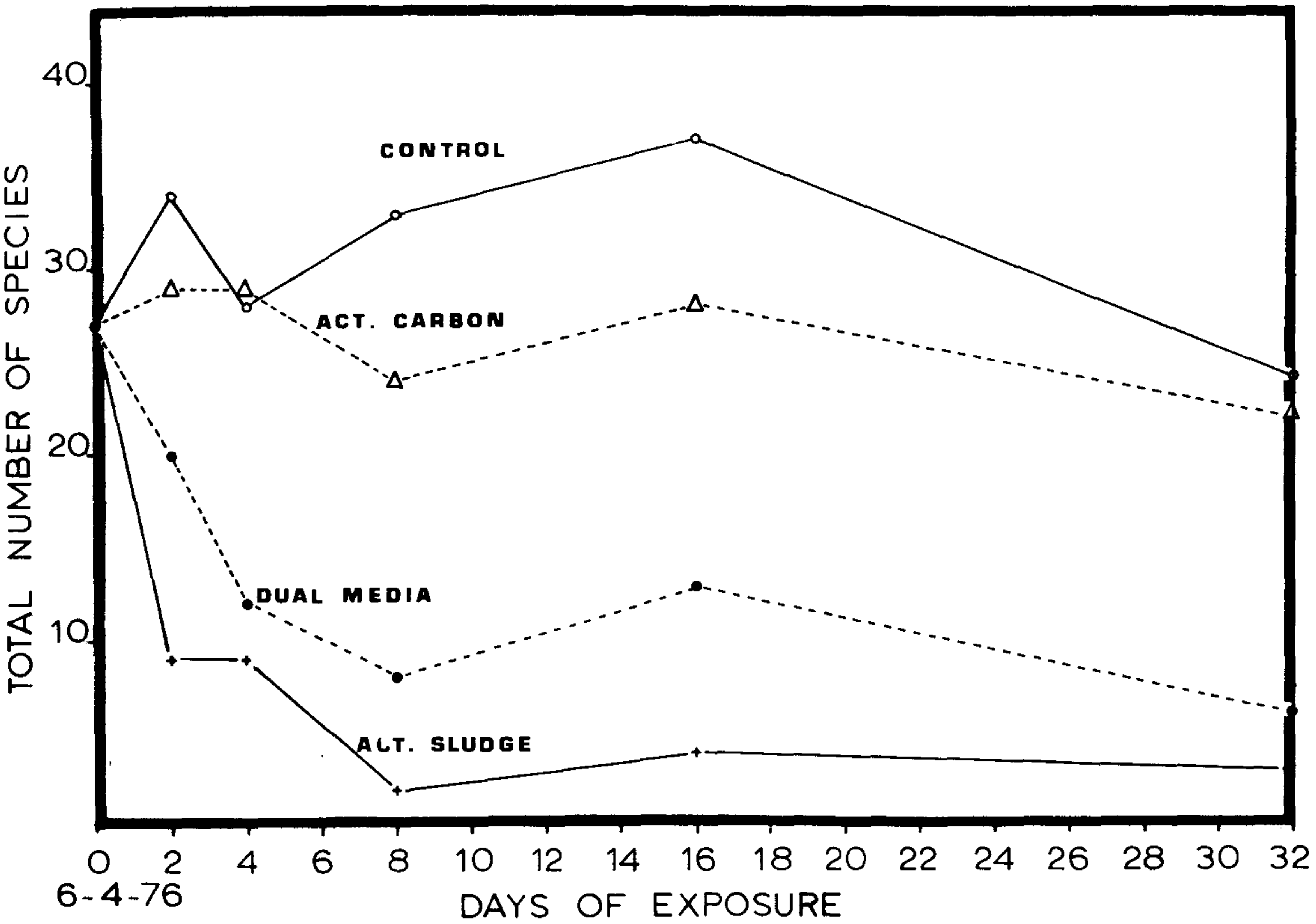


Figure 10. Effectiveness of activated sludge, BPTCT, and BATEA wastewater treatment methods at Refinery B as measured by changes in number of species of benthic macroinvertebrates, June 4 to July 6, 1976.

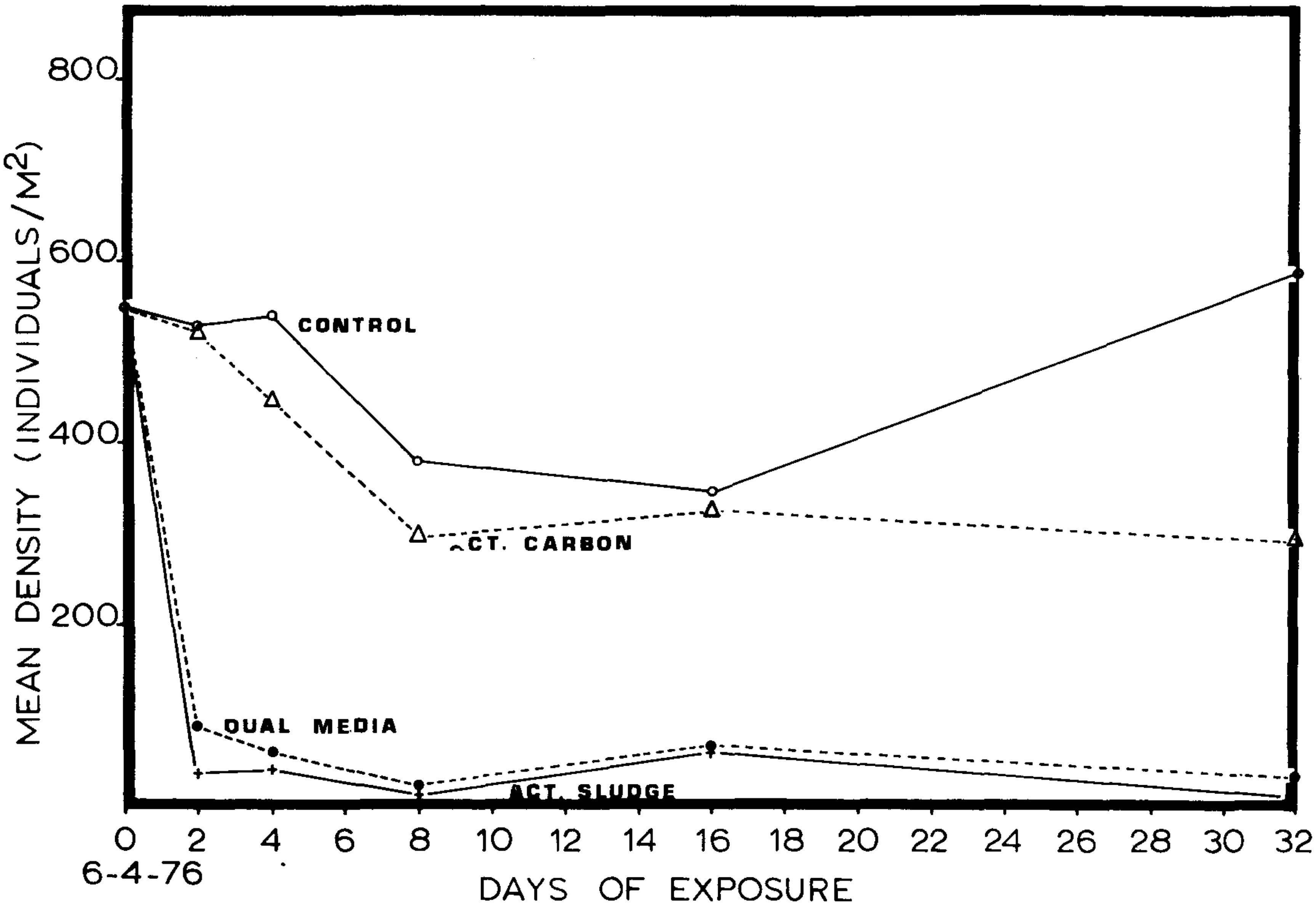


Figure 11. Effectiveness of activated sludge, BPTCT, and BATEA wastewater treatment methods at Refinery B as measured by changes in mean density of benthic macroinvertebrates, June 4 to July 6, 1976.

the total number of species (Figure 10) and mean density of individuals (Figure 11) were plotted versus time of exposure. The overall effects of the activated sludge and BPTCT effluent streams were to reduce the density of individuals and total number of species of BM's on the colonized samplers. Since some aquatic insects are more sensitive to chemical poisons than others, there was in general a decline in numbers of the sensitive species. This decline in numbers or disappearance of some species of aquatic invertebrates was generally reflected by a decrease in species diversity index ($\bar{d}$), however if all the species were equally affected by the chemical poisons, then $\bar{d}$ did not reflect the effects, since $\bar{d}$ is a measure of the equity of distribution of individuals among the species in the population sample. In these cases, the mean density of individuals and total number of species appeared to give a better measure of the effects than $\bar{d}$.

The results of chemical analyses of the treatment effluent streams showed that BATCT improved water quality by reducing the COD to an average of 24.3 mg/1, a 91% reduction, and TOC analyses showed a reduction of 86.8% (Table 10). BPTCT (dual-media filtration) reduced the suspended solids by 69% to 17 mg/1 and BATCT (dual-media plus activated carbon) reduced the suspended solids by 84% to a mean of 8.6 mg/1. The mean concentration of ammonia from the BATCT effluent stream was 15.3 mg/1 compared to 20.4 mg/1 for the activated sludge effluent stream, a reduction of 25%. Thus, the chemical data supports the biological data indicating that BATCT was an effective treatment method for this oil refinery wastewater.

Table 10. Chemical Analyses of Treatment Effluent Streams.

		Dates:								
Parameter	**Treatment Stream**	6/4/76	6/6/76	6/8/76	6/12/76	6/20/76	6/28/76	7/6/76	$\bar{x}$	SD
Alkalinity mg/l (Total)	A (Control)	89.0	-	-	-	-	-	90.0		
	B (Act. Sludge)	161.0	-	-	-	-	-	159.0		
	C (BPTCT)	178.0	-	-	-	-	-	155.0		
	D (BATCT)	117.1	-	-	-	-	-	122.0		
Hardness mg/l	A (Control)	151.3	-	-	-	-	-	126.5		
	B (Act. Sludge)	170.7	-	-	-	-	-	126.5		
	C (BPTCT)	147.4	-	-	-	-	-	106.1		
	D (BATCT)	147.4	-	-	-	-	-	114.2		
NH_3 mg/l	A (Control)	.3	.7	.3	.3	.2	-	.06	0.3	0.2
	B (Act. Sludge)	21.6	16.8	20.8	25.9	22.1	-	15.30	20.4	3.8
	C (BPTCT)	24.0	28.9	21.4	23.4	15.5	-	13.70	21.2	5.7
	D (BATCT)	21.1	14.9	18.4	15.7	13.4	-	8.10	15.3	4.4
TOC	A (Control)	11.4	4.3	7.5	4.8	3.9	10.9	5.30		
	B (Act. Sludge)	55.4	58.2	55.2	30.9	64.1	57.9	36.40		
	C (BPTCT)	55.4	61.2	52.2	31.1	20.7	28.5	34.70		
	D (BATCT)	*65.7	4.3	10.7	3.9	4.3	13.4	3.80		
		*(Sample Lost)								
COD mg/l	A (Control)	0	-	-	-	-	-	4.0		
	B (Act. Sludge)	233.1	-	-	-	-	-	296.8	264.90	45.0
	C (BPTCT)	177.5	-	-	-	-	-	175.3	176.40	1.5
	D (BATCT)	26.8	-	-	-	-	-	21.9	24.3	3.5
Sus. Solids mg/l	A (Control)	.1	.7	.5	1.4	1.7	.1	.5	0.7	0.6
	B (Act. Sludge)	11.1	68.0	51.0	26.0	93.3	77.2	55.5	54.6	28.6
	C (BPTCT)	26.2	33.5	10.2	11.2	14.4	7.8	16.1	17.0	9.4
	D (BATCT)	9.6	11.1	12.0	3.5	6.1	11.1	6.6	8.6	3.2

Table 11. Dissolved Oxygen Concentration in Test Aquaria & Artificial Streams Receiving Treatment Effluent.

Treatment	6/4/76	6/6/76	6/8/76	6/12/76	6/20/76
AF-1 Control	8.2	6.8	7.0	7.7	6.3
AF-2 Aquaria	8.0	6.8	7.1	7.8	7.0
BF-1 Act.Sludge	3.1	.5	2.9	4.7	.3
BF-2 Aquaria	5.3	.6	6.5	6.4	.7
CF-1 Dual/Media	5.4	.3	4.4	6.0	2.0
CF-2 Aquaria	5.7	.9	5.3	7.1	.5
DF-1 Act. C	7.8	3.5	5.6	4.4	5.4
DF-2 Aquaria	7.7	3.8	6.5	4.8	3.9
AM-1 Control	7.3	7.3	7.3	8.0	8.0
AM-2 Stream	7.1	7.4	7.1	8.1	8.4
BM-1 Act.Sludge	6.1	5.5	6.3	9.3	8.2
BM-2 Stream	5.3	4.3	5.7	9.1	9.6
CM-1 Dual/Media	5.9	5.6	6.6	9.2	9.0
CM-2 Stream	6.5	6.3	6.9	9.5	9.4
DM-1 Act. C	7.0	7.2	7.1	7.9	8.5
DM-2 Stream	6.3	7.3	7.2	7.8	8.5

Table 12. Temperature of Water in Test Aquaria & Artificial Streams During Exposure Period

	6/4/76	6/6/76	6/8/76	6/12/76	6/20/76
AF-1 Control	23.0	22.5	22.8	19.0	23.8
AF-2	23.0	22.5	23.0	20.5	23.3
BF-1 Act.	25.0	24.0	24.0	22.0	24.9
BF-2 Sludge	23.0	23.0	21.8	18.8	23.5
CF-1 BPTCT	23.0	23.5	23.3	20.0	24.9
CF-2	23.0	22.0	22.0	17.0	23.8
DF-1 BATCT	20.0	21.0	21.0	19.9	22.8
DF-2	21.0	21.0	21.0	19.3	23.3
AM-1 Control	25.0	25.0	25.8	24.0	21.5
AM-2	27.0	26.0	26.5	24.5	21.3
BM-1 Act.	26.0	25.5	26.0	24.0	22.0
BM-2 Sludge	26.0	27.0	26.5	24.3	21.0
CM-1 BPTCT	27.0	26.5	26.5	24.3	22.0
CM-2	27.0	26.0	26.0	24.3	20.8
DM-1	26.5	25.8	25.9	24.0	21.0
DM-2	26.0	25.8	26.0	24.0	21.0

The dissolved oxygen concentration (Table 11) and temperature (Table 12) of the water in the test aquaria and artificial streams was within acceptable ranges except for June 6. The dissolved oxygen concentration decreased to 0.5 to 0.6 mg/l and 0.3 to 0.9 mg/l in the aquaria receiving activated sludge and BPTCT effluent streams respectively. Such low concentrations undoubtedly caused a stress in the test fish and could have contributed to the mortality. The aquaria were continuously aerated throughout the test but apparently the rate of aeration was not adequate to compensate for the rate of effluent flow through the test aquaria.

Atomic absorption analyses of heavy metals in grab samples collected at the beginning of the test (Table 13) and at the end (Table 14) indicates no concentrations high enough to cause acutely lethal responses by the aquatic organisms.

Summary of Results at Refinery B.

The activated sludge treatment system at Refinery B was not performing at optimum efficiency during the bioassay evaluations. Heavy rainfall during the exposure periods increased the hydraulic loading on the treatment system since all contaminated storm water runoff from the process unit area is passed through the treatment system. During the month of April, the overall monthly mean removal of COD was only 43%, that of BOD, 77%. In the month of June, the overall removal of COD was 51% and of BOD, 86%. The system was recovering in June but was still not operating properly.

Table 13.

ATOMIC ABSORPTION SPECTROPHOTOMETRIC ANALYSIS OF REFINERY B - SPRING, 1976

BIOLOGICAL EVALUATION OF BEST PRACTICABLE AND BEST AVAILABLE WATER TREATMENT TECHNOLOGY IN PETROLEUM REFINING

6/4/76

	Na (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	Fe (ppm)	Pb (mg/l) cs*	Zn (ppm)	Cu (ppm)	Cr (mg/l) cs*	Ni (ppm)	Cl (ppm)	Cd (mg/l) cs*
A-CONTROLL												
Suspended	.19	2.0	.59	< 1.0	.26	.01	.14	< .04	.02	.1		.002
Dissolved	3.95	31.51	3.17	2.0	.16	< .01	.04	< .04	< .02	<.1		<.001
B-EFFLUENT												
Suspended	.64	3.0	.59	< 1.0	.56	.01	.31	.05	.05	<.1		.003
Dissolved	180.0	29.02	2.81	18.51	.46	.01	.18	< .04	.05	<.1		.002
C-SANDCOAL FILTER												
Suspended	.53	2.0	.59	< 1.0	.56	< .01	.22	.05	.04	<.1		.005
Dissolved	190.0	26.53	2.81	17.08	.46	.03	.11	.04	.01	<.1		.008
D-CARBON COL.												
Suspended	.42	2.0	.49	< 1.0	.36	.06	.20	.05	.03	.1		.002
Dissolved	160.0	24.04	3.90	17.08	.46	< .01	.04	< .04	< .02	<.1		.001

---

* Corrected for Matrix Interference by Standard Addition Method $CS = \frac{A_s \times C_{std}}{A_{std} - A_s}$

Table 14.

ATOMIC ABSORPTION SPECTROPHOTOMETRIC ANALYSIS OF REFINERY B - SPRING, 1976

BIOLOGICAL EVALUATION OF BEST PRACTICABLE AND BEST AVAILABLE WATER TREATMENT TECHNOLOGY IN PETROLEUM REFINING

7/6/76

	Na (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	Fe (ppm)	Pb (mg/l) cs*	Zn (ppm)	Cu (ppm)	Cr (mg/l) cs*	Ni (ppm)	Cl (ppm)	Cd (mg/l) cs*
A-CONTROL												
Suspended	<1.0	1.57	<1.0	<1.0	.23	.02	.18	.05	.02	<.1		.002
Dissolved	5.29	32.00	3.34	2.77	<.04	.02	.09	<.04	<.02	<.1		.001
B-EFFLUENT												
Suspended	<1.0	1.90	<1.0	<1.0	.66	.03	.24	<.04	.05	<.1		.002
Dissolved	17.88	31.00	4.61	12.82	.26	.03	.31	<.04	.09	<.1		.001
C-SANDCOAL FILTER												
Suspended	<1.0	1.25	<1.0	<1.0	.23	.02	.24	<.04	.04	<.1		.001
Dissolved	16.45	32.00	4.40	13.16	.15	.06	.15	<.04	.04	<.1		.002
D-CARBON COL.												
Suspended	<1.0	1.25	<1.0	<1.0	.12	.03	.21	.05	.04	<.1		.001
Dissolved	106.17	32.00	6.09	12.65	<.04	<.01	.07	<.04	<.02	<.1		.001

*Corrected for Matrix Interference by Standard Addition Method

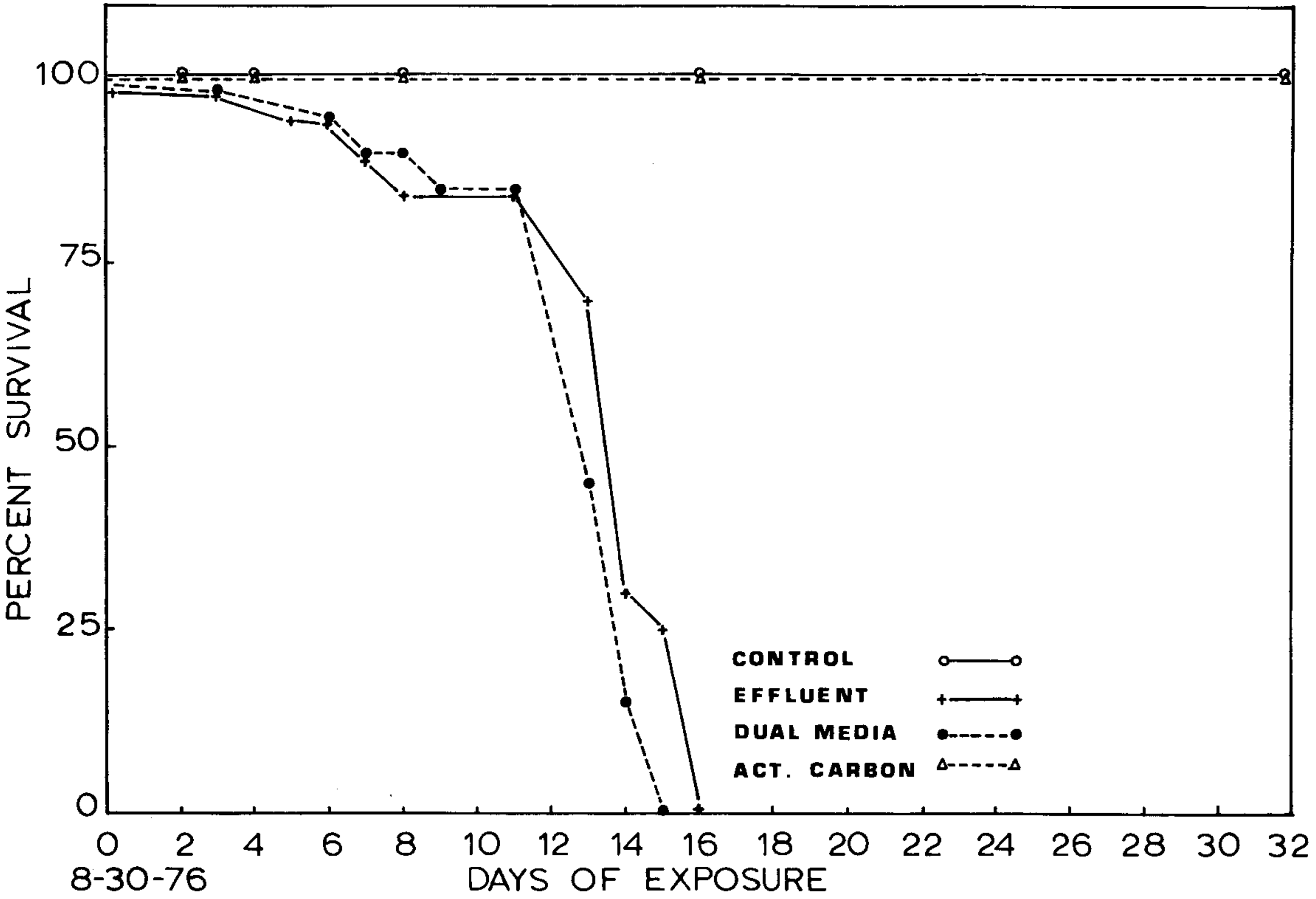
$$CS = \frac{A_s \times C_{std}}{A_{std} - A_s}$$

Evaluation at Refinery C, Fall, 1976

A 32-day exposure was conducted at Refinery C during August 30 to October 1, 1976. The results of the continuous-flow fathead minnow bioassays showed that up to day 11 of exposure only 15% mortality had occurred in the biologically treated effluent and the effluent plus dual-media filtration (BPTCT). Between day 11 and day 16 of the exposure, complete mortality occurred in the fish exposed to the effluent and the BPTCT effluent (Figure 12). There was no fish mortality in the control stream or the effluent plus activated carbon adsorption (BATEA) (Figure 12).

It appeared that the fish had acclimated to the effluent with about 15% mortality through the eleventh day of exposure. On the 12th day, a hard rain occurred which resulted in considerable surface water runoff from the refinery area. The surface water runoff flowed into the stream where our pump was located. Evidently, the surface water runoff was much more toxic than the normal lagoon effluent.

Species diversity ($\bar{d}$) of the benthic macroinvertebrates during the 32-day exposure indicated there was no significant difference between the lagoon treated refinery effluent and the control or BAT treated effluent (Figure 13). The BPT treated effluent had a slightly lower $\bar{d}$ than the other three treatment streams. The total number of taxa of the benthic macroinvertebrates exposed to the four treatment streams showed a response similar to that of $\bar{d}$, i.e. no difference between control, lagoon effluent and BAT effluent, but BPT had fewer taxa (Figure 14). The mean density of individuals indicated that the



REFINERY C

Figure 12. Effectiveness of waste stabilization lagoons, BPTCT, and BATEA wastewater treatment methods at Refinery C as measured by percent survival of fathead minnows, August 30 to October 1, 1976.

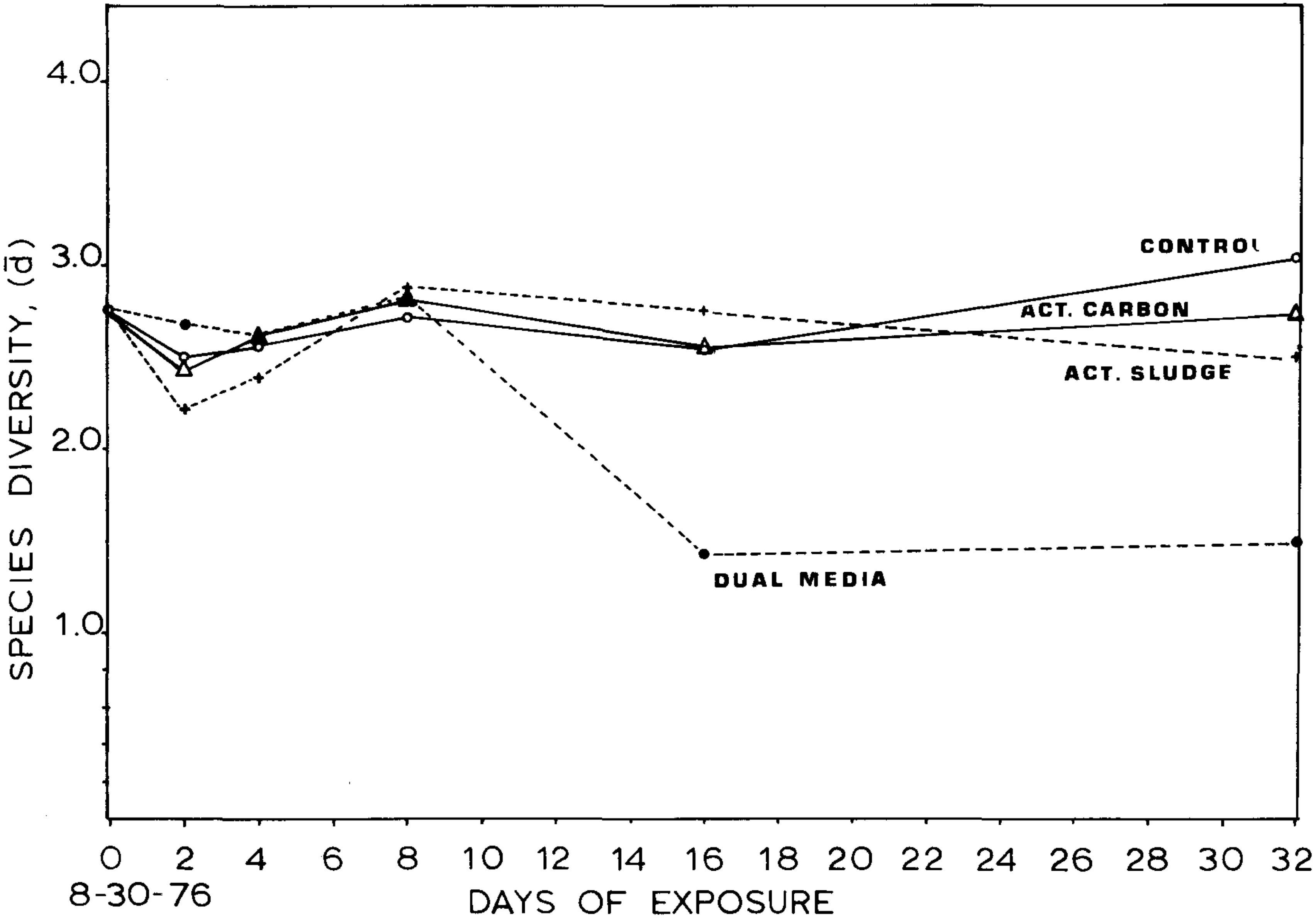


Figure 13. Effectiveness of waste stabilization lagoons, BPTCT, and BATEA wastewater treatment methods at Refinery C as measured by changes in species diversity of benthic macroinvertebrates, August 30 to October 1, 1976.

DPQ

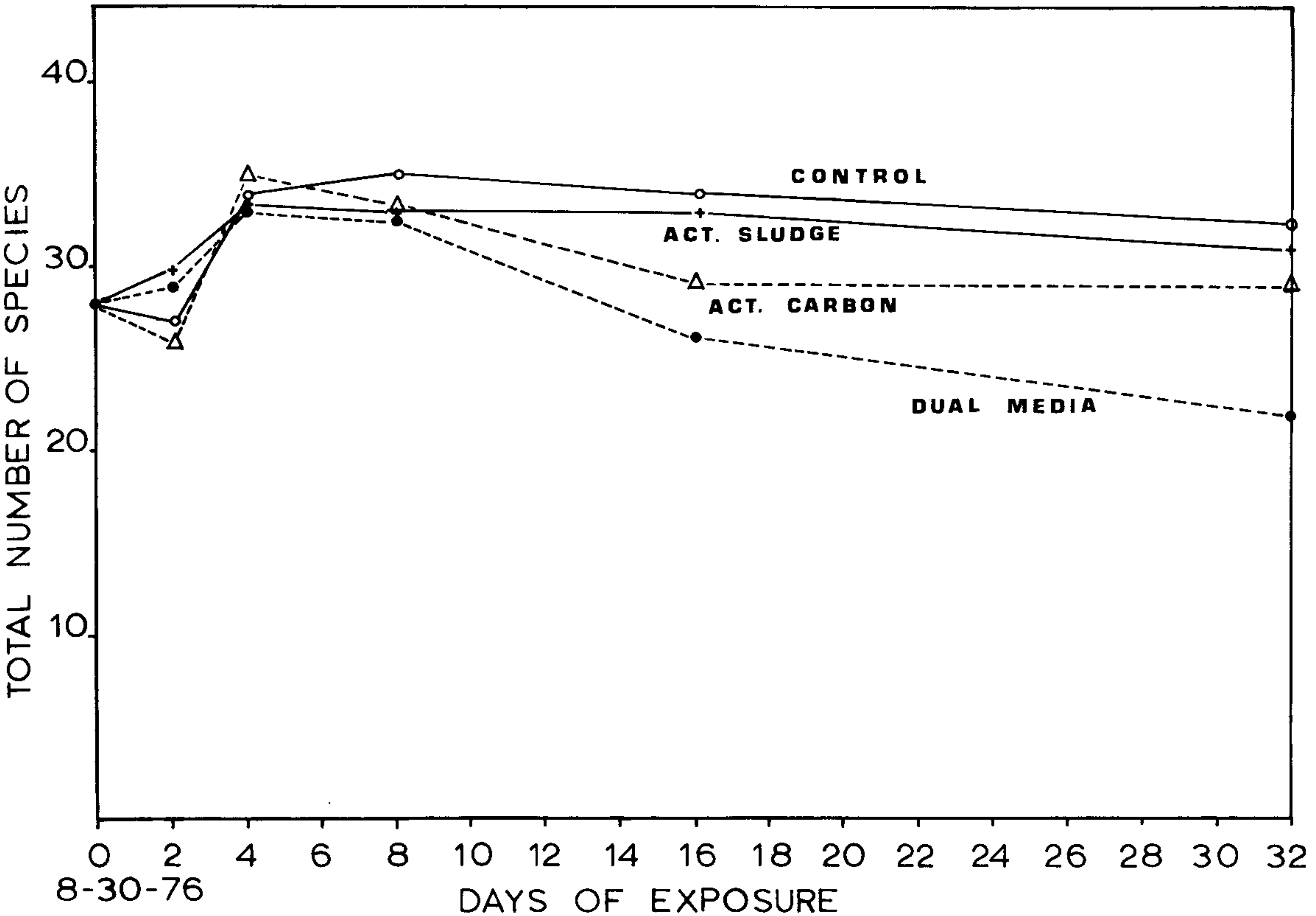


Figure 14. Effectiveness of waste stabilization lagoons, BPTCT, and BATEA wastewater treatment methods at Refinery C as measured by changes in total species of benthic macroinvertebrates, August 30 to October 1, 1976.

DPQ

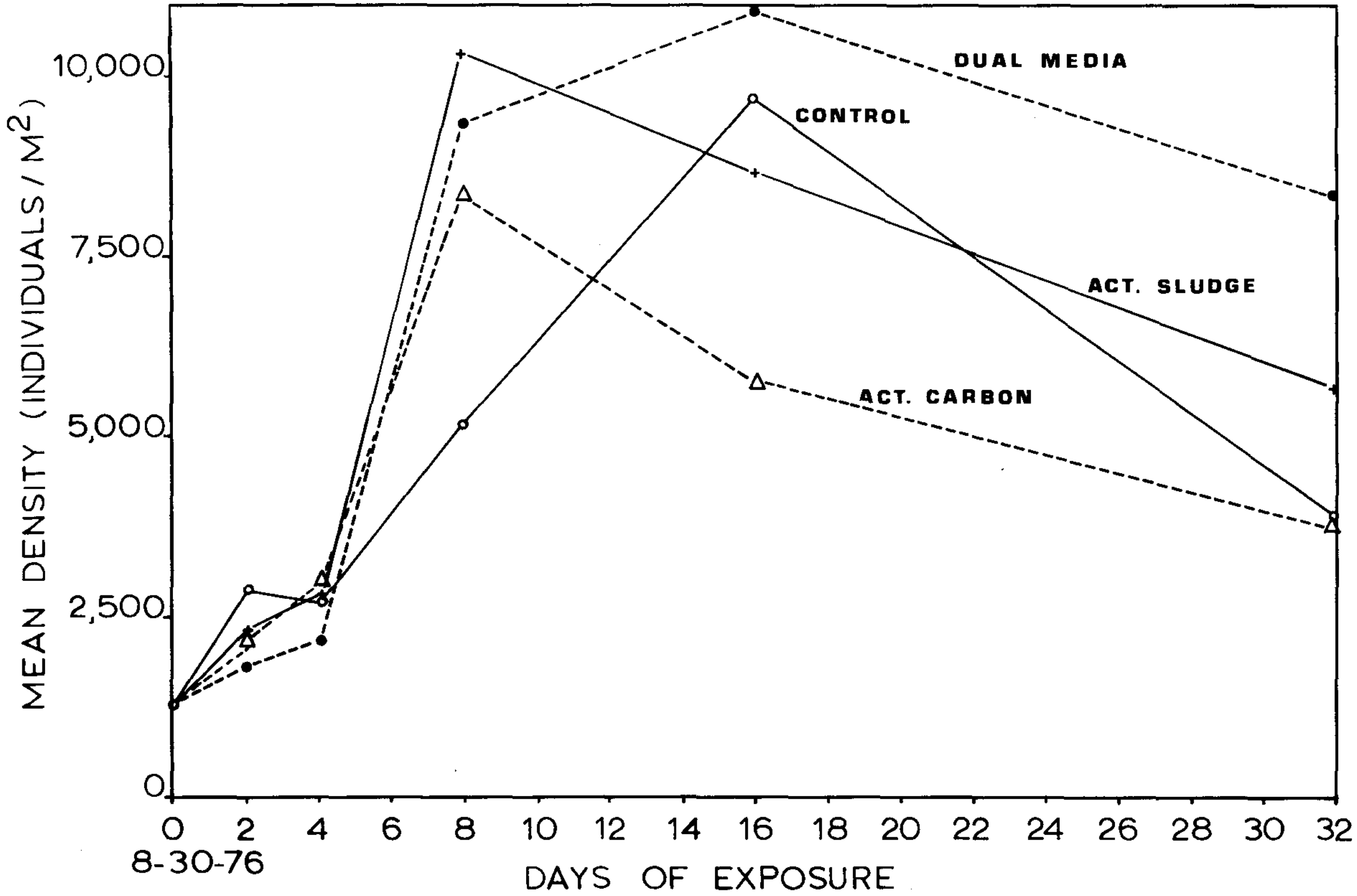


Figure 15. Effectiveness of waste stabilization lagoons, BPTCT, and BATEA wastewater treatment methods at Refinery C as measured by changes in mean density of benthic macroinvertebrates, August 30 to October 1, 1976.

the artificial stream environment was stimulatory to the benthic macroinvertebrates (Figure 15). There was significant increase in density in all four treatment streams compared to starting density. At the end of the 32-day exposure, the control and BAT streams had the lowest density as contrasted with the lagoon and BPT effluents. All of the streams had high densities of Chironomidae.

Chemical analyses of the treatment streams (Table 15) showed a 64% reduction of TOC by the BAT treatment compared to the lagoon treated effluent. BPT did not decrease TOC concentration. BPT also did not show a significant decrease in suspended solids concentration. Ammonia, alkalinity, and hardness concentration was not affected by the BPT and BAT treatments. Temperature and dissolved oxygen concentration in the fish bioassay test units was relatively constant during the exposure period (Tables 16 and 17).

The continuous probe monitor confirmed the results concluded from the grab samples, that there was very little fluctuation in pH, temperature, and conductivity (Table 16, in Appendix A). Dissolved oxygen concentration fluctuated the greatest, but none of the streams were ever less than 1.0 mg/l during the exposure.

Analyses of heavy metals at the start (Table 17) and end of the exposure (Table 18) showed no concentrations high enough to be acutely lethal, however the cadmium content in the colonization stream and in the lagoon effluent at the start was higher than the MATC (Maximum Allowable Toxicant Concentration) recommended by the National Academy of Sciences Water Quality Criteria (1972) and EPA's Water Quality Criteria (1976).

Table 15. Chemical Analyses of Treatment Effluent Streams at Refinery C.

Dates	Sample	NH_3 (mg/1)	Alkalinity (mg/1)	Hardness (mg/1)	Suspended Solids (mg/1)	TOC (mg/1)	COD (mg/1)
8/30/76	A	0.0	234	308.2	5.5	26.6	-
	B	2.5	80	558.6	43.6	48.3	189.1
	C	2.3	166	586.2	33.9	47.5	196.4
	D	2.4	93	602.5	35.7	16.5	43.6
	Ponca Creek	0.0	200	989.5	21.3	23.4	40.0
9/ 1/76	A	0.0	-	-	2.3	20.0	-
	B	2.4	-	-	26.6	53.3	-
	C	4.2	-	-	22.8	48.9	-
	D	2.6	-	-	15.8	29.2	-
9/ 3/76	A	0.1	-	-	11.2	17.9	-
	B	4.2	-	-	23.8	44.9	-
	C	5.0	-	-	32.1	50.2	-
	D	3.2	-	-	33.6	25.1	-
9/ 7/76	A	0.0	-	-	24.6	15.6	-
	B	3.9	-	-	24.1	49.8	-
	C	7.2	-	-	24.6	58.1	-
	D	4.1	-	-	19.3	15.9	-
9/15/76	A	0.0	-	-	43.3	16.4	-
	B	7.6	-	-	45.8	49.6	-
	C	8.2	-	-	31.4	50.8	-
	D	4.2	-	-	27.3	18.9	-
10/1/76	A	0.0	190	223.8	3.8	21.6	40.3
	B	3.6	155	455.4	6.5	61.0	177.4
	C	3.5	134	435.6	4.4	58.4	165.3
	D	9.3	128	415.8	2.5	29.2	80.6

A = Control
B = Effluent
C = Sand & Coal
D = Activated Carbon

Table 16. Temperature in Fathead Minnow Bioassay Tanks Refinery C.

	A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2
30 August	21.5	20.5	21.0	21.5	21.0	19.95	20.0	20.0
3 September	22.0	21.9	21.9	22.5	23.5	22.0	22.0	22.0
7 September	22.0	21.5	22.75	21.5	23.5	21.5	22.1	22.0
9 September	19.5	19.0	19.0	20.5	20.0	20.0	19.75	19.75
15 September	22.0	21.5	21.5	22.1	22.1	21.5	22.0	22.0
23 September	20.0	20.0	20.0	20.0	21.0	20.0	20.3	20.5
1 October	17.5	17.0	17.0	17.5	18.0	17.0	17.5	17.5

Table 17. Dissolved Oxygen Concentration in Fathead Minnow Bioassay Tanks - Refinery C.

	A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2
30 August	7.9	7.5	7.4	7.25	5.1	4.6	7.5	7.0
3 September	5.65	5.3	6.75	6.1	5.2	5.75	7.55	7.7
7 September	5.5	5.0	5.0	6.6	4.3	7.0	6.65	6.7
9 September	5.9	6.1	6.8	4.45	3.6	4.8	6.5	6.7
15 September	5.45	5.1	3.65	2.3	3.3	2.4	3.7	5.1
23 September	5.35	6.1	3.75	5.6	3.85	6.3	4.05	5.6
1 October	7.2	6.9	5.75	4.85	6.05	6.2	7.85	7.1

Table 18. ATOMIC ABSORPTION SPECTROPHOTOMETRIC ANALYSIS OF REFINERY C - SPRING, 1976

BIOLOGICAL EVALUATION OF BEST PRACTICABLE AND BEST AVAILABLE WATER TREATMENT TECHNOLOGY IN PETROLEUM REFINING

8/30/76

	Na (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	Fe (ppm)	Pb (mg/l) cs*	Zn (ppm)	Cu (ppm)	Cr (mg/l) cs*	Ni (ppm)	Cl (ppm)	Cd (mg/l) cs*
A-CONTROL												
Suspended	<1.0	<1.0	<1.0	<1.0	<.04	<.01	.08	<.04	<.02	<.1		.001
Dissolved	65.94	44.15	17.07	4.54	<.04	<.01	.14	<.04	<.02	<.1		.002
B-EFFLUENT												
Suspended	1.83	<1.0	<1.0	<1.0	.38	.03	.17	.05	.02	<.1		.020
Dissolved	660.86	50.84	40.59	11.89	.05	<.01	.27	<.04	<.02	<.1		.060
C-SANDCOAL FILTER												
Suspended	2.17	<1.0	<1.0	<1.0	.22	.03	.09	.19	<.02	<.1		.016
Dissolved	725.60	50.84	40.59	10.11	.13	<.01	.10	<.04	<.02	<.1		.006
D-CARBON COL.												
Suspended	2.17	<1.0	<1.0	<1.0	.13	.02	.08	<.04	<.02	<.1		.009
Dissolved	677.04	52.18	40.13	13.48	<.04	<.01	.03	<.04	<.02	<.1		.003
PONCA CREEK												
Suspended	<1.0	1.28	<1.0	<1.0	1.31	.02	.10	<.04	<.02	<.1		.027
Dissolved	21.92	34.77	11.98	3.0	<.04	<.01	.10	<.04	<.02	<.1		- .1923

*Corrected for Matrix Interference by Standard Addition Method: $CS = \dfrac{A_s \times C_{std}}{A_{std} - A_s}$

Table 18a. ATOMIC ABSORPTION SPECTROPHOTOMETRIC ANALYSIS
OF REFINERY C - FALL, 1976
BIOLOGICAL EVALUATION OF BEST PRACTICABLE AND BEST AVAILABLE
WATER TREATMENT TECHNOLOGY IN PETROLEUM REFINING 10/1/76

	Na (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	Fe (ppm)	Pb (mg/l) cs*	Zn (ppm)	Cu (ppm)	Cr (mg/l) cs*	Ni (ppm)	Cl (ppm)	Cd (mg/l) cs*
A-CONTROLL												
Suspended	<1.0	1.05	<1.0	<1.0	.10	.01	.46	<.04	<.02	<.1		.002
Dissolved	63.35	47.03	16.44	6.43	<.04	.01	.02	<.04	<.02	<.1		.005
B-EFFLUENT												
Suspended	2.05	1.49	<1.0	<1.0	1.00	.03	.72	.07	.04	<.1		.004
Dissolved	524.14	58.42	33.56	9.53	.10	<.01	.15	<.04	.03	<.1		.003
C-SAND COAL FILTERS												
Suspended	2.11	1.05	<1.0	<1.0	<.04	.01	.74	<.04	<.02	<.1		.004
Dissolved	473.05	59.29	33.16	9.46	.10	<.01	.18	<.04	.04	<.1		.005
D-CARBON COL.												
Suspended	1.79	<1.0	<1.0	<1.0	<.04	.02	.05	<.04	<.02	<.1		.002
Dissolved	460.28	59.29	31.16	9.46	<.04	<.01	.05	<.04	<.02	<.1		.005

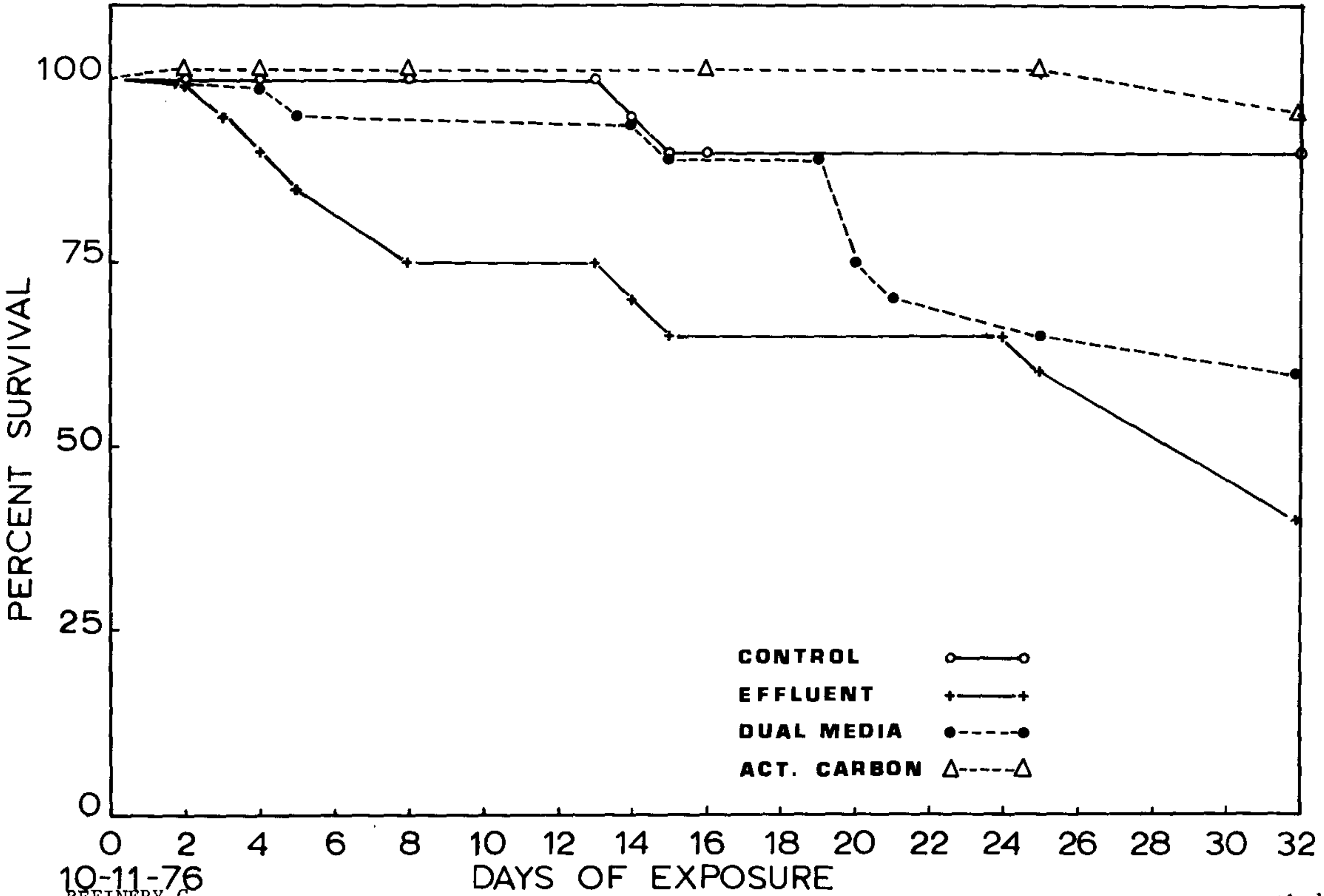
* Corrected for matrix interference by standard addition method:

$$C_s = \frac{A_s \times C_{std}}{A_{std} - A_s}$$

Exposure at Refinery C.

A second 32-day exposure was conducted at Refinery C during October 11 to November 12, 1976. There was 25% mortality of the fathead minnows between start and the 13th day of exposure to the lagoon treated effluent (Figure 16). By the 32nd day of exposure 60% mortality had occurred in the effluent stream as contrasted with 40% in the BPT treated stream, 10% in the control stream and 5% in the BAT treated stream. Attempts to spawn the fathead minnows during the exposure were not successful, however, visual observations of the fish clearly showed that male fish in the control and BAT treated streams were developing secondary characteristics such as vertical color bars, breeding tubercles and establishing spawning territories. As in the first exposure, a runoff of surface water from the refinery area may have washed some toxic substances into the receiving stream where our pump was located for picking up the lagoon effluent. This incident occurred on the 19th to 22nd day of exposure and may have caused some additional mortality when it appeared that the fish had become acclimated to the test streams.

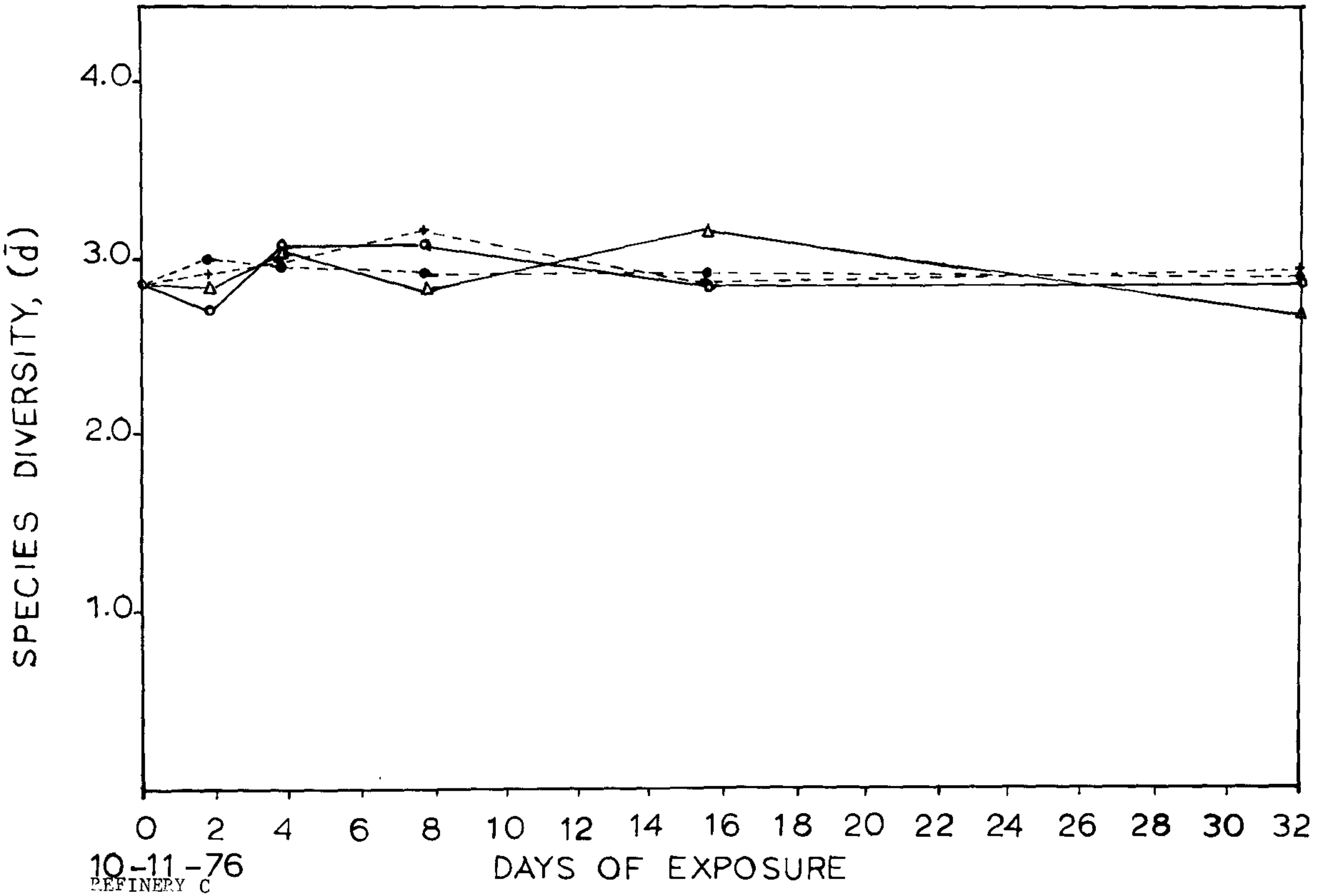
The response of the benthic macroinvertebrates clearly indicated that the lagoon treated effluent was equivalent to BPT and BAT treatment methods from the standpoint of toxicity to benthic organisms. There was no significant differences in $\bar{d}$ between the four treatment streams (Figure 17) and in total number of taxa (Figure 18). The BAT treated effluent had the highest density of individuals at the end of the exposure (Figure 19) but there was no significant differences between the control, lagoon treated and BPT treated



REFINERY C

Figure 16. Effectiveness of waste stabilization lagoons, BPTCT, and BATEA wastewater treatment methods at Refinery C as measured by percent survival of fathead minnows, October 11 to November 12, 1976.

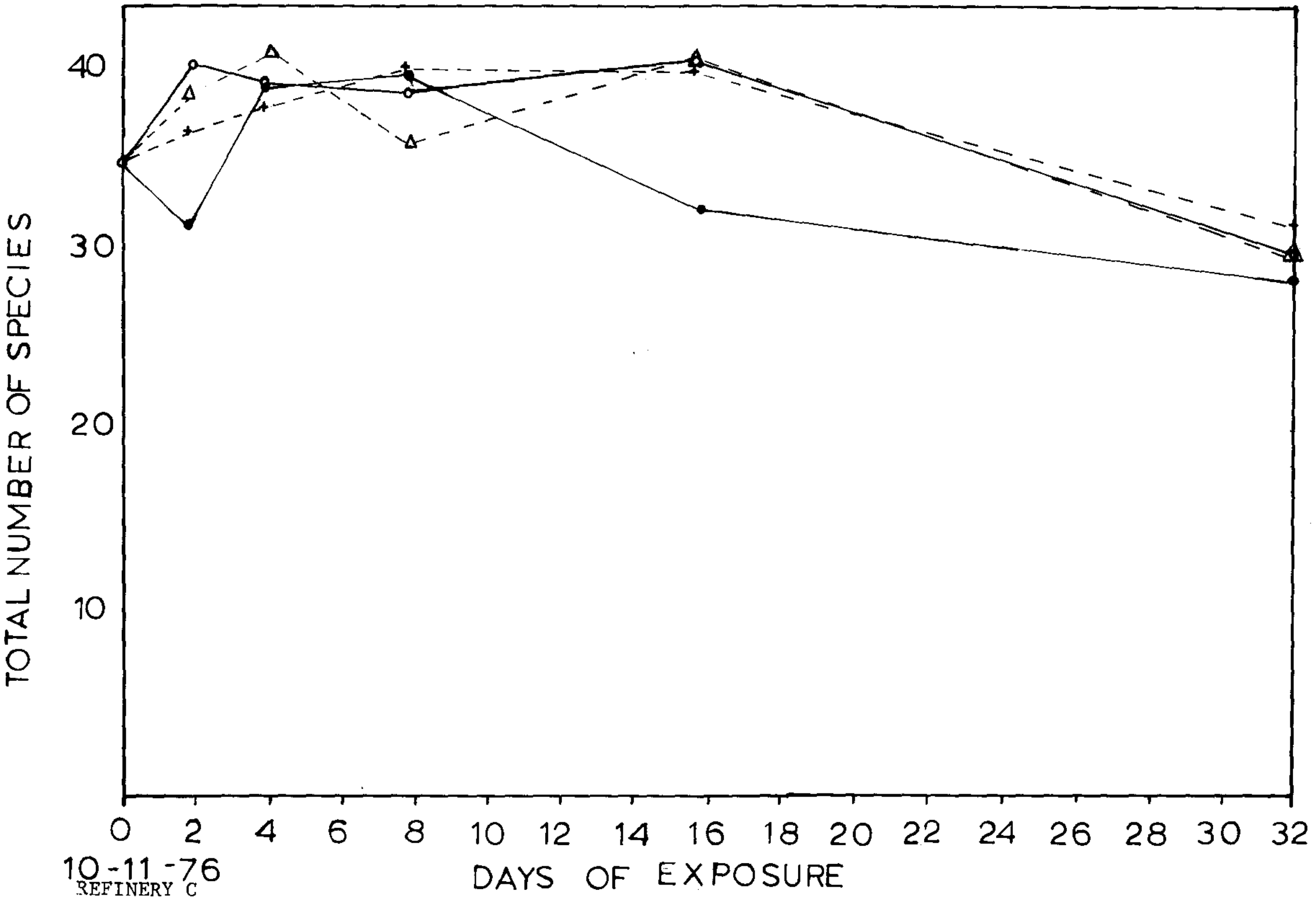
DPQ



REFINERY C

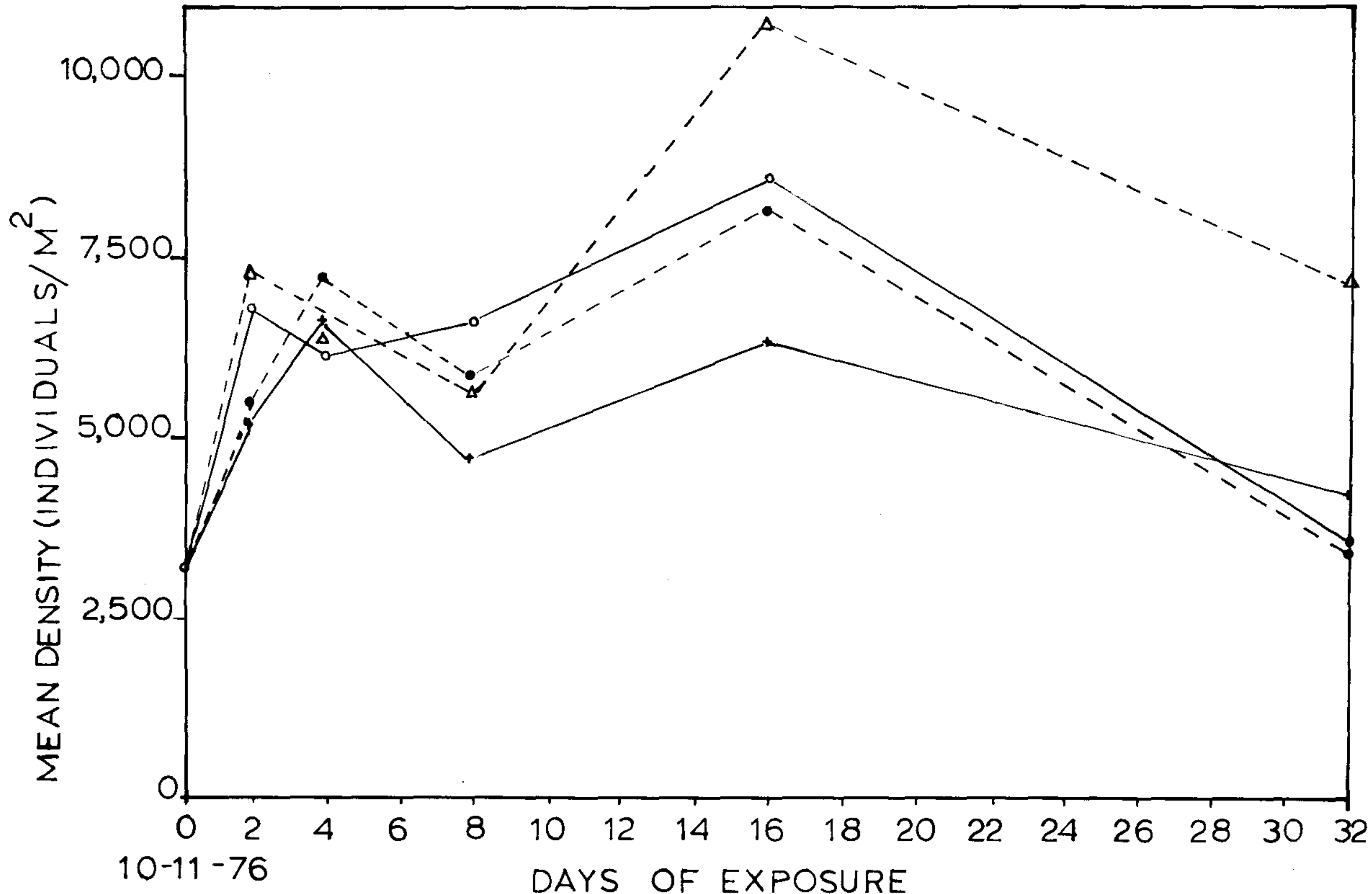
Figure 17. Effectiveness of waste stabilization lagoons, BPTCT, and BATEA wastewater treatment methods at Refinery C as measured by changes in species diversity of benthic macroinvertebrates, October 11 to November 12, 1976.

DPQ-II



REFINERY C

Figure 18. Effectiveness of waste stabilization lagoons, BPTCT, and BATEA wastewater treatment methods at Refinery C as measured by changes in total species of benthic macroinvertebrates, October 11 to November 12, 1976.



REFINERY C

Figure 19. Effectiveness of waste stabilization lagoons, BPTCT, and BATEA wastewater treatment methods at Refinery C as measured by changes in mean density of benthic macroinvertebrates, October 11 to November 12, 1976.

streams. As in the first exposure, high densities of Chironomidae were present in the benthic assemblages.

Chemical analyses of grab samples from the four treatment streams showed that the activated carbon performed better during this exposure. There was a 75% reduction of TOC as the lagoon treated effluent was passed through the activated carbon (BAT) (Table 19). As in the first exposure, dual media filtration treatment did not significantly reduce the concentration of suspended solids. In two cases, the concentration of suspended solids was as high or higher than that originally present in the lagoon treated effluent. During the exposures at Refinery C, the dual media treatment system was back-flushed with effluent for 10 minutes every hour. This method of operation was necessary to prevent clogging which had caused problems at Refinery B. No clogging occurred during the two exposures at Refinery C, however the dual media filter was not effective in removing suspended solids. Therefore, another method of operation should be devised in order to improve the effectiveness of the dual media filter.

There was a gradual decrease in temperature in the fish tanks during the exposure (Table 20), however it must not have contributed to the toxicity observed since there was no mortality in fish exposed to the control or BAT treated streams. Dissolved oxygen was high throughout the period of exposure (Table 21).

Analyses of heavy metals did not show any concentrations of heavy metals high enough to cause any toxicity (Tables 22 and 22a).

Table 19. Chemical Analyses of Treatment Effluent Streams at Ref. C.

Dates	Sample	NH_3 (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Suspended Solids (mg/l)	TOC (mg/l)	COD (mg/l)
10/11/76	B	0.7	130	480	26.6	28.6	166
	C	4.9	137	420	65.2	30.5	140.3
	D	1.6	127	1,432*	41.6	6.6	98.8
	Ponca Creek	0.0	205	220	11.7	6.0	4.0
10/13/76	A	0.0	-	-	33.0	5.5	-
	B	4.2	-	-	38.3	27.5	-
	C	5.4	-	-	37.3	28.7	-
	D	4.9	-	-	24.6	4.7	-
10/15/76	A	0.0	-	-	20.0	3.9	-
	B	4.1	-	-	32.9	25.0	-
	C	4.5	-	-	28.0	28.5	-
	D	4.6	-	-	25.3	3.6	-
10/19/76	A	0.0	-	-	10.7	2.1	-
	B	4.9	-	-	38.2	20.8	-
	C	5.5	-	-	27.9	21.1	-
	D	4.6	-	-	31.5	6.2	-
10/27/76	A	0.0	-	-	2.2	6.9	-
	B	4.6	-	-	35.9	20.8	-
	C	4.4	-	-	22.3	21.6	-
	D	3.7	-	-	12.6	4.3	-
11/12/76	A	0.0	238	273.2	1.8	6.2	23.7
	B	7.0	164	396.0	60.8	28.3	178.7
	C	6.6	153	350.0	30.3	27.2	114.8
	D	7.0	145	554.0	17.3	6.1	No Data

A = Control
B = Effluent
C = Sand & Coal
D = Activated Carbon

* Contained large quantities of suspended carbon fines.

Table 20. Temperature in Fathead Minnow Bioassay Tanks Refinery C.

	A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2
11 Oct.	18.0	17.0	17.0	17.25	18.5	17.75	18.0	18.0
13 Oct.	18.5	18.0	18.0	18.0	18.5	18.0	18.5	18.5
15 Oct.	18.0	17.5	17.0	17.5	17.75	17.5	18.0	18.0
19 Oct.	12.0	11.5	11.0	11.5	13.0	12.0	13.5	13.75
22 Oct.	15.5	13.5	13.0	13.9	14.5	14.0	15.0	15.25
27 Oct.	14.75	12.0	12.25	12.5	13.0	12.5	14.0	14.5
4 Nov.	13.0	12.0	12.25	12.9	15.25	13.0	15.25	15.25
12 Nov.	6.5	6.5	6.75	5.75	7.0	6.0	7.0	7.5

Table 21. Dissolved Oxygen Concentration in Fathead Minnow Bioassay Tanks - Refinery C.

	A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2
11 Oct.	6.6	5.7	4.6	4.05	5.9	5.3	8.1	8.4
13 Oct.	6.4	5.2	4.4	4.1	4.9	4.9	5.3	6.05
15 Oct.	6.4	5.5	4.6	4.1	4.5	5.65	3.5	6.2
19 Oct.	10.2	9.0	6.7	6.7	6.3	7.4	6.8	7.1
22 Oct.	8.7	8.4	6.25	7.9	5.5	8.7	6.25	6.75
27 Oct.	7.5	7.4	6.1	7.9	5.65	8.3	6.3	7.0
4 Nov.	11.4	10.8	6.3	6.7	7.3	5.8	5.4	8.1
12 Nov.	12.0	12.0	8.0	8.4	7.45	7.5	6.8	9.0

Table 22. ATOMIC ABSORPTION SPECTROPHOTOMETRIC ANALYSIS OF REFINERY C - FALL, 1976

BIOLOGICAL EVALUATION OF BEST PRACTICABLE AND BEST AVAILABLE WATER TREATMENT TECHNOLOGY IN PETROLEUM REFINING

10/11/76

	Na (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	Fe (ppm)	Pb (mg/l) cs*	Zn (ppm)	Cu (ppm)	Cr (mg/l) cs*	Ni (ppm)	Cl (ppm)	Cd (mg/l) cs*
A-CONTROLL												
Suspended												
Dissolved	NO SAMPLES RECEIVED											
B-EFFLUENT												
Suspended	1.54	<1.0	<1.0	<1.0	.10	.05	.13	.22	.03	<.1		.007
Dissolved	549.68	59.29	33.16	8.72	<.04	.02	.10	.12	.07	<.1		.003
C-SAND COAL FILTERS												
Suspended	1.92	1.49	<1.0	<1.0	.21	.03	1.42	.07	.04	<.1		.009
Dissolved	473.05	57.54	33.56	8.65	.10	.03	.15	<.04	.05	<.1		.004
D-CARBON COL.												
Suspended	1.73	1.49	<1.0	<1.0	.44	.01	.74	<.04	.02	<.1		.005
Dissolved	485.82	312.68	122.28	8.35	<.04	<.01	.05	<.04	<.02	<.1		.002
PONCA CREEK												
Suspended	.45	1.49	<1.0	<1.0	.77	.01	.67	<.04	<.02	<.1		.006
Dissolved	28.15	40.90	12.34	3.62	<.04	<.01	.08	<.04	<.02	<.1		.005

*Corrected for matrix interference by standard addition method:

$$C_s = \frac{A_s \times C_{std}}{A_{std} - A_s}$$

Table 22a. ATOMIC ABSORPTION SPECTROPHOTOMETRIC ANALYSIS
OF REFINERY C - FALL, 1976
BIOLOGICAL EVALUATION OF BEST PRACTICABLE AND BEST AVAILABLE
WATER TREATMENT TECHNOLOGY IN PETROLEUM REFINING 11/12/76

	Na (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	Fe (ppm)	Pb (mg/l) cs*	Zn (ppm)	Cu (ppm)	Cr (mg/l) cs*	Ni (ppm)	Cl (ppm)	Cd (mg/l) cs*
A-CONTROLL												
Suspended	<1.00	<1.00	<1.00	<1.00	.10	<.01	.04	<.04	.11	<.1		<.001
Dissolved	70.90	42.94	13.27	6.54	<.04	.02	.07	<.04	.07	<.1		..004
B-EFFLUENT												
Suspended	1.83	<1.00	<1.00	<1.00	.36	.11	.25	.08	.31	<.1		.002
Dissolved	49.62	43.48	29.19	10.49	.19	.07	.25	.12	.75	<.1		.001
C-SANDCOAL FILTER												
Suspended	2.02	<1.00	<1.00	<1.00	.19	.04	.04	.08	.15	<.1		<.001
Dissolved	407.55	42.96	28.75	10.49	.10	.01	.08	.08	.18	<.1		.002
D-CARBON COL.												
Suspended	4.07	<1.00	<1.00	<1.00	.07	.02	<.01	.04	.10	<.1		<.001
Dissolved	226.06	43.48	29.19	10.34	.80	<.01	.02	.04	.07	<.1		<.001

*Corrected for Matrix Interference by Standard Addition $C_s = \frac{A_s \times C_{std}}{A_{std} - A_s}$

Exposure at Refinery A.

Due to the mechanical difficulties encountered during the first exposure at Refinery A, it was decided to conduct a second exposure at Refinery A to obtain a more thorough evaluation of this effluent.

The fathead minnow response during this exposure (April 18 to May 20, 1977) clearly showed that the fish had acclimated to the effluent by the 12th day of exposure with 40% mortality (Figure 20). There was no additional mortality until the 24th day of exposure, when a spill occurred within the refinery which upset the activated sludge treatment system. Between the 24th day and the 32nd day of exposure, the remaining fish (60%) died, apparently as a result of the spill which upset the treatment system (Table 23). A similar pattern of mortality was observed in the BPT treated effluent, but the effect was lessened somewhat, since final mortality was 55%. No fish mortality occurred in the control or BATEA treatment streams.

Table 23. Percent Mortality of
Fathead Minnows to Different Treatments
at Refinery A, April 18 to May 20, 1977.

	*LT50 *LT50	Cumulative 32-Day Percent Mortality
Control	> 32 Days	0%
Act. Sludge	25 Days	100%
BPTCT	30 Days	55%
BATEA	> 32 Days	0%

*LT50 = estimated time at which 50% mortality occurred.

The benthic macroinvertebrate (BM) bioassays showed that all three of the effluent streams decreased species diversity ($\bar{d}$) when compared to

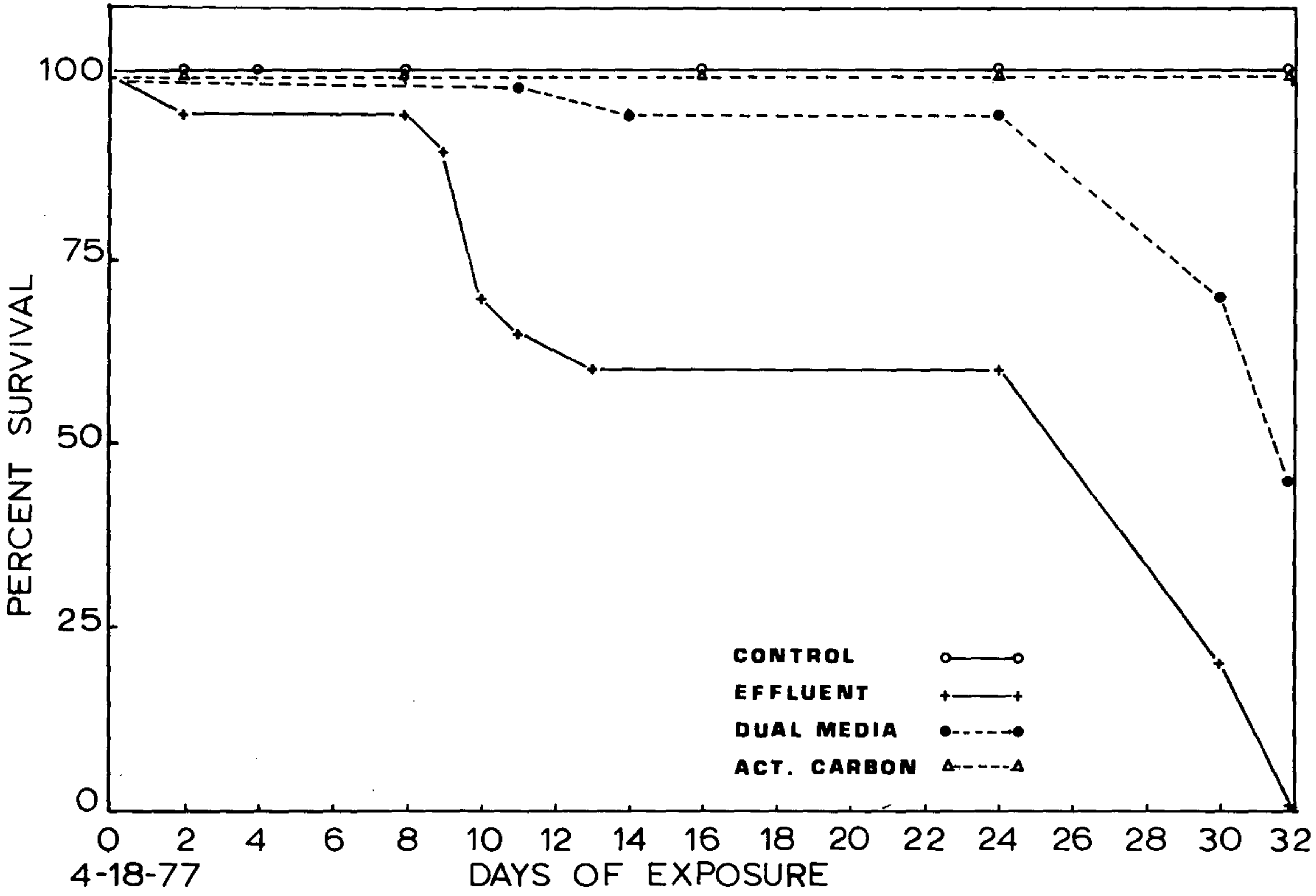


Figure 20. Percent survival of fathead minnows as a measure of the effectiveness of activated sludge, BPTCT, and BATEA treatment methods at Refinery A, April 18 to May 20, 1977.

the control stream (Figure 21). However, the degree of reduction relative to the starting diversity was minor. Neither activated carbon treatment (BATEA) nor dual-media filtration (BPTCT) of the effluent stream improved diversity as compared to the normal activated sludge treatment alone. The total number of species (Figure 22) and mean density of individuals (Figure 23) showed results similar to species diversity, i.e. control stream better quality than 3 effluent streams, but the advanced treatment of the activated sludge did not show any significant improvement in final effluent quality with respect to changes in benthic colonies during the exposure.

Based upon the fish and benthic macroinvertebrate bioassay tests, the activated sludge treatment system at Refinery A appears to be a fair to good quality effluent. Most of the fish mortality appeared to be related to a chemical spill within the refinery which upset the biological treatment system. If emergency spill containment facilities could be devised to prevent upset of the biological treatment system, this system could probably produce an effluent which would cause no acute toxicity within the receiving stream. Activated carbon adsorption treatment of the activated sludge effluent did improve the quality with respect to toxicity. The activated carbon treated effluent prevented the chemical spill from causing mortality in the fathead minnow bioassays.

Chemical analyses of the grab samples collected during this exposure showed that the activated carbon (BATEA) removed an average of 81.6% of the TOC from the activated sludge effluent (Table 24). The dual-media filter (BPTCT) removed an average of 50.5% of the suspended solids during the exposure, which was much better efficiency than obtained in the other exposures. Of all the chemical parameters

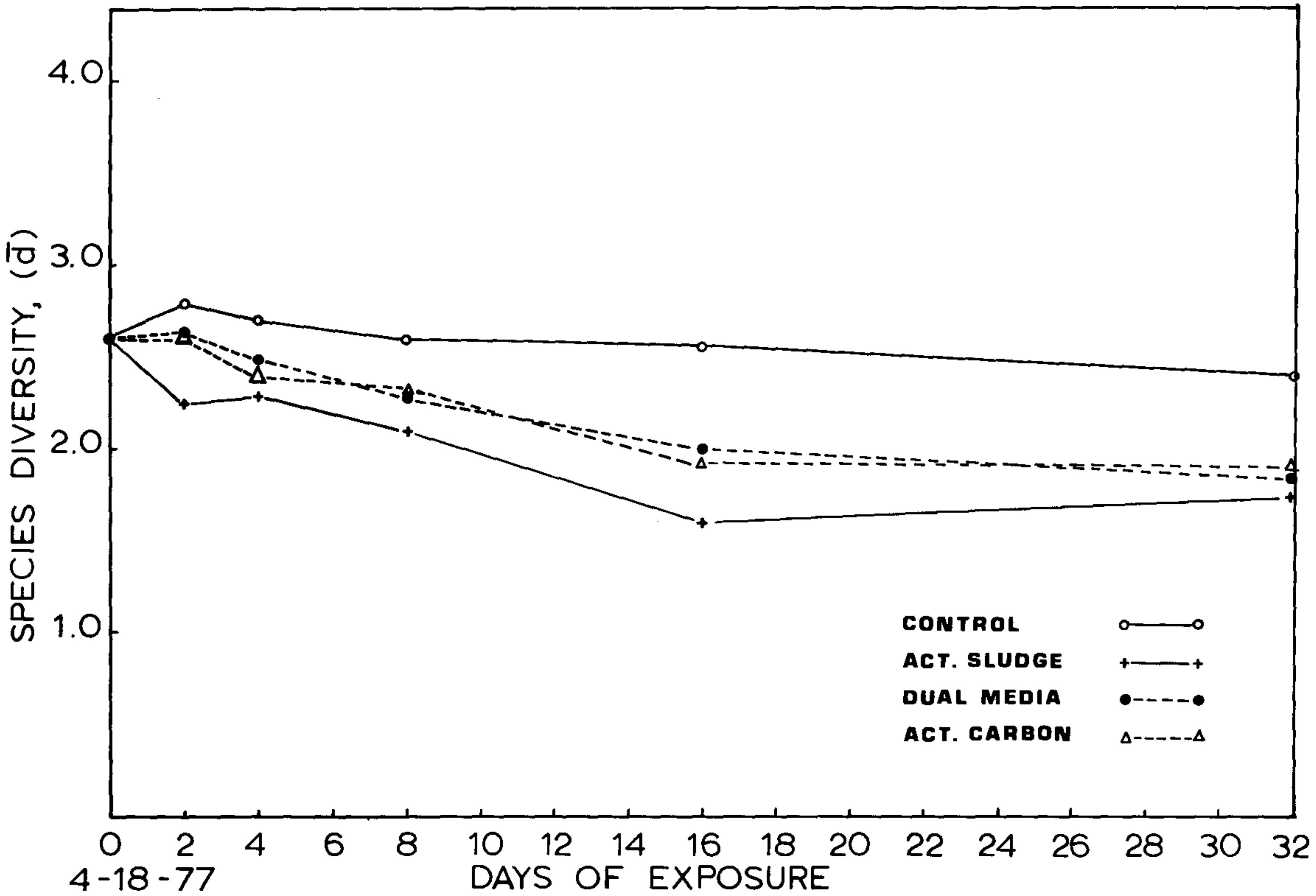


Figure 21. Effectiveness of Activated Sludge, BPTCT, and BATEA Wastewater Treatment Methods at Refinery A as Measured by Changes in Benthic Macroinvertebrate Species Diversity, April 18 to May 20, 1977.

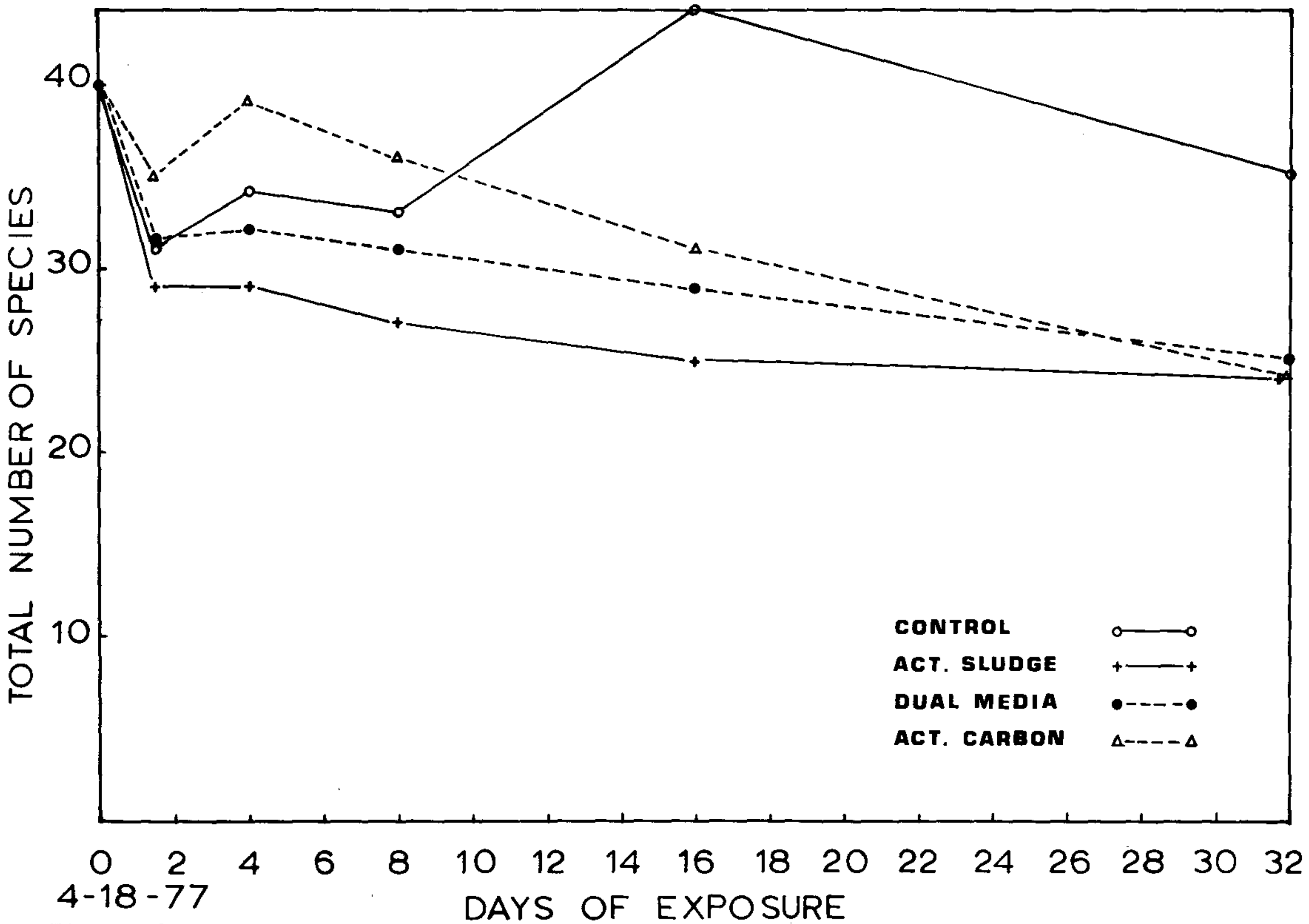


Figure 22. Effectiveness of activated sludge, BPTCT, and BATEA wastewater treatment methods at Refinery A as measured by changes in total number of taxa of benthic macroinvertebrates, April 18 to May 20, 1977.

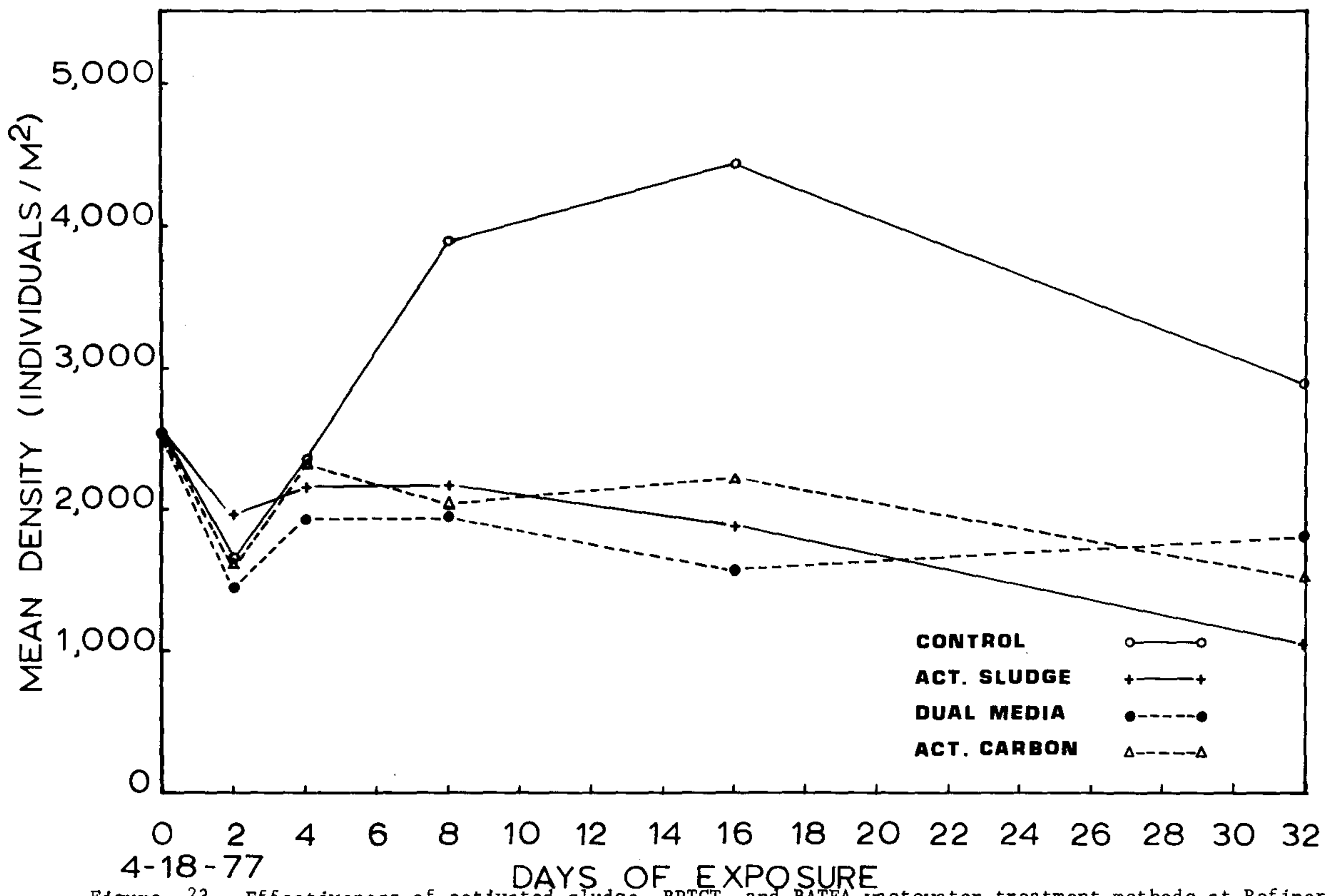


Figure 23. Effectiveness of activated sludge, BPTCT, and BATEA wastewater treatment methods at Refinery A as measured by changes in density of benthic macroinvertebrates, April 18 to May 20, 1977.

LNX

Table 24. Water Samples from Refinery A

Date		Suspended Solids	NH_3	Alkalinity	Hardness	TOC	COD	pH
4/18/77	A	10.6	0.0	114	185.7	3.0	15.4	7.10
	B	24.7	11.6	34	308.8	30.4	142.6	7.00
	C	26.7	11.2	34	278.3	23.2	69.4	6.95
	D	38.1	31.2	102	1,533.8	2.6	65.6	7.15
4/20/77	A	5.6	0.0	-	-	0.6		8.10
	B	50.0	8.8	-	-	21.6		7.10
	C	15.4	8.9	-	-	20.2		7.20
	D	16.4	15.2	-	-	4.9		7.55
4/22/77	A	1.8	0.0	-	-	19.6		8.25
	B	48.5	8.6	-	-	23.5		7.20
	C	20.8	8.3	-	-	18.9		7.05
	D	7.8	11.9	-	-	2.5		7.75
Salt Creek		29.6	0.0	-	-	7.7		7.60
4/26/77	A	4.4	0.0	-	-	4.9	15.4	8.10
	B	46.1	7.5	-	-	21.8	142.6	6.85
	C	28.2	15.4	-	-	19.9	69.4	6.60
	D	14.7	18.6	-	-	4.9	65.6	7.35
5/4/77	A	2.25	0.0	-	-	2.1		8.35
	B	23.45	14.2	-	-	24.6		7.20
	C	7.98	13.7	-	-	11.5		7.00
	D	8.82	13.0	-	-	4.7		7.10
New C Column			14.5	390	989.8	4.5		6.95
5/20/77	A	0.8	0.0	118	133.3	2.7	10.4	8.00
	B	10.0	12.3	29	407.7	21.5	79.9	7.10
	C	1.2	12.8	29	411.6	17.5	104.2	7.00
	D	1.5	15.3	30	440.9	6.8	27.8	7.30

measured, only pH showed a significant change after the chemical spill upset the treatment system on the 24th day of exposure.

The continuous ion probe monitor malfunctioned during this exposure and was not logging data during the critical period when the activated sludge system was upset. Data logged has been included in the appendix.

The eight artificial streams were nearly identical with respect to temperature (Table 25), and dissolved oxygen (Table 26) on a specific day of the exposure. Temperature did increase as the ambient air temperature increased during the exposure. Dissolved oxygen concentrations were near saturation, indicating the effectiveness of the paddlewheels for creating currents and aerating the artificial streams.

Table 25. Temperature in Benthic Macroinvertebrate Artificial Streams during Second Exposure at Refinery A, 22 April - 20 May, 1977.

	Control		Act. Sludge		BPTCT		BATEA	
	A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2
22 April	17.5	17.5	19.5	18.0	18.5	18.0	18.0	18.5
26 April	23.5	24.0	25.25	23.5	24.5	23.5	24.0	24.25
4 May	25.0	25.0	25.25	24.75	25.0	25.0	25.0	25.0
20 May	24.0	24.0	24.25	23.75	24.25	24.0	24.25	24.5

Table 26. Dissolved Oxygen Concentration in Benthic Macroinvertebrate Artificial Streams during Second Exposure at Refinery A, April 22 to May 20, 1977.

	Control		Act. Sludge		BPTCT		BATEA	
	A_1	A_2	B_1	B_2	C_1	C_2	D_1	D_2
22 April	9.05	9.45	8.0	9.1	8.8	8.7	8.8	8.6
26 April	9.1	9.6	8.2	8.6	8.2	8.4	9.4	9.4
4 May	8.8	9.3	9.7	9.4	9.3	8.9	9.0	9.0
20 May	9.2	9.9	8.9	11.2	8.8	11.2	9.0	9.1

ATOMIC ABSORPTION SPECTROPHOTOMETRIC ANALYSIS
OF REFINERY A - SPRING, 1977
BIOLOGICAL EVALUATION OF BEST PRACTICABLE AND BEST AVAILABLE WATER TREATMENT TECHNOLOGY IN PETROLEUM REFINING

4/18/77

	Na (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	Fe (ppm)	Pb (mg/l) cs*	Zn (ppm)	Cu (ppm)	Cr (mg/l) cs*	Ni (ppm)	Cl (ppm)	Cd (mg/l) cs*
A-1												
Suspended	<1.0	<1.0	<1.0	<1.0	.06	.02	<.02	<.04	<.02	<.1		<.001
Dissolved	20.17	38.62	16.90	3.65	.06	< .01	.07	<.04	<.02	<.1		.003
A-2												
Suspended	<1.0	<1.0	<1.0	<1.0	.06	< .01	.02	<.04	<.02	<.1		<.001
Dissolved	25.42	38.62	16.66	3.57	.52	< .01	.09	<.04	.16	.17		.010
B-1												
Suspended	<1.0	<1.0	<1.0	<1.0	.06	.01	.04	<.04	.03	<.1		<.001
Dissolved	230.24	59.38	24.60	13.39	.21	.01	.18	.05	.12	<.1		.020
B-2												
Suspended	<1.0	<1.0	<1.0	<1.0	.06	< .01	.04	<.04	.06	<.1		<.001
Dissolved	251.25	60.37	24.14	13.39	2.12	.27	1.17	.08	.12	<.1		.011
C-1												
Suspended	<1.0	<1.0	<1.0	<1.0	<.04	.02	.04	<.04	.07	<.1		<.001
Dissolved	243.37	61.37	23.67	13.39	.21	.02	.18	<.04	.11	<.1		.006
C-2												
Suspended	<1.0	<1.0	<1.0	<1.0	.14	.02	.06	<.04	.09	<.1		<.001
Dissolved	251.25	61.85	24.60	13.24	.37	.01	.13	<.04	.13	<.1		.015
D-1												
Suspended	<1.0	<1.20	<1.0	<1.0	.06	< .01	.02	<.04	<.02	<.1		<.001
Dissolved	293.26	453.92	98.71	13.24	<.04	.02	.09	<.04	<.02	.17		.004
D-2												
Suspended	<1.0	<1.0	<1.0	<1.0	.06	< .01	.02	<.04	<.02	<.1		<.001
Dissolved	267.00	483.58	103.38	13.39	.06	< .01	.07	<.04	<.02	<.1		.002

*Corrected for matrix interference by standard addition: $C_s = \frac{A_s \times C_{std}}{A_{std} - A_s}$

ATOMIC ABSORPTION SPECTROPHOTOMETRIC ANALYSIS
OF REFINERY A - SPRING, 1977

BIOLOGICAL EVALUATION OF BEST PRACTICABLE AND BEST AVAILABLE
WATER TREATMENT TECHNOLOGY IN PETROLEUM REFINING

5/20/77

	Na (ppm)	Ca (ppm)	Mg (ppm)	K (ppm)	Fe (ppm)	Pb (mg/l) cs*	Zn (ppm)	Cu (ppm)	Cr (mg/l) cs*	Ni (ppm)	Cl (ppm)	Cd (mg/l) cs*
A-1												
Suspended	<1.0	<1.0	<1.0	<1.0	<.04	.02	.02	<.04	<.02	<.1		<.001
Dissolved	25.42	31.21	13.16	2.95	<.04	< .01	<.02	<.04	<.02	<.1		.002
A-2												
Suspended	<1.0	<1.0	<1.0	<1.0	<.04	.02	<.02	<.04	<.02	<.1		.002
Dissolved	25.42	31.21	12.69	3.18	<.04	< .01	.03	<.04	<.02	<.1		.004
B-1												
Suspended	1.44	<1.0	<1.0	<1.0	3.42	< .01	.65	.23	2.60	<.1		<.001
Dissolved	403.55	95.47	32.54	10.90	.14	< .01	.27	.05	.04	<.1		.009
B-2												
Suspended	1.31	<1.0	<1.0	<1.0	3.26	.26	.61	.16	1.83	<.1		<.001
Dissolved	414.05	95.47	33.13	10.90	.06	.01	.33	.08	.02	<.1		.003
C-1												
Suspended	1.13	<1.0	<1.0	<1.0	3.34	1.97	2.77	.32	.85	<.1		<.001
Dissolved	387.79	91.02	31.61	10.90	<.04	< .01	.31	.05	.02	<.1		.002
C-2												
Suspended	1.27	1.20	<1.0	<1.0	2.50	1.04	2.06	.18	1.18	<.1		<.001
Dissolved	398.30	95.47	32.07	10.74	<.04	.01	.33	.05	.02	<.1		.001
D-1												
Suspended	<1.0	<1.0	<1.0	<1.0	<.04	.01	<.02	<.04	<.02	<.1		<.001
Dissolved	414.05	95.96	33.94	11.21	<.04	< .01	.05	<.04	<.02	<.1		.001
D-2												
Suspended	<1.0	<1.0	<1.0	<1.0	<.04	.02	<.02	<.04	<.02	<.1		<.001
Dissolved	408.80	95.47	33.94	11.21	.06	.02	.09	<.04	<.02	<.1		.003

*Corrected for matrix interference by standard addition: $C_s = \dfrac{A_s \times C_{std}}{A_{std} - A_s}$

Summary and Conclusions.

The results of both the continuous-flow fathead minnow and the benthic macroinvertebrate bioassays clearly indicated that sequential biological treatment-dual media filtration-activated carbon adsorption, the equivalent of EPA's Best Available Technology Economically Achievable, produced an effluent which caused no acute lethal effects as measured by these two bioassay procedures. In all but one of the evaluations, there was less than 15% mortality of the fathead minnows continuously exposed to the sequential BATEA treated oil refinery wastewater for 32 days (Table 27). The Benthic Macroinvertebrate bioassays also showed that the sequential BATEA treatment produced a final effluent which had no significant effect upon diversity or total species when exposed to the test effluent for 32 days (Table 28).

The sequential biological-dual media filtration, equivalent of EPA's Best Practicable Treatment Control Technology (BPTCT), did not appear to improve effluent quality significantly over conventional biological treatment as measured by the bioassay tests. The BPTCT system was difficult to operate on a continuous-flow basis. The anthracite coal and sand filters would not function for more than 24 hours continuously without backflushing. An automatic backflush of 10 minutes every hour had to be initiated to maintain flow. Performance of the BPTCT was not optimum as evidenced by the low percentage removal of suspended solids. During the exposure at Refinery C, large numbers of Chironomids were found growing in the

the dual media filter during the latter stage of the exposure. Backflushing was apparently not vigorous enough to wash these organisms from the filters. Therefore, in addition to the automatic backflush, the columns were also dismantled and thoroughly cleaned on the 16th day of operation.

A comparison of the bioassay tests indicates the fathead minnow continuous-flow bioassays were more sensitive to sudden changes in effluent quality than the Benthic Macroinvertebrate bioassay procedure. However, this difference may be more apparent than real. In the first exposure at Refinery C, some species of Chironomids disappeared in the biologically treated and the BPTCT effluents after 8 days of exposure but new species were found after 8 to 16 days of exposure. Apparently, the new species had migrated into the artificial streams from the oil refinery lagoons. These new species added new diversity to the benthic colonies and thus there was no decline in species diversity even though some species had disappeared from the exposed colonies. The response of the benthic macroinvertebrate community is difficult to assess. Development of various numerical indices has been beneficial, however most of these indices were developed for benthic macroinvertebrate communities which had already acclimated to a source of stress and had attained a dynamic equilibrium with the environment. The benthic macroinvertebrate communities, exposed to the test effluents for 32 days in this project, were in the early stages of responding to the new environment and had not reached a new stable community composition. As a result, the species diversity numerical index did not give as good a measure of the

Table 27. Summary of Fathead Minnow Response to Wastewater Treatments Methods Tested at Three Oil Refineries.

	Control		Biological Treatment		BPTCT		BATEA	
	LT50	Cum. Mort.	LT50	Σ % Mort.	LT50	Σ % Mort.	LT50	Σ % Mort.
Refinery A-								
1st Exposure	>32 Days	5%	20 Days	70%	> 32 Days	20%	> 32 Days	15%
2nd Exposure	>32 Days	0%	25 Days	100%	30 Days	55%	> 32 Days	0%
Refinery B-								
1st Exposure	>32 Days	0%	≈ 12 Hours	100%	≈ 12 Hours	100%	14 Days	65%
2nd Exposure	>32 Days	0%	11.5 Hours	100%	22.5 Hours	100%	> 32 Days	0%
Refinery C-								
1st Exposure	>32 Days	0%	13 Days	100%	13 Days	100%	> 32 Days	0%
2nd Exposure	>32 Days	10%	28 Days	60%	> 32 Days	40%	> 32 Days	5%

Table 28. Summary of Benthic Macroinvertebrate Response to Wastewater Treatment Methods Tested at Three Oil Refineries.

	$\bar{d}$ 32nd Day	No. of Taxa 32nd Day	$\bar{d}$ 32nd Day	No. of Taxa 32nd Day	$\bar{d}$ 32nd Day	No. of Taxa 32nd Day	$\bar{d}$ 32nd Day	No. of Taxa 32nd Day
Refinery A-								
1st Exposure	2.6	30	2.9	30	3.0	28	3.3	27
2nd Exposure								
Refinery B-								
1st Exposure	2.2	21	0.4	3	1.9	7	2.2	22
2nd Exposure	2.8	24	1.0	3	1.2	6	2.2	22
Refinery C-								
1st Exposure	3.0	32	2.5	31	1.5	22	2.7	29
2nd Exposure	2.8	30	2.9	32	2.8	28	2.6	30

effects of the test effluents as total numbers of species or mean density of individuals. Other short-term changes in the exposed benthic macroinvertebrate colonies probably were not detected by any of these measures. Shifts in species of benthics during the exposures may be highly indicative of water quality changes, however new methods will have to be developed to interpret such shifts in species composition.

The ultimate goal of aquatic toxicologists must be to develop a test which can be used to predict the potential effects, both direct and indirect, of any chemical poison upon any organism within the receiving environment. The benthic macroinvertebrate bioassay test appears to offer many advantages over single species bioassays since there are 20 to 40 species of organisms of varying sensitivities to poisons in each exposed colony. If new methods of measurement and interpretation can be developed, the benthic macroinvertebrate bioassay test may bridge the gap between single species bioassays and field surveys of aquatic communities in receiving waters.

Literature Cited

1. Stewart, N.E., Millemann, R.E., and Breese, W.P. Trans. Amer. Fish. Soc., Vol. 96, 1967, pp. 25-30.

2. Tarzwell, C.M., Jour. Wat. Pollut. Control Fed., Vol. 34, 1962, pp. 1178-1185.

3. Beak, T.W., Proceedings of the Second International Conference on Advances in Water Pollution Research. Vol. 1, 1964, pp. 191-210.

4. Gaufin, A.R. and Tarzwell, C.M., Sewage Ind. Wastes, Vol. 28, 1956, pp. 906-924.

5. Hawkes, H.A. in Biological Aspects of River Pollution. Butterworth, London, 1962, pp. 311-432.

6. Wilhm, J.L. and Dorris, T.C., Biological Science, Vol. 18, No. 6, 1968, pp. 477-480.

7. Weber, C.I., Biological Field and Laboratory Methods. Environmental Protection Agency. Cincinnati, OH, 1973.

APPENDIX A

Statistical Summary of Hourly Chemical Ion Probe Data Collected During the Evaluation Exposures.

Table 1. Daily (24 hour) mean and standard deviation of hourly conductivity (μ mhos/cm) recordings by the ion probe monitor during the first exposure at Refinery C.

	Control		Act. Sludge		Dual Media		Act. Carbon	
Date	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
8/30/76	6023.7	410.5	6326.1	478.6	942.3	78.6	332.7	104.6
8/31/76	6084.8	148.4	5758.0	281.6	864.2	116.0	227.8	117.3
9/ 1/76	5719.6	334.5	5491.4	386.7	834.6	274.0	165.9	31.7
9/ 2/76	5400.7	373.0	5017.9	296.4	315.5	100.4	253.7	19.2
9/ 3/76	4718.7	548.1	4179.9	295.6	53.5	34.8	168.3	35.0
9/ 4/76	4072.6	565.9	3546.8	327.1	31.8	31.3	99.5	46.7
9/ 5/76	3241.8	644.2	2953.4	376.5	71.9	36.9	40.9	18.7
9/ 6/76	2133.5	598.9	1886.9	308.0	* 25.9	18.2	25.5	13.2
9/ 7/76	1894.0	467.1	1426.3	239.7	* 9.6	11.8	* 22.6	11.6
9/ 8/76	2589.0	185.4	1133.8	110.6	* 4.6	11.6	* 16.3	13.2
9/ 9/76	3648.0	400.1	1642.8	499.4	* 11.3	37.8	* 26.7	37.4
9/10/76	3569.0	330.8	1502.4	229.5	* 9.5	22.4	* 15.0	22.5
9/11/76	3182.8	637.4	1114.6	389.0	* 10.0	18.6	* 11.3	16.9
9/12/76	2597.8	721.8	738.0	373.0	* 15.2	30.8	* 3.3	12.8
9/13/76	2246.7	239.8	276.6	155.9	* -3.4	13.2	* .4	9.5
9/14/76	1537.5	507.4	* 29.7	27.6	* -1.4	10.7	* -4.7	9.1
9/15/76	1140.9	547.9	* 51.8	102.0	* 1.7	21.4	* 20.1	128.0
9/16/76	* 185.1	517.7	* 18.9	48.6	* -3.4	29.9	* 79.0	187.5
9/17/76	1309.4	437.2	755.5	396.0	* 7.8	28.8	* 169.1	415.9
9/18/76	1442.2	416.2	244.9	176.9	* - .1	9.4	* -1.4	9.8
9/19/76	1560.9	262.8	121.2	70.0	* - .9	11.6	* -2.9	13.2
9/20/76	2657.9	406.5	448.4	144.9	* .4	10.0	* -1.7	10.5
9/21/76	3055.4	789.6	715.0	372.9	* -4.2	17.0	* -1.4	11.9
9/22/76	2988.6	348.3	944.5	183.1	* 7.2	21.9	* -2.1	10.6
9/23/76	1493.5	697.8	404.3	221.9	* 4.5	10.0	* -3.0	12.0
9/24/76	1495.7	728.9	454.7	364.5	* 72.7	337.5	* -5.0	12.4
9/25/76	1295.5	164.6	493.9	257.3	* -1.7	15.6	* -4.7	12.6
9/26/76	1763.6	273.4	496.9	162.4	* -6.6	17.7	* -2.0	13.0
9/27/76	2908.3	373.9	913.9	182.3	* 110.1	406.4	* -15.1	17.2
9/28/76	3322.4	753.6	1367.4	862.4	* 80.1	314.4	* -21.6	19.5
9/29/76	2426.4	365.0	761.9	141.7	* 653.6	1370.9	* -20.9	12.6

* Includes some negative numbers

Table 2. Daily (24 hour) mean and standard deviation of hourly temperatures (^{o}C) recorded by the ion probe monitor during the first exposure at Refinery C.

	Control		Act. Sludge		Dual Media		Act. Carbon	
Date	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
8/30/76	24.1	1.5	24.1	1.0	23.9	1.1	23.0	1.1
8/31/76	21.5	0.7	22.2	0.6	22.1	0.6	20.3	0.6
9/ 1/76	23.2	1.6	23.3	1.2	23.1	1.2	21.8	1.4
9/ 2/76	23.8	1.7	23.8	1.3	23.8	1.2	22.8	1.4
9/ 3/76	25.2	2.7	25.1	1.9	24.9	1.7	24.5	2.1
9/ 4/76	26.8	3.1	26.4	2.1	26.1	1.9	25.6	2.6
9/ 5/76	27.0	2.5	26.8	1.7	26.6	1.6	26.1	2.3
9/ 6/76	26.0	2.5	26.3	1.8	26.3	1.6	25.5	2.1
9/ 7/76	24.8	2.1	25.5	1.5	25.6	1.4	24.8	1.7
9/ 8/76	23.4	1.7	24.3	1.1	24.6	1.0	23.9	1.1
9/ 9/76	20.1	1.9	21.8	1.2	22.4	1.0	21.8	1.0
9/10/76	20.0	2.0	21.2	1.5	21.6	1.3	20.7	1.6
9/11/76	20.9	3.3	21.7	2.0	21.8	1.6	21.3	2.1
9/12/76	22.5	3.1	22.4	1.7	22.2	1.3	22.5	1.6
9/13/76	22.2	0.7	22.0	0.4	21.9	0.4	21.8	0.5
9/14/76	24.4	2.4	23.7	2.1	23.2	1.9	22.9	2.0
9/15/76	24.6	2.3	24.4	2.2	23.8	1.5	23.8	1.7
9/16/76	23.1	0.8	22.9	0.7	23.1	0.4	23.1	0.5
9/17/76	24.9	1.3	24.5	0.9	24.3	0.9	23.6	0.8
9/18/76	24.1	1.8	24.3	1.4	24.3	1.1	23.3	1.2
9/19/76	24.3	1.5	24.6	1.2	24.7	1.0	23.5	1.2
9/20/76	21.4	1.2	23.0	1.0	23.5	0.7	22.3	0.4
9/21/76	20.0	3.1	21.7	2.3	21.9	2.7	21.0	2.3
9/22/76	18.5	1.2	20.3	0.7	20.9	0.7	19.7	1.1
9/23/76	23.9	1.9	24.1	1.6	24.1	1.2	23.4	1.1
9/24/76	22.8	2.6	22.9	2.3	22.8	2.0	22.4	1.7
9/25/76	21.9	0.4	22.0	0.5	23.0	1.0	22.1	0.4
9/26/76	20.9	0.6	21.1	0.6	21.7	0.7	21.2	0.4
9/27/76	17.7	1.0	18.5	0.8	19.4	0.7	18.7	0.6
9/28/76	16.1	1.6	16.8	1.4	17.8	1.2	17.1	1.2
9/29/76	15.3	0.8	15.9	0.9	16.6	1.1	16.1	0.5

Table 3. Daily (24 hour) mean and standard deviation of hourly pH measurements recorded by the ion probe monitor during the first exposure at Refinery C.

	Control		Act. Sludge		Dual Media		Act. Carbon	
Date	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
8/30/76	7.6	0.1	7.3	0.1	6.9	0.0	7.0	0.1
8/31/76	7.9	0.1	7.3	0.0	6.8	0.0	6.9	0.0
9/ 1/76	7.9	0.1	7.3	0.1	6.9	0.0	6.9	0.0
9/ 2/76	7.9	0.1	7.3	0.0	6.8	0.0	6.9	0.0
9/ 3/76	7.8	0.1	7.3	0.1	6.9	0.1	6.8	0.0
9/ 4/76	7.7	0.1	7.3	0.1	6.9	0.1	6.8	0.1
9/ 5/76	7.7	0.1	7.3	0.1	6.9	0.1	6.7	0.1
9/ 6/76	7.7	0.1	7.2	0.0	6.9	0.0	6.7	0.1
9/ 7/76	7.6	0.1	7.1	0.0	6.9	0.0	6.7	0.0
9/ 8/76	7.6	0.1	7.1	0.0	6.9	0.0	6.7	0.0
9/ 9/76	7.7	0.1	7.2	0.1	7.0	0.1	6.8	0.1
9/10/76	7.7	0.1	7.2	0.1	6.9	0.0	6.9	0.0
9/11/76	7.6	0.1	7.1	0.0	6.9	0.0	6.9	0.1
9/12/76	7.6	0.1	7.1	0.0	7.0	0.0	6.9	0.0
9/13/76	7.6	0.1	7.1	0.0	7.0	0.0	6.9	0.0
9/14/76	7.4	0.1	7.1	0.0	7.0	0.0	6.9	0.0
9/15/76	7.4	0.1	7.2	0.1	7.0	0.1	7.0	0.1
9/16/76	7.0	0.1	7.0	0.1	6.9	0.0	6.9	0.1
9/17/76	7.5	0.1	7.1	0.1	7.0	0.1	7.4	0.1
9/18/76	7.6	0.1	7.1	0.1	6.9	0.0	7.3	0.0
9/19/76	7.6	0.1	7.1	0.0	6.9	0.0	7.3	0.0
9/20/76	7.7	0.1	7.1	0.0	6.9	0.0	7.3	0.0
9/21/76	7.7	0.1	7.1	0.0	7.1	0.2	7.3	0.1
9/22/76	7.7	0.1	7.1	0.0	7.0	0.0	7.3	0.1
9/23/76	7.5	0.1	7.2	0.1	7.0	0.0	7.2	0.0
9/24/76	7.5	0.1	7.2	0.1	7.1	0.2	7.2	0.0
9/25/76	7.5	0.0	7.4	0.0	7.0	0.1	7.1	0.0
9/26/76	7.5	0.0	7.3	0.0	7.0	0.0	7.1	0.0
9/27/76	7.5	0.0	7.2	0.0	7.0	0.1	7.1	0.0
9/28/76	7.5	0.1	7.3	0.1	7.0	0.1	7.1	0.0
9/29/76	7.5	0.1	7.2	0.0	7.1	0.3	7.1	0.0

Table 4. Daily (24 hour) mean and standard deviation of hourly dissolved oxygen concentrations (mg/l) recorded by the ion probe monitor during the first exposure at Refinery C.

	Control		Act. Sludge		Dual Media		Act. Carbon	
Date	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
8/30/76	1.1	0.0	3.3	0.1	3.7	0.0	3.8	0.1
8/31/76	1.1	0.0	3.4	0.1	3.8	0.0	3.0	0.0
9/ 1/76	1.1	0.0	3.5	0.1	3.9	0.1	3.9	0.0
9/ 2/76	1.1	0.0	3.5	0.1	3.9	0.0	3.9	0.0
9/ 3/76	1.1	0.1	3.3	0.1	3.7	0.1	3.7	0.1
9/ 4/76	1.0	0.0	3.0	0.1	3.5	0.1	3.5	0.1
9/ 5/76	1.0	0.0	2.9	0.1	3.4	0.0	3.4	0.0
9/ 6/76	1.0	0.0	2.9	0.1	3.4	0.0	3.4	0.0
9/ 7/76	1.1	0.0	3.0	0.1	3.4	0.0	3.4	0.0
9/ 8/76	1.1	0.0	3.0	0.1	3.4	0.0	3.4	0.0
9/ 9/76	1.1	0.0	2.8	0.2	3.3	0.1	3.4	0.1
9/10/76	1.1	0.0	2.8	0.2	3.3	0.0	3.4	0.0
9/11/76	1.2	0.0	2.9	0.1	3.3	0.0	3.4	0.0
9/12/76	1.2	0.0	2.9	0.0	3.3	0.0	3.4	0.0
9/13/76	1.2	0.0	2.8	0.1	3.3	0.0	3.3	0.0
9/14/76	1.2	0.0	2.7	0.2	3.2	0.0	3.3	0.0
9/15/76	1.3	0.5	2.1	0.8	2.9	0.4	3.0	0.5
9/16/76	3.6	1.3	3.5	1.2	3.2	0.1	3.8	1.0
9/17/76	1.3	0.1	2.5	0.5	2.8	0.5	2.9	0.3
9/18/76	1.3	0.0	2.3	0.1	2.8	0.0	2.9	0.0
9/19/76	1.2	0.0	2.3	0.1	2.7	0.0	2.8	0.0
9/20/76	1.2	0.0	2.3	0.1	2.7	0.0	2.8	0.0
9/21/76	*1.2	0.6	2.3	0.0	2.7	0.0	2.7	0.0
9/22/76	1.2	0.0	2.3	0.1	2.7	0.0	2.7	0.0
9/23/76	1.2	0.0	2.1	0.2	2.6	0.0	2.7	0.0
9/24/76	1.2	0.0	1.7	0.2	2.5	0.2	2.6	0.0
9/25/76	1.2	0.0	1.2	0.1	2.5	0.1	2.6	0.1
9/26/76	1.2	0.0	1.4	0.0	2.4	0.0	2.5	0.0
9/27/76	1.2	0.0	1.8	0.1	2.4	0.2	2.5	0.0
9/28/76	1.3	0.1	1.8	0.2	2.5	0.1	2.6	0.0
9/29/76	1.5	0.2	1.9	0.0	2.3	0.6	2.6	0.0

* Includes some negative numbers

Table 5. Daily (24 hour) mean and standard deviation of hourly conductivity (μ mhos/cm) measurements recorded by ion probe monitor during second exposure at Refinery C.

	Control		Act. Sludge		Dual Media		Act. Carbon	
Date	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
10/11/76	·*4261.9	2521.2	·*2510.8	2545.0	·*1857.2	2732.2	·*2201.9	2659.5
10/12/76	4765.1	234.3	*4362.6	1995.9	4797.7	213.8	4787.2	235.7
10/13/76	·4256.0	232.0	4009.1	1082.4	*3864.9	1473.8	·3987.7	1557.0
10/14/76	·4591.4	144.2	·4601.8	144.1	·4581.6	152.2	·4592.1	149.4
DATA LOGGER MALFUNCTIONED								
10/27/76	·4736.7	2487.4	·5650.2	2144.9	·*1695.1	3823.0	·*2011.0	4056.1
10/28/76	5143.7	138.5	5194.6	130.6	5101.1	161.7	5122.8	147.2
10/29/76	4928.5	283.8	·4973.7	293.0	4910.9	271.6	4925.1	287.4
10/30/76	3604.5	328.5	·3646.8	359.4	3600.3	325.6	3497.4	328.6
10/31/76	2486.5	259.5	·2534.5	221.0	2505.4	259.4	2504.1	264.2
11/ 1/76	·3723.2	3553.5	·*3409.7	3147.7	·*2091.8	1730.4	·*2070.3	2240.1
11/ 2/76	4966.5	284.6	*4647.2	2156.5	·5215.8	597.3	·*4936.4	1832.8
11/ 3/76	5174.6	36.1	5221.4	27.9	·5236.4	38.9	5190.1	42.6
11/ 4/76	·5754.3	2757.2	5827.4	881.5	·3684.9	1408.2	·*2735.3	2519.7
11/ 5/76	·5278.7	3878.2	7003.0	1469.7	·2427.4	594.7	·* 108.9	189.2
11/ 6/76	7637.8	1205.4	5521.1	1265.2	·2258.0	872.6	·* 64.8	160.4
11/ 7/76	7998.5	1097.2	·5867.9	728.2	·2308.6	409.8	·* 18.4	26.1
11/ 8/76	·7841.2	1841.7	6160.1	990.0	·2148.1	627.9	·* 39.5	81.0
11/ 9/76	6919.0	1182.4	4827.3	921.1	·1255.4	713.8	·* 16.9	36.5
11/10/76	·6969.0	771.1	4663.5	903.2	· 655.0	464.7	·* -14.6	18.6
11/11/76	·7091.2	1307.4	·4854.5	176.9	· 630.7	91.5	* 1.7	14.2

· Numbers not in range

* Negative numbers

Table 6. Daily (24 hour) mean and standard deviation of hourly pH measurements recorded by ion probe monitor during second exposure at Refinery C.

	Control		Act. Sludge		Duo-Media		Act. Carbon	
Date	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
10/11/76	6.5	1.3	·6.2	1.0	·6.2	1.0	·6.2	1.5
10/12/76	·6.3	0.7	·6.3	0.7	·6.2	0.8	·6.3	0.7
10/13/76	·7.4	2.0	·7.4	1.9	·7.5	1.9	·7.5	1.8
10/14/76	*6.1	2.6	6.7	0.3	6.8	0.4	6.8	0.4
DATA LOGGER MALFUNCTIONED								
10/27/76	·6.5	1.7	·6.8	1.3	·6.6	1.0	·6.6	0.9
10/28/76	5.6	0.5	5.4	0.5	5.7	0.5	5.6	0.5
10/29/76	·6.3	0.9	·6.1	1.0	·6.4	0.9	·6.3	0.9
10/30/76	9.6	0.6	9.5	0.7	9.6	0.6	9.6	0.6
10/31/76	·8.2	4.4	·8.4	4.4	·8.3	4.3	·9.0	4.0
11/ 1/76	·5.8	2.1	·5.4	2.0	·5.5	1.9	·5.7	1.8
11/ 2/76	5.7	0.5	5.5	0.5	·5.4	0.8	5.6	0.5
11/ 3/76	5.2	0.1	*4.8	1.3	5.0	0.1	5.2	0.1
11/ 4/76	·6.8	1.3	·6.6	1.1	·6.5	1.0	·6.6	1.0
11/ 5/76	8.1	0.1	7.8	0.1	7.4	0.1	7.6	0.1
11/ 6/76	8.0	0.1	7.7	0.1	7.5	0.0	7.6	0.0
11/ 7/76	8.1	0.1	7.7	0.1	7.5	0.0	7.6	0.0
11/ 8/76	8.1	0.1	*7.3	2.4	7.5	0.0	7.6	0.0
11/ 9/76	8.0	0.1	7.7	0.1	7.5	0.1	7.5	0.0
11/10/76	8.0	0.1	7.8	0.1	7.5	0.0	7.5	0.0
11/11/76	8.0	0.1	7.8	0.0	7.5	0.0	7.4	0.0

· Numbers not in range

*Negative numbers

Table 7. Daily (24 hour) mean and standard deviation of hourly dissolved oxygen (mg/l) concentrations recorded by ion probe monitor during second exposure at Refinery C.

	Control		Act. Sludge		Duo-Media		Act. Carbon	
Date	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
10/11/76	3.1	1.9	3.6	1.6	4.0	1.1	4.1	1.2
10/12/76	4.9	0.2	4.9	0.3	4.9	0.2	4.9	0.2
10/13/76	4.1	1.1	4.2	0.9	4.2	0.8	4.2	0.8
10/14/76	4.7	0.1	4.8	0.1	4.7	0.1	4.7	0.1
			DATA LOGGER MALFUNCTIONED					
10/27/76	3.3	2.1	3.7	1.3	3.7	1.3	4.2	1.4
10/28/76	5.2	0.1	*4.8	2.2	5.1	0.2	5.2	0.1
10/29/76	5.0	0.3	5.0	0.3	*4.5	2.0	5.0	0.3
10/30/76	3.6	0.3	3.7	0.4	3.6	0.3	3.6	0.3
10/31/76	2.5	0.3	2.5	0.2	2.5	0.3	2.5	0.3
11/ 1/76	1.3	1.1	1.6	0.7	1.7	1.0	2.0	1.2
11/ 2/76	•4.9	1.0	•5.0	0.9	5.0	1.0	5.0	0.7
11/ 3/76	5.3	0.0	5.4	0.0	5.4	0.0	5.4	0.0
11/ 4/76	•3.2	2.1	•3.8	1.4	•*3.8	1.9	•4.1	1.2
11/ 5/76	1.1	0.2	2.3	0.3	2.8	0.0	2.8	0.0
11/ 6/76	1.1	0.2	2.3	0.2	2.7	0.0	2.8	0.0
11/ 7/76	1.1	0.2	2.3	0.1	2.6	0.0	2.7	0.0
11/ 8/76	1.1	0.2	2.2	0.2	2.6	0.0	2.7	0.0
11/ 9/76	1.1	0.2	2.3	0.0	2.6	0.0	2.7	0.0
11/10/76	1.1	0.1	2.3	0.2	2.7	0.0	2.7	0.0
11/11/76	1.2	0.2	2.4	0.0	2.7	0.0	2.8	0.0

* Negative numbers

• Numbers not in range

Table 8. Daily (24 hour) mean and standard deviation of hourly conductivity (μ mhos/cm) measurements recorded by ion probe monitor during second exposure at Refinery A.

	Control		Act. Sludge		Dual Media		Act. Carbon	
Date	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
4/18/77	5610.1	230.1	620.9	28.8	508.9	210.1	·1188.5	467.3
4/19/77	4160.8	713.2	498.6	129.0	355.2	113.4	198.9	64.6
4/20/77	5120.3	1690.1	·1109.6	634.5	· 995.9	1477.8	166.3	43.2
DATA LOGGER MALFUNCTIONED								
4/22/77	·* 455.5	2602.2	·* 218.7	809.0	·* 119.3	980.6	·* -80.4	994.7
4/23/77	·* 371.9	1372.5	·* 366.5	907.6	·* 190.1	1015.1	·* 121.2	1036.7
4/24/77	·* 341.4	1872.0	·* 70.6	1349.2	·* 347.3	1340.2	·* 269.1	1521.4
4/25/77	·* 452.2	2719.8	·*-148.4	1818.5	·*-191.8	1810.2	·*-159.2	2072.5
4/26/77	·*-1085.9	2545.3	·*-146.6	2652.2	·* 162.1	2049.2	·* 487.4	1940.8
DATA LOGGER MALFUNCTIONED								
4/28/77	4906.3	688.7	275.0	51.4	· 69.4	24.4	· 85.2	27.5
4/29/77	4432.4	396.7	699.2	561.1	· 413.7	433.0	65.6	19.1
4/30/77	4225.1	382.4	· 930.3	422.6	· 577.1	324.6	· 68.9	15.8
5/ 1/77	4130.7	434.9	302.6	145.1	· 136.2	97.0	56.8	16.5
5/ 2/77	4282.0	584.4	296.7	116.9	· 93.6	75.4	54.3	16.0
5/ 3/77	3646.3	798.3	277.5	117.2	·* 94.9	79.4	64.8	12.4
5/ 4/77	3149.0	494.6	· 422.9	863.4	· 290.9	937.5	· 508.6	1013.3
5/ 5/77	3844.4	288.8	342.7	73.7	· 51.8	28.7	· 63.5	24.0
5/ 6/77	4784.2	418.7	361.6	73.3	·* 43.6	41.4	44.1	21.1
5/ 7/77	4139.9	139.1	140.4	29.5	· 73.1	15.7	187.6	27.9
5/ 8/77	4449.6	115.0	·1047.6	1640.5	· 785.9	1403.3	· 612.2	1097.1
DATA LOGGER MALFUNCTIONED								

· Numbers out of range

* Negative numbers

Table 9. Daily (24 hour) mean and standard deviation of hourly dissolved oxygen concentration (mg/1) recorded by ion probe monitor during second exposure at Refinery A.

	Control		Act. Sludge		Dual Media		Act. Carbon	
Date	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
4/18/77	0.5	0.0	1.2	0.1	1.2	0.1	1.4	0.1
4/19/77	0.7	0.1	1.6	0.1	1.6	0.1	1.6	0.1
4/20/77	0.7	0.2	1.6	0.1	1.7	0.1	1.7	0.1
DATA LOGGER MALFUNCTIONED								
4/22/77	*0.2	0.8	*0.3	0.7	*0.3	0.6	*0.3	0.5
4/23/77	*0.1	0.9	*0.2	0.7	*0.5	0.7	*0.4	0.7
4/24/77	•*0.4	1.2	•*0.6	0.9	•*0.1	0.8	•*0.4	0.9
4/25/77	•*0.1	1.6	•*0.4	1.2	•*0.4	1.1	•*0.4	1.1
4/26/77	•*0.9	1.9	•*0.2	1.7	•*0.2	1.3	•*0.0	1.2
DATA LOGGER MALFUNCTIONED								
4/28/77	0.5	0.0	1.9	0.0	2.0	0.0	2.0	0.0
4/29/77	0.5	0.0	1.8	0.0	1.9	0.0	1.9	0.0
4/30/77	0.5	0.0	1.7	0.0	1.7	0.0	1.7	0.0
5/ 1/77	0.5	0.0	1.6	0.0	1.6	0.0	1.6	0.0
5/ 2/77	0.5	0.0	1.7	0.1	1.8	0.1	1.7	0.1
5/ 3/77	0.6	0.0	1.8	0.1	1.9	0.1	1.8	0.1
5/ 4/77	0.6	0.1	1.7	0.4	1.8	0.3	1.8	0.3
5/ 5/77	0.5	0.0	1.6	0.0	1.7	0.0	1.7	0.1
5/ 6/77	0.5	0.0	1.5	0.0	1.6	0.0	1.6	0.0
5/ 7/77	0.4	0.0	1.2	0.0	1.4	0.0	1.4	0.0
5/ 8/77	0.4	0.1	1.0	0.4	1.1	0.4	1.2	0.4
DATA LOGGER MALFUNCTIONED								

• Numbers not in range

* Negative numbers

Table 10. Daily (24 hour) mean and standard deviation of hourly pH measurements recorded by ion probe monitor during second exposure at Refinery A.

	Control		Act. Sludge		Dual Media		Act. Carbon	
Date	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
4/18/77	7.1	0.0	6.5	0.0	6.6	0.1	6.9	0.1
4/19/77	7.2	0.0	6.5	0.0	6.5	0.0	7.0	0.0
4/20/77	7.6	0.2	6.4	0.0	6.3	0.1	7.2	0.1
DATA LOGGER MALFUNCTIONED								
4/22/77	·3.0	1.7	·2.6	1.3	·2.7	1.3	·2.8	1.6
4/23/77	2.1	0.9	2.1	0.5	2.1	0.5	2.2	0.6
4/24/77	·2.1	1.3	2.2	0.8	2.2	0.8	2.1	0.9
4/25/77	·*2.0	2.1	·*2.4	1.3	·*2.5	1.3	·*2.7	1.5
4/26/77	·*3.3	2.0	·*2.4	2.0	·*1.9	1.6	·*1.9	1.5
DATA LOGGER MALFUNCTIONED								
4/28/77	7.9	0.0	6.1	0.1	5.7	0.2	7.1	0.0
4/29/77	8.0	0.1	6.3	0.1	6.0	0.2	7.1	0.0
4/30/77	8.0	0.1	6.6	0.0	6.5	0.0	7.1	0.0
5/ 1/77	7.9	0.1	6.7	0.0	6.6	0.0	6.9	0.1
5/ 2/77	7.9	0.1	6.7	0.0	6.6	0.0	6.8	0.1
5/ 3/77	7.8	0.2	6.6	0.0	6.6	0.0	6.7	0.1
5/ 4/77	7.7	0.1	·6.9	1.1	7.0	0.6	7.1	0.5
5/ 5/77	7.6	0.0	7.7	0.0	7.6	0.0	7.6	0.0
5/ 6/77	7.7	0.0	7.6	0.0	7.7	0.0	7.7	0.0
5/ 7/77	7.9	0.0	7.9	0.0	7.9	0.0	7.9	0.0
5/ 8/77	7.9	0.0	7.9	0.0	7.9	0.0	7.9	0.0
DATA LOGGER MALFUNCTIONED								

· Numbers out of range

* Negative numbers

APPENDIX B

List of Species and Numbers of Individuals of Benthic Macroinvertebrates Collected and Identified During the Evaluations of the Oil Refinery Wastewater Treatment Methods.

Table 1. Species Composition of Benthic Macroinvertebrates Exposed to Control Lake Water During Evaluation at Oil Refinery B, April 7 to May 7, 1976.

	Days of Exposure					
	Start	2nd	4th	8th	16th	30th
Nematoda						
Unidentified sp.	1	-	-	-	-	-
Annelida						
Oligochaeta						
Unidentified Naid	-	-	-	5	23	16
Dero sp.	111	78	116	100	273	301
Chaetogaster sp.	40	44	47	36	146	211
Nais sp.	16	35	22	22	80	33
Pristina sp.	15	21	5	6	7	13
Slavina appendiculata	12	21	26	21	24	15
Stylaria lacustris	8	3	2	-	1	-
Amphichaeta americana	-	-	1	12	1	1
Naidium sp.	-	1	6	-	-	-
Pristina longiseta leidyi	-	-	-	-	2	6
Aulophorus	-	-	-	-	1	-
Arthropoda						
Crustacea						
Hyalella azteca	25	7	17	5	9	35
Insecta						
Ephemeroptera						
Caenis sp.	47	58	44	33	10	5
Stenonema tripunctatum	7	2	3	3	3	1
Stenonema heterotarsale	2	-	1	4	-	-
Coleoptera						
Deronectes sp.	8	11	12	6	4	-
Peltodytes sp.	-	-	-	1	-	-
Unid. Circulonidae (adult)	-	-	-	1	-	-
Odonata						
Unidentified Anisoptera	1	-	1	-	-	-
Trichoptera						
Unid. Hydropsychidae	-	-	-	-	-	5
Diptera						
Chironomidae						
Dicrotendipes sp.	6	13	3	2	7	4
Micropsectra sp.	6	2	3	2	1	4
Larsia sp.	4	-	-	-	-	-
Cricotopus sp.	2	1	-	-	1	6
Zavrelimyia sp.	1	1	3	-	-	1

	Start	2nd	4th	8th	16th	30th
Paratendipes sp.	1	-	-	-	-	-
Tribelos sp.	1	-	-	-	-	2
Glyptotendipes sp.	1	3	1	-	-	-
Polypedilum fallax	1	-	1	1	1	-
Cardiocladius	-	-	-	1	-	-
Chironomus sp.	-	2	3	3	5	1
Diplocladius sp.	5	-	-	-	-	-
Psectrocladius sp.	1	1	1	-	1	-
Procladius sp.	-	2	3	3	1	-
Endochironomus sp.	-	1	1	-	4	6
Trichocladius sp.	-	1	2	-	-	-
Kiefferulus	-	-	2	-	-	-
Ablabesmyia mallochi	-	1	-	-	-	-
Rheotanytarsus	-	1	3	-	3	-
Potthastia	-	-	-	1	-	-
Ceratopogoniidae						
Dasyhelia sp.	-	-	-	-	1	-
Palpomyia	2	1	-	-	3	1
Mollusca						
Physa sp.	-	-	1	1	1	4
Planorbidae						
Unidentified sp.	-	-	-	-	-	1

Table 2. Species Composition of Benthic Macroinvertebrates Exposed to Activated Sludge Treated Oil Refinery B Effluent for 30 Days, April 7 to May 7, 1976.

	Start	2nd	4th	8th	16th	30th
Nematoda						
Unidentifiable sp.	1					
Annelida						
Oligochaeta						
Dero sp.	111	-	-	-	-	1
Chaetogaster sp.	40	-	-	-	-	-
Nais sp.	16	-	-	-	-	-
Pristina sp.	15	-	-	-	-	-
Slavina appendiculata (d'Udekem)	12	-	-	-	-	-
Stylaria lacustris (Linn)	8	-	-	-	-	-
Amphichaeta americana Chen	-	-	-	-	1	3
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	25	-	-	-	-	-
Insecta						
Ephemeroptera						
Caenis sp.	47	35	60	17	5	-
Stenonema tripunctatum (Banks)	7	3	-	-	-	-
Stenonema heterotarsale (McDunnough)	2		3	1	-	-
Coleoptera						
Deronectes sp.	8	7	4	2	2	-
Odonata						
Unidentifiable Anisoptera	1	-	-	-	-	-
Diptera						
Chironomid						
Dicrotendipes sp.	6	8	12	2	1	-
Micropsectra sp.	6	13	2	1	1	-
Larsia sp.	4	-	2	-	-	
Cricotopus sp.	2	3	1	-	1	-
Zavrelimyia sp.	1	17	5		1	-
Paratendipes sp.	1	-	-	-	-	-
Tribelos sp.	1	-	-	-	-	-
Glyptotendipes sp.	1	1	1	1	-	-
Polypedilum fallax (Beck)	1	1	-	-	-	-
Chironomus sp.	-	-	-	1	-	-
Diplocladius sp.	5	-	-	-	-	-
Psectrocladius A	1	-	2	-	-	-
Psectrocladius B	-	-	1	-	-	-
Procladius sp.	-	1	-	-	1	-
Endochironomus sp.	-	3	-	-	7	-
Trichocladius sp.	-	1	-	-	-	-
Ceratapogoniidae						
Palpomyia sp.	2	2	-	-	-	-
Dasyhelia sp.	-	-	-	-	1	-

Table 3. Species Composition of Benthic Macroinvertebrates Exposed to Sequential Activated Sludge-Dual Media Filtered (BPTCT) Oil Refinery B Effluent for 30 Days, April 7 to May 7, 1976.

	Start	2nd	4th	8th	16th	30th
Nematoda						
Unidentified sp.	1	-	-	-	-	-
Annelida						
Oligochaeta						
Dero sp.	111	6	3	-	1	6
Chaetogaster sp.	40	-	-	-	-	-
Nais sp.	16	3	2	1	-	-
Pristina sp.	15	-	-	-	-	1
Slavina appendiculata (d'Udekem)	12	-	-	-	-	-
Stylaria lacustris (Linn)	8	-	-	-	-	-
Amphichaeta americana Chen	-	-	4	-	1	2
Ophidonais serpentina (Müller)	-	-	-	-	1	-
Aulophorus sp.	-	-	-	-	1	-
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	25	6	3	1	-	-
Insecta						
Ephemeroptera						
Caenis sp.	47	65	52	38	5	-
Stenonema tripunctatum (Banks)	7	3	3	2	-	-
Stenonema heterotarsale (McDunnough)	2	2	1	-	-	-
Coleoptera						
Gyrinus sp.	-	1	-	-	-	-
Tropisternus lateralis (Fabricius)	-	1	-	-	-	-
Deronectes sp.	8	7	11	8	2	-
Odonota						
Unidentifiable Anisoptera	1	-	-	-	-	-
Diptera						
Chironomid						
Dicrotendipes sp.	6	5	6	5	5	-
Micropsectra sp.	6	2	3	1	-	-
Larsia sp.	4	-	-	-	-	-
Cricotopus sp.	2	1	1	-	-	-
Zavrelimyia sp.	1	2	3	2	-	-
Paratendipes sp.	1	-	-	-	-	-
Tribelos sp.	1	1	-	-	-	-
Glyptotendipes sp.	1	2	-	-	-	1
Polypedilum fallax (Beck)	1	3	3	2	-	-
Chironomus sp.	-	1	-	-	2	-
Diplocladius sp.	1	-	-	-	-	-
Psectrocladius A	1	-	-	-	-	-

	Start	2nd	4th	8th	16th	30th
Procladius sp.	-	1	-	-	-	-
Rheotanytarsus sp.	-	-	1	-	-	-
Trichocladius sp.	-	1	-	-	-	-
Ablabesmyia mallochi (Beck)	-	1	-	-	-	-
Endochironomus sp.	-	2	-	1	16	8
Nanocladius sp.	-	-	-	1	-	-
Ceratapogoniidae						
Palpomyia sp.	-	-	-	-	4	2
Dasyhelia sp.	-	-	-	-	-	1
Mollusca						
Physa sp.	-	1	-	-	-	-
Unidentifiable Planoribidae	-	1	-	-	-	-

Table 4. Species Composition of Benthic Macroinvertebrates Exposed to Sequential Activated Sludge-Dual Media Filtered-Activated Carbon Adsorption (BATEA) Oil Refinery B Effluent for 30 Days, April 7 to May 7, 1976.

	Start	2nd	4th	8th	16th	30th
Nematoda						
Unidentifiable sp.	1	-	-	-	-	-
Annelida						
Oligochaeta						
Dero sp.	111	125	71	85	204	203
Chaetogaster sp.	40	14	11	-	12	6
Nais sp.	16	50	27	21	24	28
Pristina sp.	15	2	2	6	4	6
Slavina appendiculata (d'Udekem)	12	11	4	5	3	-
Stylaria lacustris (McDunnough)	8	1	-	-	-	-
Unidentified Naid	-	10	1	-	3	4
Amphichaeta americana Chen	-	-	-	-	1	-
Ophidonais serpentina (Müller)	-	-	-	1	-	-
Aulophorus sp.	-	1	-	-	-	2
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	25	11	11	15	17	14
Insecta						
Ephemeroptera						
Caenis sp.	47	52	57	46	26	8
Stenonema tripunctatum (Banks)	8	4	7	5	3	1
Stenonema heterotarsale (McDunnough)	1	5	1	-	-	1
Coleoptera						
Deronectes sp.	8	8	4	5	5	6
Odonota						
Unidentifiable Anisoptera	1	-	-	-	-	-
Diptera						
Chironomid sp.						
Dicrotendipes sp.	6	3	3	3	9	7
Micropsectra sp.	6	5	4	1	-	4
Larsia sp.	4	-	1	-	-	-
Cricotopus sp.	2	-	1	-	1	4
Zavrelimyia sp.	1	17	14	12	1	-
Paratendipes sp.	1	-	-	-	-	-
Tribelos sp.	1	1	-	-	-	1
Glyptotendipes sp.	1	1	1	-	2	2
Polypedilum fallax (Beck)	1	1	-	-	1	-
Chironomus	-	4	1	3	2	1
Rheotanytarsus sp.	-	1	1	1	1	-
Eukiefferulus sp.	-	-	-	-	1	-
Nanocladius sp.	-	-	-	-	1	-

	Start	2nd	4th	8th	16th	30th
Potthastia sp.	-	2	-	2	-	-
Diplocladius sp.	5	-	-	-	-	-
Trichlocladius sp.	-	-	-	-	-	-
Endochironomus sp.	-	4	1	6	5	5
Procladius sp.	-	2	1	5	4	-
Psectrocladius A	1	-	-	-	1	-
Ceratapogoniidae *Palpolyia* sp.	-	-	-	-	-	-
Mollusca						
Physa sp.	-	-	-	1	1	1

Table 5. Species Composition of Benthic Macroinvertebrates Exposed to Control Lake Water during 30 Day Test at Oil Refinery B, June 6 to July 6, 1976.

	Start	2nd	4th	8th	16th	30th
Annelida						
Oligochaeta						
Dero sp.	25	58	73	51	28	38
Slavina appendiculata (d'Udekem)	1	15	23	21	9	8
Nais sp.	-	6	4	11	1	-
Pristina longeseta leidyi Smith	1	1	6	4	2	-
Stylaria lacustris (Linn)	1	1	1	-	-	-
Amphichaeta americana Chen	1	3	11	9	4	3
Pristina sp.	3	-	2	2	-	-
Unidentified Naid	2	12	5	1	1	-
Chaetogaster sp.	-	-	1		2	15
Aulophorus sp.	-	-	1	2	-	-
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	-	31	15	36	43	61
Insecta						
Ephemeroptera						
Caenis sp.	6	11	12	15	19	195
Unidentified Baetidae	-	-	-	-	1	-
Stenonema heterotarsale (Banks)	-	1	-	-	4	1
Stenonema tripunctatum (McDunnough)	-	3	-	-	2	1
Odonota						
Unidentified Anisoptera		1	-	-	-	-
Unidentified Coenagrionidae		-	-	1	-	-
Coleoptera						
Berosus sp.	1	-	-	-	-	-
Dineutus sp.	2	-	-	1	1	-
Deronectes sp.	1	-	3	-	-	-
Gyrinnidae sp.	-	1	-	3	-	-
Peltodytes sp.	-	2	2	1	1	-
Megalopotera						
Sialis sp.	-	-	-	-	-	1
Trichoptera						
Agaylea sp.	-	-	-	-	10	-
Psychomyiid Genus A	-	-	-	-	-	22
Unidentified Hydropsychidae	-	-	-	-	2	-

	Start	2nd	4th	8th	16th	30th
Diptera						
Chironomus sp.	360	174	175	58	15	9
Procladius sp.	14	2	1	-	3	-
Rheotanytarsus sp.	5	19	34	10	15	-
Ablabesmyia mallochi	9	13	6	3	2	-
Tribelos sp.	-	1	-	-	3	1
Dicrotendipes sp.	5	27	33	47	80	9
Endochironomus sp.	1	-	-	-	1	-
Ablabesmyia ornata	7	25	17	9	3	-
Ablabesmyia aspera	10	-	5		-	-
Glyptotendipes sp.	5	6	7	2	7	9
Polypedilum fallax	3	2	1	4	1	2
Pseudochironomus sp.	-	1	-		-	-
Micropsectra sp.	2	32	14	13	15	-
Pedionomus beckae	-	1	-		-	-
Cryptochironomus sp.	-	1	-	2	-	-
Polypedilum sp.	-	3	-	2	1	1
Microtendipes sp.	-	1	1	4	6	3
Kiefferulus sp.	-	1	1	1	-	-
Zavrelimyia sp.	-	-	1	1	-	-
Corynoneura sp.	-	-	1	-	-	-
Cricotopus sp.	-	-	-	1	1	3
Conchapelma sp.	-	-	-	-	-	
Tanytarsus sp.	-	-	-	-	-	2
Labrundinia sp.	-	-	-	-	-	1
Mollusca						
Unidentified Decapoda	5	1	-	2	-	-
Unidentified Pelycypoda	-	-	1	-	-	-
Physa sp.	1	1	1	99	-	-
Ferrissia sp.	-	-	2	-	-	-

Table 6. Species Composition of Benthic Macroinvertebrates Exposed to Activated Sludge Treated Oil Refinery B Effluent for 32 Days, June 6 to July 6, 1976.

	Start	2nd	4th	8th	16th	32nd
Nematoda						
Unidentified sp.	-	-	-	-	1	-
Annelida						
Amphichaeta americana	1		1	-	36	7
Unidentified Naid	2	1	-	4	-	-
Dero sp.	25	-	-	-	-	-
Slavina appendiculata (d'Udekem)	1	-	-	-	-	-
Pristina longeseta leidyi Smith	1	-	-	-	-	-
Stylaria lacustris	1	-	-	-	-	-
Pristina sp.	3	-	-	-	-	-
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	-	-	-	-	-	-
Insecta						
Ephemeroptera						
Caenis sp.	6	-	-	-	-	-
Unidentified Baetidae	-	-	-	-	-	-
Stenonema heterotarsale (Banks)	1	-	-	-	-	-
Stenonema tripunctatum (McDunnough)	3	-	-	-	-	-
Odonata						
Unidentified Anisoptera	1	-	-	-	-	-
Unidentified Coenagrionidae	-	-	-	-	-	-
Coleoptera						
Berosus sp.	1	-	-	-	-	-
Dineutus sp.	2	-	-	-	-	-
Deronectes sp.	1	-	-	-	-	-
Unidentified Gyrinnidae	1	-	-	-	-	-
Peltodytes sp.	1	-	-	-	-	-
Diptera						
Chironomid						
Chironomus sp.	360	14	10	-	-	-
Procladius sp.	14	-	-	-	-	-
Rheotanytarsus sp.	5	3	-	-	-	-
Ablabesmyia mallochi (Beck)	9	2	-	-	-	-
Dicrotendipes sp.	5	4	11	2	5	-
Endochironomus	1	1	-	-	1	-
Ablabesmyia ornata (Beck)	7	2	-	-	-	-
Ablabesmyia aspera (Beck)	10	-	1	-	-	-
Glyptotendipes sp.	5	-	2	-	-	-
Polypedilum fallax (Beck)	3	-	-	-	-	-
Micropsectra sp.	2	3	3	-	-	-

	Start	2nd	4th	8th	16th	32nd
Kiefferulus sp.	-	1	-	-	-	-
Rheotanytarsus sp.	-	3	5	-	-	-
Ablabesmyia janta (Beck)	-	-	1	-	-	-
Cryptochironomus sp.	-	-	1	-	-	-
Tribelos sp.	-	-	-	-	-	1
Tanypus sp.	-	-	-	-	-	1
Mollusca						
Unidentified Decapoda	5					
Physa sp.	1					

Table 7. Species Composition of Benthic Macroinvertebrates Exposed to Sequential Activated Sludge Treated-Dual Media Filtered (BPTCT) Oil Refinery B Effluent for 32 Days, June 6 to July 6, 1976.

	Start	2nd	4th	8th	16th	32nd
Nematoda						
Unidentified sp.	-	4	-	1	1	
Annelida						
Amphichaeta americana Chen	1	5	9	5	18	20
Unidentified Naid	2	1	1	2	4	-
Dero	25	-	-	1	1	-
Slavina appendiculata (d'Udekem)	1	-	-	-	-	-
Pristina longeseta leidyi Smith	1	-	-	-	-	-
Stylaria lacustris (Linn)	1	-	-	-	-	-
Pristina sp.	3	-	-	-	-	-
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	-	-	-	-	-	-
Insecta						
Ephemeroptera						
Caenis sp.	6	1	1	-	-	-
Unidentified Baetidae	-	-	-	-	-	-
Stenonema heterotarsale (Banks)	1	-	-	-	-	-
Stenonema tripunctatum (McDunnough)	3	-	-	-	-	-
Coleoptera						
Berosus sp.	1	-	-	-	1	-
Dineutus sp.	2	-	-	-	-	-
Deronectes sp.	1	-	-	-	-	-
Unidentified Gyrinnidae	1	-	-	-	-	-
Peltodytes sp.	1	1	-	-	-	-
Diptera						
Chironomid						
Chironomus sp.	360	23	10	-	1	-
Procladius sp.	14	-	-	-	-	-
Rheotanytarsus sp.	5	5	7	1	-	-
Ablabesmyia mallochi (Beck)	9	1	-	-	-	-
Dicrotendipes sp.	5	14	13	10	16	-
Endochironomus	1	1	-	-	-	-
Ablabesmyia ornata (Beck)	7	11	2	-	-	-
Ablabesmyia aspera (Beck)	10	-	-	-	-	-
Glyptotendipes sp.	5	1	3	-	1	-
Polypedilum fallax (Beck)	3	1	-	-	-	-
Micropsectra sp.	2	5	3	-	-	-
Zavrelimyia sp.	-	1	-	-	-	-

	Start	2nd	4th	8th	16th	32nd
Cryptochironomus sp.	-	1	-	-	-	-
Kiefferulus sp.	-	1	1	-	-	-
Tribelos sp.	-	-	1	1	2	7
Larsia sp.	-	-	-	-	1	-
Tanypus sp.	-	-	-	-	-	1
Labrundinia sp.	-	-	-	-	-	2
Smitta sp.	-	-	-	-	-	1
Ceratapogoniidae						
Palpomyia sp.	-	-	-	-	2	-
Mollusca						
Unidentified Decapoda	-	1	-	-	-	-
Physa sp.	-	1	-	-	-	-

Table 8. Species Composition of Benthic Macroinvertebrates Exposed to Sequential Activated Sludge-Dual Media Filtered-Activated Carbon Adsorption (BATEA) Oil Refinery B Effluent for 32 Days, June 6 to July 6, 1976.

	Start	2nd	4th	8th	16th	32nd
Nematoda						
Unidentified sp.	-	1	1	1	-	-
Annelida						
Oligochaeta						
Dero sp.	25	70	52	45	48	154
Slavina appendiculata (d'Udekem)	1	2	2	-	-	-
Nais sp.	-	4	5	3	2	-
Pristina longeseta leidyi Smith	1	-	1	2	-	1
Stylaria lacustris (Linn)	1	-	-	-	-	-
Amphichaeta americana Chen	1	11	3	1	-	5
Pristina sp.	3	-	-	-	-	1
Unidentified Naid	2	-	-	4	3	2
Chaetogaster sp.	-	-	1	-	-	-
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	-	7	18	29	19	19
Insecta						
Ephemeraptora						
Caenis sp.	6	10	6	9	7	2
Unidentified Baetinae	-	-	-	-	-	23
Stenonema heterotarsale (Banks)	1	-	2	-	-	-
Stenonema tripunctatum (McDunnough)	3	-	-	1	-	-
Odonata						
Unidentified Anisoptera	1	-	-	-	-	-
Unidentified Coenagrionidae	1	-	-	-	-	-
Coleoptera						
Berosus	1	-	-	-	-	-
Dineutus	2	1	2	-	-	-
Deronectes	1	1	-	-	-	-
Gyrinnidae	-	1	-	1	-	-
Peltodytes	-	-	-	1	-	-
Trichoptera						
Psychomyiid Genus A	-	-	-	1	-	2
Diptera						
Chironomid						
Chironomus sp.	360	205	179	45	13	14
Procladius sp.	14	4	5			1
Rheotanytarsus sp.	5	16	13	11	6	2
Ablabesmyia mallochi (Beck)	9	12	5	4	2	-
Tribelos sp.	-	-	-	-	5	6
Dicrotendipes sp.	5	38	44	58	130	5

	Start	2nd	4th	8th	16th	32nd
Endochironomus sp.	1	-	-	-	-	-
Ablabesmyia ornata (Beck)	7	26	13	14	-	-
Ablabesmyia aspera (Beck)	10	-	-	-	-	-
Glyptotendipes sp.	5	5	3	13	10	3
Polypedilum fallax (Beck)	3	-	2	2	9	2
Micropsectra sp.	2	28	19	7	5	-
Polypedilum sp.	-	3	-	-	2	-
Cricotopus	-	1	-	-	1	-
Pseudochironomus	-	1	-	-	1	-
Eukiefferiella	-	1	-	-	-	-
Paratendipes	-	1	-	1	1	-
Zavrelimyia	-	1	-	-	1	-
Cryptochironomus	-	-	2	1	-	-
Kiefferulus	-	-	1	-	-	-
Microtendipes	-	-	-	2	-	-
Tanytarsus	-	-	-	-	-	1
Tanypus	-	-	-	-	-	3
Psychodidae						
Psychoda sp.	-	-	-	-	-	1
Ceratapogoniidae						
Palpomyia sp.	-	-	1	2	1	4
Megaloptera						
Sialis sp.	-	-	-	-	1	-
Mollusca						
Unidentified Decapoda	5	3	-	-	2	2
Unidentified Pelycypoda	-	-	1	-	-	-
Physa sp.	-	-	1	2	-	-
Unidentified Planoribidae	-	1	1	-	-	-

Table 9. Species Composition of Benthic Macroinvertebrates Exposed to Control Water for 32 Days, August 30 to October 1, 1976.

	Days of Exposure					
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unidentified sp.	-	13	6	3	27	10
Nematoda						
Unidentified sp.	-	-	-	-	1	-
Annelida						
Oligochaeta						
Pristina sp.	1	-	4	4	35	23
Dero sp.	34	235	364	357	485	483
Chaetogaster sp.	-	-	-	-	23	83
Nais sp.	-	-	-	3	-	-
Stylaria lacustris (Linn.)	-	-	1	-	-	-
Aulophorus sp.	-	-	-	-	2	-
Hirudinea						
Unidentified sp.	1	-	-	-	-	-
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	4	-	2	5	9	10
Arachnoidea						
Unidentified sp.	-	-	-	-	1	-
Insecta						
Neuroptera						
Clanacia sp.	-	-	1	-	-	-
Ephemeroptera						
Stenonema sp.	18	8	7	4	17	31
Caenis sp.	428	292	396	261	733	1,024
Callibaetis sp.	1	2	2	7	15	14
Odonata						
Enallagma sp.	-	5	4	5	4	3
Argia sp.	108	138	110	117	224	209
Unidentified sp.	-	-	-	-	1	1
Coleoptera						
Unidentified sp. A	-	1	-	-	2	1
Dineutus sp.	3	4	7	6	3	-
Helichus suturalis LeConte	1	-	-	-	-	-
Tropisternus lateralis (Fabricius)	-	-	-	2	-	-
Berosus sp.	-	-	-	1	1	-
Laccophilus sp.	-	-	-	-	-	-
Trichoptera						
Psychomyiid Genus A (Ross)	44	18	22	37	47	178
Agaylea sp.	10	14	20	29	15	-
Orthotrichia sp.	2	7	4	-	6	8
Unidentified sp.	-	-	1	-	-	-
Oxeythira sp.	-	1	3	9	1	-

	Start	2nd	4th	8th	16th	32nd
Hemiptera						
Unidentified sp.	-	-	1	-	-	-
Diptera						
Chironomidae						
Glyptotendipes sp.	154	514	308	411	460	540
Einfeldia sp.	193	634	946	1,615	1,412	93
Dicrotendipes nervosus (Mason)	35	10	16	55	13	8
Dicrotendipes modestus (Mason)	6	5	8	-	-	-
Polypedilum sp.	1	2	11	30	-	-
Procladius sp.	1	-	-	-	-	3
Tribelos sp.	5	14	20	70	58	42
Ablabesmyia janta (Beck)	2	6	5	19	13	2
Micropsectra sp.	4	-	2	8	-	-
Labrundinia sp.	4	9	11	9	-	-
Pseudochironomus sp.	1	-	2	-	12	-
Parachironomus sp.	1	9	7	4	-	-
Larsia sp.	1	-	-	-	-	-
Endochironomus sp.	-	1	3	4	21	12
Rheotanytarsus sp.	-	-	2	-	-	-
Tanytarsus sp.	-	-	18	-	-	-
Xenochironomus xenobalis (Mason)	-	-	-	4	-	-
Goeldichironomus sp.	-	-	-	1,321	2,480	106
Chironomus sp.	-	-	-	11	-	-
Cricotopus A	-	-	-	90	2,049	-
Cricotopus B	-	-	-	-	268	-
Tanypus sp.	-	-	-	-	-	6
Cladotanytarsus sp.	-	-	-	-	-	2
Unidentified sp. A	3	2	2	4	-	-
Ceratopogoniidae						
Palpomyia sp.	1	8	9	12	10	5
Dasyhelia sp.	-	-	-	-	-	4
Mollusca						
Planoribidae						
Unidentified sp.	-	-	-	-	3	-
Ancylidae						
Unidentified sp.	-	1	3	2	6	6
Physidae						
Unidentified sp.	-	2	-	-	-	-

Table 10. Species Composition of Benthic Macroinvertebrates Exposed to Biologically Treated Oil Refinery C Effluent for 32 Days, August 30 to October 1, 1976.

		Days of Exposure				
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unidentified sp.	-	13	6	1	4	13
Nematoda						
Unidentified sp.	-	-	-	-	1	1
Annelida						
Pristina sp.	1	-	-	1	10	273
Dero sp.	34	181	303	140	112	343
Chaetogaster sp.	-	-	-	1	-	5
Nais sp.	-	-	-	1	-	-
Aulophorus sp.	-	-	-	1	1	1
Hirudinea						
Unidentified sp.	1	-	-	-	-	-
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	4	1	1	1	5	15
Arachnoidea						
Unidentified sp.	-	-	-	-	1	1
Hydracarina						
Unidentified sp.	-	1	-	-	-	-
Insecta						
Ephemeroptera						
Stenonema sp.	18	8	17	4	5	7
Caenis sp.	428	223	236	244	246	650
Callibaetis sp.	1	4	6	4	3	-
Odonata						
Enallagma sp.	-	-	1	-	2	6
Argia sp.	108	103	137	100	198	129
Unidentified sp.	-	-	1	1	1	-
Coleoptera						
Unidentified sp. A	-	1	-	-	1	1
Dineutus sp.	3	8	6	5	2	-
Tropisternus lateralis (Fabricius)	1	-	3	5	19	3
Berosus sp.	-	-	-	-	1	-
Enochrus sp.	-	-	-	-	-	5
Helophorus sp.	-	-	-	-	-	1
Laccophilus sp.	-	-	-	-	1	-
Unidentified sp. B	-	-	-	-	-	1
Trichoptera						
Psychomyiid Genus A (Ross)	44	34	44	64	53	96
Agaylea sp.	10	4	10	27	10	-

	Start	2nd	4th	8th	16th	32nd
Oxeythira sp.	2	1	2	1	-	-
Orthotrichia sp.	2	1	2	2	-	5
Diptera						
Chironomidae						
Glyptotendipes sp.	154	418	342	865	760	433
Einfeldia sp.	193	769	1,142	2,136	1,094	12
Dicrotendipes nervosus(Mason)	35	14	58	216	46	-
Polypedilum sp.	1	1	17	42	-	-
Dicrotendipes modestus(Mason)	6	4	6	-	-	-
Procladius sp.	1	-	-	-	-	-
Tribelos sp.	5	13	32	300	418	92
Ablabesmyia janta (Beck)	2	11	22	170	333	-
Micropsectra sp.	4	2	6	19	-	-
Labrundinia sp.	4	3	8	130	-	-
Pseudochironomus sp.	1	-	5	-	-	-
Parachironomus sp.	1	7	34	254	-	-
Larsia sp.	1	-	-	-	29	-
Paracladopelma sp.	-	1	2	-	-	-
Endochironomus sp.	-	3	2	137	351	-
Cryptochironomus sp.	-	1	-	-	-	-
Clinotanypus sp.	-	1	-	-	-	-
Goeldichironomus sp.	-	-	3	3,488	3,573	2,354
Chironomus sp.	-	-	3	354	-	248
Conchapedopia sp.	-	-	1	-	-	-
Xenochironomus xenobalis(Mason)	-	-	1	-	-	-
Tanypus sp.	-	-	-	221	-	-
Cricotopus A	-	-	-	87	253	128
Cricotopus B	-	-	-	-	12	26
Unidentified sp. A	3	2	-	-	-	-
Unidentified sp. B	-	-	-	-	-	1
Ceratopogoniidae						
Palpomyia sp.	1	9	5	3	3	2
Mollusca						
Planoribidae						
Unidentified sp.	-	-	-	-	4	-
Physidae						
Unidentified sp.	-	-	-	1	-	1
Ancylidae						
Unidentified sp.	-	-	-	-	5	12

Table 11. Species Composition of Benthic Macroinvertebrates Exposed to Sequential Biological-Dual Media Filter Treated Oil Refinery C Effluent for 32 Days, August 30 to October 1, 1976.

	Days of Exposure					
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unidentified sp.	-	2	4	7	2	-
Annelida						
Oligochaeta						
Pristina sp.	1	-	-	10	11	52
Dero sp.	34	131	258	212	22	44
Aulophorus sp.	-	-	1	1	1	-
Nais sp.	-	-	-	1	-	-
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	4	1	1	1	6	4
Arachnoidea						
Unidentified sp.	-	-	-	-	-	2
Insecta						
Ephemeroptera						
Stenonema sp.	18	12	11	5	3	1
Caenis sp.	428	359	304	151	243	264
Callibaetis sp.	1	4	5	1	-	1
Odonata						
Argia sp.	108	200	143	132	219	162
Enallagma sp.	-	2	2	3	3	4
Unidentified sp.	-	-	-	1	-	-
Coleoptera						
Unidentified sp. A	-	-	-	-	1	-
Helichus suturalis LeConte	1	-	-	-	-	-
Dineutus sp.	3	5	3	3	3	-
Enochrus sp.	-	-	-	-	-	1
Tropisternus lateralis (Fabricius)	-	-	-	2	41	21
Berosus sp.	-	-	2	-	2	1
Hydrophilidae						
Unidentified sp. C	-	-	-	-	1	-
Dytiscidae						
Unidentified sp. D	-	-	-	-	1	-
Sphaeriidae						
Unidentified sp. E	-	-	1	-	-	-
Trichoptera						
Psychomyiid Genus A (Ross)	44	25	14	25	18	41
Agaylea sp.	10	13	11	18	13	-
Orthotrichia sp.	2	1	5	4	3	6
Oecetis sp.	-	1	-	-	-	-
Oxeythira sp.	-	1	2	3	-	-

	Start	2nd	4th	8th	16th	32nd
Diptera						
Chironomidae						
Glyptotendipes sp.	154	335	198	1,413	716	723
Dicrotendipes nervosus(Mason)	35	15	31	318	20	-
Polypedilum sp.	1	4	14	-	-	-
Einfeldia sp.	193	476	824	2,181	1,732	
Procladius sp.	1	-	2	-	-	-
Tribelos sp.	5	11	7	100	28	55
Ablabesmyia janta (Beck)	2	9	7	79	-	-
Micropsectra sp.	4	-	11	-	-	-
Labrundinia sp.	4	4	9	20	-	-
Pseudochironomus sp.	1	3	-	-	-	-
Larsia sp.	1	1	-	12	-	-
Parachironomus sp.	1	5	21	34	-	-
Dicrotendipes modestus(Mason)	-	1	3	-	-	-
Endochironomus sp.	-	1	1	-	21	-
Chironomus sp.	-	1	-	181	-	85
Cryptochironomus sp.	-	1	-	-	-	-
Rheotanytarsus sp.	-	-	1	-	-	-
Tanypus sp.	-	-	1	178	-	-
Goeldichironomus	-	-	-	2,718	8.651	4,494
Cricotopus sp. A	-	-	-	252	190	370
Cricotopus sp. B	-	-	-	-	-	5
Unidentified sp.	3	2				
Ephydridae						
Unidentified sp.	-	-	-	-	1	-
Ceratopogoniidae						
Forcipomyia sp.	-	-	1	-	-	-
Palpomyia sp.	1	2	2	11	2	1
Mollusca						
Ancylidae						
Unidentified sp.	-	-	-	1	-	-

Table 12. Species Composition of Benthic Macroinvertebrates Exposed to Sequential Biological-Dual Media Filter-Activated Carbon Treated Oil Refinery C Effluent for 32 Days, August 30 to October 1, 1976.

	Days of Exposure					
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unidentified sp.	-	12	4	14	1	8
Nematoda						
Unidentified sp.	-	-	-	-	-	1
Annelida						
Pristina sp.	1	-	6	11	5	42
Dero sp.	34	63	395	193	169	491
Aulophorus sp.	-	-	1	3	-	-
Nais sp.	-	-	-	4	-	-
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	4	2	2	2	2	7
Arachnoidea						
Unidentified sp.	-	-	-	-	-	2
Insecta						
Ephemeroptera						
Stenonema sp.	18	13	13	7	8	18
Caenis sp.	428	376	444	222	230	493
Callibaetis sp.	1	2	4	22	4	-
Odonata						
Argia sp.	108	120	195	109	160	210
Enallagma sp.	-	2	6	5	4	2
Unidentified sp.	-	1	-	-	-	1
Coleoptera						
Unidentified sp. A	-	-	1	-	-	-
Dineutus sp.	3	7	7	3	1	-
Berosus sp.	-	-	-	-	-	1
Helophorus sp.	-	-	-	-	2	-
Tropisternus lateralis (Fabricius)	-	-	2	-	13	
Copelatus sp.	-	-	-	-	1	
Trichoptera						
Psychomyiid Genus A (Ross)	44	13	14	87	21	117
Agaylea sp.	10	18	17	52	30	
Orthotrichia sp.	2	3	1	-	4	10
Oxeythira sp.	-	2	8	18	2	
Diptera						
Chironomidae						
Glyptotendipes sp.	154	194	295	487	567	728
Dicrotendipes nervosus(Mason)	35	29	16	65	43	6
Polypedilum sp.	1	2	6	424	-	-
Einfeldia sp.	193	1,066	827	1,135	1,058	29
Procladius sp.	1	-	-	-	-	-
Tribelos sp.	5	12	17	448	34	55

	Start	2nd	4th	8th	16th	32nd
Unidentified sp.	3	-	1	-	-	8
Ablabesmyia janta (Beck)	2	9	14	23	6	-
Micropsectra sp.	4	-	2	6	-	-
Labrundinia sp.	4	6	4	815	-	-
Pseudochironomus sp.	1	3	3	-	-	-
Parachironomus sp.	1	6	12	17	-	-
Paratendipes sp.	-	-	3	-	-	-
Kiefferulus sp.	-	-	1	-	-	-
Endochironomus sp.	-	-	2	408	8	4
Cladotanytarsus sp.	-	-	1	-	-	-
Chironomus sp.	-	-	-	51	9	41
Cricotopus sp. A	-	-	-	29	1,134	380
Cricotopus sp. B	-	-	-	-	110	30
Psectrocladius sp.	-	-	-	6	-	-
Goeldichironomus sp.	-	-	-	2,423	1,322	612
Tanypus sp.	-	-	-	-	-	6
Dicrotendipes modestus (Mason)	6	4	4	45	-	-
Ceratopogoniidae						
Palpomyia sp.	1	6	4	14	5	2
Forcipomyia sp.	-	-	1	-	-	-
Mollusca						
Ancylidae						
Unidentified sp.	-	-	-	4	4	6

Table 13. Species Composition of Benthic Macroinvertebrates Exposed to Control Water for 32 Days at Oil Refinery C, October 11 to November 12, 1976.

	Days of Exposure					
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unidentified sp.	2	1	21	11	13	-
Nematoda						
Unidentified sp.	-	2	6	1	-	-
Annelida						
Oligochaeta						
Dero sp.	360	537	603	951	985	180
Nais sp.	22	35	63	52	69	-
Aulophorus furcatus	5	2	2	7	1	-
Unidentified sp.	7	3	31	48	52	1
Pristina longiseta leidyi	3	3	3	3	5	1
Stylaria lacustris	1	10	4	6	4	-
Chaetogaster	-	17	123	208	115	5
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	5	9	10	16	14	7
Arachnoidea						
Unidentified sp.	1	-	-	-	2	2
Insecta						
Megaloptera						
Sialis sp.	-	-	-	-	-	1
Ephemeroptera						
Stenonema sp.	17	18	14	13	12	15
Caenis sp.	879	817	913	817	840	440
Callibaetis sp.	-	4	2	1	4	1
Stenonema bipunctatum	-	-	-	-	-	1
Odonata						
Argia sp.	286	179	144	138	143	113
Enallagma sp.	12	5	8	11	9	1
Triacanthagyna sp.	2	1	-	-	-	1
Coleoptera						
Dubiraphia sp.	9	-	-	-	1	-
Tropisternus sp.	-	1	1	4	-	-
Berosus sp.	-	1	-	-	-	1
Dineutus sp.	-	-	-	1	-	-
Deronectus sp.	-	-	-	-	1	-
Helophorus sp.	-	-	-	-	1	-
Trichoptera						
Orthotrichia sp.	45	44	72	74	66	24
Oecetis sp.	1	1	-	-	1	-
Agraylea sp.	1	3	4	8	14	3
Glossosoma sp.	-	7	3	7	3	-
Psychomyiid Genus A	229	211	175	59	160	67

	Start	2nd	4th	8th	16th	32nd
Corixidae						
Unidentified sp.	-	-	1	-	1	-
Chironomidae						
Glyptotendipes sp.	330	2,451	1,477	1,468	2,154	871
Einfeldia sp.	199	1,112	1,164	1,240	1,886	970
Tanypodinae sp.	13	18	30	20	42	20
Dicrotendipes *nervosus*(Mason)	13	68	63	72	58	49
Tribelos sp.	6	67	80	94	110	85
Endochironomus	3	2	-	5	12	31
Dicrotendipes *modestus*	2	19	6	26	-	6
Polypedilum sp.	3	-	6	3	-	-
Parachironomus sp.	1	13	-	-	4	-
Rheotanytarsus sp.	1	17	9	-	-	-
Chironomus sp.	1	-	-	-	-	5
Micropsectra sp.	1	-	-	-	-	-
Smitta sp.	1	1	-	-	-	-
Cricotopus A	-	43	59	91	288	86
Cricotopus B	-	51	44	79	112	26
Goeldichironomus sp.	-	45	33	7	38	107
Rheotanytarsus sp.	-	1	-	11	-	-
Psectrocladius sp.	-	-	6	-	-	-
Kiefferulus sp.	-	-	6	-	-	-
Pseudochironomus sp.	-	-	-	3	-	-
Corynoneura sp.	-	-	-	-	6	-
Ceratopogoniidae						
Palpomyia sp.	7	40	16	34	28	9
Alluandomyia sp.	-	2	-	-	-	-
Mollusca						
Physidae						
Unidentified sp.	3	-	5	3	1	-
Planorbidae						
Unidentified sp.	-	-	3	1	3	-
Ancylidae						
Unidentified sp.	-	-	1	3	2	-

Table 14. Species Composition of Benthic Macroinvertebrates Exposed to Lagoon Treated Oil Refinery C Effluent for 32 Days, October 11 to November 12, 1976.

	Days of Exposure					
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unidentified sp.	2	1	6	5	1	1
Nematoda						
Unidentified sp.	-	-	1	-	-	-
Annelida						
Oligochaeta						
Dero sp.	360	360	894	404	1,003	935
Nais sp.	22	26	33	24	1	3
Aulophorus furcatus	5	2	5	2	1	4
Unidentified sp.	7	7	36	15	20	4
Pristina longiseta leidyi	3	1	2	1	3	2
Stylaria lacustris	1	3	4	3	8	-
Chaetogaster sp.	-	-	2	1	2	-
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	5	7	5	7	16	3
Isopoda						
Unidentified sp.	-	1	-	-	-	-
Arachnoidea						
Unidentified sp.	1	-	-	-	-	-
Insecta						
Ephemeroptera						
Caenis sp.	879	666	542	357	366	184
Stenonema sp.	17	7	14	5	8	1
Callibaetis sp.	-	-	-	1	-	-
Odonata						
Argia sp.	286	159	124	149	133	115
Enallagma sp.	12	12	3	6	10	2
Unidentified sp.	2	-	-	-	-	-
Coleoptera						
Dubiraphia sp.	9	-	-	-	-	-
Berosus sp.	-	1	-	-	1	-
Enochrus sp.	-	1	-	-	-	-
Tropisternus lateralis	-	-	1	1	-	1
Paracymus	-	-	-	1	-	-
Agabus	-	-	-	1	-	-
Unidentified sp.	-	-	-	-	1	-
Trichoptera						
Orthotrichia sp.	45	48	71	32	24	3
Psychomyiid Genus A	229	129	115	114	156	57
Oecetis sp.	1	-	-	-	-	-
Agraylea sp.	1	2	6	3	6	-
Glossosoma sp.	-	2	4	1	2	-

	Start	2nd	4th	8th	16th	32nd
Oxyethira sp.	-	-	1	-	-	-
Corixidae						
Unidentified sp.	-	-	9	6	3	-
Simuliidae						
Simulium sp.	-	-	-	2	-	-
Tipulidae						
Limonia sp.	-	-	-	1	-	-
Hebridae						
Merragata brevis(Usinger)	-	-	-	-	-	1
Chironomidae						
Glyptotendipes sp.	330	1,418	1,470	1,057	1,552	980
Einfeldia sp.	199	846	1,051	1,014	1,274	899
Tanypodinae sp.	13	92	92	53	44	36
Dicrotendipes nervosus(Mason)	13	92	92	53	44	36
Tribelos sp.	6	37	75	11	148	102
Endochironomus sp.	3	27	24	4	22	49
Dicrotendipes modestus(Mason)	2	6	4	3	14	5
Polypedilum sp.	3	-	-	3	-	-
Parachironomus sp.	1	4	-	6	22	5
Rheotanytarsus sp.	1	2	8	6	7	-
Chironomus sp.	1	-	-	6	-	-
Micropsectra sp.	1	-	15	-	-	-
Smitta sp.	1	-	-	-	-	-
Goeldichironomus	-	340	879	465	345	150
Ablabesmyia peleensis(Beck)	-	6	6	-	-	-
Cricotopus A	-	1	-	3	21	81
Pseudochironomus sp.	-	6	-	-	-	-
Cricotopus B	-	-	27	8	7	9
Psectrocladius sp.	-	2	23	-	-	-
Alluaridomyia sp.	-	-	-	-	-	1
Kiefferulus sp.	-	-	-	-	-	5
Ceratopogoniidae						
Palpomyia sp.	7	14	16	15	18	5
Mollusca						
Planorbidae						
Unidentified sp.	-	-	-	-	5	1
Ancylidae						
Unidentified sp.	-	-	1	-	1	-
Physidae						
Unidentified sp.	3	-	1	1	3	1

Table 15. Species Composition of Benthic Macroinvertebrates Exposed to Sequential Lagoon Treated-Dual-Media Filtered (BPTCT) Oil Refinery C Effluent for 32 Days October 11 to November 12, 1976.

	Days of Exposure					
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unidentified sp.	2	6	7	5	2	2
Nematoda						
Unidentified sp.	-	-	3	1	-	-
Annelida						
Oligochaeta						
Dero sp.	360	522	973	461	851	513
Nais sp.	22	27	55	2	79	5
Aulophorus furcatus	5	6	5	6	1	-
Unidentified sp.	7	15	43	6	43	8
Pristina longiseta leidyi	3	4	5	2	3	1
Stylaria lacustris	1	7	5	-	4	-
Chaetogaster sp.	-	3	1	1	6	-
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	5	9	6	3	10	-
Arachnoidea						
Unidentified sp.	1	1	-	2	1	1
Insecta						
Ephemeroptera						
Stenonema sp.	17	7	10	16	13	-
Caenis sp.	879	586	712	747	515	180
Callibaetis sp.	-	-	1	1	2	-
Odonata						
Argia sp.	286	130	177	202	120	99
Enallagma sp.	12	3	8	7	8	2
Unidentified sp.	2	-	2	-	-	-
Coleoptera						
Dubiraphia sp.	9	-	-	-	-	-
Berosus sp.	-	1	-	-	-	1
Dineutus sp.	-	-	1	-	-	-
Tropisternus lateralis(Usinger)	-	-	-	4	-	-
Berosus sp.	-	-	-	2	-	-
Copelatus sp.	-	-	-	1	-	-
Aydrovatus sp.	-	-	-	1	-	-
Trichoptera						
Orthotrichia sp.	45	48	71	35	53	9
Psychomyiid Genus A	229	167	63	41	143	37
Oecetis sp.	1	-	-	1	-	1
Agraylea sp.	1	4	1	2	6	-
Glossosoma sp.	-	2	3	5	4	-
Corixidae						
Unidentified sp.	-	10	2	1	1	1

	Start	2nd	4th	8th	16th	32nd
Chironomidae						
Glyptotendipes sp.	330	1,185	1,728	1,124	1,864	863
Einfeldia sp.	199	861	1,084	1,074	1,984	746
Tanypodinae sp.	13	29	48	43	30	18
Dicrotendipes nervosus (Mason)	13	22	29	61	118	80
Tribelos sp.	6	26	53	45	110	54
Endochironomus sp.	3	19	6	11	8	39
Dicrotendipes modestus (Mason)	2	7	7	6	-	2
Polypedilum sp.	3	-	7	-	-	-
Parachironomus sp.	1	-	-	-	15	-
Rheotanytarsus sp.	1	-	-	-	-	7
Chironomus sp.	1	-	12	-	-	2
Micropsectra sp.	1	-	11	-	-	-
Smitta sp.	1	-	-	-	-	-
Pseudochironomus sp.	-	4	-	-	-	3
Goeldichironomus sp.	-	749	920	750	709	340
Ablabesmyia peleensis (Beck)	-	-	6	-	-	-
Larsia sp.	-	-	7	-	-	-
Ablabesmyia janta	-	-	-	4	-	-
Cricotopus A	-	-	-	6	46	62
Cricotopus B	-	-	-	-	6	6
Ceratopogoniidae						
Palpomyia sp.	7	23	21	8	28	8
Dasyhelia sp.	-	-	1	-	-	-
Mollusca						
Physidae						
Unidentified sp.	3	3	2	3	1	-
Planorbidae						
Unidentified sp.	-	-	-	-	3	-

Table 16. Species Composition of Benthic Macroinvertebrates Exposed to Sequential Lagoon Treated-Dual-Media Filtered-Activated Carbon Adsorption (BATEA) Oil Refinery C Effluent for 32 Days, October 11 to November 12, 1976.

	Days of Exposure					
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unidentified sp.	2	5	9	14	18	4
Nematoda						
Unidentified sp.	-	1	1	1	1	-
Annelida						
Oligochaeta						
Stylaria lacustris	1	5	3	5	3	-
Dero sp.	360	578	769	928	2,113	1,058
Nais sp.	22	45	58	12	101	4
Aulophorus furcatus	5	4	1	8	2	2
Unidentified sp.	7	33	39	20	45	13
Pristina longiseta leidyi	3	7	6	-	12	7
Chaetogaster sp.	-	2	3	-	156	279
Arthropoda						
Crustacea						
Hyalella azteca (Saussure)	5	10	22	10	2	1
Arachnoidea						
Unidentified sp.	1	-	1	1	-	-
Insecta						
Ephemeroptera						
Stenonema sp.	17	17	12	7	7	7
Caenis sp.	879	1,250	689	745	1,235	322
Callibaetis sp.	-	-	1	2	2	1
Odonata						
Argia sp.	286	171	172	137	181	108
Enallagma sp.	12	3	6	5	10	3
Unidentified sp.	2	1	-	1	-	-
Coleoptera						
Dubiraphia sp.	9	-	-	-	-	-
Helichus suturalis	-	1	-	-	-	-
Deronectus sp.	-	-	1	-	-	-
Berosus sp.	-	-	1	-	-	-
Copelatus sp.	-	-	-	1	-	-
Helophorus sp.	-	-	-	1	-	-
Trichoptera						
Orthotrichia	45	71	71	51	88	33
Psychomyiid Genus A	229	112	93	65	115	78
Oecetis sp.	1	1	1	-	-	-
Agraylea sp.	1	7	-	6	28	11
Glossosoma sp.	-	4	1	1	3	-

	Start	2nd	4th	8th	16th	32nd
Corixidae						
Unidentified sp.	-	3	1	2	1	-
Chironomidae						
Glyptotendipes sp.	330	2,244	1,590	1,334	2,525	2,012
Einfeldia sp.	199	1,282	1,068	971	1,782	1,268
Tanypodinae sp.	13	29	34	17	9	31
Dicrotendipes nervosus(Mason)	13	37	59	42	70	68
Tribelos sp.	6	101	108	104	170	23
Endochironomus sp.	3	20	7	8	74	24
Dicrotendipes modestus(Mason)	2	7	6	-	31	-
Polypedilum sp.	3	-	-	8	11	-
Parachironomus sp.	1	-	-	-	-	-
Rheotanytarsus sp.	1	4	5	-	-	8
Chironomus sp.	1	-	7	5	62	70
Micropsectra sp.	1	-	-	-	-	6
Smitta sp.	1	-	-	-	-	-
Goeldichironomus sp.	-	132	326	213	381	550
Psectrocladius sp.	-	14	-	-	-	-
Cladotanytarsus	-	7	-	-	-	-
Cricotopus A	-	-	41	22	323	21
Cricotopus B	-	1	-	-	19	23
Tanypus sp.	-	7	-	-	-	-
Ablabesmyia janta (Beck)	-	-	11	5	10	-
Pseudochironomus	-	-	5	-	11	-
Clinotanypus sp.	-	-	-	-	28	-
Pedionomus beckae(Beck)	-	-	-	-	-	7
Coelotanypus sp.	-	4	-	-	-	-
Psychodidae						
Unidentified sp.	-	-	1	-	-	-
Ceratopogoniidae						
Palpomyia sp.	7	22	17	7	39	8
Mollusca						
Physidae						
Unidentified sp.	3	3	5	1	1	-
Planorbidae						
Unidentified sp.	-	1	-	-	-	5
Ancylidae						
Unidentified sp.	-	-	-	-	-	2

Table 17. Species Composition of Benthic Macroinvertebrates Exposed to Control Tap Water at Refinery A, April 18 to May 20, 1977.

	Days of Exposure					
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unidentified sp.	-	51	59	63	41	36
Nematoda						
Unidentified sp.	4	-	-	-	-	10
Annelida						
Oligochaeta						
Nais sp.	200	148	304	656	530	799
Dero sp.	185	459	793	1,221	1,531	2,130
Slavina appendiculata	5	64	103	154	384	742
Chaetogaster sp.	24	36	50	145	271	725
Pristina sp.	-	-	2	1	-	31
Amphichaeta americana	1	2	-	2	4	9
Enchytraeidae						
Unidentified sp.	-	-	-	-	-	2
Hirudinea						
Unidentified sp.	-	-	-	-	-	1
Arthropoda						
Crustacea						
Hyalella azteca	-	10	11	21	21	30
Decapoda						
Unidentified sp.	-	-	1	-	1	-
Insecta						
Megaloptera						
Sialis sp.	-	1	5	2	4	-
Ephemeroptera						
Caenis sp.	89	46	87	68	31	11
Stenonema sp.	1	-	3	-	2	-
Odonata						
Argia sp.	1	15	20	13	10	11
Unidentified sp.	3	-	1	-	-	-
Tetragoneuria sp.	-	-	-	-	-	2
Coleoptera						
Deronectes sp.	5	-	-	-	1	-
Berosus sp.	-	4	5	3	12	5
Unid. sp. A	1	5	3	-	4	-
Peltodytes	-	-	1	2	4	-
Paracymus	-	-	-	-	1	1
Unid. sp. B	-	-	-	-	-	1
Plecoptera						
Perlesta sp.	-	-	-	-	-	1

	Start	2nd	4th	8th	16th	32nd
Trichoptera						
Psychomyiid Genus A	5	10	8	9	7	2
Orthotrichia sp.	1	2	-	2	1	-
Agraylea sp.	2	-	-	-	1	1
Oecetis sp.	-	3	-	-	-	-
Diptera						
Unid. sp. A	1	2	2	2	-	-
Unid. sp. B	-	-	-	-	1	-
Unid. sp. C	-	-	-	-	1	-
Unid. sp. D	-	-	-	-	-	1
Chironomidae						
Glyptotendipes sp.	1,242	411	421	743	802	366
Endochironomus sp.	57	-	-	-	2	-
Ablabesmyia mallochi	93	2	-	2	6	-
Procladius	11	2	2	3	3	9
Dicrotendipes sp.	7	-	-	-	1	-
Micropsectra sp.	33	-	-	-	1	2
Monopelopia sp.	3	-	-	-	-	-
Pseudochironomus sp.	4	-	-	4	-	-
Trissocladius sp.	10	-	1	-	-	-
Cladotanytarsus sp.	6	-	-	-	-	-
Guttipelopia sp.	4	-	-	-	-	-
Tribelos sp.	59	8	10	6	5	-
Chironomus sp.	31	-	1	1	20	7
Dicrotendipes modestus	43	1	1	1	11	-
Dicrotendipes nervosus	10	33	21	104	4	-
Ablabesmyia americana	2	1	-	-	-	-
Rheotanytarsus sp.	6	-	-	2	3	-
Einfeldia sp.	11	5	13	5	33	2
Polypedilum sp.	4	1	1	4	1	-
Conchapelopia sp.	4	-	-	-	-	-
Ablabesmyia janta	6	37	43	44	1	-
Parachironomus sp.	-	1	1	2	-	-
Stilobezzia sp.	-	1	-	-	-	-
Kiefferulus sp.	-	2	-	-	6	-
Psectrocladius sp.	-	-	1	-	2	-
Tanypus sp.	-	-	-	-	-	7
Cricotopus sp.	-	-	-	-	-	1
Tanytarsus sp.	-	-	-	-	-	5
Ceratapogoniidae						
Palpomyia sp.	6	25	32	24	37	18
Mollusca						
Physidae						
Unid. sp.	-	3	1	3	13	29
Planorbidae						
Unid. sp.	1	-	3	2	3	52

Table 18. Species Composition of Benthic Macroinvertebrates Exposed to Activated Sludge Treated Oil Refinery A Effluent, April 18 to May 20, 1977.

	Days of Exposure					
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unid. sp.	-	-	1	-	-	1
Nematoda						
Unid. sp.	4	3	-	-	2	1
Annelida						
Oligochaeta						
Nais sp.	200	119	315	157	133	552
Dero sp.	185	629	876	931	1,177	989
Slavina appendiculata	5	13	22	15	16	-
Chaetogaster sp.	24	22	29	23	6	7
Pristina sp.	-	-	1	-	-	-
Amphichaeta americana	1	-	-	-	15	28
Enchytraeidae						
Unid. sp.	-	-	-	-	-	15
Arthropoda						
Crustacea						
Hyalella azteca	-	3	3	2	-	-
Decapoda						
Unid. sp.	-	2	-	1	-	-
Insecta						
Megaloptera						
Sialis sp.	-	2	1	-	1	3
Ephemeroptera						
Caenis sp.	89	64	60	43	9	-
Stenonema sp.	1	1	1	-	-	-
Odonata						
Argia sp.	1	25	12	15	8	9
Unid. sp.	3	-	1	-	-	-
Coleoptera						
Deronectes sp.	5	1	-	-	-	-
Berosus sp.	-	-	3	1	3	3
Unid. sp. A	1	1	2	-	-	-
Unid. sp. B	-	-	-	-	-	1
Peltodytes sp.	-	-	-	1	1	-
Trichoptera						
Psychomyiid Genus A	5	13	10	9	8	2
Orthotrichia sp.	1	-	1	-	-	-
Agraylea sp.	2	-	-	-	-	-
Oecetis sp.	-	1	-	-	-	-

	Start	2nd	4th	8th	16th	32nd
Diptera						
Unid. sp. A	1	2	3	2	-	-
Unid. sp. C	-	-	-	-	-	4
Unid. sp. E	-	-	-	-	-	46
Chironomidae						
Glyptotendipes sp.	1,242	705	391	599	164	69
Endochironomus sp.	57	-	-	-	-	-
Ablabesmyia mallochi	93	-	-	5	-	-
Procladius sp.	11	3	22	5	2	-
Dicrotendipes sp.	7	-	-	1	-	-
Micropsectra sp.	33	-	1	-	1	-
Monopelopia sp.	3	-	-	-	-	-
Pseudochironomus sp.	4	-	-	2	-	-
Trissocladius sp.	10	-	-	-	-	-
Cladotanytarsus sp.	6	-	-	-	-	-
Guttipelopia sp.	4	-	-	-	-	-
Tribelos sp.	59	4	8	-	6	-
Chironomus sp.	31	3	-	3	5	-
Dicrotendipes modestus	43	1	-	1	1	3
Dicrotendipes nervosus	10	8	14	19	1	-
Ablabesmyia americana	2	-	-	-	-	-
Rheotanytarsus	6	-	-	-	-	-
Einfeldia sp.	11	9	4	3	21	2
Polypedilum sp.	4	7	1	4	2	-
Conchapelopia sp.	4	-	-	-	-	-
Ablabesmyia janta	6	54	34	29	-	-
Parachironomus sp.	-	1	2	-	-	1
Labrundinia sp.	-	-	1	-	-	-
Tanypodinae sp.	-	-	-	1	-	-
Larsia sp.	-	-	-	1	-	-
Kiefferulus sp.	-	-	-	-	1	-
Cricotopus sp.	-	1	1	1	-	4
Tanypus sp.	-	-	-	-	-	37
Tanytarsus sp.	-	-	-	-	-	3
Ceratopogoniidae						
Palpomyia	6	19	22	25	31	9
Mollusca						
Physidae						
Unid. sp.	-	1	-	-	-	-
Planorbidae						
Unid. sp.	1	-	-	4	1	-

Table 19. Species Composition of Benthic Macroinvertebrates Exposed to Sequential Activated Sludge-Dual Media Filtered Oil Refinery A Effluent April 18 to May 20, 1977.

	Days of Exposure					
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unid. sp.	-	7	5	-	-	1
Nematoda						
Unid. sp.	4	2	-	-	-	1
Annelida						
Oligochaeta						
Nais sp.	200	134	282	171	117	1,222
Dero sp.	185	499	763	898	733	1,235
Slavina appendiculata	5	29	36	29	11	-
Chaetogaster sp.	24	38	45	73	2	1
Pristina sp.	-	-	-	-	-	1
Amphichaeta americana	1	1	1	1	5	-
Enchytraeidae						
Unid. sp.	-	-	-	-	-	87
Hirudinea						
Unid. sp.	-	1	-	-	1	-
Arthropoda						
Crustacea						
Hyalella azteca	-	4	4	2	1	-
Decapoda						
Unid. sp.	-	3	1	-	-	-
Arachnoidea						
Unid. sp.	-	-	-	-	-	-
Insecta						
Megaloptera						
Sialis sp.	-	-	2	1	5	-
Ephemeroptera						
Caenis sp.	89	64	58	44	8	1
Stenonema sp.	1	-	1	1	-	-
Odonata						
Argia sp.	1	12	19	11	10	8
Unid. sp.	3	-	-	-	-	-
Tetragoneuria sp.	-	-	-	1	-	1
Coleoptera						
Deronectes sp.	5	-	1	-	-	-
Unid. sp. A	1	6	2	2	-	-
Berosus sp.	-	2	6	8	3	14
Peltodytes sp.	-	1	2	1	5	1

	Start	2nd	4th	8th	16th	32nd
Trichoptera						
Psychomyiid Genus A	5	7	11	4	5	2
Orthotrichia sp.	1	1	1	1	-	-
Agraylea sp.	2	-	-	-	-	-
Oecetis sp.	-	1	-	-	-	-
Diptera						
Unid. sp. A	1	1	-	1	-	-
Unid. sp. C	-	-	-	-	-	43
Unid. sp. E	-	-	-	-	-	36
Chironomidae						
Glyptotendipes sp.	1,242	329	313	339	387	97
Endochironomus sp.	57	-	-	-	-	-
Ablabesmyia mallochi	93	-	-	-	4	-
Procladius sp.	11	12	13	1	3	1
Dicrotendipes sp.	7	-	-	1	1	-
Micropsectra	33	-	-	1	1	-
Monopelopia sp.	3	-	-	-	-	-
Pseudochironomus sp.	4	-	-	-	1	-
Trissocladius sp.	10	1	-	-	-	-
Cladotanytarsus sp.	6	-	-	-	-	-
Guttipelopia sp.	4	-	-	-	-	-
Tribelos sp.	-	-	-	-	-	-
Chironomus sp.	31	-	2	3	3	-
Dicrotendipes modestus	43	1	2	-	4	-
Dicrotendipes nervosus	10	16	12	11	3	-
Ablabesmyia janta	2	-	-	-	-	-
Rheotanytarsus sp.	6	-	-	-	-	-
Einfeldia sp.	11	2	1	3	9	5
Polypedilum sp.	4	4	1	3	2	-
Conchapelopia sp.	4	-	-	-	-	1
Ablabesmyia janta	6	32	26	17	3	-
Cryptochironomus sp.	-	-	1	-	-	4
Tanypodinae sp.	-	-	1	1	11	-
Tanypus sp.	-	-	-	-	1	2
Cricotopus sp.	-	-	-	-	-	2
Tanytarsus sp.	-	-	-	-	-	2

Table 20. Species Composition of Benthic Macroinvertebrates Exposed to Sequential Activated Sludge-Dual Media-Activated Carbon Treated Oil Refinery A Effluent, April 18 to May 20, 1977.

	Days of Exposure					
	Start	2nd	4th	8th	16th	32nd
Turbellaria						
Unid. sp.	-	64	46	3	3	3
Nematoda						
Unid. sp.	4	-	-	2	-	4
Annelida						
Oligochaeta						
Nais sp.	200	136	408	194	56	800
Dero sp.	185	603	945	883	674	1,178
Slavina appendiculata	5	6	9	1	-	1
Chaetogaster sp.	24	9	4	4	-	-
Pristina sp.	-	-	1	-	1	1
Amphichaeta americana	1	-	1	-	16	16
Enchytraeidae						
Unid. sp.	-	-	-	-	-	12
Arthropoda						
Crustacea						
Hyalella azteca	-	19	9	11	8	7
Decapoda						
Unid. sp.	-	3	1	1	-	-
Arachnoidea						
Unid. sp.	-	-	-	-	-	1
Insecta						
Megaloptera						
Sialis sp.	-	-	-	3	3	-
Ephemeroptera						
Caenis sp.	89	41	59	48	27	3
Stenonema sp.	2	-	-	-	-	-
Hexagenia sp.	-	-	-	-	-	1
Odonata						
Argia sp.	1	19	27	12	17	6
Unid. sp.	3	-	-	-	-	-
Tetragoneuria sp.	-	-	-	-	1	-
Coleoptera						
Deronectes sp.	5	3	1	1	-	-
Unid. sp. A	-	-	-	-	-	-
Berosus sp.	-	6	10	3	3	4
Peltodytes sp.	-	2	6	6	1	-

	Start	2nd	4th	8th	16th	32nd
Trichoptera						
Psychomyiid Genus A	5	10	5	8	19	-
Orthotrichia sp.	6	5	1	-	-	-
Agraylea sp.	1	-	-	-	3	-
Oecetis sp.	-	2	1	1	-	-
Diptera						
Unid. sp. A	1	3	2	2	-	-
Unid. sp. E	-	-	-	-	-	1
Chironomidae						
Glyptotendipes sp.	1,242	465	334	405	986	295
Endochironomus sp.	57	-	-	1	2	-
Ablabesmyia mallochi	93	-	1	11	3	-
Procladius sp.	11	1	1	3	4	-
Dicrotendipes sp.	7	-	-	-	-	-
Micropsectra sp.	33	1	1	3	-	-
Monopelopia sp.	3	-	-	-	-	-
Pseudochironomus sp.	4	-	1	-	-	-
Trissocladius sp.	10	-	-	-	-	-
Guttipelopia sp.	4	-	-	-	-	-
Tribelos sp.	59	3	7	2	-	-
Chironomus sp.	31	2	1	1	8	79
Dicrotendipes modestus	43	2	1	-	10	-
Dicrotendipes nervosus	10	12	16	18	10	-
Cladotanytarsus sp.	6	-	-	-	-	-
Ablabesmyia americana	2	-	-	-	-	-
Rheotanytarsus sp.	6	-	1	1	-	-
Einfeldia sp.	1	6	2	14	23	-
Polypedilum sp.	11	5	19	12	1	-
Conchapelopia	4	-	-	-	-	-
Ablabesmyia janta	4	49	32	30	3	-
Tanypodinae sp.	-	1	1	-	1	-
Larsia sp.	-	2	-	-	-	-
Kiefferulus sp.	-	2	-	1	1	-
Cryptochironomus sp.	-	-	1	-	-	-
Pentaneura sp.	-	-	1	-	-	-
Labrundinia sp.	-	-	-	1	-	-
Psectrocladius sp.	-	-	-	1	-	-
Tanytarsus sp.	-	-	-	-	2	9
Tanypus sp.	-	-	-	-	6	1
Parachironomus sp.	-	-	-	-	2	18
Cricotopus sp.	-	-	-	-	-	6
Ceratopogoniidae						
Palpomyia sp.	6	32	24	48	32	11
Dasyhelia	-	-	-	-	1	-
Mollusca						
Physidae						
Unid. sp.	-	1	1	-	-	1
Planorbidae						
Unid. sp.	1	3	2	-	-	-
Pelycypoda						
Unid. sp.	-	-	-	-	-	1