EPA-670/2-74-056
JULY 1974

Environmental Protection Technology Series

DEVELOPMENT OF ON-SHORE TREATMENT SYSTEM FOR SEWAGE FROM WATERCRAFT WASTE RETENTION SYSTEM

National Environmental Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

EPA-670/2-74-056
July 1974

DEVELOPMENT OF ON-SHORE TREATMENT SYSTEM FOR SEWAGE FROM WATERCRAFT WASTE RETENTION SYSTEM

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Contract No. 68-32-0220
Program Element No. 1BB038

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OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment - air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The appreciable growth of recreational activity in this country has presented an additional burden on our land and water resources. Recreational watercraft waste is a minor fraction of the waste flow from land based sources. Their presence, however, in our environment contributes to the total ecological problem we face today and demands that we develop waste treatment solutions that are technically and economically feasible.

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ABSTRACT

A two-phase program developed and demonstrated a new method for on-shore treatment of sewage from recreational watercraft. Phase I characterized wastes and chemical additives associated with recirculating/retention systems. Statistical analysis determined probable ranges of waste characteristics as a function of watercraft type and location. Typical wastes had suspended solids and biochemical oxygen demand of 2000 mg/l. Respirometer studies evaluated toxicity of additives to activated sludge. Treatability of chemical/sewage mixtures was determined from pilot-scale activated sludge plant operations. Cell yield coefficients were calculated. Photomicrographs recorded physical changes to activated sludge. Concentrations greater than 20 mg/l zinc or 120 mg/l formaldehyde caused adverse effects to the activated sludge process. Phase II field tested full-scale physical-chemical treatment equipment operating on watercraft wastes. Average removal efficiencies for suspended solids, biochemical and chemical oxygen demand, phosphate, and zinc were greated than 90 percent. Effluent coliform was less than 10 MPN/100 ml. Discharge solids were nonodorous and innocuous. Postchlorination increased total-nitrogen removal from 30 to 70 percent. Operating costs for wastes having approximately 2000 mg/l SS and BOD_5 were $6.2/Kl ($23.5/1000 gal.). Auxiliary treatment cost for zinc removal and postchlorination was $1.5/Kl ($5.7/1000 gal.).

This report was submitted in fulfillment of Contract No. 68-32-0220 by FMC Corporation, Advanced Products Division, San Jose, California, under the sponsorship of the Environmental Protection Agency. Work was completed as of December 1973.

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ACKNOWLEDGMENTS

The authors wish to convey their appreciation to Mr. David J. Cesareo, Project Officer, and Mr. William J. Librizzi, Chief, Watercraft Wastes Branch, U.S. Environmental Protection Agency for their continual guidance throughout the performance of this contract.

The authors express their gratitude to the 46 harbormasters, fuel dock operators, and marina managers that participated in the waste sample collection program and marina surveys.

We thank the manufacturers of chemical toilet additives that furnished confidential information regarding the composition of their products. This information added significant value to this report.

Special acknowledgment is due Mr. Temple A. Reynolds, Assistant Superintendent, Mr. William Stephenson, Chief of Park Maintenance, and all park personnel of Lake Mead National Recreational Area, National Park Service, for their cooperation and assistance during the demonstration phase of this contract.

SECTION I

CONCLUSIONS

The following conculsions are based on empirical results and characteristic facts determined during this research.

1. Wastes from retention systems onboard recreational watercraft have suspended solids (SS) and biochemical oxygen demand (BOD_5) of approximately 2000 mg/l, coliform populations of 10^9 MPN/100 ml, deep coloring, and various amounts of chemical pollutants.

2. Chemical additives used in recirculating/retention waste systems employ surfactants, perfumes, dyes, and bacteriostats of zinc, formaldehyde, and quaternary ammonium compounds. These additives have varying effects on the aerobic respiration rate of activated sludge. With increased concentration, zinc additives are highly toxic while formaldehyde and quaternary ammonium additives are initially biodegradable but become toxic at higher concentrations.

3. Biological treatability of wastewater from recreational watercraft is a function of chemical additive concentration and waste characteristics. Wastewaters having more than 20 mg/l zinc or 120 mg/l formaldehyde (from chemical additives) cause significant disruption of the activated sludge process with loss of removal efficiency.

4. Comparative studies with a laboratory respirometer and a pilot-scale activated sludge plant show similar results in the determination of relative toxicity and treatability of sewages containing specific chemical additives.

5. The demonstrated physical-chemical process provides a high level of treatment of recreational watercraft wastes with greater than 90 percent removal of SS, BOD_5, chemical oxygen demand (COD), and phosphate. Effluent coliform is less than 10 MPN/100 ml. Solid filter cake discharge is nonodorous and innocuous.

6. Auxiliary treatment of process effluent can attain greater than 90 percent total zinc removal while postclorination demonstrates the ability to significantly increase total-nitrogen removal.

7. Complete physical-chemical treatment of watercraft wastes having approximately 2000 mg/l SS and 1000 mg/l BOD_5 costs \$6.2/kl (\$23.5/1000 gal). Chemical cost for standard treatment is \$3.9/kl (\$14.9/1000 gal) and power cost is \$0.7/kl (\$2.7/1000 gal). Auxiliary treatment cost for zinc removal and postchlorination is \$1.5/kl (\$5.7/1000 gal).

SECTION II

RECOMMENDATIONS

This program was concerned only with a portion of the chemical-contaminated wastewaters requiring adequate treatment by federal law. Major problems exist with conventional biological treatment of industrial wastewaters and land recreational wastes. Proposed federal guidelines[1] will prohibit wastewater discharges to publicly owned treatment works that may induce a treatment process upset and subsequent loss of treatment efficiency. Best practical water pollution control technology is required to meet the growing demands for a cleaner environment. To achieve this objective, the following recommendations are made:

1. Test and evaluate the demonstrated system as a pretreatment method for removing zinc and other heavy metals, oils and grease, and suspended solids from industrial wastewaters.

2. Determine the applicability and effectiveness of the demonstrated system as an unattended roadside sanitary treatment facility in recreational areas and along highways.

3. Test and evaluate the demonstrated system for on-shore complete treatment of saltwater sanitary sewage and bilgewater from commercial and military vessels.

4. Design, develop, and evaluate new treatment methods capable of efficient, economical removal of nitrogen compounds from wastewater.

5. Conduct a research program to establish standard procedures utilizing respirometer equipment to determine the relative treatability and toxicity of polluted wastewaters.

SECTION III

INTRODUCTION

NATURE OF PROBLEM

Historically, the nation's waterways have been the recipients of man's wastes from both land and watercraft sources. While active Government programs are providing facilities to treat wastewaters from our cities and industries, marine vessels of all types have in the past continued to dump raw sewage.

The harmful effects of discharges of untreated sewage into the waterways include (1) virus and bacteria that can infect people, directly or through marine life, with various diseases; (2) excessive oxygen demands that reduce the life supporting oxygen concentration of the water; (3) upset of the aquatic environment by blocking sunlight with suspended or floating solids, as well as sludge layers on the bottom; and (4) the aesthetic insult created by floating sewage solids. The mobility of marine vessels allows discharge of sewage wastes almost anywhere and any time. This creates a specific hazard to public health, recreational and port facilities, and commercial fishing industries. In 1970 the Federal Government started action to control the discharge of sewage from vessels. The Water Quality Improvement Act of 1970 called for prohibition of discharge of untreated or inadequately treated sewage into or upon the navigable waters of the United States. The U.S. Environmental Protection Agency (EPA) was delegated the responsibility of establishing effluent standards for marine sanitation devices, while the U.S. Coast Guard was given the responsibility of promulgating the implementation regulations. In June 1972, the EPA proposed a no-discharge standard[2], which replaced the initial proposed standards requiring the equivalent of secondary treatment. In March 1974, the Coast Guard proposed certification procedures and design and construction requirements for marine sanitation devices[3]. These regulations will become effective for new vessels after 2 years from promulgation and after 5 years for existing vessels.

Compliance with a no-discharge standard can be achieved on large vessels via several approaches, including treatment and reuse or recirculation of the effluent for flushwater, liquid evaporation and solids incineration, or by total destruction by injection into a boiler system. For smaller, recreational watercraft, these approaches are not feasible or economical. Sanitary wastes must be retained onboard in recirculating/ retention waste systems. Chemical additives containing bacteriostatic agents and perfumes are commonly used in conjunction with these systems to control the sewage odor. On-shore pumpout facilities are employed to remove these wastes from the individual watercraft.

The availability of adequate treatment facilities for these wastes is a major problem in most recreational areas. Pumpout facilities are often many miles from the collection system of municipal treatment plants. The treatability of these wastes by conventional biological methods is often variable, because of toxic effects from certain chemical additives. Without sufficient dilution, these wastes may cause significant upset and loss of removal efficiency to the activated sludge process. After heavy weekend recreational activity, shock loadings of these wastes have seriously disrupted small municipal treatment plants.[4]

Advanced physical-chemical processes have been developed as an alternative to conventional wastewater treatment methods. Employing no biological activity, physical-chemical systems are capable of a high degree of treatment, independent of the presence of toxic materials. With variable design capacities and automatic operation, this approach is ideally suited for application to the treatment of recreational watercraft wastes.

In 1968 the Advanced Products Division, FMC Corporation, San Jose, California, began development of a physical-chemical waste treatment system. The process includes disinfection, chemical clarification, adsorption by activated carbon, and filtration. Chemicals employed are a bactericide, flocculant, activated carbon, and filter aid. The system is automatically controlled on a demand basis with instantaneous on-off operation. Construction materials have been designed to withstand a saltwater marine environment.

OBJECTIVE

The objective of this program was to develop and demonstrate a new, effective system for on-shore complete treatment of sewage pumped from recreational watercraft waste retention systems. Complete treatment was defined as 90 percent removal of biochemical oxygen demand (BOD_5), suspended solids (SS), nitrogen, phosphorous, and disinfection as required to meet local, state, and federal regulations. To achieve this objective efficiently, the program was divided into two distinct and separate phases. Phase I involved the characterization of watercraft wastes and verification that the proposed system was capable of complete treatment. Phase II involved the field demonstration of a full-scale treatment unit operating on actual watercraft waste pumpage. This program was to be completed over a 12-month period.

SCOPE OF WORK

The scope of Phase I included the following tasks:

1. Waste Characterization. Samples of waste were collected from recreational watercraft having retention/recirculating sanitary systems. Each sample was analyzed in the laboratory for chemical and biological parameters. Chemical content, flow volume, and variations throughout a boating season were established for watercraft wastes over a broad geographical region.

2. Description of Chemical Additives. A survey of manufacturers and suppliers of chemical additives was performed to determine the types and composition of chemicals used in conjunction with retention/recirculating systems. A survey of marinas established the types and use of the most common additives. Laboratory studies determined the relative effects of common chemical additives on activated sludge.

3. Biological Treatment of Watercraft Wastes. Respirometer studies determined the relative effects of chemically treated wastes on activated sludge. A pilot-scale activated sludge plant was operated on various chemical/domestic waste mixtures. Treatability data and toxic effects were determined.

4. Process Studies. Simulated watercraft wastes containing various chemical additives were processed in the laboratory and on full-scale demonstration equipment to determine the capability of complete treatment. Process modifications were made to achieve this objective.

The scope of work in Phase II involved the following activities:

1. Test Site Selection. Freshwater and saltwater locations were surveyed for consideration as a demonstration site. Final selection was determined on the basis of the number and types of boats, flow volume of boat waste pumpage, and length of boating season.

2. Process Field Testing. A full-scale treatment unit was demonstrated for 8 weeks at Lake Mead, Nevada. All watercraft waste pumpage at two marinas was processed. Samples were collected daily for analysis, and operating data were recorded.

3. Process Evaluation. Removal efficiencies were calculated from laboratory analytical data. Cost of operation was determined from chemical and power consumptions. Maintenance requirements were listed. Characteristics and disposal of solid filter cake were established.

SECTION IV

CHARACTERISTICS OF WATERCRAFT WASTES

WASTE SAMPLING

A program was designed to sample wastes from the basic types of recreational watercraft located in freshwater and saltwater in various regions of California and Nevada. Between March and July 1973, 65 waste samples were collected at 8 freshwater and 8 saltwater marina locations. Forty-six samples were taken from individual boats, while 19 composite samples were collected from waste storage tanks containing boat pumpage.

Sampling was done at fuel docks, pumpout facilities, and at individual moorings. With the owner's permission, the entire undiluted contents of the boat holding tank or recirculating toilet were transferred to a suitable container by means of a positive displacement diaphragm pump. No tank flush water was included in the sample. After noting the total volume, the waste sample was gently mixed by hand or electric stirrer. Larger samples (greater than 100 liters) were mixed by recirculation through the diaphragm pump. A 2-liter portion of the blended sample was transferred to a sterile polyethylene bottle and immediately packed in ice for preservation at 4°C. Composite pumpout wastes in storage tanks were first agitated by recirculation through the diaphragm pump, then transferred to sample containers. Total waste volume was estimated from tank dimensions and waste level.

All samples were transported in ice chests to the Environmental Engineering Laboratories, FMC Corporation, Santa Clara, California, for immediate setup or analysis. The normal sample holding period was 5 hours, with a maximum of 14 hours for samples from Southern California.

RESULTS

The source of each waste sample was characterized by the watercraft type and length, waste system capacity, and pumpout frequency. Each waste sample was described by total volume, approximate age, chemical additive used, and type of flush water (freshwater or saltwater). Sample analysis included 15 characteristic parameters describing wastewater. All analytical procedures were done in accordance with the EPA's Methods for Chemical Analysis of Water and Wastes[5]. Table 1 gives the descriptive details and analytical results of seven waste samples. Because of the quantity of tabular information, the data describing all 65 waste samples are given in Appendix A. The results of analyses for 22 heavy metal elements are given in Appendix B.

Analytical data were treated statistically to interpret the results of the sample collection program. Six boat categories were established for comparison. Samples were collected on the basis of individual and composite sources, fresh and saltwater locations, and boat type. A computer program automatically sorted data according to category and determined maximum, minimum, and average values for each parameter. In addition, a weighted average was determined using the total waste volume at the sample source as the weighting factor. A value range, 95 percent confident to contain the true parameter value, was also calculated. The six boat sample categories listed below were statistically treated in this manner.

1. Powerboats and Sailboats

2. Houseboats

3. Powerboats, Sailboats, and Houseboats

4. Powerboats and Sailboats on Lake Mead

5. Houseboats on Freshwater

6. Houseboats on Saltwater

Results of individual samples (those taken directly from a boat) were used to determine the statistical results of all categories except number 4. Only composite samples (those taken from waste-storage tanks of pumpout facilities) were used to describe Lake Mead watercraft wastes. (Composite waste samples are diluted 50 to 100 percent with flushwater used to rinse the waste retention system.)

Houseboats are defined as mobile live-aboard watercraft with pontoon flotation structure. Most houseboats sampled in this program were public rentals that carry an average of 3 people for 4 days. It was noted that the characteristics and volume of waste pumpage from rental houseboats varied significantly as a function of the weather, boating season, and crew complement.

Table 1. ANALYSIS OF RECREATIONAL WATERCRAFT WASTE SAMPLES*

Sample Number	1	2	3	4	5	6	7
Code Number	382-11-1	382-21-1	382-27-1	382-28-1	382-30-1	382-31-1	382-32-1
Sample Type	Composite	Individual	Individual	Individual	Individual	Composite	Individual
Collection Date	3-08-73	3-17-73	3-22-73	3-22-73	3-22-73	3-22-73	3-22-73
Location	Lake Mead	Alameda	San Diego	San Diego	Mission Bay	San Diego	Harbor Island
Marina Number	1	5	6	6	7	6,7	8
Water Type	Fresh	Salt	Salt	Salt	Salt	Salt	Salt
Boat Type & Length	Composite	House, 36'	Power, 38'	Power, 38'	Power, 48'	Composite	Power, 42'
Chemical Additive	Composite	T-5, Kraft-Chem	T-5	T-5	Aqua-Chem	T-5, Aqua-Chem	T-5, Aqua-Chem
Waste Volume (1)	1,325	30	24	17	850	- - -	150
Waste Age	6 days	1 week	5 days	5 days	2.5 weeks	9 days	1 week
Sample Analysis							
SS (mg/1)	900	950	7,840	2,590	200	2,000	8,240
VSS (mg/1)	590	670	6,910	2,260	160	1,680	6,320
TS (%)	0.24	0.95	2.04	0.44	0.16	0.72	2.50
TVS (%)	0.08	0.50	1.35	0.29	0.08	0.49	1.65
TOC (mg/1)	640	1,590	5,300	1,100	390	1,530	4,130
SOC (mg/1)	280	1,360	2,150	330	330	820	2,780
BOD_5 (mg/1)	630	1,590	3,410	1,700	680	1,910	4,020
COD (mg/1)	2,460	3,960	8,560	3,860	1,560	5,500	12,510
T-N (mg/1)	450	880	3,110	410	65	760	5,850
NH_3-N (mg/1)	390	105	830	260	23	200	830
T-PO_4 (mg/1)	91	460	370	210	14	160	650
Zinc (mg/1)	360	449	234	144	None detected	43	1,331
Conductivity (MHO)	4,750	4,500	11,200	3,000	1,500	3,800	11,000
pH	7.7	5.5	8.2	8.8	7.2	7.8	6.6
Coliform (MPN/100 ml)	50×10^6	190	23×10^7	62×10^7	62×10^3	23×10^3	12×10^5

*Typical Results - See Appendix A for all 65 samples

Table 2 gives the statistical results describing the characteristics of undiluted-waste pumpage from retention/recirculating systems onboard recreational powerboats and sailboats (Category 1). The results for all six categories are given in Appendix C. Specific details of the number of samples in each category are included.

To characterize the recreational boating community and its facilities, each marina or marine location that supplied waste samples was surveyed for the following characteristics: number of boats, boat types and average lengths, percentage of boats with onboard sanitary waste systems, waste holding capacity, existence of pumpout facilities, disposition of pumpout wastes, and common brands of chemical toilet additives used or sold. Table 3 gives these results for 16 marine locations sampled during this waste characterization program.

DISCUSSION

Results of the waste characterization indicated that pumpage from recreational watercraft is highly concentrated, deeply colored, and contains variable amounts of toxic materials. Typical waste pumpage from recreational watercraft had the following characteristic ranges:

SS	1400 to 3400 mg/l
TOC	1500 to 2900 mg/l
BOD_5	1700 to 3500 mg/l
COD	4400 to 7900 mg/l
T-N	1600 to 2000 mg/l
Coliform	10^2 to 10^{10} MPN/100 ml
Zinc	25 to 250 mg/l

With nearly exclusive use of freshwater makeup in watercraft toilet systems, the geographical location of the boat in freshwater or saltwater had no significant effect on the wastewater characteristics. Houseboat wastes were generally more concentrated than wastes from powerboats and sailboats. Season variations most directly affected the volume and characteristics of wastes from rental houseboats. A rental houseboat with 10 passengers operating in Lake Shasta, California for 7 days yielded 340 l (90 gal) of wastewater having 20,000 mg/l SS and 15,000 mg/l BOD_5[6].

Table 2. STATISTICAL RESULTS OF WASTE CHARACTERIZATION DATA

Category 1. Powerboats and Sailboats [a]

Wastewater Parameter	Minimum Value	Maximum Value	Value Range	Arithmetic Mean	Weighted Arithmetic Mean(b)	Standard Deviation(c)	95-Percent Confidence Limits(d)
SS (mg/l)	72	9,050	8,978	2,860	1,940	580	3,100 780
VSS (mg/l)	63	6,910	6,847	2,310	1,520	450	2,420 620
TS (%)	0.11	4,83	4.72	1,87	1.58	0.36	2.30 0.86
TVS (%)	0.03	2.19	2.16	0.87	0.60	0.14	0.88 0.32
TOC (mg/l)	390	6,100	5,710	2,360	1,800	390	1,020 2,580
SOC (mg/l)	330	4,700	4,370	1,550	1,270	280	1,830 710
BOD_5 (mg/l)	30	9,230	9,200	2,710	1,960	350	2,660 1,260
COD (mg/l)	1,160	15,420	14,260	6,180	5,210	960	7,130 3,290
T-N (mg/l)	19	5,850	5,831	1,840	1,270	380	2,030 510
NH_3-N (mg/l)	8	3,970	3,962	1,050	630	170	970 290
T-PO_4 (mg/l)	14	1,180	1,166	370	250	70	390 110
Zinc (mg/l)	0.0	1,330	1,330	276	150	88	326 0
Conductivity (MHO)	1,200	40,200	39,000	18,000	16,100	4,000	24,100 8,100
pH	5.3	8.8	3.5	7.7	7.6	0.2	8.0 7.2
Coliform (MPN/100 ml)	45	6.2×10^8	6.2×10^8	4.5×10^7	1.0×10^7	1.5×10^7	4.5×10^7 0

(a) Sample Details: Total - 20; Powerboats - 7, Sailboats - 13.

(b) Mean value after weighting each sample according to total volume of waste present at time of sampling.

(c) Root-mean-square of the deviations of the weighted measured values from the true value.

(d) Value range that is 95-percent confident to contain the true mean value.

Table 3. MARINA SURVEY DATA

Marina Number	Name and Location	Boat Type and Average Length	Total Boats - Percent w/Heads	Percent w/Holding Tank - Average Capacity (gal)	Pumpout Facility - Discharged to	Chemical Additives Sold or Used
1	Lake Mead Marina P. O. Box 96 Boulder City, NV 89005	Power, Sail, House - 28'	450 76%	76% 20	Yes Oxidation Pond	T-5, Inca-Gold, Aqua-Chem
2	Las Vegas Boat Harbor P. O Box 771 Henderson, NV 89105	Power, Sail, House - 25'	220 70%	70% 10	Yes Oxidation Pond	Spyce, Lan-O-Sheen, T-5, Aqua-Chem
3	Calville Bay Marina 2103 Western Avenue Las Vegas, NV 89102	Power, Sail, House - 25'	610 33%	33% 25	Yes Oxidation Pond	T-5, Aqua-Chem, Inca-Gold
4	Echo Bay Resort P. O. Box 386 Overton, NV 89040	Power, Sail, House - 19'	120 13%	13% 5	Yes Oxidation Pond	T-5, Aqua-Chem
5	Ballena Bay Yacht Harbor 1150 Ballena Blvd. Alameda, CA 94501	Power, Sail House - 32'	481 80%	47% 12	Yes City Sewer	T-5, Aqua-Chem, Kraft-Chem Pink Magic
6	Pt. Loma Sportfishing Assn. 1403 Scott Street San Diego, CA 92106	Power (fishing) 50'	800 98%	>5% 8	No None	T-5, Aqua-Chem
7	Islandia Hotel Marina 1441 Quivera Road San Diego, CA 92109	Power, Sail 32'	256 80%	50% 8	Yes City Sewer	Aqua-Chem, Kraft-Chem
8	Harbor Island Marina 2040 Harbor Island Drive San Diego, CA 92101	Power, Sail, House - 40'	565 95%	>5% 20	Yes City Sewer	T-5, Aqua-Chem
9	Dana Point Harbor 25005 Dana Drive Dana Point, CA 92629	Power, Sail 33'	1,400 75%	10% 10	Yes City Sewer	T-5, Inca-Gold, KN-48, Aqua-Chem
10	Marina Fuel & Services 1 Bora Bora Way Marina Del Rey, CA 90291	Power, Sail 35'	5,800 95%	15% 25	Yes City Sewer	T-5, Aqua-Chem, Inca-Gold, Kraft-Chem, Corlon Chem-67
11	Channel Islands Harbor 3900 Pelican Way Oxnard, CA 93030	Power, Sail, House - 28'	1,100 75%	20% 10	Yes City Sewer	T-5, Aqua-Chem, Hydrochlor
12	Peninsula Yacht Anchorage Peninsula Drive Oxnard, CA 93030	Power, Sail 32'	400 70%	30% 10	No None	T-5, Aqua-Chem, Kraft-Chem
13	International Houseboats 21112 Ventura Blvd. Woodland Hills, CA 91364	House - 42'	85 100%	100% 80	Yes Holding Tank Truck Haul	T-5, Kraft-Chem
14	Village West Marina 6650 Embarcadero Drive Stockton, CA 95207	House - 36'	10 100%	100% 90	Yes City Sewer	T-5, Wilcox-Crittenden (Cl_2)
15	Rainbow Bridge Marina Lake Powell Utah	House, Power 22'	100 80%	80% 20	Yes Package biological treatment plant	T-5, Aqua-Chem
16	Holiday Harbor P. O. Box 112 O'Brien, CA 96070	House, Power 30'	350 57%	57% 50	Yes Holding Tank Truck Haul	T-5, Aqua-Chem

The largest volumes of waste pumpage occurred during July and August. Approximately 85 percent of all boat pumpout activity occurred Friday through Monday. The average onboard waste-retention time was 17 days.

The most commonly used chemical toilet additives had ingredients of zinc sulfate or formaldehyde. The range of zinc concentrations found in individual waste samples was 0 to 3530 mg/l, with an average of 46 mg/l. Samples were not analyzed for formaldehyde.

Heavy metal analysis of 64 waste samples showed no presence of arsenic, beryllium, molybdenum, or selenium. Mercury was detected in six samples at a concentration ranging from 6 to 9 mg/l. Relatively low concentrations (less than 0.2 mg/l) of cadmium, chromium, copper, lead, manganese, nickel, and silver were found in most samples. Significantly high concentrations of aluminum, calcium, magnesium, tin, potassium, iron, and sodium were determined. Toxic levels of certain metals were indicated by individual samples having concentrations as high as 104 mg/l cadmium, 79 mg/l lead, 3540 mg/l zinc, and 13.5 mg/l copper.

SECTION V

CHARACTERISTICS OF CHEMICAL ADDITIVES

CHEMICAL COMPOSITION

A survey of manufacturers and suppliers was conducted to determine the types and composition of chemicals used in conjunction with waste retention/recirculating systems. Nine companies were selected from a list of all known manufacturers of bacteriostatic chemicals as representing the market and the spectrum of chemicals used in recreational waste systems. A letter of transmittal and a questionnaire were sent to each company requesting their cooperation in supplying general characteristics of their product, which included recommended dosages, safety cautions, generic chemical composition, acidity-alkalinity, and heavy metal content. The results of this survey are given in Table 4.

The three basic types of active ingredients employed in chemical toilet additives are (1) zinc salts, (2) formalin or paraformaldehyde, and (3) quaternary ammonium compounds. Dense dyes and perfumes are normally present to mask offending color and reodorize the sewage contents. Surfactants and water softeners are used to help solubilize the waste solids. Liquid additives are mostly aqueous solutions with small amounts of alcohol.* All additives are toxic if ingested and harmful to skin and eyes. Careful handling is required, especially with those containing formaldehyde.

Since the time of this survey, several new additives have been marketed to replace older ones, especially those containing zinc salts. The list of active ingredients has expanded to include substituted phenols, available chlorine, and so-called "concentrated bacterial enzymes."

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*Formalin is a 37-percent aqueous solution of formaldehyde with 7 to 15 percent methanol.

Table 4. CHARACTERISTICS OF CHEMICAL TOILET ADDITIVES

Chemical Code	Dosage (gm/l) [a]	Form	Color	pH Range	Active Ingredient [b, c]	Other Ingredients	Heavy Metals
40	4.5-1.5	Liquid	Blue	6-8	35% Formaldehyde	Alcohol, perfume, surfactant, dye	None
20	3.9	Powder	Green	6-8	Paraformaldehyde	Perfume, dye	Pb, Cu, Ni, Fe
83	3.8	Liquid	Blue	6-8	Formaldehyde	Alcohol, perfume, surfactant dye	No data
96	4.5-1.5	Liquid	Blue	6-8	28.5% Formaldehyde	Alcohol, perfume, surfactant, dye	None
26	4.4-2.0	Powder	Blue	6-7	87% Zinc Sulfate Monohydrate	Perfume, surfactant, dye	Zn
33	1.5	Powder	Blue	6-7	87% Zinc Sulfate Monohydrate	Perfume, surfactant, dye	Zn
38	1.7	Granule	Blue-Green	6-8	Quaternary Ammonium Salt	Perfume, surfactant, dye	None
57	1.5	Powder	Blue	6-8	Paraformaldehyde	Perfume, surfactant, dye	No data
71	1.5	Powder	Blue	6-8	Paraformaldehyde	Perfume, surfactant, dye	No data
15	1.2	Liquid	Blue	6-8	10% Quaternary Ammonium Salts	Dye	None

[a] Recommended dosage levels vary according to the application and size of recirculating/retention sanitary systems.

[b] Liquid formaldehyde-type additives employ formalin, which is 37% formaldehyde and 10% methanol.

[c] Paraformaldehyde is a formaldehyde polymer prepared by concentrating formalin at reduced pressure.

CHEMICAL USAGE

Survey results from 16 marine locations indicated that the most commonly used chemical additives contain zinc salts and formaldehyde. Chemical Additive Codes 26 and 40 were used 85 percent of the time. This popularity was explained by satisfaction with the product or by compliance with the recommendations of the chemical toilet manufacturer. Most of these manufacturers market their own additives. Boat owners stated that recommended dosages were satisfactory for short periods of time, but that additional charges were required to suppress odor after 5 to 10 days.

TOXICITY TO ACTIVATED SLUDGE

The primary function of chemical toilet additives is as a bacteriostat, which suppresses normal respiration and growth of bacteria. The result is less gas production by the bacteria and a reduction or control of unpleasant odors. This method can be effective when holding sanitary wastes, although much concern exists over how these wastes are later disposed of and their effect on biological wastewater treatment systems. The same bacteriostatic effect can reduce the level of biological treatment and result in sub-quality process effluent.

An experimental program was conducted to measure the relative toxicity of various chemical additives to unacclimated activated sludge aerated for 30 hours without feed. A Princeton Aqua-Science Aerobic Treatability Unit (Model EG-300),* measuring dissolved oxygen (DO), was used to determine a reference respiration rate of activated sludge as well as respiration rates of this sludge in the presence of varying concentrations of chemical additive. A comparison of these rates gave a qualitative determination of the biodegradability or toxicity of the specific chemical additive.

Seven different additives representing the three basic types of bacteriostatic compounds were characterized at five different chemical concentrations. Activated sludge was obtained from the FMC Environmental Engineering Laboratories, who operate a package treatment plant (Chicago Pump, Model SL-144) at 190 kl/day (50,000 gal/day) on municipal sewage from Santa Clara, California.

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*Princeton Aqua-Science, 789, Jersey Avenue, New Brunswick, New Jersey.

A standard operating procedure was followed for all determinations with the respirometer. This included constant temperature, aeration, agitation, and mixed liquor volatile suspended solids (MLVSS). Fresh mixed liquor was aerated without feed for a minimum of 30 hours to achieve the endogenous state. After adjusting the volatile suspended solids concentration by diluting with water, a 600-ml portion of diluted mixed liquor was placed in the reaction vessel, agitated, and aerated for 20 minutes and adjusted to $25^{o}C \pm 1^{o}C$. At the end of aeration, a zero-time dissolved oxygen reading was taken, followed by additional readings as a function of time, until 30 minutes had passed. Since the rate of disappearance of dissolved oxygen from the activated sludge mixed liquor is equal to the dissolved oxygen uptake rate of microbial respiration, the slope of the straight line portion of a plot of dissolved oxygen versus time was defined as the reference respiration rate (k_r). Using the same procedure, a relative respiration rate (k) was determined with each additive at its recommended dosage and four other concentrations.

Figures 1, 2, and 3 are plots of dissolved oxygen content versus time for mixed liquors containing various concentrations of formaldehyde, zinc, and quaternary ammonium chemical additives. Table 5 gives a summary of all respiration rate data from studies on seven chemical additives. It was interpreted that relative respiration rates (k) less than the corresponding reference respiration rate (k_r) indicated deleterious effects by the presence of the chemical additive. Similarly, k values greater than k_r indicated that the specific additive was biodegradable and supplied nutrients to the sludge, resulting in increased microbial respiration. At the recommended dosage of all except one additive tested, k values were substantially less than k_r values. Respiration rates increased as chemical additive concentration decreased. At low concentrations of formaldehyde and quaternary ammonium additives, the k values were greater than k_r, while both zinc additives gave k values that only approached k_r. These results indicated that zinc additives at all concentrations greater than 15 to 20 mg/l exhibited a deleterious or toxic effect on activated sludge. Formaldehyde and quaternary ammonium additives exerted a toxicity at high concentrations but were biodegradable at lower concentrations.

For comparison, the percent of relative respiration rate ($k/k_r \times 100$) calculated from rate data for each chemical additive concentration. Values greater than 100 indicated the biodegradability of the chemical additive while values less than 100 indicated toxicity. Values of 100 indicated that the relative respiration rate (k) equaled the reference respiration rate (k_r), and that the additive had no effect on the respiration rate of the activated sludge.

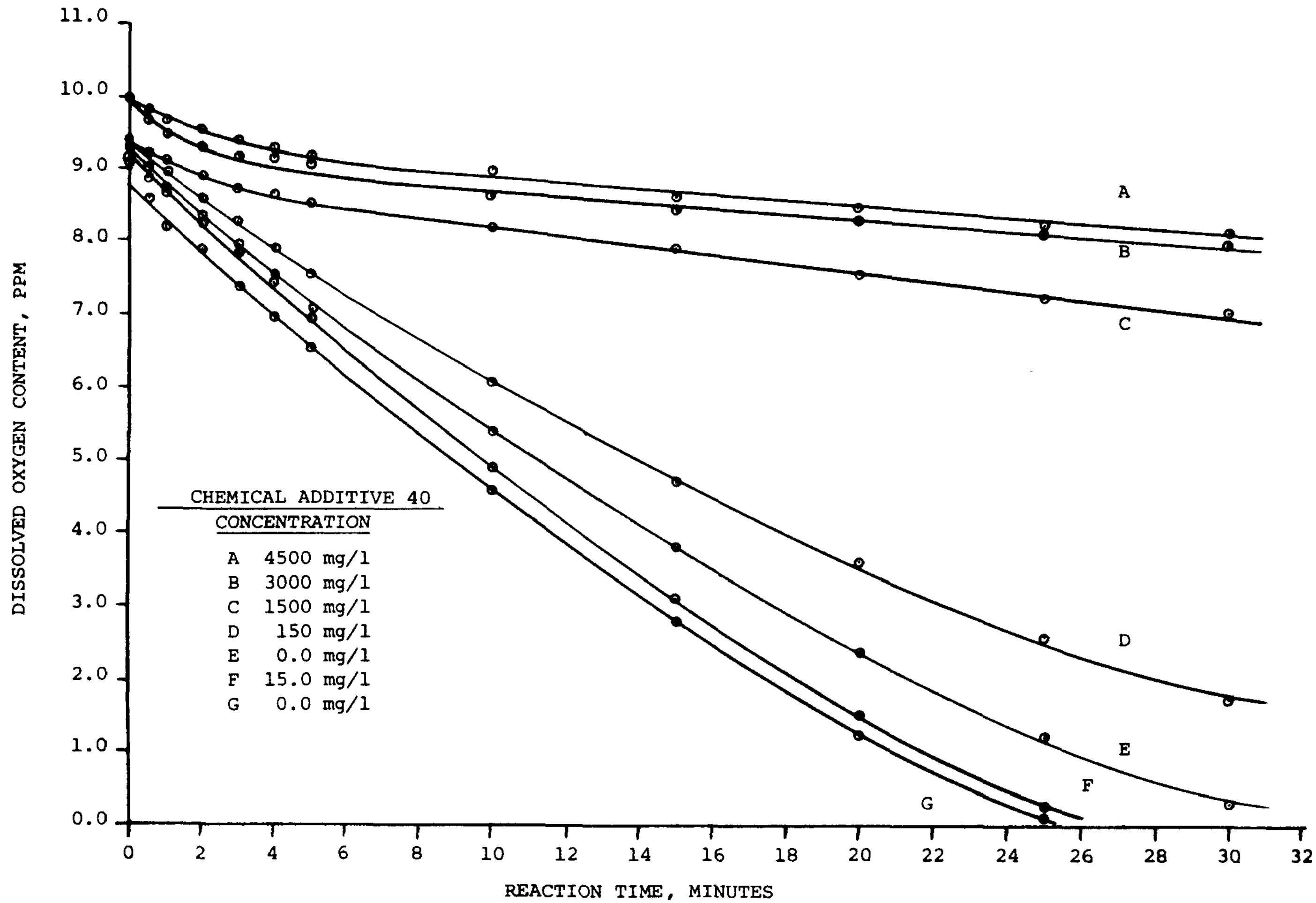


Figure 1. Rate of change in mixed liquor dissolved oxygen content as a function of formaldehyde chemical additive concentration

Note: Plots E and G represent reference respiration rate data for mixed liquor with no chemical additive.

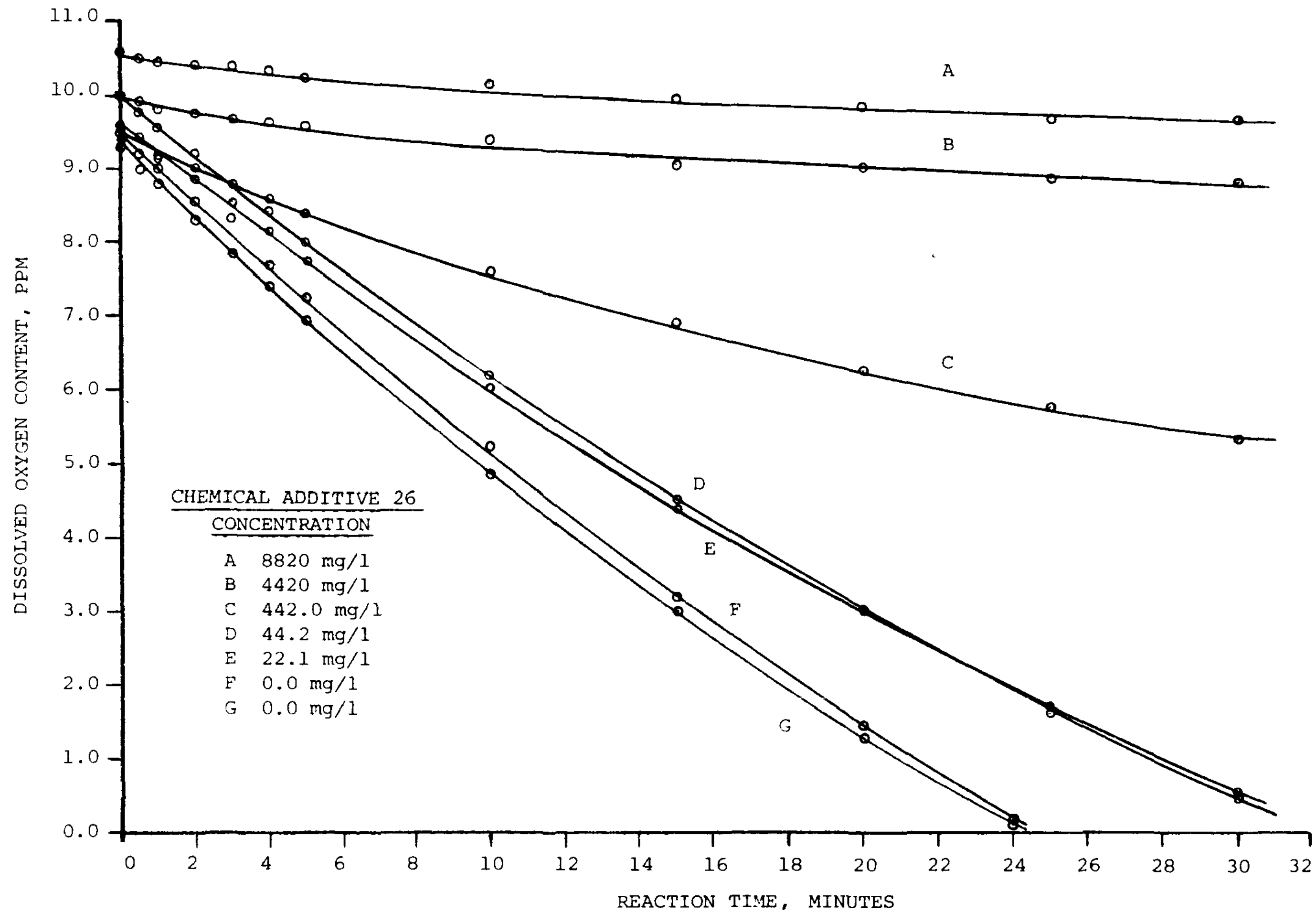


Figure 2. Rate of change in mixed liquor dissolved oxygen content as a function of zinc sulfate chemical additive concentration

Note: Plots F and G represent reference respiration rate data for mixed liquor with no chemical additive.

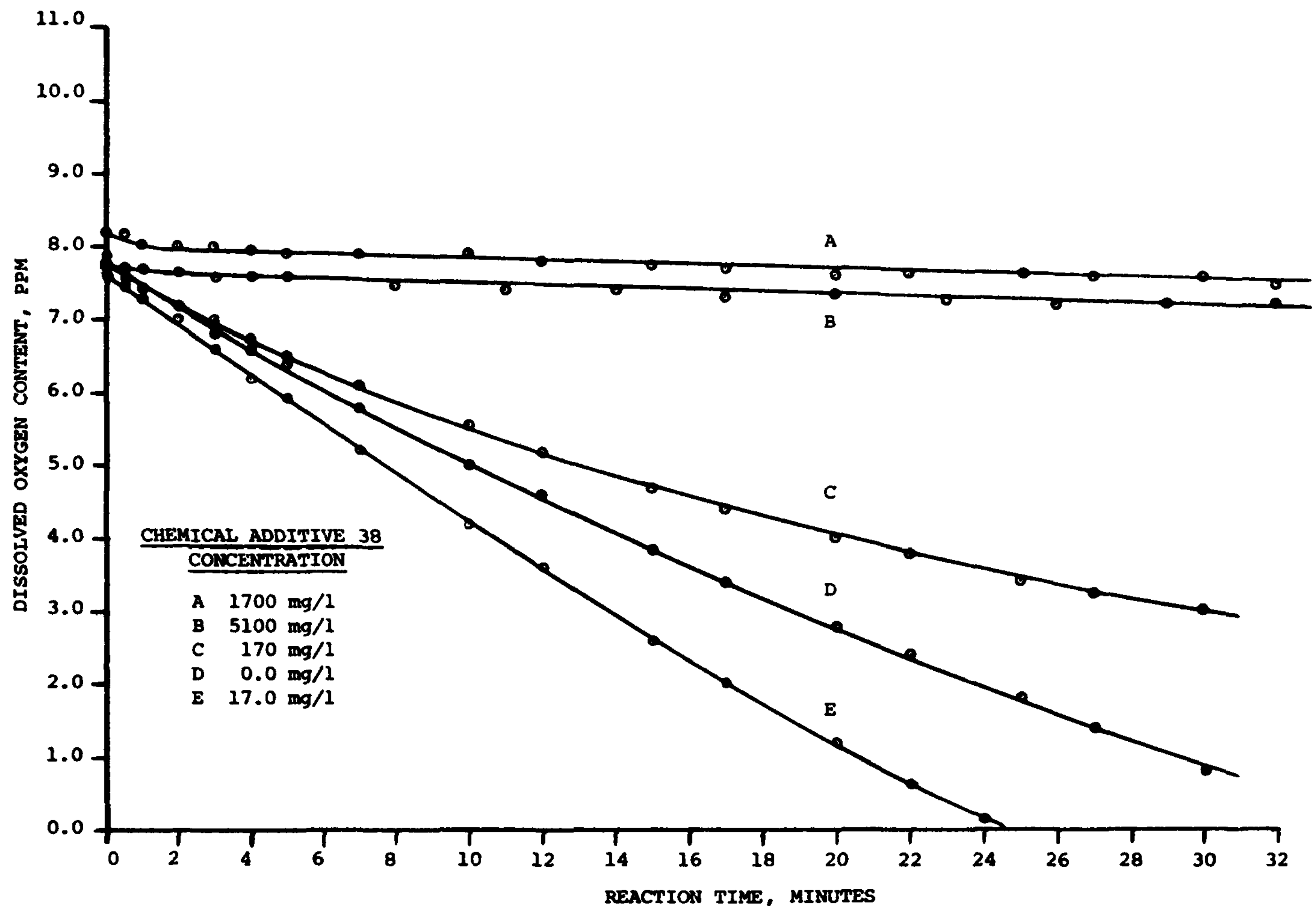


Figure 3. Rate of change in mixed liquor dissolved oxygen content as a function of quaternary ammonium chemical additive concentration

Note: Plot D represents reference respiration rate data for mixed liquor having no chemical additive.

Table 5. RESPIRATION RATE DATA FOR ACTIVATED SLUDGE MIXED LIQUOR CONTAINING CHEMICAL TOILET ADDITIVES

Chemical Code [a]	Chemical Concentration (mg/l)	MLSS/MLVSS (mg/l/mg/l)	Reference Rate, k_r (mg/l/min)	Relative Rate, k (mg/l/min)	Percent Relative Rate, $k/k_r \times 100$
40	4,500 [b]	1250/1010	0.366	0.049	13.4
40	3,000	1250/1010	0.366	0.050	13.7
40	1,500	1390/1140	0.379	0.067	17.7
40	150	1390/1140	0.379	0.325	85.8
40	15	1390/1140	0.379	0.404	106.6
83	11,250	2055/1715	0.236	0.063	26.7
83	3,750 [b]	2060/1920	0.242	0.131	54.1
83	375	2060/1920	0.242	0.401	165.7
83	37.5	2060/1920	0.242	0.252	104.1
33	4,500	2390/1955	0.343	0.053	15.5
33	3,000	2670/2240	0.344	0.070	20.3
33	1,500 [b]	2670/2240	0.344	0.084	24.4
33	750	2670/2240	0.344	0.102	29.7
33	750	2670/2240	0.344	0.096	27.9
33	150	2670/2240	0.344	0.154	44.8
33	15	2390/1955	0.343	0.315	91.8
96	13,500	2055/1715	0.204	0.025	12.3
96	4,500 [b]	2055/1715	0.204	0.029	14.2
96	450	2055/1715	0.204	0.180	88.2
96	45	2055/1715	0.204	0.400	196.1
20	11,760	1485/1255	0.261	0.098	37.5
20	3,920 [b]	1485/1255	0.261	0.317	121.5
20	392	1485/1255	0.261	0.428	164.0
20	39.2	1485/1255	0.261	0.527	201.9
38	5,100	1300/1095	0.243	0.021	8.6
38	1,700 [b]	1300/1095	0.243	0.019	7.8
38	170	1300/1095	0.243	0.185	76.1
38	17	1300/1095	0.243	0.327	134.6
26	8,820	1115/915	0.408	0.027	6.6
26	4,420 [b]	1260/1030	0.430	0.041	9.5
26	442	1260/1030	0.430	0.148	34.4
26	44.2	1260/1030	0.430	0.355	82.6
26	22.1	1115/915	0.408	0.346	84.8

a Chemical code number legend: Formaldehyde Type = 20, 40, 83, 96. Zinc Salt Type = 26,33. Quaternary Ammonium Type = 38.

b Recommended dosage concentration.

Figures 4A and 4B show plots of the percent of relative respiration rate versus chemical additive concentration. The maximum nontoxic chemical additive concentration was estimated from these graphs at the point where each plot intersected the 100 percent relative rate value. The dilution factor required to lower the chemical additive concentration from its recommended dosage to this maximum nontoxic concentration was calculated with the result given in Table 6.

Table 6. TOXICITY DATA AND DILUTION REQUIREMENTS FOR CHEMICAL TOILET ADDITIVES

Chemical Code	Active Ingredient	Recommended Dosage (mg/l)	Maximum Non-Toxic Conc (mg/l)[a]	Dilution Factor[b]
26	Zinc Sulfate	4420	20	220
33	Zinc Sulfate	1500	15	100
20	Formaldehyde	3920	5900	1.0
40	Formaldehyde	4500	55	80
83	Formaldehyde	3750	2350	1.6
96	Formaldehyde	4500	400	11
38	Quaternary Ammonium Salt	1700	110	15

[a] Maximum chemical additive concentration that does not adversely affect the respiration rate of activated sludge.

[b] Volume dilution required of chemical additive at its recommended dosage to eliminate any adverse effect on respiration rate of activated sludge.

DISCUSSION

Respirometer data indicated a low tolerance of zinc by activated sludge. The maximum zinc additive concentrations that had no adverse effect

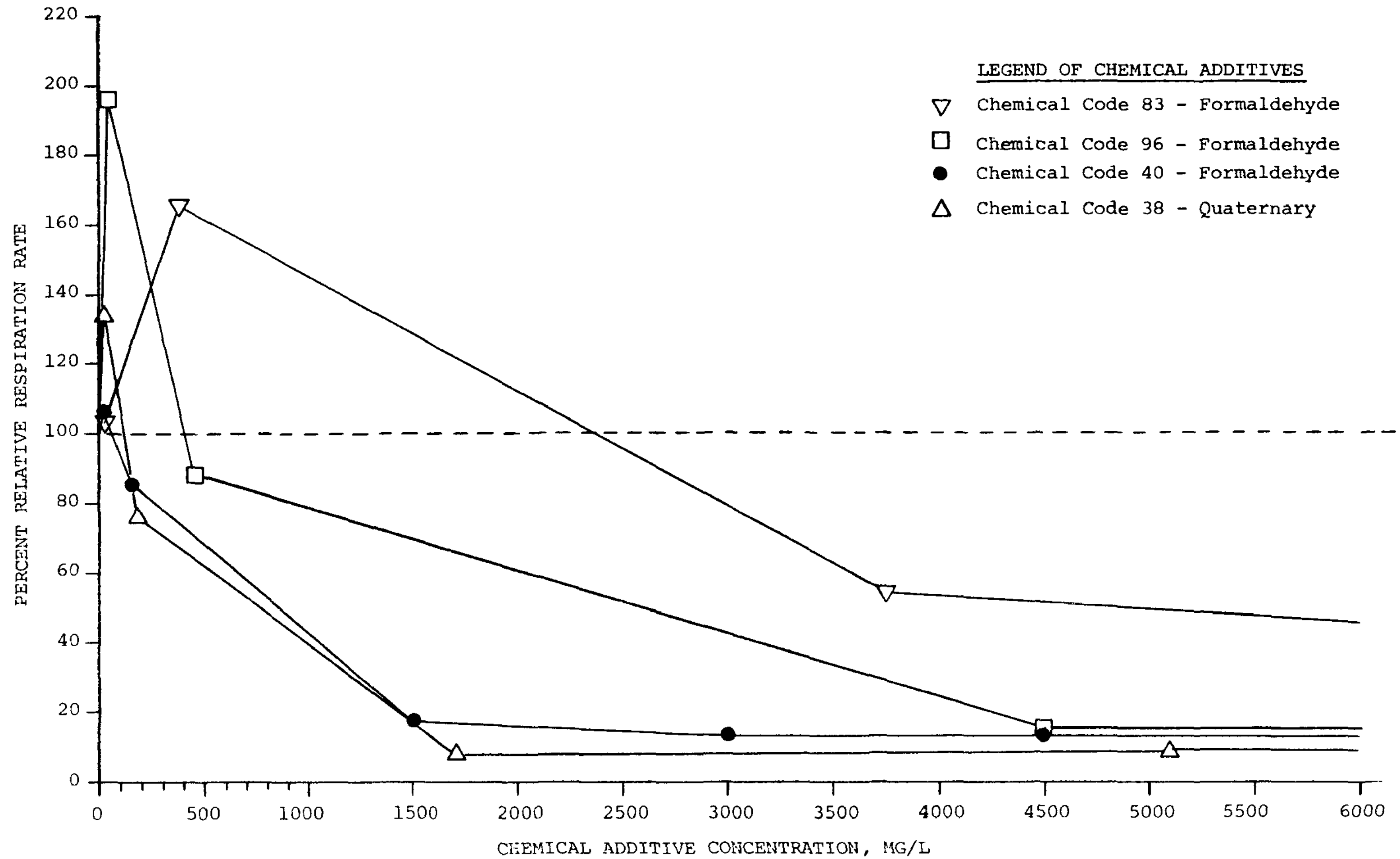


Figure 4A. Effect of chemical additive concentration on activated sludge respiration rate

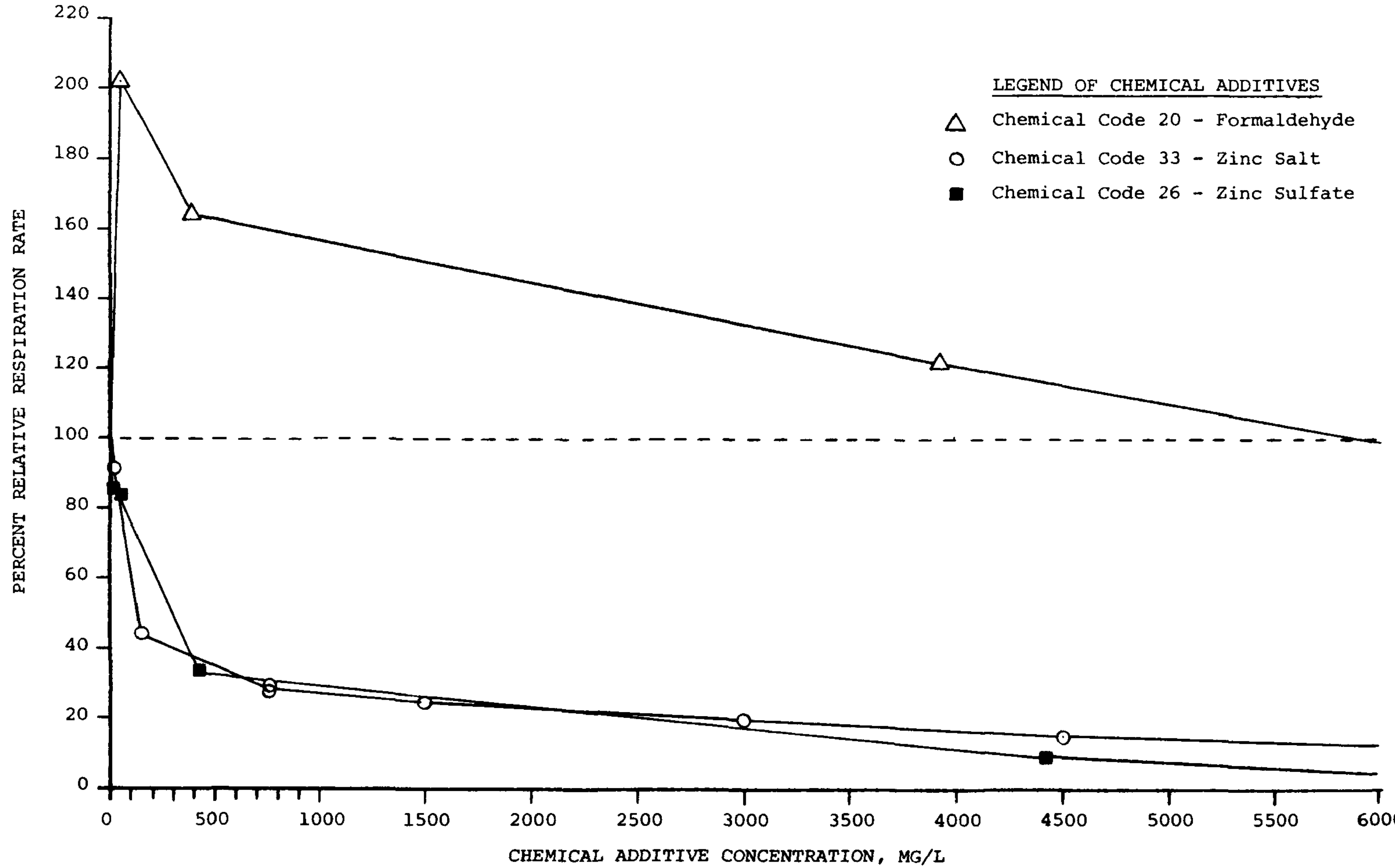


Figure 4B. Effect of chemical additive concentration on activated sludge respiration rate on activated sludge respiration rate ranged from 15 to 20 mg/l. Based on the chemical content, the calculated zinc concentration was 5 to 7 mg/l. This result agrees quite well with the reported maximum level of 5.0 to 10 mg/l zinc that will not produce an adverse effect on activated sludge treatment efficiency[7,8,9].

Formaldehyde additives had varying effects on activated sludge. Each additive was biodegradable over a certain concentration range, and within this range the percent of relative rate data went through a maximum indicating a point of greatest nutrient value to the activated sludge microorganisms. These maximum values varied significantly. The concentrations at which these additives began to have adverse effects on respiration rate also varied significantly. Chemical Code 40 showed toxic effects at 50 mg/l, while Chemical Code 20 was biodegradable at concentrations greater than 550 mg/l. These results may be explained by differences in the composition and/or the solubility of additive ingredients. Liquid additives employing formalin were toxic at much lower concentrations than solid additives using paraformaldehyde. Methylene blue, present in certain liquid additives as a dye, will have a definite toxic effect on most bacteria.

A maximum concentration of 55 mg/l of Chemical Code 40 had no adverse effect on respiration rate. The calculated formaldehyde concentration was 20 mg/l. This additive was 95 percent formalin with methyl blue, perfumes, and surfactants. The reported toxic concentration of formaldehyde in domestic sewage is 135 to 175 mg/l[10]. The significant difference in these results suggests additional toxicity from ingredients other than formaldehyde. On the other hand, in the presence of sewage, formaldehyde may readily react with proteins resulting in a lower free-formaldehyde concentration available to microorganisms. In this case, higher initial formaldehyde concentration is required in the presence of sewage to produce the same toxic effect on activated sludge. The absolute accuracy of toxic concentrations determined in this study is questionable because interpolation of values from limited data results in a large probable error. Therefore, only qualitative significance should be given to these results.

To avoid the toxic effects of specific additives, significant volume dilution is required. Ten liters of waste containing the recommended dosage of zinc additive may require dilution with as much as 2200 liters of water or domestic sewage before eliminating its adverse effect on activated sludge treatment efficiency.

SECTION VI

TREATABILITY OF SEWAGE CONTAINING CHEMICAL ADDITIVES

Respirometer studies of activated sludge/sewage mixtures were made to determine relative respiration rates as a function of sewage suspended solids and chemical additive concentration. Comparison of these rates indicated the relative treatability of such sewages and the maximum tolerable concentrations of zinc and formaldehyde that would not have adverse effects on the activated sludge process.

RESPIROMETER STUDIES

Using fresh raw body wastes, several series of sewage samples were prepared with a suspended solids range of 900 to 9000 mg/l. Zinc, formaldehyde, and quaternary ammonium chemical additives were added at their recommended concentrations to specific samples. An undiluted sewage sample having no chemicals served as a control. Portions of each sample were analyzed for various chemical and biological parameters. This analysis was repeated after aging all samples at 25°C for 72 hours.

Activated sludge mixed liquor was aerated for 30 hours without feed to establish its endogenous state. The reference respiration rate (k_r) of this mixed liquor was determined by procedures described in Section V. Mixtures of activated sludge and chemically treated sewage were prepared to maintain a constant loading factor (mg/l BOD_5//mg/l MLVSS) for each series of sewage suspended solids. After aeration for 20 minutes to saturate this mixture with dissolved oxygen, the rate of change in mixed liquor dissolved oxygen content was measured as a function of time, and a relative respiration rate (k) was determined for each mixture. For comparison of these data, percent relative respiration rate values (k/k_r x 100) were calculated for each sewage sample.

Table 7 gives the characteristics of sewage samples involved in this study. Sample 1 describes the original sewage sample with no chemical additives. Sample 2 describes that same sewage after 72 hours aging.

Table 7. CHARACTERISTICS OF SANITARY SEWAGE CONTAINING CHEMICAL TOILET ADDITIVES

Sample Number	1	2	3	4	5	6	7
Chemical Additive Type	Control	Control	Zinc[a]	Zinc[a]	Form.[b]	Form.[b]	Quat.[c]
Additive Code No.	---	---	26	26	40	40	38
Additive Conc. (gm/l)	0	0	4.4	4.4	1.5	1.5	1.7
Age of Waste (hrs)	0	72	72	72	72	72	72
SS (mg/l)	10,400	10,000	12,900	6,400	10,200	4,900	10,600
VSS (mg/l)	9,000	7,900	9,100	4,400	8,200	4,000	8,200
COD (mg/l)	20,800	14,600	24,100	12,100	24,200	10,000	21,500
BOD_5 (mg/l)	7,300	6,400	7,200	2,700	7,100	3,200	5,700
TOC (mg/l)	7,600	7,400	7,400	3,200	6,800	3,300	8,400
SOC (mg/l)	4,000	4,200	3,500	1,500	4,200	1,900	3,900
T-N (mg/l)	4,600	4,600	4,500	2,100	4,500	2,200	4,800
pH	9.0	9.1	7.4	7.4	8.7	8.1	9.2
CONDUCTIVITY (MHO)	18,000	23,000	16,500	8,600	16,000	7,700	20,500
COLIFORM (MPN/100 ml)	13×10^{10}	6×10^{6}	6×10^{6}	2×10^{5}	5×10^{4}	6×10^{6}	2×10^{5}

[a] Zinc sulfate.

[b] Formaldehyde.

[c] Quaternary ammonium compound.

Their comparison shows a moderate decrease in COD and BOD_5 with a slight increase in SOC after 72 hours. These results are evidence of normal decomposition and stabilization by microbial activity. Samples 3 through 7 were all prepared from the control (Sample 1). Specific chemical additive was added to undiluted control sewage and aged for 72 hours. These results are given under Samples 3, 5, and 7. Similarly, control sewage was diluted 100 percent with tap water (halving the constituent concentrations), mixed with specific chemical additives, and aged for 72 hours. These results are given under Samples 4 and 6.

Comparison of the aged control sewage (Sample 2) to the same sewage treated and aged with specific chemical additives (Samples 3, 5, and 7) provides a basis for evaluating the effects of specific additives on the waste characteristics. The zinc sulfate additive in Sample 3 caused a significant increase in SS while formaldehyde had no similar effect on Sample 5. Both additives caused a major increase in COD and a slight increase in BOD_5. SOC was actually decreased in Sample 3, possibly by the insolubilization of zinc organic salts. Formaldehyde indicated no effect on SOC. Quaternary ammonium additive appeared to cause a slight increase in COD and TOC but a decrease in BOD_5 and SOC. Formaldehyde additive had the greatest effect in reducing the coliform population.

The interpretation of these results must be qualified. Under the dynamic conditions of aging concentrated sewages, it is impossible to determine the true net effect of the chemical additives. Comparison between these sewage samples provides at best only qualitative data. Samples 4 and 6 may only be compared to each other as an indication of specific additive effects on more dilute wastewater.

Table 8 gives the treatability data as a function of sewage suspended solids and chemical additive concentration. Percent relative respiration rate values for zinc and quaternary ammonium-treated sewages are less than those for the control. Formaldehyde treated sewages have rates greater than the control. These results are shown graphically in Figure 5 as a plot of percent relative respiration rate versus sewage suspended solids. Separate plots are given for the control and each chemically treated sewage. The limiting condition of zero suspended solids concentration represents infinitely dilute sewage. Data points at this limit are the percent relative respiration rate values for activated sludge mixed liquor having a recommended dosage of specific chemical additive.

These results were used to evaluate qualitatively the treatability of simulated holding tank wastewaters. As defined, percent relative respiration rate values greater than 100 indicate greater microbial respiration activity compared to the endogenous state. This is the re-

Table 8. TREATABILITY DATA AS A FUNCTION OF SEWAGE SUSPENDED SOLIDS AND CHEMICAL TOILET ADDITIVES

Chemical Additive[a]	Sewage SS (mg/l)	MLSS/MLVSS (mg/l//mg/l)	Load Factor (mg/l BOD_5//mg/l MLVSS)	Reference Rate, k_r (mg/l//min)	Relative Rate, k (mg/l//min)	Percent Relative Rate, k/k_r x 100
None, raw sewage	9,980	2250/1890	0.339	0.302	1.28	422
Formaldehyde, Code 40	0[b]	1390/1140	---	0.379	0.400	106
	760	2140/1890	0.039	0.207	0.801	387
	4,920	2250/1890	0.341	0.302	1.760	580
	10,240	2325/1955	0.380	0.212	1.670	788
Zinc-Sulfate, Code 26	0[b]	1260/1030	---	0.430	0.041	9.6
	1,600	2140/1890	0.027	0.207	0.132	63.8
	6,420	2250/1890	0.216	0.302	0.333	110
	12,940	2325/1955	0.305	0.212	1.04	490
	13,240	2140/1890	0.270	0.207	0.660	319
Quaternary,	0[b]	1300/1095	---	0.243	.019	7.8
Code 38	10,580	2250/1890	0.272	0.302	0.350	116

[a] Each chemical additive was used at maximum recommended dosage concentration .

[b] Chemical additive at maximum recommended dosage concentration in activated sludge mixed liquor.

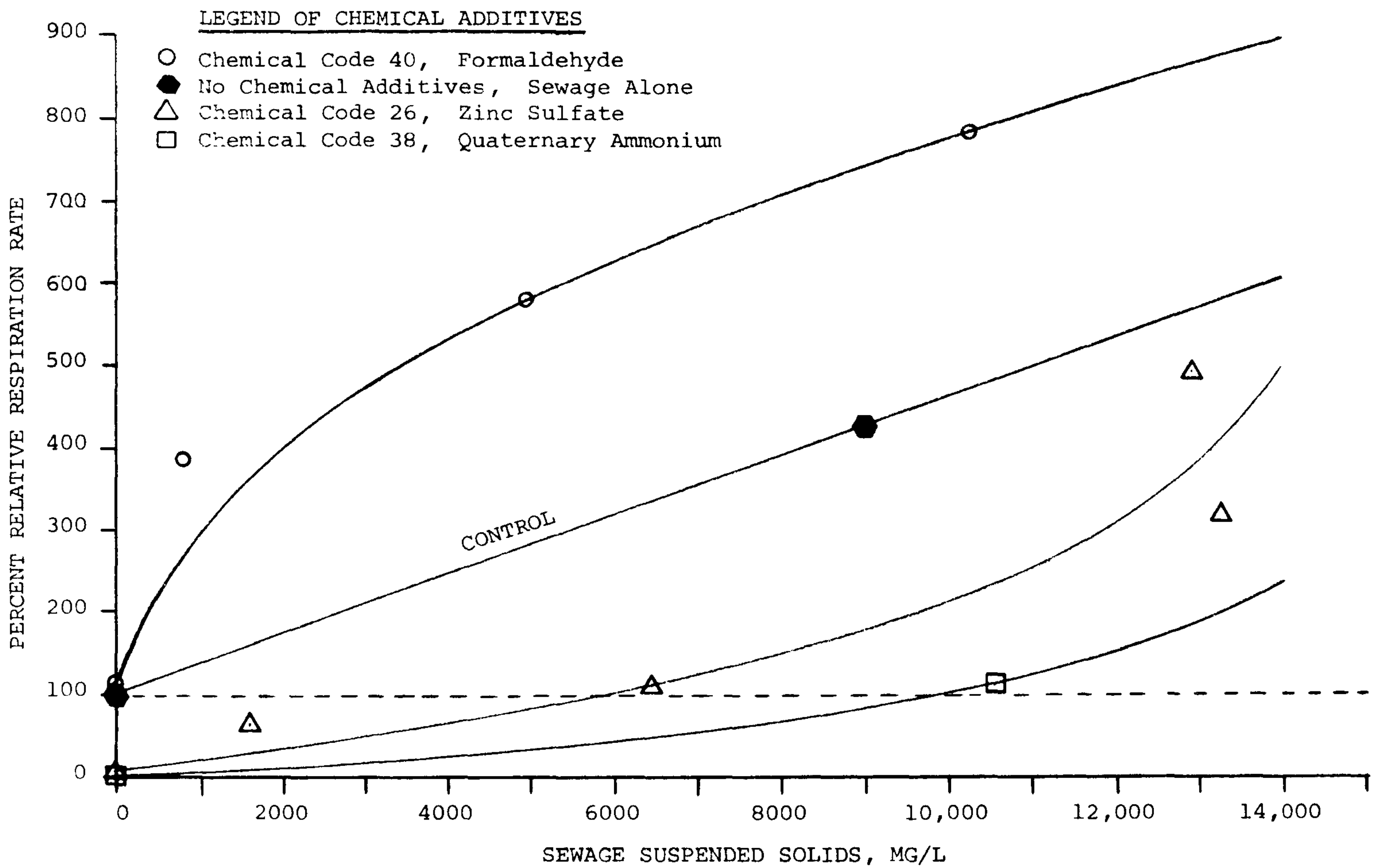


Figure 5. Relative sewage treatability as a function of chemical additive and sewage suspended solids

sult of the presence of biodegradable nutrients available for assimilation by microorganisms. Conversely, values less than 100 indicate a condition of microbial activity that is less than its normal endogenous respiration rate. This results from the inactivation or death of microorganisms caused by the presence of toxic substances. The application of relative respiration rate as an indication of sewage treatability is based on this logic.

Results indicated that treatability of sewage was a function of specific chemical additive and sewage strength. At low suspended solids, zinc-treated and quaternary ammonium-treated sewages were toxic to activated sludge. With increased solids concentration, these sewages were less toxic. Sewages containing formaldehyde were biodegradable over a broad range of suspended solids concentration with no adverse effects on activated sludge. Significant evidence was given to indicate that the treatability of sewages containing formaldehyde additives was much greater than those containing zinc or quaternary ammonium chemical additives.

Additional respirometer studies were conducted to evaluate the relative treatability of domestic sewage mixtures containing increased amounts of chemically treated wastes. Combining domestic sewage with industrial wastewaters before treatment is common practice. The effect of increased chemical additive concentration on activated sludge was determined under simulated mixed sewage conditions.

Identical waste samples were charged with 4.5 mg/l of zinc and formaldehyde additives (Codes 26 and 40) and aged at 25°C for 72 hours. Portions of these wastes were combined with fresh settled domestic sewage to give domestic/chemical sewage mixtures of 50/50 and 75/25 percent, respectively, by volume. These mixtures, having approximately 3300 mg/l SS, were added at a constant loading factor of 1.6 to 1.8 to activated sludge mixed liquor which had been previously characterized for the reference respiration rate. Each activated sludge/sewage mixture was then aerated and analyzed for its relative respiration rate. This same procedure was applied to the domestic sewage having 114 mg/l SS and the original full-strength chemical waste samples. Table 9 gives the respiration rate data for this study.

Sewages containing formaldehyde-treated wastes had greater respiration rates than those containing the zinc additive. Relative respiration rate data indicated that the treatability of sewage mixtures containing zinc was less than the untreated domestic sewage, indicating toxicity to activated sludge. As the volume percent of zinc-treated wastes increased, the toxic effect also increased. These results are shown in Figure 6. Since percent of chemical waste composition

Table 9. TREATABILITY DATA AS A FUNCTION OF SEWAGE COMPOSITION AND CHEMICAL TOILET ADDITIVES

Chemical Additive[a]	Sewage Composition	Sewage SS (mg/l)	Load Factor (mg/l BOD_5//mg/l MLVSS)	MLSS/MLVSS (mg/l//mg/l)	Reference Rate, k_r (mg/l//min)	Relative Rate, k (mg/l//min)	Percent Relative Rate $k/k_r \times 100$
None	100% Domestic	114	0.170	2280/1910	0.205	0.633	310
Formaldehyde, Code 40	75% Domestic, 25% Chemical	3321	0.183	2280/1910	0.205	0.930	453
	50% Domestic, 50% Chemical	3300	0.181	2280/1910	0.205	0.974	476
	100% Chemical, 0% Domestic	3300	0.216[b]	---	---	---	490[c]
Zinc-Sulfate, Code 26	75% Domestic, 25% Chemical	2640	0.160	2280/1910	0.205	0.579	282
	50% Domestic, 50% Chemical	3050	0.182	2280/1910	0.205	0.563	275
	100% Chemical 0% Domestic,	3300	0.16[b]	---	---	---	50[c]

[a] Each chemical additive used at maximum recommended dosage concentration.

[b] Calculated value.

[c] Value taken from Figure 4 at 3300 mg/l suspended solids.

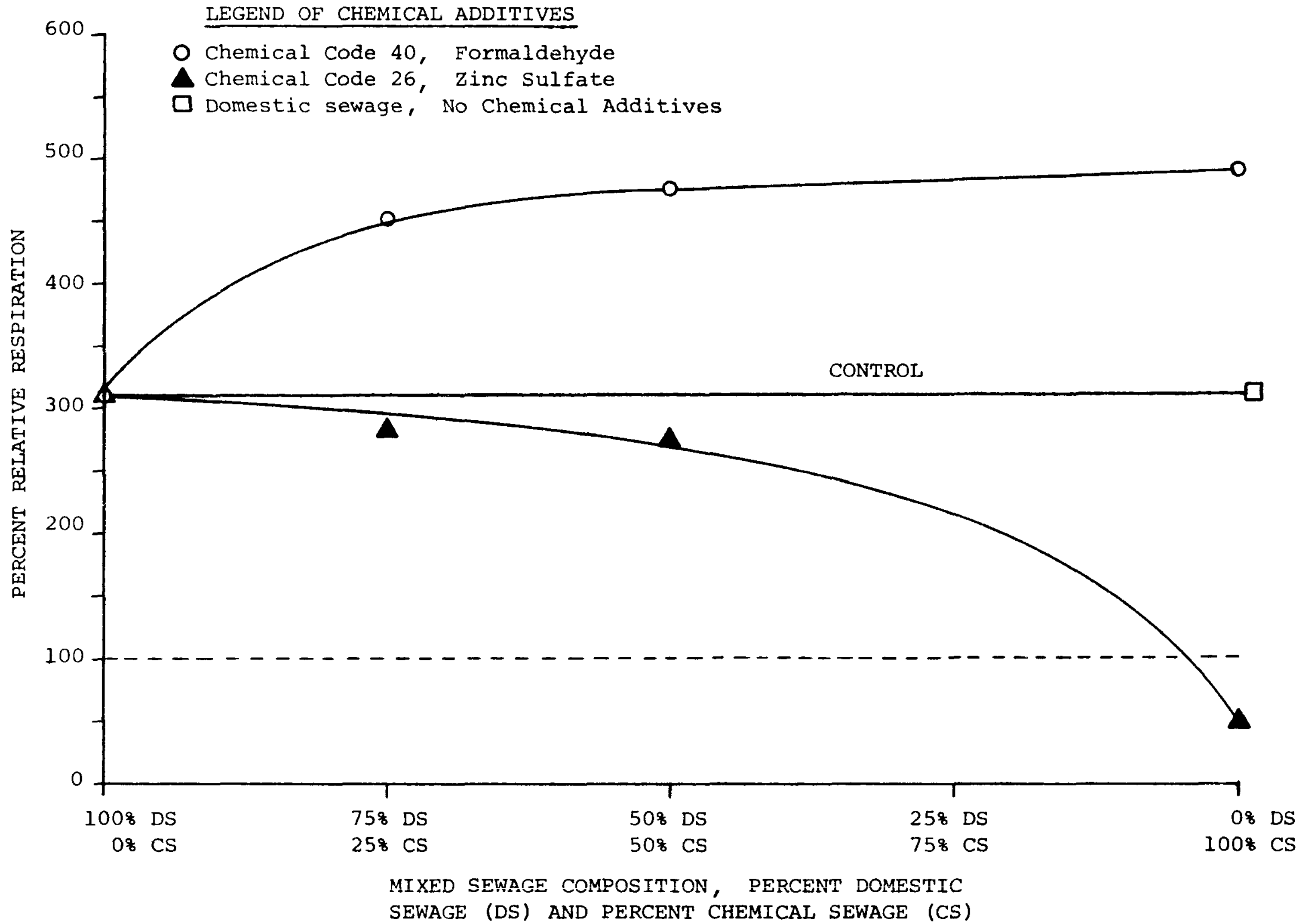


Figure 6. Relative sewage treatability as a function of percent chemical waste composition

can be equated to chemical additive concentration, substantial evidence is given that increased zinc concentrations resulted in decreased sewage treatability. Sewages containing formaldehyde had relative respiration rate values greater than the untreated domestic sewage and, as formaldehyde concentration increased, the relative treatability of these sewages increased and then reached a plateau.

DISCUSSION

A relative indication of the maximum tolerable zinc concentration in sewage that will not have an adverse effect on the activated sludge process was given in the respiration rate data. Toxic effects from increased zinc concentration were indicated by percent relative respiration rage values less than those for the domestic sewage control. A sewage composition of 3 percent zinc treated waste (97 percent domestic sewage) gave the first measurable effect of toxicity. This is shown in Figure 6 as the point of separation between the plots for the domestic sewage control and zinc treated sewage mixtures. The calculated zinc concentration of this sewage mixture was 40 mg/l. These results indicated that sewage mixtures containing more than 40 mg/l zinc have adverse effects on the activated sludge process. This zinc content will occur in sewage mixtures that contain approximately 3 percent (by volume) of undiluted waste charged with the recommended dosage of zinc-type chemical additives. Undiluted waste refers to the original sewage from recirculating/retention systems. It is common practice to flush these systems after emptying. Typical rinsing dilutes the waste pumpage volume by 50 percent. In this case, the maximum tolerable amount of zinc-treated wastes would be approximately 5 percent by volume.

Formaldehyde-treated wastes gave no sign of toxicity to activated sludge. Previous respirometer studies showed that formaldehyde additives are biodegradable at low concentrations and cause an increase in the relative respiration rate of activated sludge. High concentrations of formaldehyde in sewage would be expected to have toxic effects on activated sludge. This result is not shown here. Formaldehyde is very reactive and will combine readily with proteins and ammonia[11]. The extent of formaldehyde reaction with sewage ingredients will determine the free formaldehyde-concentrations and its effect on microorganisms. Low formaldehyde concentrations will be biodegradable as nutrients; large concentrations will be toxic. Therefore, the effect of formaldehyde on sewage treatability is a function of sewage characteristics as well as formaldehyde concentrations.

Sewage characteristics have similar effects on the toxicity of zinc and quaternary ammonium compounds. Chemical reactions may remove these constituents from solution and reduce their net toxic effect. Zinc ion will readily complex with proteinaceous colloids as well as combine with microbial floc[9]. Quaternary ammonium salts completely dissociate in water, and quaternary ammonium ions are very reactive with bases and alcohols common in proteins and carbohydrates. The ability of microorganisms to assimilate specific reaction products will affect the treatability of the sewage, and the extent of reaction will determine the remaining concentration of chemical additive ingredients and their effect on the activated sludge. Therefore, treatability of sewage is a function of both chemical additive concentration and sewage characteristics.

SECTION VII

ACTIVATED SLUDGE TREATMENT OF CHEMICAL WASTES

Respirometer studies produced the significant result that biological treatment of sewage was adversely affected by the presence of specific chemical additives at relatively low concentrations. Since the correlation between aerobic respiration rate and treatability was strictly qualitative, a detailed activated sludge treatment study was conducted to substantiate the respirometer results.

Domestic sewage from a common source was mixed with varying amounts of specific chemical wastes and fed to three replicate, activated sludge plants. One plant was operated on domestic sewage alone as a control. The loading factor was held constant for all three plants. Differences in effluent quality, organic removal efficiencies, and cell yield values between the control and test units were attributed to the presence of the specific chemical additives.

The objective of this study was to determine the level of specific chemical waste that can be tolerated in wastewaters without reducing the efficiency of the activated sludge treatment process. The efficiency of the process to remove specific chemical additives was also to be evaluated.

PLANT OPERATION

The activated sludge treatment process was simulated in a 210-liter (55-gallon) drum reactor equipped with a sintered ceramic air diffuser. Three replicate reactors were used: one as a control and two as test plants. A "fill and draw" technique was employed twice daily with aeration periods of 6 and 12 hours to simulate diurnal flow patterns in plug flow plants. Mixed liquor volatile suspended solids were maintained constant by proper wasting. Feed, effluent, and mixed liquor samples were taken twice daily for analysis. Each feed cycle continued for five days.

PREPARATION OF FEED CHEMICAL SEWAGE

Fresh sanitary wastes from portable toilets at local construction sites were blended in a 950-liter tank. The measured suspended solids concentration was 17,500 mg/l. Portions of this waste were diluted with water until each had a suspended solids concentration of 2100 mg/l, representative of typical watercraft waste pumpage.

Based on the manufacturer's recommended dosage, 841 grams of formaldehyde additive (Code 40) was added to 190 liters of prepared waste. The calculated formaldehyde concentration of this waste sample was 1575 mg/l. Similarly, 835 grams of zinc additive (Code 26) was mixed with 190 liters of identical waste. The calculated zinc concentration of this mixture was 1400 mg/l. Both chemically treated waste samples were aged at 25°C for 3.5 days, separated into 11- and 19-liter portions, and refrigerated at 2°C.

Portions of each chemically treated sewage sample were analyzed immediately after their preparation and then analyzed again after 3.5 days aging. Similarly, the control sewage without chemicals was analyzed after equal aging. Comparisons between chemically treated and untreated aged sewage samples showed significant differences because of the presence of the specific additive. Zinc treated wastes showed a significant increase in SS with a loss in TOC, possibly caused by the zinc complexing with colloidal solids. Similar aged wastes containing formaldehyde had nearly doubled concentrations of COD, BOD, and SOC. Both coliform and total bacteria contents of the chemically treated sewages were greatly reduced. The measured formaldehyde concentration of the aged waste was reduced because of chemical reaction and evaporation losses. Unfortunately, no data were obtained describing the original control sewage to allow more accurate comparisons between unaged (zero time) chemically treated and untreated sewage samples.

PROCEDURES

Each drum reactor was charged with 75 liters (20 gallons) of activated sludge taken from a package treatment plant processing 190 kl/day (50,000 gal/day) of domestic sewage from Santa Clara, California. Fresh settled domestic sewage from the same source was added and the mixture aerated for 6 hours. Supernatant effluent was removed after 2 hours of settling, and domestic sewage was again fed to each reactor followed by 12 hours of aeration. This procedure was repeated for 5 consecutive days with proper wasting of mixed liquor to give a healthy, stabilized activated sludge in each reactor with a 1200 mg/l average mixed liquor volatile suspended solids concentration (MLVSS).

Table 10. COMPARISON OF CHEMICALLY TREATED FEED SEWAGES FOR ACTIVATED SLUDGE PILOT PLANT STUDIES

Parameter	Control	Sample A		Sample B	
Active Chemical:	None	Formaldehyde[a]		Zinc[b]	
Age (days):	3.5	0	3.5	0	3.5
SS (mg/l)	2,080	2,420	2,260	3,460	3,760
VSS (mg/l)	1,673	2,010	1,950	2,370	2,300
TS (%)	0.37	0.49	0.51	0.83	0.86
TVS (%)	0.23	0.32	0.34	0.47	0.49
TOC (mg/l)	1,240	1,830	1,920	1,330	1,035
SOC (mg/l)	550	1,225	1,260	560	530
BOD_5 (mg/l)	1,140	2,560	2,500	1,450	1,630
COD (mg/l)	2,740	5,400	5,320	2,880	2,090
T-N (mg/l)	820	600	625	425	590
NH_3-N (mg/l)	196	410	210	175	190
pH	8.9	7.4	7.1	6.9	7.2
T-PO_4 (mg/l)	210	218	213	270	240
Conductivity (MHO)	4,000	6,600	4,700	3,100	4,000
Zinc (mg/l)	0.5	---	---	1,400[c]	1,300
Formaldehyde (mg/l)	<0.2	1,575[c]	<1,100	---	---
Coliform (MPN/100 ml)	23×10^7	---	23×10^1	---	<45
Total Bacteria (SPC)[b]	14×10^6	---	50	---	170

[a] Chemical Code 40

[b] Chemical Code 26

[c] Calculated values based on chemical additive composition

[d] Standard Plate Count· the number of organisms per milliliter of sample

Three series of mixed sewages containing 1, 5, and 12 percent (by volume) of chemical waste were treated by the activated sludge process for 5 consecutive days. A two-cycle per day "fill and draw" technique was followed with aeration periods of 6 and 12 hours. Feed sewage samples were prepared twice daily, using fresh, settled, domestic sewage and chemical sewage. Refrigerated feed chemical waste samples were warmed to ambient temperature and diluted 50 percent by volume with fresh water. This dilution accounted for the flush water commonly used to clean the holding tank or toilet system after the initial pumpout. Specified volumes of diluted chemical wastes and fresh domestic sewage were mixed and fed to respective reactors. The volume of each mixed sewage feed sample was controlled to maintain a constant loading factor of 0.25 in each reactor.

Samples of feed waste and supernatant effluent were collected from each reactor twice daily, composited, and analyzed for 11 chemical and biological parameters. Samples of mixed liquor were taken after the 12-hour aeration period and analyzed for SS, VSS, temperature, pH, conductivity, and DO content. Mixed liquor was periodically removed from each reactor to maintain constant MLVSS. A sludge volume index (SVI) was determined for each mixed liquor as a measure of its settleability. Mixed liquor samples were examined microscopically for changes in microorganism population, sludge size, and configuration. Photomicrographs were taken to show the physical results of any toxic effects from increasing zinc and formaldehyde concentration.

RESULTS

Differences in effluent quality and degree of treatment between the control and test reactors gave evidence of the relative effects of specific amounts of zinc- and formaldehyde-treated wastes. Table 11 gives the average removal efficiencies for activated sludge treatment of various domestic/chemical sewage mixtures. Characteristics of these feed sewages and corresponding effluents are also given.

Activated sludge treatment of feed sewage mixtures (1 percent by volume zinc-treated wastes, 99 percent by volume domestic sewage) having 9 mg/l zinc gave effluents that had slightly higher concentrations of TOC, SOC, COD, SS and turbidity compared to those of the control. No relative difference in BOD_5 removal was noted. However, some indication of loss of reliability of BOD_5 data due to toxic effects of zinc is given in the lower removal efficiencies of TOC, SOC, and COD. Other feed sewage mixtures (1 percent by volume formaldehyde-treated waste, 99 percent domestic sewage) having 10 mg/l formaldehyde gave effluents that showed no significant difference in quality compared to the control.

Table 11. RESULTS OF ACTIVATED SLUDGE TREATMENT OF SEWAGES CONTAINING CHEMICALLY TREATED WASTES

Chemical in Feed Sewage	Chemical Conc. (mg/l)	Volume Percent of Chemical Waste	T O C Average Feed (mg/l)	T O C Average Effluent (mg/l)	T O C Average Percent Removal	S O C Average Feed (mg/l)	S O C Average Effluent (mg/l)	S O C Average Percent Removal	C O D Average Feed (mg/l)	C O D Average Effluent (mg/l)	C O D Average Percent Removal
None	0	Control	118	11	90	62	8	86	215	22	90
Formaldehyde	10.4	1.0	120	12	90	57	9	84	193	15	92
Zinc	9.3	1.0	126	14	89	56	10	83	210	27	87
None	0	Control	123	8	93	62	6	90	365	30	92
Formaldehyde	378[a]	(36)	(382)	(91)	(76)	(263)	(62)	(76)	(1,580)	(295)	(81)
Zinc	47	5	147	20	86	81	13	84	425	59	86
None	0	Control	111	9	92	65	7	90	300	18	94
Formaldehyde	140	13.3	248	36	85	202	32	84	510	110	78
Zinc	113	12.1	163	33	80	97	22	77	390	93	76
			SUSPENDED SOLIDS			TURBIDITY			B O D		
None	0	Control	116	7.3	94	76	3	96	204	8	96
Formaldehyde	10.4	1.0	142	6.4	95	78	3	96	206	10	96
Zinc	9.3	1.0	162	10.0	94	84	5	94	186	7	96
None	0	Control	144	6.8	95	59	5	91	210	7	97
Formaldehyde	378[a]	(36)	(458)	(58)	(87)	(111)	(27)	(76)	(1,305)	(71)	(95)
Zinc	47	5.0	237	26	89	82	11	87	272	12	96
None	0	Control	100	3.9	96	54	6	90	220	3	98
Formaldehyde	140	13.3	257	15	94	84	8	90	336	10	97
Zinc	113	12.1	354	45	87	110	22	80	312	10	97

[a]Slug feed for six hours of mixed sewage having 380 mg/l formaldehyde followed by a continuous feed of uncontaminated domestic sewage for 4.5 days. All other feed sewages including the control were added continuously for 5 days.

A significant drop in effluent quality and decreased removal efficiency occurred with treatment of feed sewage mixtures having 47 mg/l zinc. This feed sewage consisted of 5 percent by volume zinc-treated wastes and 95 percent by volume domestic sewage. A similar decrease in effluent quality occurred with the treatment of feed sewages having 140 mg/l formaldehyde. This feed sewage consisted of 13 percent by volume formaldehyde-treated wastes and 87 percent domestic sewage.

The results of slug feeding mixed sewage having 36 percent chemical waste and a formaldehyde concentration of 380 mg/l are given in parentheses in Table 11. After 6 hours of slug feeding, uncontaminated domestic sewage was fed to the reactor for the following 4.5 days. A major upset of the biological process occurred as evidenced by a significant drop in effluent quality. Increase in TOC and BOD_5 may have resulted from the chemical addition, but SS data does indicate a drop in treatment performance. Normal process efficiency and effluent quality were restored 72 hours after initial shock loading. Figure 7 shows the effluent characteristics for 5 consecutive days following slug feeding.

Microscopic examinations were made of mixed liquor samples throughout each treatment series and photomicrographs were taken periodically to compare sludge characteristics. Mixed liquor contaminated with 9 mg/l zinc for 5 days showed no significant difference as compared to the uncontamined control. The full range of microorganisms characteristic of active healthy sludge was present. Sludge colonies were spherical, normal size, and contained equal amounts of bacteria filaments. At 47 mg/l zinc, a significant reduction was noted in the number and type of microorganisms. Populations of ciliated and flagellated organisms were most reduced. Sludge colonies became fragmented and bacteria filaments were significantly reduced. At 113 mg/l zinc, very little biological life was detected. Rotifers, flagellated protozoa, and free-swimming ciliated protozoa were killed, while stalked ciliated protozoa were inactivated. Sludge size was greatly reduced and fractured and no bacteria filaments were present. These changes in sludge characteristics as a function of zinc concentration are pictured in Figure 8.

Mixed liquor samples containing varying amounts of formaldehyde were similarly examined and photographed. At 10 mg/l formaldehyde, no significant difference was detected when compared to the mixed liquor from the uncontaminated control reactor. Mixed liquor samples contaminated with 140 mg/l formaldehyde for 5 days showed a slightly smaller microorganism population than the control. Flagellated and ciliated protozoa and rotifers were present in reduced numbers. Sludge colonies became quite clustered and bacteria filaments were greatly reduced. The changes in sludge characteristics as a function of formaldehyde concentration are pictured in Figure 9.

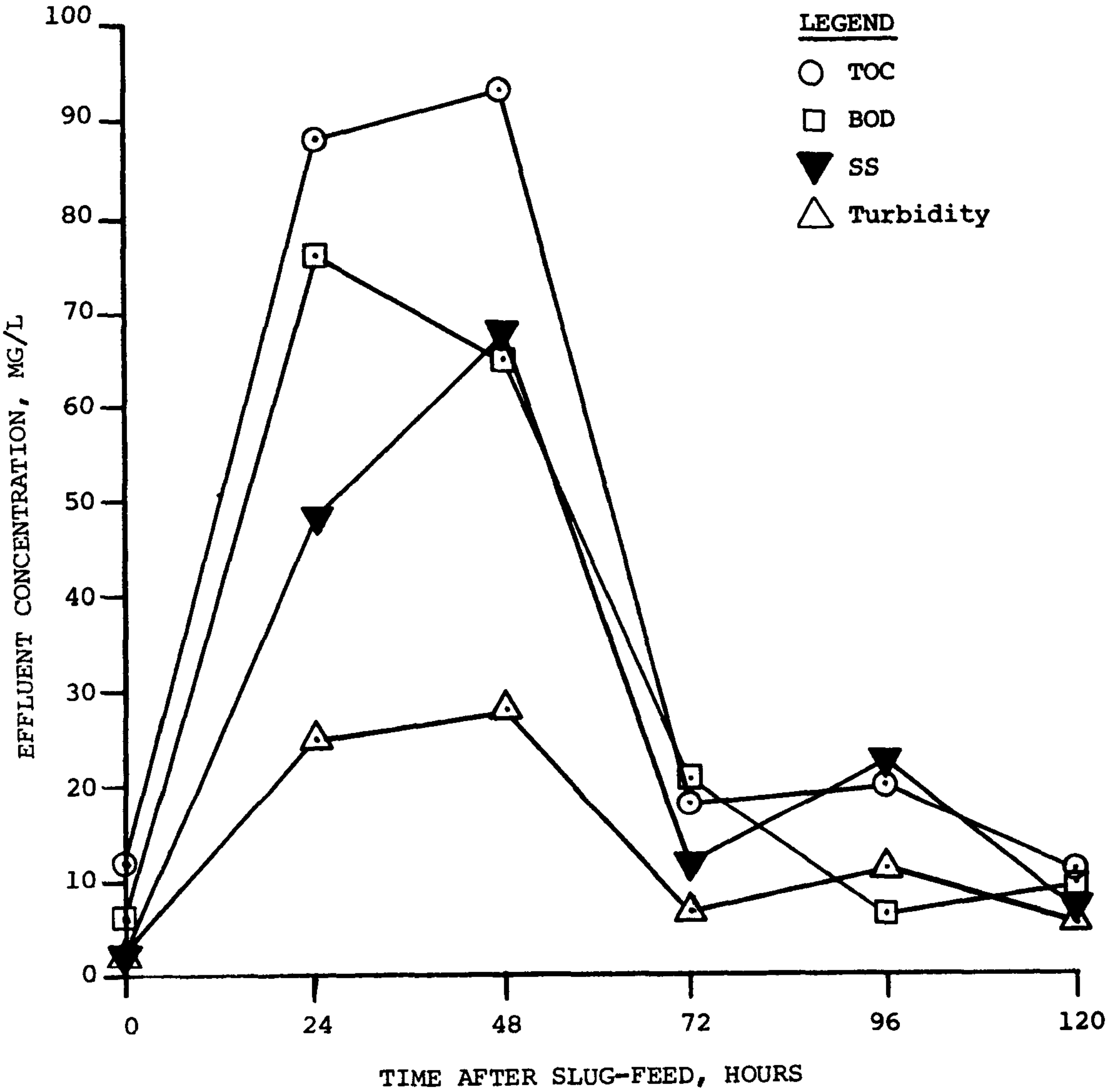
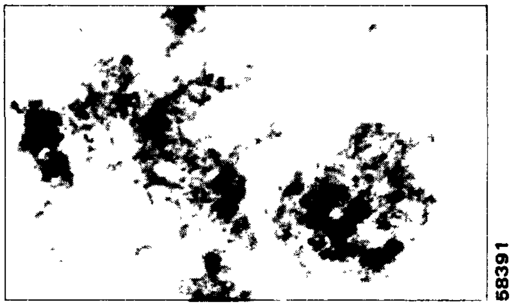
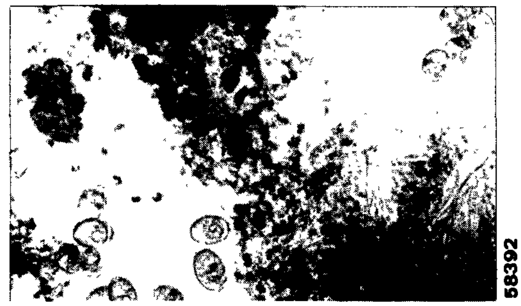


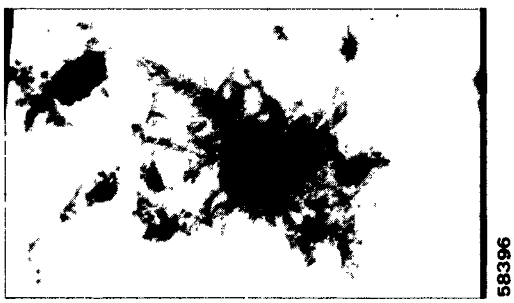
Figure 7. Effluent characteristics after slug-feed of 380 mg/l formaldehyde



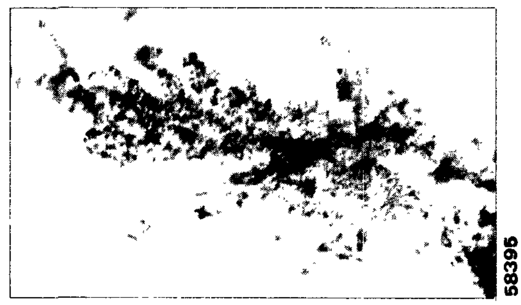
A. Control - No Zinc (35X)



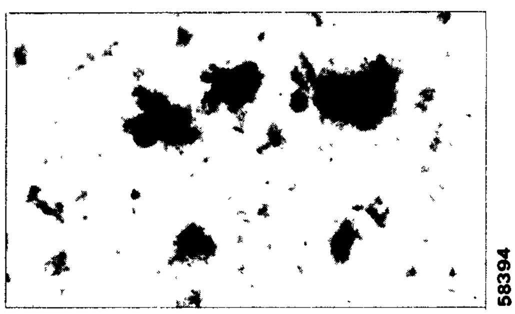
B. Control - No Zinc (100X)



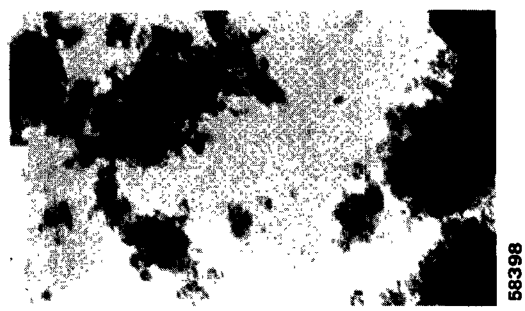
C. 9 mg/l Zinc, 5 days (35X)



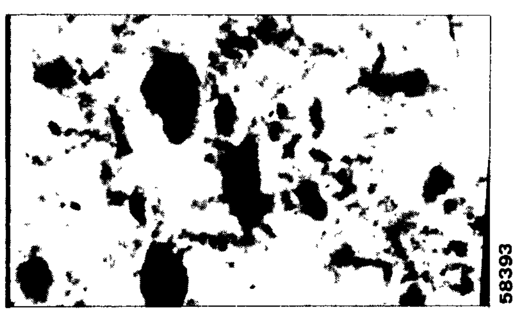
D. 9 mg/l Zinc, 5 days (100X)



E. 47 mg/l Zinc, 5 days (35X)



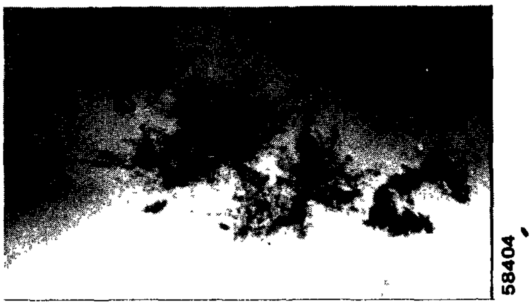
F. 47 mg/l Zinc, 5 days (100X)



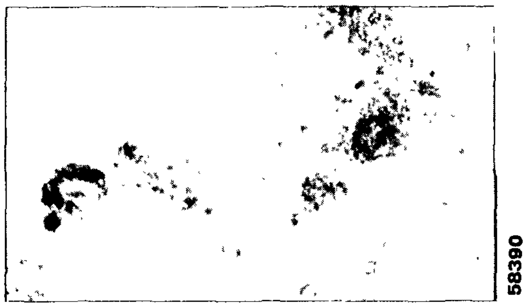
G. 113 mg/l Zinc, 5 days (35X)

H. 113 mg/l Zinc, 5 days (100X)

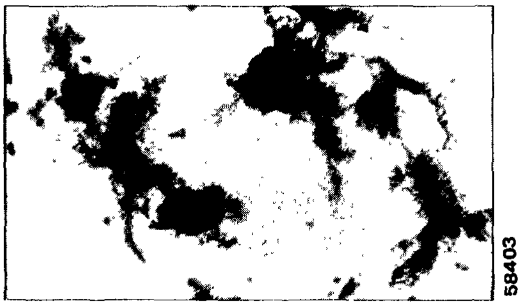
Figure 8. Photomicrographs of activated sludge exposed to increased zinc concentrations



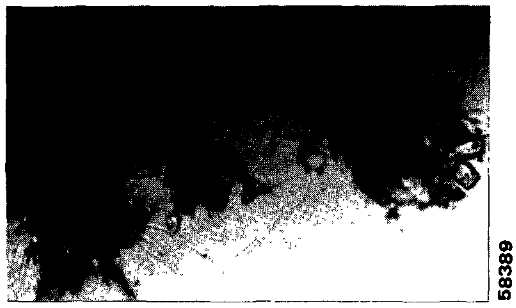
A. Control. No Formaldehyde (35X)



B. Control. No Formaldehyde (100X)

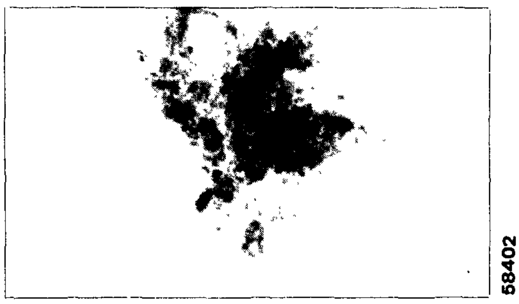


C. 10 mg/l Form., 5 days (35X)

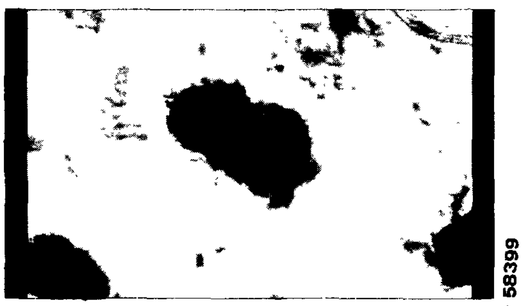


D. 10 mg/l Form., 5 days (100X)

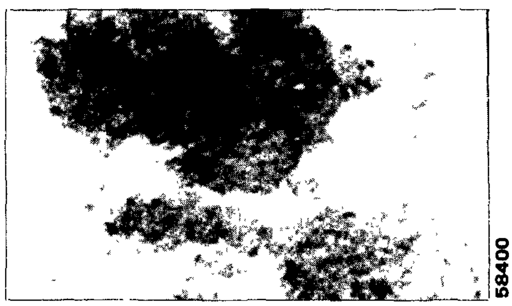
E. 380 mg/l Form., Slug-Feed (35X)



F. 380 mg/l Form., Slug-Feed (100X)



G. 140 mg/l Form., 5 days (35X)



H. 140 mg/l Form., 5 days (100X)

Figure 9. Photomicrographs of activated sludge exposed to increased formaldehyde concentrations

Slug feeding of mixed sewage containing 378 mg/l formaldehyde caused relatively little change in the activated sludge characteristics. After an initial reduction in rotifers and flagellated protozoa, normal populations of microorganisms were attained within 48 hours after shock loading.

Material balances were determined for each treatment series in order to best describe the dynamic operation of the activated sludge process when treating different sewage mixtures. The average daily increase of MLVSS was determined as a measure of the plant's production of biomass. The average daily removal of total organic carbon (TOC) was determined as a measure of food consumption. BOD removal data normally used for this measure were not applied, because of questionable results relating to the toxic effects of the chemical additives. The ratio of these values, ΔMLVSS/ΔTOC, provides a useful measure of biological activity that can be compared to different plants or within the same plant treating different sewages. For purposes of this research, loading factors and MLVSS concentrations were kept relatively constant in the control and two test plants. This condition allowed the comparison of biological activity between plants, with any differences indicating the effects of zinc and formaldehyde in feed sewages. These results are given in Table 12.

A more accurate measure of the biological activity of each activated sludge plant was determined by calculating a cell yield coefficient, Ky, as defined by the following expressions:

$$\Delta \text{MLVSS} = \text{Ky}\,(\Delta \text{TOC}) - (\text{MLVSS})\,(\text{C})\,(k_e) \qquad (1)$$

$$\text{Ky} = \left[\frac{\Delta \text{MLVSS}}{\Delta \text{TOC}}\right] + \left[\frac{\text{MLVSS}}{\Delta \text{TOC}}\right] (\text{C})\,(k_e) \qquad (2)$$

Where Ky = cell yield coefficient

ΔMLVSS = average change in MLVSS per unit time, day^{-1}

ΔTOC = average removal in TOC per unit time, day^{-1}

MLVSS = average mass of MLVSS, gm

C = biodegradability factor

k_e = endogenous respiration rate, day^{-1}

Table 12. CELL YIELD CHARACTERISTICS FOR ACTIVATED SLUDGE TREATMENT OF CHEMICALLY TREATED SEWAGES

Chemical Additive	Chemical Conc. (mg/l)	Average MLVSS (gm)	Δ MLVSS $(\frac{mg/l}{day})$	Δ TOC $(\frac{mg/l}{day})$	$\frac{\Delta TOC}{MLVSS}$ $(\frac{mg/l}{gm})$	$\frac{\Delta MLVSS}{\Delta TOC}$	Ky	Percent TOC Removed
None (Control)	---	207	21.3	23.0	0.11	0.93	0.70	90
Formaldehyde	10.4	212	23.9	25.7	0.12	0.93	0.72	90
Zinc	9.3	207	23.5	25.1	0.12	0.94	0.72	89
None (Control)	---	228	28.2	27.0	0.12	1.04	0.75	93
Zinc	47	220	25.5	26.6	0.12	0.96	0.71	86
None (Control)	---	235	24.8	23.3	0.10	1.06	0.79	92
Formaldehyde	140	250	37.6	39.2	0.16	0.96	0.65	85
Zinc	113	225	38.3	41.9	0.19	0.91	0.60	80

The endogenous respiration rate of each plant's mixed liquor was determined during 50 days of continued aeration without feed. The volatile suspended solids concentration was determined each day and plotted as a function of time. Applying standard equations given in the literature[12, 13], the endogenous respiration rates and biodegradability factors were calculated.* All three mixed liquors had equal endogenous rates of 0.064 day^{-1} and biodegradability factors of 0.55, 0.51, and 0.52 for the control, formaldehyde-treated, and zinc-treated sludges, respectively. These data were applied to equation (2) with the resulting cell yield coefficients for each treatment series presented in Table 12.

The disposition of zinc in the activated sludge process was followed by analysis of feed and effluent samples. These results are given in Table 13. Total zinc concentration was determined by atomic absorption analysis of the sample ash redissolved in acid. The range of values was quite large. The original amount of zinc added was calculated from feed sewage volume data and the known zinc concentration (1400 mg/l) of undiluted chemical waste. No sludge samples were analyzed for zinc content, but previous work[9] reports zinc removal by microbial flocculation with zinc accumulation in the sludge.

Table 13. ZINC DISPOSITION IN ACTIVATED SLUDGE PROCESS

Zinc Added (mg/l)	Average Total Zinc Concentration, (mg/l)	
	Feed Sewage	Effluent
0	1.2	0.7
9	5.8	2.2
47	41.0	5.3
113	120.0	12.0

*In unpublished works, Hobbs has derived equations defining the biodegradability factor, C. This derivation is given in Appendix D.

DISCUSSION

Comparison of $\Delta MLVSS/\Delta TOC$ and Ky values indicated a decrease in biomass production and microbial activity as the volume percent of chemically treated wastes was increased in the feed sewage. Feed sewages containing 1 percent (by volume) of chemical waste and 10 mg/l zinc or formaldehyde had little or no effect on activated sludge. However, a significant reduction in biological activity resulted with feed sewages containing 47 mg/l zinc (5 percent by volume zinc-treated wastes) and 140 mg/l formaldehyde (13 percent by volume formaldehyde-treated wastes). Lower removal efficiencies and effluent quality data substantiated these results.

A maximum nontoxic zinc concentration of 15 to 20 mg/l was determined from a plot of normalized Ky values versus zinc concentration. This range agrees very well with zinc toxicity data reported in the literature[7, 8, 9]. These results indicated that sewages having more than 2.5 percent (by volume) of zinc-treated wastes would have adverse effects on the activated sludge process. The zinc concentration of these sewages would be greater than 20 mg/l based on zinc additive dosage and 50 percent dilution of the original waste with flush water.

Effluent qualities, removal efficiency data, and cell yield values indicated that the maximum nontoxic concentration of formaldehyde was 100 to 120 mg/l. Gellman and Henkelekian[10] reported a higher toxic range of 135 to 175 mg/l formaldehyde from laboratory respirometer studies. Gilcreas[14] reported that 100 mg/l formaldehyde completely halted the operation of a sludge digester and that similar formaldehyde concentrations in wastes from a penicillin plant caused major upset of a municipal treatment system. It was concluded that sewage containing more than 120 mg/l formaldehyde would have an adverse effect on the activated sludge process.

Since specific formaldehyde additives had such varied effects on activated sludge respiration rate, it is difficult to predict the maximum tolerable percentage of formaldehyde-treated wastes in general. For the specific formaldehyde additive (Code 40) used in the completely mixed studies of this work, it can be stated that sewages having more than 12 percent (by volume) formaldehyde-treated wastes will cause upset and loss of removal efficiency to the activated sludge process. The formaldehyde concentration of these sewages would be greater than 120 mg/l, based on recommended dosages of chemical additive Code 40 and 50 percent dilution of original wastes with flushwater.

SECTION VIII

PROCESS DESCRIPTION

The FMC Waste Treatment System employs a physical/chemical process to treat sanitary sewage and other wastes. Chemicals are added to condition the sewage, which is then filtered to remove suspended solids. The system operates automatically on demand, with instantaneous on-off treatment capability. Influent sewage flow may be constant or variable, with no loss in degree of treatment.

During the process, chemicals are added automatically in proportion to the influent sewage flow rate. The type and function of each chemical is as follows:

1. Bactericidal Agent. A bactericidal agent, chlorine, is used to destroy bacteria and inactivate viruses present in sewage so that the effluent water and solid filter cake are free of live pathogenic organisms.

2. Activated Carbon. Powdered activated carbon is used to adsorb certain soluble organic compounds in sewage that could not be removed by filtration. Once adsorbed, they are readily removed by filtering out the spent carbon particles.

3. Flocculating Agent. A flocculating agent, aluminum sulfate, is used to destabilize the colloidal particles of sewage. The result is the coagulation of many small colloidal particles into large flocs, which are removed by filtration.

4. Filter Aid. A filter aid, diatomaceous earth, is used to assist the filtration process. Diatomaceous earth is a finely divided, insoluble, rigid material that will not compact or channel when forming a mat during filtration. This maintains the filtration rate by preventing fine gelatinous solids from blinding the filter surface.

The basic process, shown schematically in Figure 10, involves four operations: (1) comminution, (2) disinfection, (3) flocculation, and (4) vacuum filtration.

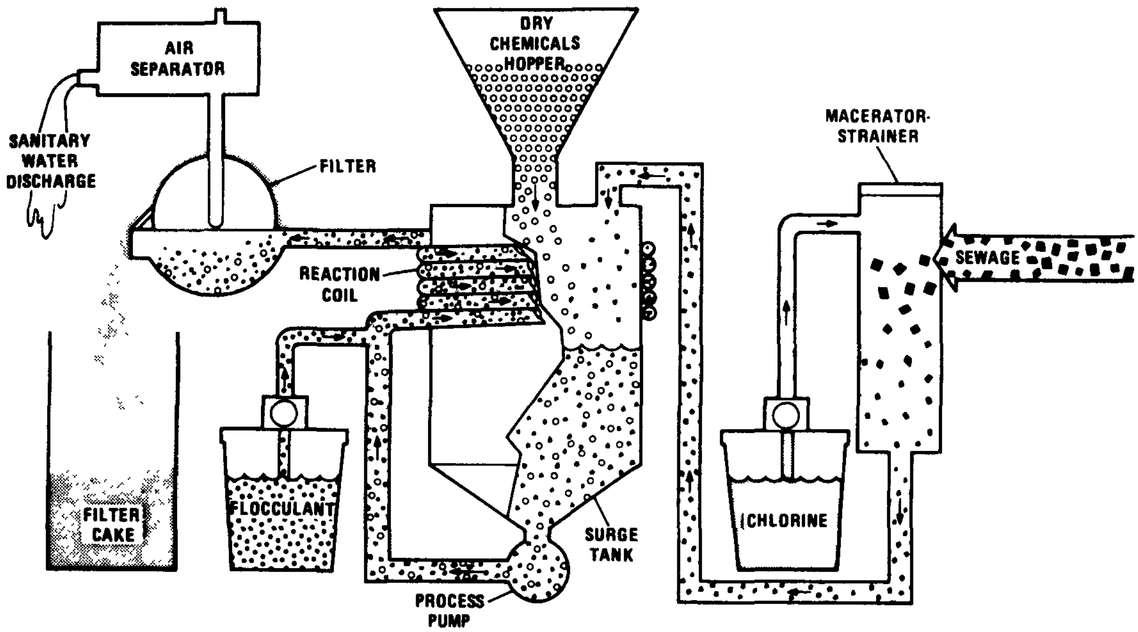


Figure 10. Schematic drawing of FMC waste treatment system

Influent wastes are coarsely screened and comminuted to reduce solid particle size. A bactericidal agent (aqueous chlorine) is added automatically with a metering pump. This treated mixture flows to an agitated surge tank designed to handle anticipated load fluctuations. A dry chemical mixture of activated carbon and filter aid is added automatically to the surge tank by a vibrating feed mechanism supplied from a hopper above the tank. At a set level, sewage in the surge tank is moved by a low-volume pump into a reactor coil wound around the surge tank. Before entering the coil, chemical flocculant is added automatically to the sewage/chemical mixture by a metering pump. The coagulated sewage mixture then flows to a rotary vacuum filter, which separates solids from the liquid. Sewage solids, filter aid, and carbon retained on the drum filter fabric are removed with a "wire doctor blade." The clear effluent passes through an air separator tank before being discharged. The solid filter cake is accumulated and disposed as sanitary landfill.

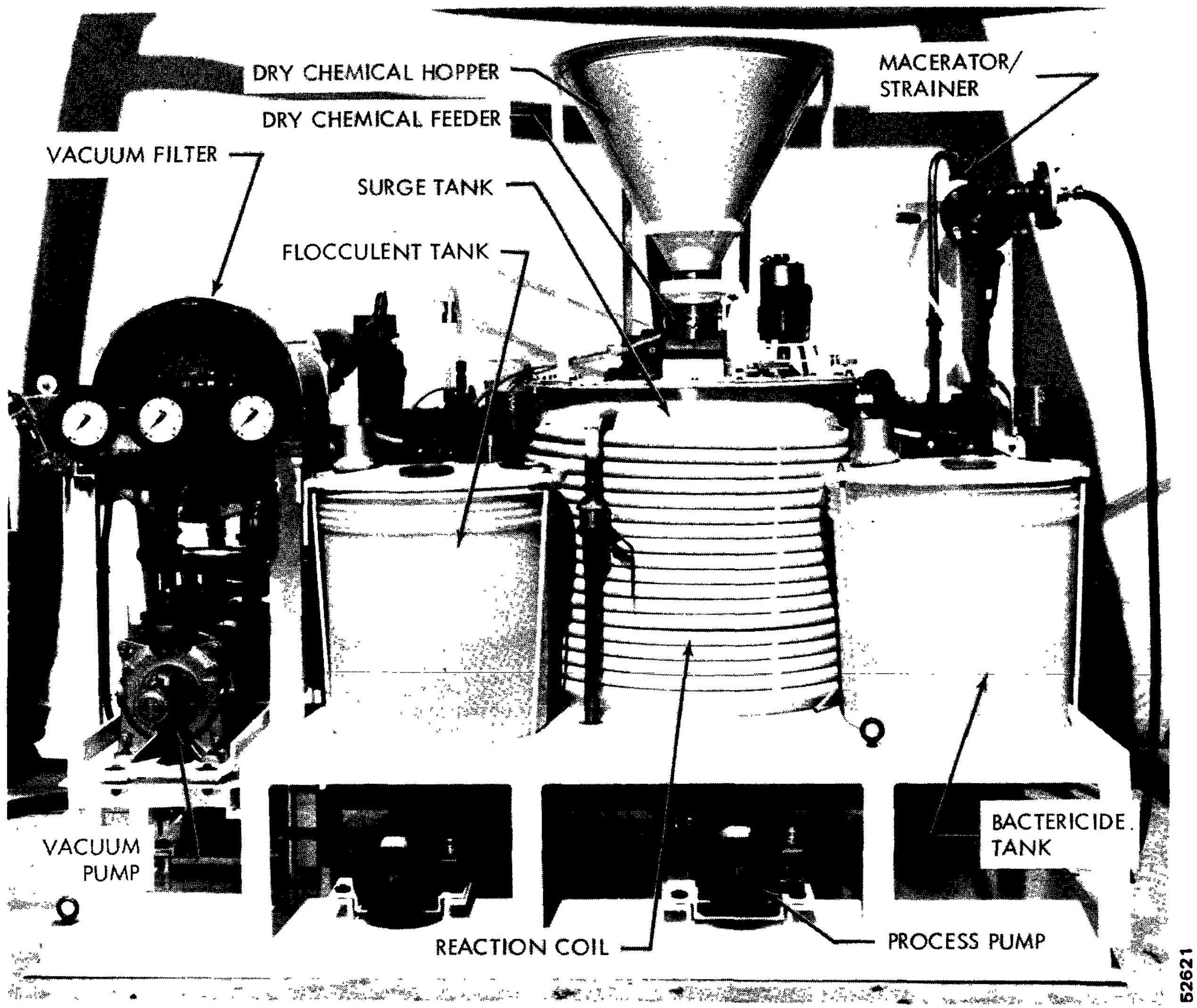


Figure 11. Photograph identifying major components of the FMC waste treatment system, model 50-2000

Complete automatic operation is accomplished with a magnetic flow meter, electrical timers, relays, and liquid-level sensors. Fail-safe intelligence systems prevent the unit from operating if any component fails. An alarm system sounds a warning of low chemical level and, if not replenished, the system automatically shuts off.

Figure 11 is a photograph of the FMC Waste Treatment System Model 50-2000, with major components identified. An aluminum frame houses copper-nickel plumbing and shielded electric motors. Overall dimensions are 239 cm long, 122 cm high, and 203 cm wide, with a total empty weight of 1135 kg (2500 pounds). Maximum electrical demand is 12 kva, using three-phase 220- or 440-volt current. The design flow capacity for processing domestic sewage is 15 kl/day (4000 gal/day) at an average flow rate of 9.5 l/min (2.5 gal/min).

SECTION IX

LABORATORY PROCESS STUDIES

The demonstrated physical-chemical waste treatment system was originally designed and developed as a marine sanitation device to treat sanitary, galley, and shower wastes onboard ships. During 2 years of development, extensive testing and evaluation was done at the laboratory bench and pilot-plant levels. A 1000-hour performance test was conducted on a full-scale preproduction model. Fresh sanitary wastes having an average concentration of 800 mg/l SS and 300 mg/l BOD_5 were used in testing. During 29 days of operation, the average removal efficiencies of SS, BOD_5, and TOC were 96, 89, and 79, respectively.

The treatability of marine holding tank wastes was also investigated. Using actual boat wastes from a marina on Bethel Island, California, the basic physical-chemical process was evaluated, first in the laborabory and then with full scale-equipment. A clear process effluent having a slight blue color was obtained from processing 180 gallons of holding tank wastes having 1460 mg/l SS, 850 mg/l BOD_5, and deep blue coloring. The percent reduction in SS and BOD_5 was 98 and 94 percent, respectively. These developmental test results indicated the feasibility of the proposed system to achieve a high level of treatment of holding tank wastes.

For purposes of this research, a detailed process study program was conducted to evaluate the ability of the proposed system to completely treat recreational watercraft wastes containing chemical additives. The effect of specific bactericidal agents on the process was determined. The removal efficiencies of SS, BOD_5, nitrogen compounds, phosphates, and zinc were investigated and optimized with process modifications.

PROCEDURE

Raw body wastes no more than 3 days old were collected from portable toilets at construction sites. These fresh wastes ranged from 10,000 to 20,000 mg/l SS and 6,000 to 15,000 mg/l BOD_5. Portions of these wastes were diluted with water and/or fresh domestic sewage to give 1140- to

1890-liter (300- to 500-gallon) batches of waste with SS and BOD_5 concentration ranges of 1,000 to 3,000 mg/l and 800 to 3,000 mg/l, respectively. These ranges of waste concentration were intentionally chosen to represent the stronger portion of holding tank samples identified during the waste characterization program. Specific chemical additives (Codes 26 and 40), having zinc and formaldehyde ingredients, were added separately and/or together to various waste batches. After thorough mixing, these treated wastes were aged outside for 2 to 3 days.

Each process run involved the treatment of 950 to 1900 l (250 to 500 gal) of simulated holding tank wastewater. A 3000 l storage tank supplied wastewater to the demonstrated full-scale treatment plant. Influent sewage flow rate was maintained constant during each run at a range of 3.7 to 7.6 l/min (1.0 to 2.0 gal/min). Initial startup adjustments required the setting of timer relays controlling the amounts of liquid alum, liquid chlorine, and powdered dry chemical (filter aid and diatomaceous earth) added automatically to the influent flow. The applied vacuum across the rotary filter was manually set by adjusting a bypass valve on the inlet side of the vacuum pump. At this point the equipment was operated "hands off" on automatic control. When the supply of influent waste was depleted, the equipment processed the remaining contents of the surge tank and then automatically shut off. During operation, composite samples of influent sewage and process effluent were separately collected and immediately analyzed for characteristic parameters. Chemical and power consumption data were recorded for each run. During these runs, the aluminum ion concentration (per liter of sewage) was maintained at 100 mg/l and the dry chemical concentration at 1.9 gm/l. The process pH was 4.0 to 4.2. Previous laboratory studies had determined that this pH, lower than the conventional alum flocculating pH range of 5.5 to 7.0, was optimum for maintaining a suitable vacuum filtration rate. At higher pH values the aluminum hydroxide floc tended to blind the filter fabric.

RESULTS

Average results of nine process runs using simulated holding tank wastes are given in Table 14. The presence of zinc and formaldehyde appeared to have no significant effect on the removal efficiency of suspended solids, organic nitrogen, phosphates, and turbidity. However, SOC, BOD_5, ammonia nitrogen (NH_3-N), and COD removals were reduced. Wastes containing 1400 mg/l zinc from treatment with Chemical Additive Code 26 showed a decrease in removal efficiency of BOD_5 and COD when com-

Table 14. FULL-SCALE PROCESS RESULTS ON CHEMICALLY TREATED SEWAGES

Parameter	Control[a]			Zinc Treated Wastes[b]			Formaldehyde Treated Wastes[c]		
	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal
SS (mg/1)	2,670	59	98	3,010	115	96	830	67	92
VSS (mg/1)	1,690	28	98	2,000	43	98	590	25	96
TOC (mg/1)	1,180	177	85	1,320	145	89	970	420	57
SOC (mg/1)	475	160	66	330	163	51	670	410	39
BOD_5 (mg/1)	1,450	312	79	1,300	350	73	2,980	1,750	41
COD (mg/1)	2,650	445	83	1,940	475	76	4,890	2,280	53
T-N (mg/1)	380	250	34	380	235	38	290	200	31
NH_3-N (mg/1)	230	170	27	230	165	28	155	140	10
T-PO_4 (mg/1)	60	13	78	63	16	75	65	12	82
Turbidity (JTU)	270	20	93	300	30	90	150	10	93
Color (O.D.)	30	2	93	61	3	95	40	0.5	98
pH	8.2	4.2	---	7.5	4.0	---	7.5	4.2	---

[a] Average results from six process runs using sewage containing approximately 100 mg/1 formaldehyde.

[b] Average results from two process runs using control sewage treated with 1,400 mg/1 zinc from Chemical Additive Code 26.

[c] Results of a single process run using diluted control sewage treated with 1,500 mg/1 formaldehyde from Chemical Additive Code 40.

pared to untreated wastes. The effect of 1500 mg/l formaldehyde from Chemical Additive Code 40 was a significant reduction in effluent quality. Because of limited data from a single process run at this high formaldehyde concentration, these results were taken qualitatively. The significant decrease in organic removal efficiency may be explained by the contribution of BOD_5 and COD from formaldehyde itself. Previous work in this research study demonstrated the biodegradability of formaldehyde, and the literature[15,16] reports specific BOD_5 values for various formaldehyde concentrations. Formaldehyde may readily bind with proteins present in urine and feces and consequently be removed with flocculated colloidal matter as a solid phase component. If the formaldehyde concentration exceeds the binding capacity of the sewage, free formaldehyde will be present. Because of high solubility and small, symmetrical molecular size, free formaldehyde would not be effectively removed by carbon adsorption during physical-chemical treatment. The process effluent would have significant BOD_5 and COD concentrations from residual free formaldehyde.

Evidence of this formaldehyde effect is given in the process run data. A portion of simulated holding tank wastes having 1000 mg/l suspended solids and 100 mg/l formaldehyde was processed by the FMC equipment. The remaining waste was charged with 1500 mg/l formaldehyde by adding the recommended dosage of Chemical Additive Code 40. After 30 hours of aging, these wastes were similarly processed. The BOD_5, COD, and soluble organic carbon (SOC) data for influent and effluent samples taken from these runs are given in Table 15.

Since identical wastes differing only in formaldehyde concentration were similarly processed, the difference in influent characteristics may be taken as a measure of the effect of added formaldehyde. The difference of 1860 mg/l BOD_5 between the two influent wastes indicates the BOD_5 contribution from 1500 mg/l formaldehyde. This result compares with the calculated value of 1650 mg/l determined from empirical BOD_5 data for formaldehyde[15]. The difference between the two effluents of 1505 mg/l BOD_5 indicates a nearly complete carryover of formaldehyde. Evidence of this same effect is given in COD and SOC data. These results indicate that physical-chemical processes cannot readily handle large concentrations of formaldehyde.

PROCESS MODIFICATIONS

During the process studies, several operating variables were adjusted to optimize the operation. The feed concentration of alum flocculant was increased 50 percent to give an aluminum ion concentration of 200 mg/l.

Table 15. EFFECT OF FORMALDEHYDE ON PROCESS TREATMENT RESULTS

Process Run Number	Formaldehyde Concentration (mg/1)	BOD_5 (mg/1)			COD (mg/1)			SOC (mg/1)		
		Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal
07-16	100	1,120	245	78	1,940	175	91	310	79	75
07-17	1,600	2,980	1,750	41	4,890	2,280	53	670	410	39
Variance	1,500	1,860	1,505	37	2,950	2,105	38	360	331	36

Simultaneously, sodium bisulfate was added as an acidifying agent to the alum (aluminum sulfate) solution. As a result, the process was maintained more consistently at a pH of 4.0 to 4.5 with significant improvement in effluent turbidity and phosphate removal. Dry chemical mixture was changed from 3:1 to 2.5:1 parts filter aid to activated carbon*, and its feed rate was increased 50 percent to 4 gm/l. This resulted in improved SOC, BOD_5, and color removal. The average process rate was decreased from 7.6 to 4.5 l/min with general improvement in operating efficiency. At this point, the proposed physical-chemical system had demonstrated its ability to reduce the suspended solids and phosphate concentrations of simulated holding tank wastes by 90 percent, as well as control the coliform count of the process effluent at a level below 20 MPN/100 ml. Average BOD_5 removal was 76 percent, while total nitrogen removal was only 27 percent.

AERATION

In an attempt to improve the removal efficiencies of nitrogen compounds and BOD_5, the effect of short term aeration of wastes before treatment was investigated. Fresh, raw body wastes were diluted with water to a suspended solids concentration of 2150 mg/l. Equal portions of this waste were separately charged with zinc and formaldehyde chemical additives at their recommended dosages, mixed together, diluted 50 percent with water, and aged for 16 hours. No pH adjustment was made of the sewages. This chemically treated waste was aerated for 24 hours at 2.0 cfm with mild stirring. Grab sewage samples were taken after various aeration times and analyzed for critical diagnostic parameters. Analytical results indicated no significant conversion of organic nitrogen to ammonia by bacterial hydrolysis while TOC, SOC, and BOD_5 concentrations were unchanged. It was concluded from these studies that short-term (2 to 24 hours) aeration of chemically treated holding tank wastes at pH 7.3 had little or no effect on organic removal. Ammonia removal by aeration of wastewater at an adjusted pH of 10 to 12 was not tried. The literature[17] reports this pH range to be most effective for ammonia removal by aeration.

CHLORINATION

The effectiveness of increasing amounts of available chlorine added before physical-chemical treatment was investigated using pilot-plant test equipment. Chemically treated wastes prepared for aeration

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*A low surface area, large particle size activated carbon, Nuchar KD, was used to minimize the strike through of carbon into the process effluent during vacuum filtration.

studies were pretreated with increasing amounts of chlorine added as a hypochlorite solution (70 percent available chlorine) by means of an adjustable feed pump. Influent sewage flow rate was maintained at 5.7 l/min (1.5 gal/min). Analysis of influent and effluent samples indicated no significant increase in removal efficiencies of BOD_5, COD, total nitrogen (T-N), and ammonia nitrogen (NH_3-N) when treated with chlorine concentrations of 0 to 200 mg/l. Effluent samples indicated no measurable free chlorine. These results agree with the literature[12] which reports that chlorine oxidation of concentrated wastes having high COD values is relatively ineffective and uneconomical. It was concluded that prechlorination would only be employed for bacteriostatic control and not used as a process method for reduction of organic matter.

Postchlorination of residual organic compounds present in the process effluent was investigated as a method of increasing the overall removal efficiencies of BOD_5 and total nitrogen (T-N). Hypochlorite oxidation of urea was characterized in the laboratory by following the rate of SOC removal as a function of time at different urea and chlorine concentrations. A pseudo first-order rate constant of 0.13 min^{-1} was determined from urea concentration of 330 mg/l at pH 7.7, reacted at 25°C with 1500 mg/l available chlorine. Similar rate studies on actual process effluent having 66 mg/l SOC, 44 mg/l T-N, and 39 mg/l BOD_5 gave a rate constant of 0.006 min^{-1} calculated from SOC removal data. The initial chlorine concentration was 550 mg/l.

Chemically treated wastes prepared for previous aeration studies were processed by the demonstration system. The resulting effluent was separated into four equal volumes, charged with varying amounts of calcium hyprochlorite, stirred slowly for 40 minutes, stopped with sodium sulfite, and analyzed for diagnostic parameters. These results, given in Table 16, indicated that significant reduction of residual organic matter can be accomplished by postchlorination of process effluent. With 2725 mg/l available chlorine reacting for 40 minutes, the overall removal efficiency of T-N was increased from 25 to 73 percent, while NH_3-N removal increased from 29 to 66 percent. TOC and SOC removal efficiencies were increased from 70 to 86 percent and 57 to 76 percent, respectively. These results indicated that BOD_5 removal would also be significantly improved. Based on SOC data, the calculated pseudo first-order rate constant was 0.010 min^{-1}, and the reaction half-life time was 69 minutes, meaning that 50 percent of the SOC remaining in the effluent would be removed in 69 minutes. A retention time of 3.4 hours would be required to remove 87.5 percent of the SOC originally present.

Table 16. EFFLUENT CHLORINATION DATA

Parameter		Influent	Effluent A	Effluent B	Effluent C	Effluent D
Available Chlorine Feed	(mg/l)	0	0	745	1,490	2,725
Reaction Time	(min)	---	0	40	40	40
TOC	(mg/l)	1,140	340	272	210	165
SOC	(mg/l)	760	326	252	219	183
T-N	(mg/l)	704	526	395	289	193
NH_3-N	(mg/l)	502	355	322	233	170

It was decided that postchlorination of process effluent would be piloted for improving the overall removal efficiencies of BOD_5 and T-N. A simple chlorination system consisting of a chlorine feed pump and retention coil was assembled. Using a positive displacement pump, process effluent from the treatment unit was moved at a constant rate of 1.9 to 5.7 l/min (0.5 to 1.5 gal/min), while a sodium hypochlorite-sodium hydroxide solution was added automatically with a precision metering pump. Base was used to raise the process pH from 4.5 to 6.0-9.0. The chlorinated effluent flowed through a 2-inch PVC pipe retention coil, consisting of 26-foot pipe loops, having a total capacity of 107 gallons. Retention time in the coil was maintained constant at 60 to 120 minutes by controlling discharge flow rates.

Preliminary testing of the postchlorination system was conducted using simulated holding tank wastes charged with recommended dosages of zinc and formaldehyde chemical additives. After normal processing of sewage by the demonstration waste treatment system, the effluent was treated with 2000 to 3000 mg/l available chlorine and retained for 40 to 150 minutes. Samples of chlorinated effluent were dechlorinated with sodium thiosulfate and analyzed for various parameters. Operating difficulties were experienced in controlling the process pH and flow rate. BOD_5 and COD results were incomplete because of lost samples caused by interference from excess, unknown amounts of sodium thiosulfate. Overall removal efficiencies of TOC and SOC were increased approximately 10 to 15 percent, while T-N and NH_3-N removals were increased 50 to 60 percent. These qualitative results demonstrated that the proposed system, coupled with postchlorination, indicated an ability to process chemical holding tank wastes to a level of treatment approaching 90 percent removal.

ZINC REMOVAL

Since watercraft wastes may contain significant amounts of zinc (50 to 1500 mg/l) which is known to be toxic to most microorganisms, its removal was a goal of complete waste treatment. Laborabory studies determined that zinc was quantitatively removed from solution as a zinc hydroxide-carbonate precipitate when reacted with sodium carbonate at pH 9.5. Actual process effluent containing 1400 mg/l zinc was adjusted to pH 9.5 with sodium carbonate, and after mild stirring for 5 minutes, the precipitate was removed by filtration, giving a clear filtrate having less than 0.3 mg/l zinc determined by atomic absorption analysis. Solubility studies of zinc hydroxide carbonate showed a significant pH dependence with a minimum solubility at pH 9.5. At pH 8.5, the residual zinc content of the filtrate was 4.2 mg/l.

Using these characteristics, a zinc removal system was designed to treat normal process effluent. Basic components were a chemical feeder for addition of base, a reaction coil where the zinc precipitate develops and flocculates, and a filter to separate the solid precipitate from the liquid effluent. For efficient utilization of equipment, the zinc removal process was incorporated into the postchlorination equipment. The same metering pump and reaction coil were used. Laboratory studies determined the proper amount of sodium carbonate or sodium hydroxide to be added to the sodium hypochlorite solution that, when added to the process effluent, would give a chlorinating process pH of 8.5 to 9.5, with a hypochlorite concentration of 2700 mg/l. Process flow rate was maintained constant at 1.9 to 5.7 l/min (0.5 to 1.5 gal/min) by means of a positive displacement pump. From the outlet of the coils, the treated effluent was filtered through a GAF pressure bag filter containing a polyester filter bag having a rated porosity of 5 microns. Preliminary testing showed that a constant filtration rate was maintained during the short term tests if the filter bag was originally precoated with diatomaceous earth.

This equipment was evaluated during the process run studies operating on simulated holding tank wastes. Approximately 1500 l of aged wastes having a zinc concentration of 750 mg/l were processed by the demonstration waste treatment system and the resulting process effluent was treated for zinc removal. Composite samples of effluent before and after treatment were analyzed for total zinc by the atomic absorption method. At a final effluent pH of 9.9, the zinc concentration had been reduced from 268 mg/l in the original process effluent to 1.5 mg/l, demonstrating the system's ability to remove over 90 percent of the zinc originally present.

SECTION X

PROCESS FIELD TESTING

Phase II of this program involved extensive field testing of the full-scale preproduction Model 50-2000 FMC Waste Treatment System. The Lake Mead National Recreational Area, Boulder City, Nevada, was selected as the demonstration site after a thorough survey of marine locations in all areas of California and Nevada. Test equipment was transported to the site in a 40-foot demonstration trailer owned by FMC Corporation. After simple hook-up to waste supply and electrical power, operational testing began. Pumpage from watercraft holding tanks was processed daily for a total of 8 weeks. Analytical tests were performed to describe the degree of treatment and data were recorded to define the operating costs.

SITE SELECTION AND DESCRIPTION

A survey was conducted of 46 public and private marinas having nearly 18,300 boats located in freshwater and saltwater in areas of California and Nevada. Each marina was described by the following characteristics: number of boats, average length, number of boats with onboard toilet facilities, number of boats with waste retention/recirculating systems, existence of boat pumpout facilities, means of waste disposal, availability of electrical power (three-phase 220 or 440 volts), and willingness to cooperate in a demonstration program. The specific characteristics of 16 marinas involved in this survey as well as a waste characterization program were given previously in Table 3, Section IV. A summary of survey results from all 46 marinas is given in Table 17.

The results of this marina survey indicated low percentages of boats equipped with waste retention / recirculating systems and few pumpout facilities, especially at saltwater marinas. All freshwater locations covered in this survey had existing regulations prohibiting overboard discharge of sanitary sewage. Therefore, the percentage of boats with waste retention systems was significantly higher than at saltwater marinas. Similarly, the pumpout frequencies and waste volume flows were appreciably higher. In Southern California, the larger coastal

Table 17. SUMMARY OF MARINA SURVEY RESULTS

Location	Marinas[a]	Boats[b]	Average Length	Percent With Toilets	Percent With Waste Retention	Average Holding Capacity	Pumpout Facilities	Total Weekly Pumpout Flow[c]
Saltwater	15	11,094	10.1 m (31 ft)	88%	16%	68 l (18 gal)	9	7,400 l (1,960 gal)
Freshwater[d]	31	7,177	7.5 m (23 ft)	42%	26%	95 l (25 gal)	21	62,500 l (16,500 gal)
Totals and Weighted Averages[e]	46	18,271	9.2 m[e] (28 ft)	70%[e]	20%[e]	79 l[e] (21 gal)	30	29,000 l[e] (7,700 gal)

[a] Each marina surveyed had at least 100 moored boats.

[b] Total number of boats included powerboats, sailboats, and houseboats.

[c] Total volume flow of pumpout wastes per week during peak boating season estimated from marina pumpout frequency and average boat waste holding capacity.

[d] All freshwater locations surveyed had existing regulations prohibiting the overboard discharge of sanitary wastes.

[e] Average results weighted proportionally to the number of boats in freshwater and saltwater.

marinas reported less than 1 percent boat usage of pumpout facilities. At Marina del Rey, California, one fuel dock operates the only pumpout facility for 21 separate marinas having a total boat population of nearly 6000. The reported frequency of individual boat pumpouts during July and August (peak season months) was only 18 to 25 times per week. The only significant volumes (greater than 500 gal/week) of watercraft waste pumpage occurred at marinas on large freshwater lakes where no-discharge ordinances were enforded. Marinas at Lake Mead and Lake Shasta reported the largest watercraft waste flows of 7.6 to 17.0 kl (2000 to 4500 gal) per week. Lake Shasta was excluded as a potential demonstration site because three-phase 220-volt current was not available at the marinas willing to cooperate in the demonstration program.

Lake Mead National Recreation Area, under the jurisdiction and administration of the National Park Service, U.S. Deptment of Interior, was chosen as the field demonstration site. Located 25 miles from Las Vegas, Nevada, this 3000-square-mile area encloses two large lakes, deserts, canyons, and plateaus. The mild, arid climate permits year-round enjoyment of over 5 million visitors each year, making it the fifth most active National Park in the United States. Lake Mead, 115 miles long with 550 miles of shoreline, was created by the construction of Hoover Dam.

Lake Mead has six marinas of varing size, with moorings for approximately 2500 boats. Although power boating and sport fishing are the dominant activity, sailboats compose 35 to 40 percent of the boat population. Conventional pontoon houseboats operate on Lake Mead only as power boats, since no long-term onboard living is permitted. Trailered boats contribute significantly to the load factor of Lake Mead. During the summer season, the count of trailered boats entering the park reaches 20,000 per month. Although the average boat length at Lake Mead is only 16 feet, nearly 50 percent (1200) of the moored boats have waste retention systems, with an average 50 gallon holding capacity.

A no-discharge regulation for sanitary wastes has been in effect and enforced at Lake Mead for 7 years. Pumpout facilities, located at each marina and boat harbor, are owned and maintained by the National Park Service. Use of the facilities is free, with self-service by the boat owner. Each pumpout station consists of a floating platform containing an electric-driven diaphragm pump, suction hose, 700-gallon waste storage tank, freshwater flush line, level controlled transfer pump, and piping system leading to shore. Special adaptors and pipe connectors are supplied to secure the pumpout hose to the boat's waste deck fitting. It is estimated that during the summer months a total of 15,000 liters (4,000 gallons) of watercraft wastes are pumped each week.

On-shore wastewater treatment involves oxidation-evaporation lagoons. Sanitary and galley wastewater from each marina is combined with pumpout wastes and transferred by lift pump to remote oxidation ponds. Sewage from trailer parks, campsites, and resident motels is also pumped to lagoons by means of a common collection system. Three lagoon systems serve Lake Mead, each receiving 76 to 190 kl (20,000 to 50,000 gal) per day. Periodically these ponds are dried, and the accumulated solids are removed. At this date, three new waste treatment plants offering secondary treatment are being planned to replace the oxidation ponds, which cannot provide adequate treatment of the Park's increasing wastewater flows.

Lake Mead Marina, located near the western entrance of the Park and 4 miles from Boulder City, Nevada, was chosen as the physical location for the test equipment. Being the largest and most visited marine in the park, it provided the largest volume of watercraft wastes. The marina moored 450 boats averaging 28 feet in length, and 340 boats had waste holding systems. Two large excursion boats, making daily trips to Hoover Dam, also operated from this marina. The average weekly flow of 5700 liters (1500 gal) of pumpage came primarily on Friday through Monday. To increase the total volume of pumpage available for demonstration processing, boat wastes pumped at a nearby marina were truck-hauled to Lake Mead Marina and deposited for treatment. This source supplied an additional 1900 liters (500 gal) per week.

EQUIPMENT INSTALLATION

The demonstration system, housed in a 40-foot trailer, was transported to Lake Mead Marina and located in the overflow parking section 100 feet from the water. This equipment is pictured in Figure 12. Adjacent to the trailer was an electrical utility stand having three-phase 220-volt current, junction box, and power meter. Direct connection of leads to this junction box supplied the necessary power to the test equipment. A 3000-liter (800-gal) supply tank placed ahead of the trailer was connected to the waste supply line coming from the floating pumpout station. This line was normally connected to a lift pump. A waste supply line and centrifugal transfer pump were attached to the holding tank outlet and the sewage inlet of the trailer. A freshwater line was connected to the trailer to supply a laboratory faucet and utility hoses. A garden hose joined the effluent outlet located under the trailer with the suction side of the existing sewage lift pump. No marina wastes, only boat wastes, were supplied to the test equipment. To prevent the possibility of overflow from the holding tank, a bypass valve and line were arranged to allow direct flow of wastes from the pumpout station to the lift pump, except when specifically directed to the tank.

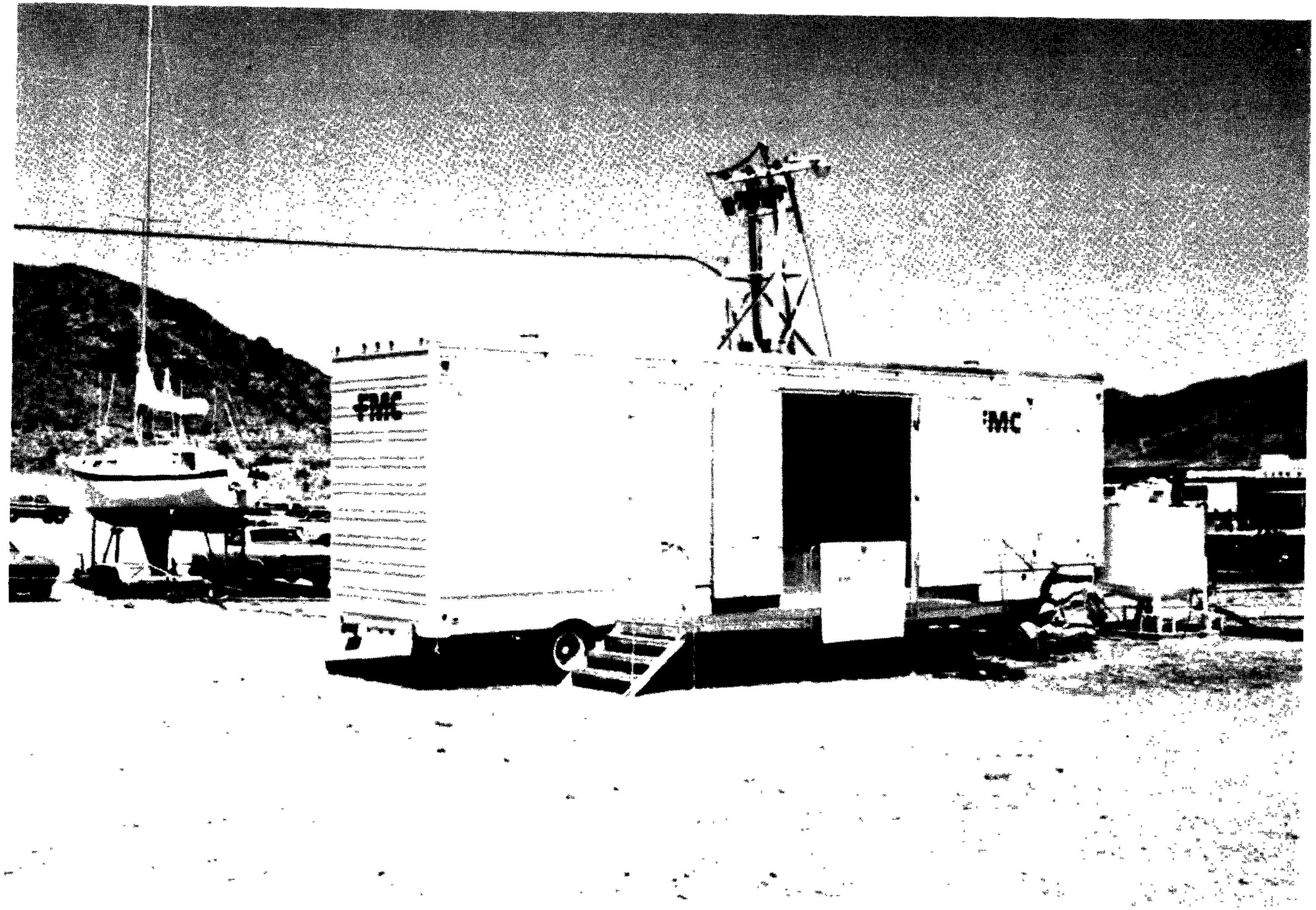

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Figure 12. Demonstration trailer housing treatment equipment located at Lake Mead, Nevada

OPERATIONAL PROCESSING

After functional testing of mechanical and electrical systems, the demonstration equipment was operated on water while calibration curves of feed pumps, flow meters, and level controls were confirmed. Using the trailer laboratory facilities, composite waste samples were analyzed for suspended solids, pH, color, and buffering capacity. With this information, process chemical solutions were prepared at appropriate concentrations, and dry chemical feed rates were calculated for various influent flow rates. Actual wastes were then processed under different conditions to establish in general the optimum degree of treatment based on visual inspection of the effluent. The zinc removal post-chlorination equipment was pressure tested and the base requirement for pH control determined. This preliminary testing required two men for 3 days.

Operational processing began on August 22, 1973 and continued for 8 weeks to October 16. Because of heavy weekend activity, test equipment was normally operated from Thursday through Monday, 5 days a week, for a total of 35 operating days. During this time, 42,000 liters (11,000 gal) of watercraft wastes were treated by the demonstration equipment. A daily volume of 950 to 1900 liters (250 to 500 gal) was processed at an average rate of 4.1 l/min (1.1 gal/min). Auxiliary zinc removal postchlorination equipment was operated for 14 days. Samples of influent, effluent, and solid filter cake were regularly collected for analysis of various parameters, and records were kept of operating conditions and chemical consumptions. One technician monitored the equipment, collected samples, and recorded operating data.

A standard procedure was followed each operating day. Wastes accumulated in the storage tank of the pumpout station were transferred ashore to the 3000-liter holding tank. Records were made of total waste volume, chemical feed rates, chemical levels, and time. Once the control panel was set to automatic operation, waste was transferred from the outside holding tank to a 340-liter (90-gal) supply tank equipped with level controls. Influent rates to the demonstration system were manually adjusted to 3.8 to 4.6 l/min (1.0 to 1.2 gal/min) as indicated by a magnetic flowmeter and recorder. Primary and secondary vacuums of filtration equipment were adjusted to 28 to 18 cm (11 and 7 inches) of mercury, while air-blow pressure was set to maintain proper removal of filter cake at the "wire doctor blade." At this point, the process was left to operate automatically and unattended.

Every 20 minutes, samples of influent waste and process effluent were taken and properly composited. Grab samples for coliform analysis were collected in sterile bottles containing sufficient sodium sulfite to reduce any free chlorine. Solid filter cake samples were sealed in special containers after removing a portion for total solids analysis. All samples were refrigerated at $4^{o}C$. Process control was monitored by periodic analysis of effluent pH, turbidity, and total chlorine. When processing was complete and the equipment had automatically shut down, records were again made of chemical levels and time. Total solid filter cake production was weighed and recorded. Volume of process effluent was read from a recording flowmeter in the effluent line and total power consumption was taken from a kwh-meter.

Zinc removal and postchlorination auxiliary treatment used a reactant solution consisting of 6 gallons of water, 6 gallons of 14 percent sodium hypochlorite, and 1600 ml of 50 percent sodium hydroxide. A precision metering pump delivered this solution at 120 ml/min to process effluent that was pumped at 3.8 l/min through reaction coils and pressure filter. Under these conditions, the available chlorine content was 2660 mg/l with a retention time of 90 minutes and a process pH of 9.5. The metering pump ran simultaneously with a positive displacement pump supplying effluent for treatment. In this mode of operation, effluent samples were collected after pressure filtration. Chemical consumption and process rate were recorded at the end of operation.

SECTION XI

PROCESS EVALUATION

Evaluation of the demonstration physical-chemical system was based on operating results determined from analysis of samples taken each operating day during the 8-week test period. Chemical and power consumption data were used to determine cost of operation. Process removal efficiencies for various chemical and biological parameters were determined for each of the 35 operating days. Average operating results were calculated for comparative evaluation of the effectiveness of postchlorination and zinc removal processes.

SAMPLE ANALYSIS

Composite samples of influent waste and process effluent collected each operating day were analyzed for SS, VSS, TS, TVS, TOC, SOC, BOD_5, COD, T-N, NH_3-N, T-PO_4, pH, conductivity, and turbidity. Grab samples of solid filter cake collected twice a week were analyzed for TS, TVS, BOD_5, coliform, and zinc. Influent and effluent grab samples taken on the same 2 days per week were analyzed for zinc, formaldehyde, and coliform. Sample preservation and analytical procedures were done in accordance with EPA's Methods for Chemical Analysis of Water and Wastes[2]. Zinc and formaldehyde analyses were performed by West Coast Technical Service, Inc., Cerritos, California. Atomic absorption analysis of the acid dissolved sample ash was used for zinc determination, while formaldehyde was determined colorimetrically by the chromatropic acid method[18]. BOD_5 and COD analyses were performed by Clair A. Hill and Associates, Redding, California, and the remaining analytical work was done by the Environmental Engineering Laboratories, FMC Corporation, San Jose, California. Samples were air-transported within 6 hours to respective laboratories where analyses were immediately begun.

Preliminary BOD_5 determinations on influent waste samples gave evidence of toxic effects of zinc and other chemical contaminants. BOD_5 results varied significantly as a function of waste sample dilution. Dilution samples having a greater volume percent of waste consistently gave lower

BOD_5 results. On diluted seeded samples containing 0.5, 1.0, and 5.0 ml of watercraft waste per 300 ml, the BOD_5 determinations were 1400, 830, and 330 mg/l, respectively. Similar results were obtained with different domestic sewage seed materials after strict sample pretreatment to remove any oxidants.

It was concluded that toxic effects of zinc and other possible contaminants present in the wastes were the cause of the variances in BOD_5 results. The zinc content of waste samples from Lake Mead averaged 340 mg/l with a range of 8 to 1114 mg/l. Brown and Andrew[19] reported the suppression of BOD_5 results by the effect of zinc. For domestic sewage containing 50 mg/l zinc, the measured BOD_5 was 45 percent of the true value. With as little as 5 mg/l zinc, the variance was nearly 30 percent between true and measured BOD_5 values.

In order to minimize the toxic effect, all BOD_5 determinations on influent watercraft wastes and solid filter cake were done on highly diluted samples having 0.1 to 0.5 ml of sample per 300 ml. Average results of duplicate samples having the highest dilution that showed at least 1 mg/l residual dissolved oxygen (DO) and a minimum depletion of 2 mg/l DO were chosen as most reliable.

A glucose-glutamic acid standard solution was analyzed for BOD_5 to check the quality of dilution water, the effectiveness of the seed, and the analyst's technique. The resulting mean BOD_5 value of 229 mg/l compared very well to the reported standard value of 218 mg/l[20] when using a fresh, settled sewage seed.

ANALYTICAL RESULTS

A complete record of analytical and process data for each day of operation at Lake Mead is given in Appendix E. Analytical results characterized daily composite influent and effluent wastewater samples with 17 diagnostic parameters including chemical, physical, biological, and microbiological tests. Process data included daily chemical and power consumptions, process rate, and total processed volume.

A summary of analytical results from samples collected the first 21 days of normal operational processing is given in Table 18. Zinc removal postchlorination equipment was not operated during this time. A broad range of influent waste concentrations were processed to a high degree of treatment. Suspended solids, BOD_5, and COD removals all averaged 97 percent. While total-phosphate ($T\text{-}PO_4$) was nearly quantitatively removed (98 percent average), nitrogen compounds received little treatment as evidenced by total-nitrogen (T-N) and ammonia nitrogen ($NH_3\text{-}N$) removal efficiencies of 30 and 25 percent, respectively. Zinc

Table 18. RESULTS OF LAKE MEAD TESTING[a]

Parameter		Influent Waste[b]			Process Effluent[b]			Percent Removal
		Average	Maximum	Minimum	Average	Maximum	Minimum	Average
SS	(mg/l)	1,920	7,420	360	55	130	10	97
VSS	(mg/l)	1,315	5,320	240	18	35	6	99
TS	(%)	0.35	0.86	0.23	0.50	0.79	0.37	--
TVS	(%)	0.20	0.66	0.09	0.16	0.24	0.10	--
TOC	(mg/l)	670	1,590	250	32	86	14	95
SOC	(mg/l)	144	230	95	26	78	11	82
COD	(mg/l)	4,400	18,600	1,100	114	310	41	97
BOD	(mg/l)	1,600	4,010	220	44	170	2	97
T-N	(mg/l)	340	480	230	240	320	114	30
NH_3-N	(mg/l)	290	480	133	214	305	109	25
T-PO_4	(mg/l)	260	910	76	5.0	13.0	<0.2	98
pH		8.1	8.8	7.5	4.4	4.8	4.0	--
Conductivity	(MHO)	3,150	4,300	2,250	5,000	7,200	3,800	--
Turbidity	(JTU)	145	250	100	21	65	. 3	86
Zinc	(mg/l)	48	96	26	21	53	6	56
Formaldehyde	(mg/l)	8.9	27	1.8	2.2	3.7	0.7	75
Coliform	(MPN/100 ml)	$17x10^8$	$62x10^8$	$23x10^5$	4	10	<3	--

[a]Standard processing using FMC Waste Treatment System Model 50-2000. No auxiliary treatment for zinc removal or postchlorination.

[b]Analytical data represents 21 separate process days from 22 August to 27 September 1973.

Table 19. RESULTS OF LAKE MEAD TESTING WITH ZINC REMOVAL AND POSTCHLORINATION TREATMENT[a]

Parameter		Influent Waste[b]			Process Effluent[b]			Percent Removal Average
		Average	Maximum	Minimum	Average	Maximum	Minimum	
SS	(mg/l)	2,060	3,080	890	19	39	5.0	99
VSS	(mg/l)	1,690	2,590	610	4.2	12	1.0	99
TS	(%)	0.37	0.57	0.25	1.11	1.50	0.47	--
TVS	(%)	0.23	0.38	0.11	0.13	0.24	0.06	--
TOC	(mg/l)	885	1,420	510	48	128	12	95
SOC	(mg/l)	150	380	65	37	94	8	76
COD	(mg/l)	4,700	3,800	1,450	250	540	38	95
BOD	(mg/l)	1,510	3,700	300	58	155	2	96
T-N	(mg/l)	280	360	81	95	230	2	66
NH_3-N	(mg/l)	230	290	38	85	215	<1	63
T-PO_4	(mg/l)	104	175	40	0.8	3.0	<0.2	99
pH		8.1	9.0	7.3	8.3	11.0	3.2	--
Conductivity	(MHO)	3,000	3,500	2,100	12,800	18,000	5,800	--
Turbidity	(JTU)	180	280	125	7.4	10	5.0	96
Zinc	(mg/l)	46	65	13	3.6	12.0	1.0	92
Formaldehyde	(mg/l)	9.8	17.5	4.1	2.8	5.3	1.0	71
Coliform	(MPN/100 ml)	14×10^8	35×10^8	72×10^6	3	5	<3	--

[a]Chlorination Conditions: 2660 mg/l free chlorine, 90 minute retention time at 30-32°C.

[b]Analytical data represents 14 separate process days from 27 September to 16 October 1973.

and formaldehyde removals averaged 56 and 75 percent, respectively. Effluent coliform content was consistently below 10 MPN/100 ml.

The results of zinc removal and postchlorination processing are given in Table 19 which represents 14 days of processing. Postchlorination resulted in a significant increase in removal of nitrogen compounds. T-N and NH_3-N removals were nearly doubled to 66 and 63 percent, respectively. Suspended solids, BOD_5, COD, and T-PO_4 removal efficiencies all averaged greater than 95 percent. Average effluent turbidity was reduced from 21 to 10 JTU* with the additional filtration of the auxiliary treatment. Postchlorination had no significant effect on removal of formaldehyde because of its very high break-point chlorine demand. Removal of zinc was increased to 92 percent with auxiliary treatment at pH 8.5 to 11.0. Optimum removal efficiency was attained at pH 9.5.

Grab samples of solid filter cake discharged from the rotary vacuum filter were taken during 21 days of operation and were individually analyzed. The average results of these tests are given in Table 20. Total solids (TS) averaged 31.7 percent and total volatile solids (TVS) averaged 10.7 percent. Dry filter cake production averaged 13.2 kg/kl (110 lb/1000 gal) based on effluent volume. Approximately 4.4 kg of this cake were sewage solids with the remaining 8.8 kg being filter aid and diatomaceous earth. The zinc content of the cake averaged 1.5 mg/q of dry solids. Influent wastewaters had an average zinc concentration of 45 mg/l. BOD_5 determinations on fresh, wet cake samples averaged 53 mg/g of dry solids. A material balance over the process showed fair agreement between total zinc and BOD_5 contents of influent wastes compared to total effluent and filter cake contents. A more accurate balance may have been achieved had composite cake samples been collected instead of grab samples.

Table 20. CHARACTERISTICS OF SOLID FILTER CAKE

Parameter		Average	Maximum	Minimum
TS	(%)	31.7	34.6	27.5
TVS	(%)	10.7	12.9	8.9
BOD_5	(mg/gm)[a]	53	105	12
Coliform	(MPN/gm)[a]	65	340	10
Zinc	(mg/gm)[a]	1.5	5.4	0.1

[a]Per gram of dry solids cake.

*JTU is Jackson Turbidity Units

Coliform determinations on wet cake samples averaged 22 MPN/g of wet solids (65 MPN/g of dried solids) with a range of 3 to 120 MPN/g of wet solids. These results indicated good control of coliform population in the filter cake. No total bacteria or virus analyses were performed. Disinfection was achieved by adding 500 to 700 mg/l available chlorine during standard processing. Residual chlorine content of the process effluent was 0.3 to 1.2 mg/l. Samples of wet filter cake aged in sealed containers for 10 to 30 days at 22°C produced no detectable sulfides and were not malodorous. Other cake samples dried at room temperature for 3 days had no measurable coliform.

Laboratory analyses of filter cake solids produced during preliminary field testing gave the following average results on a dry solids basis: 51 mg/g BOD_5, 70 MPN/g coliform, and 1.3 mg/g zinc. These data were presented to the Nevada State Divisions of Health and Environmental Protection as well as the inspector's office of Clark County. Permission was obtained from these parties to dispose of the filter cake solids as sanitary landfill. No special permits were required. Filter cake solids were accumulated in a plastic bag during plant operation and then discarded in a solid waste hopper used by the marina. Twice weekly these hoppers were emptied in an authorized landfill area outside of Las Vegas.

CHEMICAL AND POWER CONSUMPTION

Average consumption rates of process chemicals and electrical power are given in Table 21. A recording kilowatt-hour (kwh) meter measured the power requirements of the demonstrated treatment unit excluding auxiliary postchlorination and zinc-removal equipment. Total power requirements for motors associated with auxiliary treatment was estimated at less than 0.3 kwh. Dry chemical (filter aid and diatomaceous earth) feed rate remained basically constant over the entire test period, even though influent waste characteristics varied substantially.* Power consumption varied slightly as a function of process rate and influent waste concentration. Heavier wastes required longer processing times by rotary vacuum filtration equipment. Based on an average power consumption of 5.4 kwh per hour of operation, a total of 22 kwh was required to process 1000 l (264 gal) of watercraft wastewater at a rate of 4.1 l/min (1.1 gal/min).

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*Dry chemical feed requirements are proportional to influent waste concentration. On automatic operation, dry chemical feed rate is set for the highest expected waste concentration. This condition results in excess chemical consumption and overtreatment of less concentrated influent wastewaters.

Table 21. CHEMICAL AND POWER CONSUMPTION AND COST DATA

Treatment	Process Chemicals	Consumption Rate		Unit Price[a]	Operating Cost	
		kg/kl	lb/M gal	¢/lb	$/kl	$/M gal
Standard	Calcium Hypochlorite[b]	1.1	9.2	50.6	1.23	4.66
	Aluminum Sulfate	3.0	25.0	7.9	0.52	1.98
	Sodium Bisulfate	1.0	8.3	2.75	0.06	0.23
	Filter Aid (Celite 501)	7.1	59.3	8.25	1.29	4.89
	Carbon (Nuchar KD)	2.9	24.2	13.0	0.83	3.15
	Total	15.1	126.0	-	3.93	14.91
Post Chlorination	Sodium Hydroxide	0.4	3.4	7.0	0.06	0.24
	Sodium Hypochlorite[c]	15 l/kl	15 gal/M gal	35.0/gal	1.39	5.25
	Total	-	-	-	1.45	5.49
Zinc Removal	Sodium Hydroxide	0.8	6.7	7.0	0.12	0.47
Power (3-phase 240 volts)[d]		22 kwh/kl	83 kwh/M gal	3.20¢/kwh[e]	0.70	2.66

[a] Effective prices of November 23, 1973, Chemical Marketing Reporter, December 3, 1973. Schnell Publishing Co., Inc.

[b] 65 percent available chlorine used in aqueous solution for disinfection.

[c] 14 percent solution of sodium hypochlorite having 180 gm/l available chlorine. Used only for postchlorination.

[d] Power requirements for standard treatment based on an average of 5.4 kwh at a process rate of 4.1 l/min.

[e] Effective rate by Public Gas and Electric Company, San Jose, California, December, 1973. Based on continuous operation with a total monthly demand of approximately 4000 kwh.

OPERATING COSTS

Average costs of treatment chemicals and power requirements for the demonstration system are given in Table 21. Total cost for standard treatment was \$4.63/kl (\$17.57/1000 gal). Postchlorination of effluent at pH 7 with 2700 mg/l available chlorine cost \$1.45/kl (\$5.49/1000 gal). Zinc removal from the effluent at pH 9.5 cost \$0.12/kl (\$0.47/1000 gal). Complete treatment consisting of all three operations cost \$6.20/kl (\$23.50/1000 gal). Current prices for truckload quantities of treatment chemicals were used in cost calculations. Electrical power costs were determined using current price quotations of 3.2¢/kwh. California Public Gas and Electric Company quoted this price based on continuous plant operation in San Jose, California with a monthly total power demand of approximately 4000 kwh.

MAINTENANCE

Daily routine maintenance service involved resupply of process chemicals and disposal of solid filter cake. Lubrication of pumps and bearings was done monthly. All mechanical and electrical components functioned properly and no equipment failures occurred during the 8-week test period. Under the field test operating conditions, one man managed the plant and supplied treatment chemicals.

OPERATING PROBLEMS

No major operating problems were experienced. Fluctuation in voltage of supplied power caused periodic trip-out of equipment which was later remedied with electrical modifications. Consistent operation occurred after long periods of down time with no plugging of equipment. Level sensors controlling the operation of the rotary vacuum filter equipment required periodic cleansing of accumulated solids. This was done automatically with a small wash line from the effluent discharge pump. Channeling of dry chemical in the feed hopper resulted in a decreased feed rate to the surge tank. This problem was significantly reduced by installing cross baffles in the hopper. Process control of pH was constant with varying influent waste concentrations. Only when cleaning chemicals in the waste seriously changed the normal influent pH was it necessary to adjust the process chemical feed rate for pH control.

Auxiliary equipment for zinc removal and postchlorination functioned properly. The retention coil and pressure filter did not leak at a maximum test loading of 586 dynes/m^2 (120 psi). A single bag filter was used during testing without plugging, and a constant process rate of 3.8 l/min was maintained. An antisiphon device and check valve were required on the hypochlorite feed pump.

SECTION XII

DISCUSSION

The reliability and accuracy of BOD_5 data obtained during field testing requires discussion. The BOD test is an empirical bio-assay-type procedure, consequently, the results obtained are influenced greatly by the presence of toxic substances or use of a poor seeding material. For industrial wastes containing toxic chemicals, the standard 5-day incubation period is often insufficient for proper stabilization[20]. Toxic substances cause a decrease in microbial assimilation and oxidation of organic matter present in the waste which results in less depletion of dissolved oxygen. Since the BOD test measures the dissolved oxygen consumed by microbial activity, the empirical result is low compared to the true value. Evidence of this effect has been shown in this work and is reported in the literature[19, 20, 21]. After a variable time lag, microorganisms become acclimated to these toxic substances. A stabilized waste results, which approaches normal microbial activity and yields a more accurate BOD result. Considering these facts, the BOD testing of such waste should involve the determination of the complete oxidation curve and the ultimate or total carbonaceous BOD.

Since this approach was outside the scope of contract finances, 5-day BOD determinations were made on very dilute samples of influent waste and filter cake solids (to reduce toxic material concentrations). Those dilutions showing a minimum residual DO of 1 mg/l and depletions of at least 2 mg/l were averaged and reported. There is no acceptable method for determining the accuracy of the BOD test, but the procedure followed in this work should have given BOD_5 results with a mean standard deviation of 17 to 20 percent. Additional information relating to the oxygen-demanding characteristics of wastes involved in this program are given by TOC, SOC, and COD results where determinations are not affected by the presence of toxic materials.

Process results indicated a net increase in total dissolved solids (TDS) concentration after treatment by the demonstration system. This is explained by addition of treatment chemicals. Calculating the TDS as the difference between TS and SS, influent wastes averaged 1610 mg/l TDS.

With standard treatment, the process effluent averaged 4945 mg/l TDS for a net increase of 3335 mg/l TDS. Based on average chemical consumption, the addition of aluminum sulfate, sodium bisulfate, and calcium hypochlorite totaled 1500 mg/l, which accounts for the TDS increase. Similarly, chemicals added during zinc removal and postchlorination contributed even more TDS. After auxiliary treatment, the effluent TDS averaged 11,100 mg/l for a net increase of 9490/mg/l. Besides normal treatment chemicals, sodium hydroxide and sodium hypochlorite additions totaled 7520 mg/l which accounts for this increase in TDS. It should be recognized that the TDS loading in the effluent is exceptionally high. Further studies are required to optimize process chemical treatment to reduce the effluent TDS concentration.

Postchlorination of process effluent increased the removal efficiency of nitrogen from 30 to 66 percent. Treatment involved an available chlorine concentration of 2700 mg/l with 90 minutes retention at pH 9.5. These nitrogen removal results are in basic agreement with preliminary results obtained in the laboratory (see Section IX). In recent work on ammonia-nitrogen (NH_3-N) removal for wastewaters[22], the EPA reports a requirement of 10 mg free chlorine to remove 1 mg of ammonia-nitrogen by break-point chlorination. During these studies on secondary effluents, little or no chlorine demand was determined for other wastewater constituents. This case does not exist in the postchlorination of watercraft waste effluent following physical-chemical treatment. Soluble organic chemicals like formaldehyde and methanol, not readily removed during standard treatment, remain in the effluent to exert a chlorine demand. The application of 2700 mg/l free chlorine to effluent having approximately 250 mg/l ammonia-nitrogen was insufficient to achieve complete removal of ammonia-nitrogen. The presence of other compounds having real chlorine demands may explain these results*. Without further work, no statements can be made regarding the limit of nitrogen removal that can be achieved by postchlorination at higher free chlorine concentrations and longer retention times. This approach of breakpoint chlorination for nitrogen removal is quite expensive and inefficient. Other possible methods for approaching the objective of 90 percent total nitrogen removal include air stripping of effluent at pH 10.5[17], ion exchange with clinoptilolite[23] (a natural mineral ore with ion exchange properties), a biological nitrification-denitrification[24]. Major work remains to be done in this field before a high degree of nitrogen removal can be achieved efficiently and economically.

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*No residual chlorine data was obtained on chlorinated effluent samples but a strong chlorine odor was detected.

The high operating cost of the demonstrated system requires qualification and discussion. Disposition of concentrated chemically polluted wastewaters will utimately be decided by the availability of adequate treatment facilities and not the cost of operation. Since public recreational activities are concentrated in rural land and marine areas, access to municipal treatment plants may be impossible or prohibitively expensive. Truck transportation of wastes is becoming increasingly expensive, with rates as high as \$40/1000 l (\$150/1000 gal) reported in Washington and Northern California[25]. In many sanitary districts, chemical wastes will not be received for treatment because of the serious upset and loss of operating efficiency caused to biological treatment plants. A great number of municipal sanitary treatment plants are presently overloaded, and they do not have additional flow capacity to treat recreational watercraft wastes which require 10 to 220 times dilution before toxic effects are eliminated.

Results of field testing at Lake Mead have shown the demonstration system to provide greater than 90 percent removal of SS, COD, and BOD_5 from recreational sanitary wastes containing chemical toilet additives. These results, combined with variable capacity design and automatic on-demand operation, indicate that the demonstration system offers an effective method for the treatment of low volume flows of concentrated chemical wastes where conventional biological treatment would be inadequate and troublesome.

SECTION XIII

REFERENCES

1. Pretreatment of Discharge to Publicly Owned Treatment Works, U.S. Environmental Protection Agency. Washington, D.C. Office of Water Programs Operations, 1973. P 1-15.

2. Federal Register, Washington, D.C., 37 (122): 12391-12393, June 23, 1972.

3. Federal Register, Washington, D.C., 39 (42): 8038-8044, March 1, 1974.

4. Personal Communication. Contra Costa County Sanitary District, Antioch, California, February, 1973.

5. Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, Water Quality Office, Cincinnati, Ohio, 1971. 310 p.

6. Personal Communication, Holiday Harbor Marina, O'Brien, California, May 1973.

7. Barth, E.B., et al, Summary Report on the Effects of Heavy Metals on the Biological Treatment Process. Journal WPCF, 37 (1) :86-96, 1965.

8. McDermott, G.N., et al, Zinc in Relation of Activated Sludge and Anaerobic Digestion. In: Proc. 17th. Industrial Waste Conference, Purdue University, Lafayette, Ind., 1962. P 461-475.

9. Interaction of Heavy Metals and Biological Sewage Treatment Processes. U. S. Public Health Service, Cincinnati, Ohio. 999-WP-22. U.S. Department of Health, Education, and Welfare. May 1965. p 61-78.

10. Gellman, I., and H. Heukelekian, Biological Oxidation of Formaldehyde. Sewage and Ind. Wastes. 22:1321, 1950.

11. Noller, Carl R. Textbook of Organic Chemistry. 2nd Edition. Philadelphia, W.B. Sounders Company, 1958. p 655

12. McKinney, Ross, E. Microbiology for Sanitary Engineers. New York, McGraw-Hill Book Company, Inc., 1962. p 194-198.

13. Lampe, Wallace D. The Rate of Endogenous Respiration in a Completely Mixed Activated Sludge System. M.S. Thesis, University of Iowa, Iowa City, Iowa. 1966.

14. Gilcreas, F. W. Inhibition of Sludge Digestion by Penicillin Manufacturing Wastes. Sewage Works Eng. 17:360, 1946.

15. Heukelekian, H. and M.C. Rand, Biochemical Oxygen Demand of Pure Organic Compounds. Sewage and Ind. Westes 27(9), 1955.

16. Stafford, W. and H.J. Northrup, The BOD of Textile Chemicals. In: Proc. Amer. Assoc. Text. Chem. and Colorests. 1955.

17. Benneworth, N.E. and N.G. Morris, Removal of Ammonia by Air Stripping, J. Water Pol. Control. 71(5):485-492, 1972.

18. Boos, R.N. Anal Chem. 20:964, 1948.

19. Brown, P. and P.R. Andrew, Some Effects of Zinc on the Performance of Laboratory-Scale Activated Sludge Units. Jour. Water Pol. Control. 71(5):549-555, 1972.

20. Standard Methods for the Examination of Water and Wastewater. 13th Edition. New York, New York, Amer. Public Health Assoc., Amer. Water Works Assoc., Water Pol. Control Fed. 1971. p 489-495.

21. Rudolfs, W., et al. Review of the Literature on Toxic Materials Affecting Sewage Treatment Processes, Streams, and BOD Determinations. Sewage and Ind. Wastes. 22:1157, 1950.

22. Cowan, J. U.S. Environmental Protection Agency, Cincinnati, Ohio. Unpublished report.

23. Slechta, A.F., and G.L. Culp, Water Reclamation Studies at the South Tahoe Public Utility District. J. Water Pol. Control Fed. 39(5):787-814, May 1967.

24. Downing, A.L., et al. Nitrification in the Activated Sludge Process. J. Inst. Sewage Purif. (Brit.), 130, 1964.

25. Personal Communication, Lake Shasta National Recreational Area, Redding, California. May 1973.

SECTION XIV

APPENDICES

Appendix A. ANALYSIS OF RECREATIONAL WATERCRAFT WASTE SAMPLES

Sample Number	1	2	3	4	5	6	7
Code Number	382-11-1	382-21-1	382-27-1	382-28-1	382-30-1	382-31-1	382-32-1
Sample Type	Composite	Individual	Individual	Individual	Individual	Composite	Individual
Collection Date	3-08-73	3-17-73	3-22-73	3-22-73	3-22-73	3-22-73	3-22-73
Location	Lake Mead	Alameda	San Diego	San Diego	Mission Bay	San Diego	Harbor Island
Marina Number	1	5	6	6	7	6,7	8
Water Type	Fresh	Salt	Salt	Salt	Salt	Salt	Salt
Boat Type & Length	Composite	House, 36'	Power, 38'	Power, 38'	Power, 48'	Composite	Power, 42'
Chemical Additive	Composite	T-5, Kraft-Chem	T-5	T-5	Aqua-Chem	T-5, Aqua-Chem	T-5, Aqua-Chem
Waste Volume (l)	1,325	30	24	17	850	- - -	150
Waste Age	6 days	1 week	5 days	5 days	2.5 weeks	9 days	1 week
Sample Analysis							
SS (mg/l)	900	950	7,840	2,590	200	2,000	8,240
VSS (mg/l)	590	670	6,910	2,260	160	1,680	6,320
TS (%)	0.24	0.95	2.04	0.44	0.16	0.72	2.50
TVS (%)	0.08	0.50	1.35	0.29	0.08	0.49	1.65
TOC (mg/l)	640	1,590	5,300	1,100	390	1,530	4,130
SOC (mg/l)	280	1,360	2,150	330	330	820	2,780
BOD_5 (mg/l)	630	1,590	3,410	1,700	680	1,910	4,020
COD (mg/l)	2,460	3,960	8,560	3,860	1,560	5,500	12,510
T-N (mg/l)	450	880	3,110	410	65	760	5,850
NH_3-N (mg/l)	390	105	830	260	23	200	830
T-PO_4 (mg/l)	91	460	370	210	14	160	650
Zinc (mg/l)	360	449	234	144	None detected	43	1,331
Conductivity (MHO)	4,750	4,500	11,200	3,000	1,500	3,800	11,000
pH	7.7	5.5	8.2	8.8	7.2	7.8	6.6
Coliform (MPN/100 ml)	50×10^6	190	23×10^7	62×10^7	62×10^3	23×10^3	12×10^5

Appendix A. ANALYSIS OF RECREATIONAL WATERCRAFT WASTE SAMPLES

Sample Number	8	9	10	11	12	13	14
Code Number	382-35-1	382-36-1	382-34-1	382-33-1	382-37-1	382-38-1	382-39-1
Sample Type	Individual	Individual	Individual	Composite	Individual	Individual	Individual
Collection Date	3-23-73	3-23-73	3-23-73	3-23-73	3-24-73	3-24-73	3-24-73
Location	Harbor Island	Harbor Island	Harbor Island	Harbor Island	Dana Point	Dana Point	Dana Point
Marina Number	8	8	8	8	9	9	9
Water Type	Salt	Salt	Salt	Salt	Salt	Salt	Salt
Boat Type & Length	Sail, 25'	Sail, 28'	House, 18'	Composite	Power, 36'	Power, 28'	Sail, 22'
Chemical Additive	Aqua-Chem	T-5	Aqua-Chem	T-5, Aqua-Chem	T-5	KN-48	T-5
Waste Volume (1)	9	26	45	- - -	13	15	14
Waste Age	2 weeks	1.5 weeks	1 week	1.4 weeks	10 days	3 months	5 months
Sample Analysis							
SS (mg/1)	5,240	9,050	430	4.360	290	110	290
VSS (mg/1)	4,640	6,640	310	3.480	160	80	100
TS (%)	3.25	2.33	2.90	2.61	1.00	0.64	0.86
TVS (%)	2.07	1.34	0.67	1.52	0.52	0.45	0.48
TOC (mg/1)	5,450	6,100	850	6,880	1,230	700	580
SOC (mg/1)	4,700	4,030	750	4,230	1,220	650	540
BOD_5 (mg/1)	5,800	2,600	1,580	5,810	6,780	9,230	30
COD (mg/1)	15,420	12,770	3,370	11,560	2,720	2,640	1,160
T-N (mg/1)	990	4,800	2,310	4,620	1,310	2,910	1,370
NH_3-N (mg/1)	990	3,970	2,145	3,130	130	2,730	720
T-PO_4 (mg/1)	1,180	840	72	800	120	26	45
Zinc (mg/1)	9	544	None detected	882	1,042	41	425
Conductivity (MHO)	17,000	26,500	40,000	24,500	6,000	40,000	8,000
pH	7.2	8.60	7.8	8.7	5.3	8.7	7.3
Coliform (MPN/100 ml)	<45	14×10^2	90	<45	<45	280	<45

Appendix A. ANALYSIS OF RECREATIONAL WATERCRAFT WASTE SAMPLES

Sample Number	15	16	17	18	19	20	21
Code Number	382-40-1	382-42-1	382-41-1	382-43-1	382-44-1	382-45-1	382-46-1
Sample Type	Individual	Individual	Composite	Composite	Individual	Individual	Individual
Collection Date	3-24-73	3-24-73	3-24-73	3-25-73	3-25-73	3-25-73	3-25-73
Location	Dana Point	Dana Point	Dana Point	Marina Del Rey	Marina Del Rey	Marina Del Rey	Marina Del Rey
Marina Number	9	9	9	10	10	10	10
Water Type	Salt	Salt	Salt	Salt	Salt	Salt	Salt
Boat Type & Length	Sail, 32'	Sail, 28'	Composite	Composite	Sail, 32'	Sail, 24'	Power, 32'
Chemical Additive	Aqua-Chem	Inca-Gold	T-5, Inca Gold, KN-48, Aqua-Chem	T-5, Aqua-Chem	T-5	T-5	Aqua-Chem
Waste Volume (1)	14	19	- - -	180	15	5	9
Waste Age	3 weeks	2 weeks	8 weeks	1 month	3 months	2 months	1 day
Sample Analysis							
SS (mg/1)	72	85	920	1,520	2,750	1,940	4,990
VSS (mg/1)	63	80	910	1,440	2,160	1,000	4,690
TS (%)	0.11	1.28	1.24	1.29	0.98	0.98	4.04
TVS (%)	0.03	0.82	0.38	0.49	0.63	0.45	1.25
TOC (mg/1)	480	2,630	840	1,380	1,270	880	3,250
SOC (mg/1)	400	2,580	720	800	510	700	1,040
BOD_5 (mg/1)	1,040	2,280	680	1,560	450	440	3,010
COD (mg/1)	1,290	4,990	2,780	4,070	2,920	3,600	12,600
T-N (mg/1)	19	2,660	1,550	720	720	1,350	3,000
NH_3-N (mg/1)	8	300	970	430	430	870	2,670
T-PO_4 (mg/1)	30	760	76	390	220	420	590
Zinc (mg/1)	N.D.	N.D.	264	90	317	500	N.D.
Conductivity (MHO)	1,200	6,800	16,000	13,400	7,400	10,200	40,100
pH	7.9	6.4	7.5	7.4	8.2	8.7	7.5
Coliform (MPN/100 ml)	<45	23 x 106	<45	62×10^3	450	<45	23×10^6

Appendix A. ANALYSIS OF RECREATIONAL WATERCRAFT WASTE SAMPLES

Sample Number	22	23	24	25	26	27	28
Code Number	382-47-1	382-48-1	382-50-1	382-49-1	382-51-1	382-52-1	382-53-1
Sample Type	Individual	Individual	Individual	Composite	Individual	Individual	Individual
Collection Date	3-25-73	3-25-73	3-25-73	3-25-73	3-26-73	3-26-73	3-26-73
Location	Marina Del Rey	Marina Del Rey	Marina Del Rey	Marina Del Rey	Channel Islands	Channel Islands	Channel Islands
Marina Number	10	10	10	10	11	11	12
Water Type	Salt	Salt	Salt	Salt	Salt	Salt	Salt
Boat Type & Length	Sail, 55'	Sail, 24'	Power, 42'	Composite	Power, 38'	Power, 32'	Sail, 42'
Chemical Additive	Aqua-Chem	Inca Gold	Corlon Chem 67	T-5, A-C, KC, C-67, I-G	Hydrachlor	Hydrachlor	T-5
Waste Volume (1)	245	26	19	- - -	210	90	11
Waste Age	6 weeks	5 months	3 weeks	9 weeks	1 week	1 week	2 weeks
Sample Analysis							
SS (mg/1)	2,210	1,550	3,920	3,730	2,420	2,730	720
VSS (mg/1)	1,470	1,230	3,470	2,690	2,140	2,230	450
TS (%)	3.11	3.54	0.93	2.76	3.43	4.83	0.88
TVS (%)	0.81	1.00	0.55	0.73	0.80	2.19	0.55
TOC (mg/1)	4,280	1,140	1,840	2,500	1,820	2,650	1,980
SOC (mg/1)	3,360	530	890	1,100	1,120	1,560	1,670
BOD_5 (mg/1)	3,410	760	940	1,810	2,880	2,800	1,890
COD (mg/1)	10,590	3,900	4,210	7,090	7,090	7,140	4,060
T-N (mg/1)	1,430	1,160	1,060	1,850	1,720	1,790	1,080
NH_3-N (mg/1)	990	1,010	260	1,640	1,510	1,590	780
T-PO_4 (mg/1)	690	195	260	470	260	280	170
Zinc (mg/1)	7	7	263	55	16	11	640
Conductivity (MHO)	40,200	38,000	6,200	35,000	40,200	40,100	5,200
pH	8.5	8.5	6.7	8.5	8.7	8.6	5.9
Coliform (MPN/100 ml)	23×10^3	60	230	23×10^5	23×10^5	62×10^5	62×10^4

Appendix A. ANALYSIS OF RECREATIONAL WATERCRAFT WASTE SAMPLES

Sample Number	29 [a]	30 [b]	31 [c]	32	33	34	35
Code Number	382-54-1	382-55-1	382-56-1	382-57-1	382-58-1	382-60-1	382-59-1
Sample Type	Individual	Individual	Individual	Individual	Individual	Individual	Composite
Collection Date	4-1-73	4-1-73	4-1-73	4-1-73	4-1-73	4-1-73	4-1-73
Location	Alameda	Alameda	Alameda	Alameda	Alameda	Alameda	Alameda
Marina Number	5	5	5	5	5	5	5
Water Type	Salt	Salt	Salt	Salt	Salt	Salt	Salt
Boat Type & Length	House, 34'	House, 34'	House, 34'	House, 42'	House, 42'	House, 36'	Composite
Chemical Additive	Kraft-Chem	Kraft-Chem	Kraft-Chem	T-5	Pink Magic	T-5	T-5, K-C, Pink Magic
Waste Volume (1)	18	12	13	23	18	45	- - -
Waste Age	2 weeks	2 weeks	2 weeks	1 month	3 days	2 weeks	2 weeks
Sample Analysis							
SS (mg/1)	7,360	7,560	3,110	2,100	1,660	6,920	5,420
VSS (mg/1)	5,840	6,040	2,560	1,490	1,510	5,600	4,960
TS (%)	1.93	1.27	0.47	1.03	0.55	1.19	1.00
TVS (%)	0.89	0.81	0.30	0.59	0.36	0.68	0.51
TOC (mg/1)	5,140	4,200	1,720	2,190	1,450	3,400	2,920
SOC (mg/1)	3,200	1,250	520	1,780	1,070	1,140	1,240
BOD_5 (mg/1)	5,640	3,760	1,180	1,280	1,070	3,210	3,200
COD (mg/1)	17,200	13,590	5,190	3,820	3,630	10,260	8,520
T-N (mg/1)	3,050	1,270	450	2,240	1,020	1,830	1,820
NH_3-N (mg/1)	2,450	800	230	850	690	1,530	1,510
T-PO_4 (mg/1)	1,130	1,010	380	720	385	720	670
Zinc (mg/1)	2	N.D.	N.D.	121	7	142	29
Conductivity (MHO)	17,000	6,200	2,300	6,200	3,500	8,500	8,000
pH	8.9	8.1	7.8	7.0	8.5	8.9	9.0
Coliform (MPN/100 ml)	70×10^8	24×10^8	24×10^8	70×10^8	<45	62×10^6	62×10^7

(a) Original pumpage from recirculating toilet - 4.5 gallon capacity.
(b) First flush pumpage with 3 gallons fresh water.
(c) Second flush pumpage with 3 gallons fresh water.

Appendix A. ANALYSIS OF RECREATIONAL WATERCRAFT WASTE SAMPLES

Sample Number	36	37	38	39	40	41	42
Code Number	382-61-1	382-62-1	382-63-1	382-64-1	382-65-1	382-66-1	382-67-1
Sample Type	Individual	Individual	Individual	Individual	Composite	Individual	Individual
Collection Date	4-4-73	4-4-73	4-4-73	4-4-73	4-4-73	4-4-73	4-4-73
Location	Walnut Grove	Walnut Grove	Walnut Grove	Walnut Grove	Walnut Grove	Stockton	Stockton
Marina Number	13	13	13	13	13	14	14
Water Type	Fresh	Fresh	Fresh	Fresh	Fresh	Fresh	Fresh
Boat Type & Length	House, 42'	House, 42'	House, 42'	House, 42'	House, 42'	House, 36'	House, 36'
Chemical Additive	Kraft-Chem	Kraft-Chem	Kraft-Chem	Kraft-Chem	Kraft-Chem	Wilcox-Crittenden	T-5
Waste Volume (l)	30	30	30	30	- - -	340	19
Waste Age	5 days	4 days	2 days	3 days	3 days	5 days	2 months
Sample Analysis							
SS (mg/l)	860	256	48	128	457	523	3,500
VSS (mg/l)	650	196	30	88	297	336	3,490
TS (%)	0.79	0.51	0.40	0.95	0.72	0.39	1.55
TVS (%)	0.37	0.26	0.20	0.68	0.43	0.20	0.80
TOC (mg/l)	2,370	1,750	1,230	3,000	2,200	1,010	4,230
SOC (mg/l)	1,940	1,590	1,180	2,840	1,980	760	3,170
BOD_5 (mg/l)	2,780	1,730	490	2,470	1,890	1,360	5,990
COD (mg/l)	7,020	3,850	1,430	8,690	5,430	3,400	14,820
T-N (mg/l)	2,090	1,370	1,250	1,470	1,540	1,020	4,660
NH_3-N (mg/l)	1,830	1,130	330	380	900	850	4,070
T-PO_4 (mg/l)	450	470	405	440	425	290	1,090
Zinc (mg/l)	None detected	None detected	None detected	38	10	None detected	104
Conductivity (MHO)	12,400	4,300	3,000	4,200	6,000	5,700	24,000
pH	9.1	7.9	7.5	5.7	5.7	7.6	9.3
Coliform (MPN/100 ml)	23×10^7	62×10^6	23×10^7	23×10^7	23×10^7	24×10^9	62×10^3

Appendix A. ANALYSIS OF RECREATIONAL WATERCRAFT WASTE SAMPLES

Sample Number	43	44	45	46	47	48 [a]	49 [b]
Code Number	382-68-1	382-69-1	382-73-1	382-74-1	382-75-1	382-77-1	382-76-1
Sample Type	Individual	Composite	Composite	Individual	Composite	Composite	Composite
Collection Date	4-4-73	4-4-73	4-8-73	4-8-73	4-8-73	4-8-73	4-8-73
Location	Stockton	Stockton	Lake Mead	Lake Mead	Lake Mead	Lake Mead	Lake Mead
Marina Number	14	14	1	1	1	2	2
Water Type	Fresh	Fresh	Fresh	Fresh	Fresh	Fresh	Fresh
Boat Type & Length	House, 36'	House, 36'	Composite	House, 42'	Composite	Composite	Composite
Chemical Additive	Wilcox Crittenden	T-5, Wilcox Crittenden	T-5, Inca Gold	T-5	Composite	Composite	Composite
Waste Volume (1)	340	- - -	1,700	210	1,850	560	190
Waste Age	5 days	2 weeks	2 days	2 weeks	2 days	2 weeks	2 weeks
Sample Analysis							
SS (mg/1)	1,360	2,070	1,790	2,030	1,720	1,660	7,630
VSS (mg/1)	830	1,360	1,090	1,450	830	1,000	5,170
TS (%)	0.27	0.89	0.56	0.69	0.37	0.53	1.65
TVS (%)	0.15	0.43	0.27	0.35	0.15	0.30	1.13
TOC (mg/1)	740	2,480	1,530	1,500	990	1,420	3,500
SOC (mg/1)	410	1,700	490	1,100	400	690	830
BOD_5 (mg/1)	750	3,820	800	850	570	1,000	2,060
COD (mg/1)	1,310	8,360	5,510	2,740	3,140	4,120	13,720
T-N (mg/1)	510	2,630	1,480	1,420	520	1,120	1,400
NH_3-N (mg/1)	420	2,270	1,300	1,160	410	950	1,020
T-PO_4 (mg/1)	130	640	370	240	250	260	980
Zinc (mg/1)	58	60	610	149	202	220	1,114
Conductivity (MHO)	4,000	15,000	4,400	5,600	3,600	7,000	6,800
pH	9.2	9.6	8.4	7.3	8.5	8.8	8.6
Coliform (MPN/100 ml)	62×10^5	23×10^2	62×10^5	24×10^9	62×10^7	23×10^6	23×10^7

(a) Sample taken near the surface of wastes, 2 feet above transfer pump suction.
(b) Sample taken from bottom of tank below transfer pump suction.

Appendix A. ANALYSIS OF RECREATIONAL WATERCRAFT WASTE SAMPLES

Sample Number	50 [a,b]	51 [a,c]	52 [b]	53 [c]	54	55	56
Code Number	382-70-1	382-72-1	382-79-1	382-80-1	382-83-1	382-84-1	382-85-1
Sample Type	Composite	Composite	Composite	Composite	Individual	Individual	Individual
Collection Date	4-8-73	4-8-73	4-8-73	4-8-73	4-21-73	4-21-73	4-22-73
Location	Lake Mead	Lake Mead	Lake Mead	Lake Mead	Lake Powell	Lake Powell	Lake Powell
Marina Number	3	3	4	4	15	15	15
Water Type	Fresh	Fresh	Fresh	Fresh	Fresh	Fresh	Fresh
Boat Type & Length	Composite	Composite	Composite	Composite	House, 36'	House, 36'	House, 36'
Chemical Additive	Composite	Composite	Composite	Composite	T-5	T-5	T-5
Waste Volume (l)	760	790	190	1,600	19	190	30
Waste Age	2 months	2 months	1 month	1 month	10 hours	1 week	10 hours
Sample Analysis							
SS (mg/l)	11,310	30,500	164	1,170	3,160	7,600	13,680
VSS (mg/l)	8,930	19,100	100	670	2,000	6,080	11,550
TS (%)	1.98	5.17	0.31	0.29	1.60	1.44	3.88
TVS (%)	1.39	3.21	0.08	0.16	1.19	0.95	2.88
TOC (mg/l)	2,650	12,460	400	720	3,410	3,610	10,220
SOC (mg/l)	1,210	1,260	300	260	1,690	2,170	5,470
BOD_5 (mg/l)	3,930	10,400	230	660	3,770	4,920	11,550
COD (mg/l)	27,360	54,700	940	2,440	14,680	13,710	27,770
T-N (mg/l)	590	1,480	660	370	1,910	1,910	5,350
NH_3-N (mg/l)	550	1,430	590	290	370	1,880	780
T-PO_4 (mg/l)	1,700	4,830	65	250	630	1,090	1,670
Zinc (mg/l)	238	3,527	8	68	742	541	1,192
Conductivity (MHO)	7,400	6,600	5,300	1,600	5,800	11,500	12,400
pH	8.8	7.6	9.0	7.5	6.8	8.2	5.9
Coliform (MPN/100 ml)	23×10^2	24×10^9	23×10^3	23×10^7	21×10^2	23×10^7	620

(a) Floating waste-storage tank out of order and full of settled waste solids.
(b) Sample taken near surface of wastes above transfer pump suction.
(c) Sample taken from bottom of tank.

Appendix A. ANALYSIS OF RECREATIONAL WATERCRAFT WASTE SAMPLES

Sample Number	57	58	59	60	61	62	63
Code Number	7-09-01	7-02-02	7-09-03	7-09-04	7-09-05	7-09-06	7-09-07
Sample Type	Individual	Individual	Individual	Individual	Individual	Individual	Individual
Collection Date	7-9-73	7-9-73	7-9-73	7-9-73	7-9-73	7-9-73	7-9-73
Location	Walnut Grove	Walnut Grove	Walnut Grove	Walnut Grove	Walnut Grove	Walnut Grove	Walnut Grove
Marina Number	13	13	13	13	13	13	13
Water Type	Fresh	Fresh	Fresh	Fresh	Fresh	Fresh	Fresh
Boat Type & Length	House, 42'	House, 42'	House, 42'	House, 42'	House, 42'	House, 42'	House, 42'
Chemical Additive	T-5	Kraft-Chem	Kraft-Chem	Kraft-Chem	Kraft-Chem	Kraft-Chem	Kraft-Chem
Waste Volume (1)	30	34	32	30	34	34	30
Waste Age	3 days	3 days	3 days	3 days	3 days	3 days	3 days
Sample Analysis							
SS (mg/1)	9,730	1,840	4,290	930	15,430	1,570	3,280
VSS (mg/1)	8,340	1,280	3,170	610	13,670	1,410	2,640
TS (%)	2.00	1.03	2.06	0.48	3.84	1.59	3.76
TVS (%)	1.37	0.67	1.61	0.33	2.84	0.88	3.04
TOC (mg/1)	5,350	2,500	5,970	1,730	13,540	4,450	10,800
SOC (mg/1)	3,080	1,370	3,300	1,430	5,150	3,650	9,730
BOD_5 (mg/1)	7,970	1,820	7,140	2,650	19,300	8,480	14,400
COD (mg/1)	15,400	3,530	12,700	4,150	22,900	12,300	30,100
T-N (mg/1)	4,060	860	2,970	1,330	5,840	6,960	7,830
NH_3-N (mg/1)	3,010	190	780	970	4,280	3,190	2,550
T-PO_4 (mg/1)	1,400	140	1,900	790	990	1,980	1,430
Zinc (mg/1)	390	12	29	None detected	5	None detected	None detected
Conductivity (MHO)	18,300	5,400	8,600	6,400	24,300	22,700	18,300
pH	9.2	5.2	7.1	8.7	8.9	9.0	8.0
Coliform (MPN/100 ml)	62×10^5	23×10^7	24×10^9	63×10^3	24×10^9	23×10^7	62×10^6

Appendix A. ANALYSIS OF RECREATIONAL WATERCRAFT WASTE SAMPLES

Sample Number	64	65					
Code Number	5-27-01	5-27-01					
Sample Type	Composite	Composite					
Collection Date	5-27-73	5-30-73					
Location	Shasta Lake	Shasta Lake					
Marina Number	16	16					
Water Type	Fresh	Fresh					
Boat Type & Length	House, 42'	House, 42'					
Chemical Additive	Aqua-Chem	Aqua-Chem					
Waste Volume (1)	1,200	1,200					
Waste Age	3 days	1 week					
Sample Analysis							
SS (mg/1)	20,200	21,900					
VSS (mg/1)	18,700	17,100					
TS (%)	2.71	3.12					
TVS (%)	2.08	2.44					
TOC (mg/1)	10,950	8,400					
SOC (mg/1)	300	290					
BOD_5 (mg/1)	14,400	12,100					
COD (mg/1)	37,800	37,800					
T-N (mg/1)	1,600	1,450					
NH_3-N (mg/1)	830	820					
T-PO_4 (mg/1)	1,870	2,010					
Zinc (mg/1)	3	9					
Conductivity (MHO)	14,000	15,000					
pH	8.0	8.2					
Coliform (MPN/100 ml)	62×10^6	62×10^5					

Appendix B. WASTE CHARACTERIZATION DATA RESULTS OF ATOMIC ABSORPTION ANALYSIS FOR TWENTY-TWO ELEMENTS[a]

All Units mg/l	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead
382-21-1	7	N.D.	N.D.	N.D.	0.12	380	N.D.	N.D.	0.2	1.7	0.3
382-27-1	10	N.D.	N.D.	N.D.	0.07	360	N.D.	N.D.	0.4	2.8	0.3
382-28-1	7	N.D.	N.D.	N.D.	0.2	1540	N.D.	N.D.	0.6	5.6	0.5
382-28-1A	N.D.	N.D.	N.D.	N.D.	1.79	670	0.7	0.1	N.D.	5.0	1.1
382-29-1	10	N.D.	N.D.	N.D.	0.13	300	N.D.	N.D.	0.6	4.3	0.3
382-29-1A	7	N.D.	N.D.	N.D.	N.D.	540	N.D.	0.1	0.2	5.0	N.D.
382-30-1	5	N.D.	N.D.	N.D.	0.14	220	N.D.	N.D.	0.6	1.4	0.4
382-31-1	5	N.D.	N.D.	N.D.	0.18	250	0.1	N.D.	0.6	2.5	N.D.
382-32-1	6	N.D.	N.D.	N.D.	1.36	670	0.1	N.D.	0.1	4.9	0.5
382-33-1	24	N.D.	N.D.	N.D.	0.95	970	0.1	N.D.	0.2	3.6	0.2
382-34-1	3	N.D.	N.D.	N.D.	N.D.	30	0.1	N.D.	0.3	1.5	0.5
382-35-1	3	N.D.	N.D.	N.D.	N.D.	400	0.2	N.D.	0.5	1.7	N.D.
382-36-1	20	N.D.	N.D.	N.D.	0.70	310	0.4	N.D.	0.5	2.8	0.3
382-37-1	16	N.D.	N.D.	N.D.	0.30	120	0.2	N.D.	0.3	1.8	N.D.
382-38-1	4	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.8	2.5	N.D.
382-39-1	5	N.D.	N.D.	N.D.	1.80	150	N.D.	N.D.	0.4	1.5	N.D.
382-40-1	4	N.D.	N.D.	N.D.	N.D.	140	N.D.	N.D.	N.D.	1.0	N.D.
382-41-1	11	N.D.	N.D.	N.D.	0.33	150	0.2	N.D.	0.7	2.1	N.D.
382-42-1	13	N.D.	N.D.	N.D.	N.D.	120	0.5	N.D.	1.2	2.5	0.4
382-43-1	6	N.D.	31	N.D.	0.18	280	0.1	N.D.	0.5	3.6	N.D.
382-44-1	4	N.D.	N.D.	N.D.	0.55	70	0.1	N.D.	0.2	1.5	0.4

[a]All results given in units of milligrams per liter.

Note: N.D. = None detected

Appendix B. WASTE CHARACTERIZATION DATA RESULTS OF ATOMIC ABSORPTION ANALYSIS FOR TWENTY-TWO ELEMENTS[a]

All Units mg/1	Magnesium	Manganese	Mercury	Molybdenium	Nickel	Potassium	Selinium	Silver	Sodium	Tin	Zinc
382-21-1	140	0.5	N.D.	N.D.	N.D.	388	N.D.	0.2	1610	N.D.	449
382-27-1	30	0.4	N.D.	N.D.	0.5	642	N.D.	0.3	1702	26	234
382-28-1	68	0.7	N.D.	N.D.	N.D.	539	N.D.	0.2	645	21	144
382-28-1A	65	0.2	N.D.	N.D.	1.1	93	N.D.	0.5	1738	42	28
382-29-1	51	0.3	N.D.	N.D.	N.D.	62	N.D.	0.4	635	37	34
382-29-1A	65	0.5	N.D.	N.D.	0.6	104	N.D.	0.6	718	N.D.	43
382-30-1	56	N.D.	N.D.	N.D.	N.D.	208	N.D.	N.D.	693	41	N.D.
382-31-1	50	0.2	N.D.	N.D.	N.D.	354	N.D.	0.3	823	40	43
382-32-1	125	3.6	N.D.	N.D.	N.D.	800	N.D.	N.D.	1690	27	1331
382-33-1	275	1.9	N.D.	N.D.	N.D.	1298	N.D.	0.2	2520	20	882
382-34-1	721	N.D.	N.D.	N.D.	0.2	883	N.D.	0.3	7680	35	N.D.
382-35-1	111	N.D.	N.D.	N.D.	N.D.	2110	N.D.	0.3	3059	38	9
382-36-1	35	1.1	N.D.	N.D.	0.3	910	N.D.	0.4	2182	20	544
382-37-1	55	2.0	N.D.	N.D.	0.4	296	N.D.	0.3	1170	50	1042
382-38-1	678	N.D.	N.D.	N.D.	N.D.	945	N.D.	0.6	7610	35	41
382-39-1	42	2.5	N.D.	N.D.	0.4	189	N.D.	0.2	946	34	425
382-40-1	36	0.5	N.D.	N.D.	N.D.	15	N.D.	0.2	700	N.D.	N.D.
382-41-1	188	0.8	N.D.	N.D.	0.4	890	N.D.	0.5	2540	28	264
382-42-1	11	N.D.	N.D.	N.D.	0.3	393	N.D.	0.7	1622	50	N.D.
382-43-1	320	0.7	N.D.	N.D.	0.7	207	N.D.	0.5	2561	30	90
382-44-1	28	1.4	N.D.	N.D.	0.7	309	N.D.	0.4	1052	60	317

[a]All results given in units of milligrams per liter.

Note: N.D. = None detected

Appendix B. WASTE CHARACTERIZATION DATA RESULTS FOR ATOMIC ABSORPTION ANALYSIS FOR TWENTY-TWO ELEMENTS[a]

All Units mg/l	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead
382-45-1	5	N.D.	N.D.	N.D.	0.64	200	N.D.	N.D.	1.1	3.1	0.2
382-46-1	4	N.D.	N.D.	N.D.	N.D.	1140	N.D.	N.D.	0.6	2.7	N.D.
382-46-1A	1	N.D.	N.D.	N.D.	N.D.	1550	2.5	0.3	2.4	15.7	N.D.
382-47-1	5	N.D.	N.D.	N.D.	0.04	400	0.1	N.D.	2.3	9.0	0.2
382-47-1A	1	N.D.	N.D.	N.D.	N.D.	630	0.5	0.3	2.1	11.1	N.D.
382-48-1	3	N.D.	N.D.	N.D.	0.05	1100	0.2	N.D.	13.5	1.5	N.D.
382-48-1A	1	N.D.	N.D.	N.D.	N.D.	600	1.0	N.D.	13.4	6.6	N.D.
382-49-1	3	N.D.	N.D.	N.D.	0.14	390	0.5	N.D.	5.8	3.9	N.D.
382-50-1	40	N.D.	N.D.	N.D.	0.20	2300	0.4	N.D.	0.6	2.3	N.D.
382-51-1	7	N.D.	N.D.	N.D.	N.D.	620	0.6	N.D.	11.5	4.6	0.3
382-52-1	10	N.D.	N.D.	N.D.	N.D.	500	0.2	N.D.	10.8	3.4	0.2
382-53-1	3	N.D.	N.D.	N.D.	0.40	590	0.7	N.D.	0.8	3.1	0.3
382-54-1	14	N.D.	N.D.	N.D.	0.11	1150	3.0	0.2	0.3	14.6	0.2
382-55-1	21	N.D.	N.D.	N.D.	N.D.	1150	0.4	N.D.	0.5	8.0	N.D.
382-56-1	12	N.D.	N.D.	N.D.	N.D.	580	0.4	N.D.	0.5	3.7	N.D.
382-57-1	4	N.D.	N.D.	N.D.	0.13	3550	0.1	N.D.	N.D.	2.4	N.D.
382-58-1	4	N.D.	N.D.	N.D.	N.D.	610	N.D.	N.D.	1.0	0.6	N.D.
382-59-1	12	N.D.	N.D.	N.D.	N.D.	240	N.D.	N.D.	0.5	2.5	N.D.
382-60-1	4	N.D.	N.D.	N.D.	0.13	600	N.D.	N.D.	0.9	3.7	0.2
382-61-1	9	N.D.	N.D.	N.D.	0.01	130	0.2	0.2	N.D.	3.5	N.D.
382-62-1	20	N.D.	N.D.	N.D.	104	N.D.	N.D.	N.D.	N.D.	2.3	79
382-63-1	3	N.D.	N.D.	N.D.	N.D.	280	0.1	N.D.	N.D.	2.1	N.D.
382-64-1	3	N.D.	N.D.	N.D.	0.13	130	0.2	N.D.	N.D.	2.4	N.D.

[a]All results given in units of milligrams per liter.

Note: N.D. = None detected

Appendix B. WASTE CHARACTERIZATION DATA RESULTS OF ATOMIC ABSORPTION ANALYSIS FOR TWENTY-TWO ELEMENTS[a]

All Units mg/l	Magnesium	Manganese	Mercury	Molybdenium	Nickel	Potassium	Selinium	Silver	Sodium	Tin	Zinc
382-45-1	62	0.6	N.D.	N.D.	0.6	543	N.D.	0.7	1505	32	500
382-46-1	1250	N.D.	N.D.	N.D.	0.6	962	18	0.7	9410	45	N.D.
382-46-1A	1538	3.2	N.D.	N.D.	2.8	819	N.D.	1.5	9730	N.D.	N.D.
382-47-1	680	N.D.	N.D.	N.D.	0.7	814	N.D.	1.4	7680	32	7
382-47-1A	1090	N.D.	N.D.	N.D.	0.9	1069	N.D.	1.0	9130	33	6
382-48-1	906	N.D.	N.D.	N.D.	0.9	890	N.D.	7.0	10110	51	7
382-48-1A	1330	N.D.	N.D.	N.D.	1.4	1029	N.D.	6.5	9040	18	6
382-49-1	650	0.5	N.D.	N.D.	1.0	637	N.D.	3.2	6870	50	55
382-50-1	60	1.7	N.D.	N.D.	1.1	714	N.D.	0.7	1236	56	263
382-51-1	N.D.	N.D.	N.D.	N.D.	1.1	787	N.D.	5.9	9400	56	16
382-52-1	580	N.D.	N.D.	N.D.	1.0	773	N.D.	5.6	9500	57	11
382-53-1	36	1.7	N.D.	N.D.	1.0	417	N.D.	0.7	1106	31	640
382-54-1	21	0.8	9.0	N.D.	2.6	1302	N.D.	0.4	2580	35	2
382-55-1	22	0.5	N.D.	N.D.	0.9	470	N.D.	0.6	1334	N.D.	N.D.
382-56-1	N.D.	0.6	N.D.	N.D.	1.1	137	N.D.	0.6	893	38	N.D.
382-57-1	34	N.D.	N.D.	N.D.	0.7	820	N.D.	0.5	1550	21	121
382-58-1	N.D.	N.D.	N.D.	N.D.	0.5	367	N.D.	0.5	985	54	7
382-59-1	3	N.D.	N.D.	N.D.	0.6	420	N.D.	0.6	1510	40	29
382-60-1	200	N.D.	N.D.	N.D.	1.0	447	N.D.	0.8	1578	29	142
382-61-1	N.D.	N.D.	N.D.	N.D.	0.8	746	N.D.	0.4	1242	23	N.D.
382-62-1	30	0.3	N.D.	N.D.	0.8	252	N.D.	0.3	1053	49	N.D.
382-63-1	N.D.	N.D.	N.D.	N.D.	0.8	169	N.D.	0.8	1114	40	N.D.
382-64-1	4	0.2	N.D.	N.D.	0.5	297	N.D.	0.3	1112	39	38

[a]All results given in units of milligrams per liter.

Note: N.D. = None detected

Appendix B. WASTE CHARACTERIZATION DATA RESULTS OF ATOMIC ABSORPTION ANALYSIS FOR TWENTY-TWO ELEMENTS[a]

All Units mg/l	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead
382-65-1	1	N.D.	N.D.	N.D.	N.D.	52	0.7	N.D.	N.D.	5.3	N.D.
382-66-1	N.D.	N.D.	N.D.	N.D.	0.35	140	0.1	N.D.	0.2	3.7	N.D.
382-67-1	N.D.	N.D.	N.D.	N.D.	0.10	440	N.D.	N.D.	1.7	3.9	N.D.
382-68-1	4	N.D.	N.D.	N.D.	0.10	90	N.D.	N.D.	0.4	3.7	N.D.
382-69-1	2	N.D.	N.D.	N.D.	0.05	1650	0.2	N.D.	0.9	4.4	N.D.
382-70-1	5	N.D.	N.D.	N.D.	0.95	640	2.5	N.D.	1.6	14.6	0.5
382-72-1	72	N.D.	7	N.D.	4.48	2050	6.3	N.D.	22.3	74.7	6.2
382-73-1	14	N.D.	5	N.D.	0.99	460	2.4	N.D.	3.2	16.1	2.1
382-74-1	22	N.D.	N.D.	N.D.	0.13	180	0.6]	N.D.	N.D.	4.8	N.D.
382-75-1	3	N.D.	N.D.	N.D.	0.38	380	1.0	N.D.	1.2	7.3	1.1
382-76-1	55	N.D.	9	N.D.	2.08	1250	4.0	N.D.	14.1	35.8	23.9
382-77-1	10	N.D.	N.D.	N.D.	0.09	420	9.3	N.D.	3.1	34.6	2.5
382-78-1	N.D.	N.D.	N.D.	N.D.	N.D.	410	1.6	N.D.	N.D.	5.7	N.D.
382-79-1	N.D.	N.D.	N.D.	N.D.	N.D.	200	1.7	N.D.	0.3	20.3	0.4
382-80-1	1	N.D.	N.D.	N.D.	N.D.	570	1.6	N.D.	0.1	6.7	0.2
382-81-1	1	N.D.	N.D.	N.D.	N.D.	290	2.3	N.D.	N.D.	9.1	0.2
382-83-1	4	N.D.	N.D.	N.D.	1.9	600	0.1	0.2	0.8	21.4	0.4
382-84-1	6	N.D.	N.D.	N.D.	1.8	530	0.1	N.D.	0.7	12.3	0.7
382-85-1	26	N.D.	N.D.	N.D.	N.D.	490	0.2	0.2	1.0	5.2	0.7
382-86-1	3	N.D.	N.D.	N.D.	N.D.	360	0.1	N.D.	0.1	0.9	0.2
Detection Limits	0.03	1	0.1	0.01	0.01	0.1	0.1	0.02	0.01	0.01	0.02

[a]All results given in units of milligrams per liter.

Note: N.D. = None detected

Appendix B. WASTE CHARACTERIZATION DATA RESULTS OF ATOMIC ABSORPTION ANALYSIS FOR TWENTY-TWO ELEMENTS[a]

All Units mg/l	Magnesium	Manganese	Mercury	Molybdenium	Nickel	Potassium	Selenium	Silver	Sodium	Tin	Zinc
382-65-1	26	N.D.	N.D.	N.D.	0.9	422	N.D.	0.5	1170	31	10
382-66-1	23	0.1	N.D.	N.D.	0.8	222	N.D.	0.2	937	30	N.D.
382-67-1	9	N.D.	7	N.D.	0.6	786	N.D.	1.1	2560	50	104
382-68-1	19	N.D.	N.D.	N.D.	0.6	78	N.D.	0.5	756	25	58
382-69-1	50	1.1	N.D.	N.D.	0.8	690	N.D.	0.7	1708	39	60
382-70-1	49	N.D.	N.D.	N.D.	2.3	302	N.D.	1.3	1090	56	238
382-72-1	504	11.0	9	N.D.	4.3	258	N.D.	11.5	1220	37	3527
382-73-1	44	2.2	5	N.D.	1.3	188	N.D.	2.0	951	21	610
382-74-1	44	0.4	N.D.	N.D.	1.2	260	N.D.	0.5	1032	51	149
382-75-1	39	0.9	N.D.	N.D.	1.5	709	N.D.	1.1	814	27	202
382-76-1	122	3.1	5	N.D.	4.0	203	N.D.	7.5	891	17	1114
382-77-1	22	1.4	N.D.	N.D.	5.5	345	N.D.	2.0	837	38	220
382-78-1	16	0.3	N.D.	N.D.	1.2	48	N.D.	0.4	620	N.D.	N.D.
382-79-1	9	0.5	N.D.	N.D.	1.3	216	N.D.	0.6	1026	10	8
382-80-1	57	0.5	6	N.D.	1.6	346	N.D.	0.4	793	N.D.	68
382-81-1	27	N.D.	N.D.	N.D.	1.7	44	N.D.	0.4	642	N.D.	N.D.
382-83-1	49	1.0	N.D.	N.D.	0.3	412	N.D.	0.3	1285	N.D.	742
382-84-1	73	0.6	N.D.	N.D.	0.3	358	N.D.	0.1	1216	N.D.	541
382-85-1	53	0.8	N.D.	N.D.	0.3	890	N.D.	0.3	1910	N.D.	1192
382-86-1	30	N.D.	N.D.	N.D.	0.2	220	N.D.	0.5	617	25	N.D.
Detection Limits	0.1	0.01	0.5	0.01	0.01	0.01	0.1	0.01	0.01	0.02	0.01

[a]All results given in units of milligrams per liter.

Note: N.D. = None detected

Appendix C. STATISTICAL RESULTS OF WASTE CHARACTERIZATION DATA

Category 1. Powerboats and Sailboats [a]

Wastewater Parameter	Minimum Value	Maximum Value	Value Range	Arithmetic Mean	Weighted Arithmetic Mean(b)	Standard Deviation(c)	95-Percent Confidence Limits(d)
SS (mg/l)	72	9,050	8,978	2,860	1,940	580	3,100 780
VSS (mg/l)	63	6,910	6,847	2,310	1,520	450	2,420 620
TS (%)	0.11	4,83	4.72	1,87	1.58	0.36	2.30 0.86
TVS (%)	0.03	2.19	2.16	0.87	0.60	0.14	0.88 0.32
TOC (mg/l)	390	6,100	5,710	2,360	1,800	390	1,020 2,580
SOC (mg/l)	330	4,700	4,370	1,550	1,270	280	1,830 710
BOD_5 (mg/l)	30	9,230	9,200	2,710	1,960	350	2,660 1,260
COD (mg/l)	1,160	15,420	14,260	6,180	5,210	'960	7,130 3,290
T-N (mg/l)	19	5,850	5,831	1,840	1,270	380	2,030 510
NH_3-N (mg/l)	8	3,970	3,962	1,050	630	170	970 290
T-PO_4 (mg/l)	14	1,180	1,166	370	250	70	390 110
Zinc (mg/l)	0.0	1,330	1,330	276	150	88	326 0
Conductivity (MHO)	1,200	40,200	39,000	18,000	16,100	4,000	24,100 8,100
pH	5.3	8.8	3.5	7.7	7.6	0.2	8.0 7.2
Coliform (MPN/100 ml)	45	6.2×10^8	6.2×10^8	4.5×10^7	1.0×10^7	1.5×10^7	4.5×10^7 0

(a) Sample Details: Total - 20; Powerboats - 7, Sailboats - 13.

(b) Mean value after weighting each sample according to total volume of waste present at time of sampling.

(c) Root-mean-square of the deviations of the weighted measured values from the true value.

(d) Value range that is 95-percent confident to contain the true mean value.

Appendix C. STATISTICAL RESULTS OF WASTE CHARACTERIZATION DATA

Category 2. Houseboats[a]

Wastewater Parameter	Minimum Value	Maximum Value	Value Range	Arithmatic Mean	Weighted Arithmatic Mean(b)	Standard Deviation(c)	95-Percent Confidence Limits(d)
SS (mg/1)	48	15,430	15,382	3,810	3,030	780	4,590 1,470
VSS (mg/1)	30	13,670	13,640	3,120	2,390	670	3,730 1,050
TS (%)	0.27	3.90	3.63	1.53	1.03	0.21	1.45 0.61
TVS (%)	0.15	3.04	2.89	0.96	0.63	0.15	0.93 0.33
TOC (mg/1)	740	13,540	12,800	3,940	2,610	590	3,790 1,430
SOC (mg/1)	410	9,730	9,320	2,530	1,650	350	2,350 950
BOD_5 (mg/1)	490	19,300	18,810	4,870	3,290	820	4,930 1,650
COD (mg/1)	1,310	30,100	28,790	10,430	7,280	1,510	10,300 4,260
T-N (mg/1)	510	7,830	7,320	2,730	1,810	300	2,410 1,210
NH_3-N (mg/1)	105	4,280	4,175	1,510	1,190	200	1,590 790
T-PO_4 (mg/1)	72	1,980	1,908	820	580	110	800 360
Zinc (mg/1)	0.0	1,192	1,192	166	145	53	251 39
Conductivity (MHO)	3,000	40,000	37,000	11,780	9,100	1,640	12,380 5,820
pH	5.2	9.3	4.1	7.8	8.1	0.2	8.5 7.7
Coliform (MPN/100 ml)	45	2.4×10^{10}	2.4×10^{10}	3.8×10^{9}	6.9×10^{9}	2.3×10^{9}	11.5×10^{9} 2.3×10^{9}

(a) Sample Details: Total - 23.

(b) Mean value after weighting each sample according to total volume of waste present at time of sampling.

(c) Root-mean-square of the deviations of the weighted measured values from the true value.

(d) Value range that is 95-percent confident to contain the true mean value.

Appendix C. STATISTICAL RESULTS OF WASTE CHARACTERIZATION DATA

Category 3. Powerboats, Sailboats, and Houseboats[a]

Wastewater Parameter	Minimum Value	Maximum Value	Value Range	Arithmatic Mean	Weighted Arithmatic Mean(b)	Standard Deviation(c)	95-Percent Confidence Limits(d)
SS (mg/1)	48	15,430	15,382	3,370	2,430	490	3,410 1,450
VSS (mg/1)	30	13,670	13,640	2,750	1,910	400	2,710 1,110
TS (%)	0.11	4.83	4.72	1.69	1.34	0.21	1.76 0.92
TVS (%)	0.03	3.04	3.01	0.92	0.62	0.10	0.82 0.42
TOC (mg/1)	390	13,540	13,150	3,200	2,170	350	2,870 1,470
SOC (mg/1)	330	9,730	9,400	2,080	1,440	220	1,880 1,040
BOD_5 (mg/1)	30	19,300	19,270	3,860	2,560	450	3,460 1,660
COD (mg/1)	1,160	30,100	28,940	8,460	6,140	890	7,920 4,360
T-N (mg/1)	19	7,830	7,811	2,310	1,510	260	2,030 2,550
NH_3-N (mg/1)	8	4,280	4,272	1,290	880	140	1,160 600
T-PO_4 (mg/1)	14	1,980	1,966	610	400	68	536 264
Zinc (mg/1)	0.0	1,330	1,330	220	150	50	250 50
Conductivity (MHO)	1,200	40,200	39,000	14,700	12,900	2,220	17,340 8,460
pH	5.2	9.3	4.1	7.8	7.9	0.14	8.2 7.6
Coliform (MPN/100 ml)	45	2.4×10^{10}	2.4×10^{10}	2.1×10^9	3.1×10^9	1.2×10^9	5.5×10^9 0.7×10^9

(a) Sample Details: Total - 43; Power and Sailboats - 20, Houseboats - 23.

(b) Mean value after weighting each sample according to total volume of waste present at time of sampling.

(c) Root-mean-square of the deviations of the weighted measured values from the true value.

(d) Value range that is 95-percent confident to contain the true mean value.

Appendix C. STATISTICAL RESULTS OF WASTE CHARACTERIZATION DATA

Category 4. Watercraft on Lake Mead[a]

Wastewater Parameter	Minimum Value	Maximum Value	Value Range	Arithmatic Mean	Weighted Arithmatic Mean(b)	Standard Deviation(3)	95-Percent Confidence Limits(d)
SS (mg/l)	164	7,630	7,466	2,130	1,590	400	2,300 790
VSS (mg/l)	100	5,170	5,070	1,360	930	270	1,470 390
TS (%)	0.24	1.65	1.41	0.58	0.42	0.09	0.60 0.24
TVS (%)	0.08	1.13	1.05	0.32	0.21	0.06	0.33 0.09
TOC (mg/l)	400	3,500	3.00	1,340	1,090	200	1,490 690
SOC (mg/l)	260	1,100	840	540	420	68	556 284
BOD_5 (mg/l)	230	2,060	1,830	850	720	100	920 520
COD (mg/l)	940	13,720	12,780	4,380	3,670	770	5,210 2,130
T-N (mg/l)	370	1,480	1,110	930	790	170	1,130 450
NH_3-N (mg/l)	290	1,300	1,010	760	660	150	960 360
T-PO_4 (mg/l)	65	980	9.5	310	260	55	370 150
Zinc (mg/l)	8.0	1,114	1,106	340	310	89	488 132
Conductivity (MHO)	1,600	7,000	5,400	4,880	3,990	580	5,150 2,830
pH	7.3	9.0	1.7	8.3	8.1	0.19	8.5 7.7
Coliform (MPN/100 ml)	2.3×10^4	2.4×10^{10}	2.4×10^{10}	3.1×10^9	8.8×10^8	1.5×10^9	11.8×10^9 0

(a) Sample Details: Total - 8; taken from four different floating waste-storage tanks.

(b) Mean value after weighting each sample according to total volume of waste present at time of sampling.

(c) Root-mean-square of the deviations of the weighted measured values from the true value.

(d) Value range that is 95-percent confident to contain the true mean value.

Appendix C. STATISTICAL RESULTS OF WASTE CHARACTERIZATION DATA

Category 5. Houseboats on Freshwater[a]

Wastewater Parameter	Minimum Value	Maximum Value	Value Range	Arithmatic Mean	Weighted Arithmatic Mean(b)	Standard Deviation(c)	95-Percent Confidence Limits(d)
SS (mg/l)	48	15,430	15,382	4,010	3,010	945	4,900 1,120
VSS (mg/l)	30	13,670	13,640	3,320	2,370	810	3,990 750
TS (%)	0.27	3.90	3.63	1.56	0.96	0.24	1.44 0.48
TVS (%)	0.15	3.04	2.89	1.08	0.63	0.19	1.01 0.25
TOC (mg/l)	740	13,540	12,800	4,470	2,660	730	4,120 1,200
SOC (mg/l)	410	9,730	9,320	2,880	1,690	445	2,580 800
BOD_5 (mg/l)	490	19,300	18,810	5,740	3,430	1,010	5,450 1,410
COD (mg/l)	1,310	30,100	28,790	11,630	7,370	1,840	11,050 3,690
T-N (mg/l)	510	7,830	7,320	3,020	1,800	450	2,700 900
NH_3-N (mg/l)	190	4,280	4,090	1,590	1,160	245	1,650 670
T-PO_4 (mg/l)	130	1,980	1,850	900	595	130	855 335
Zinc (mg/l)	0.0	1,192	1,192	185	150	65	280 20
Conductivity (MHO)	3,000	24,300	21,300	11,250	8,180	1,400	10,980 5,380
pH	5.2	9.3	4.1	7.8	8.2	0.25	8.7 7.7
Coliform (MPN/100 ml)	620	2.4×10^{10}	2.4×10^{10}	4.3×10^9	7.7×10^9	2.8×10^9	13.3×10^9 2.1×10^9

(a) Sample Details: Total - 17.

(b) Mean value after weighting each sample according to total volume of waste present at time of sampling.

(c) Root-mean-square of the deviations of the weighted measured values from the true value.

(d) Value range that is 95-percent confident to contain the true mean value.

Appendix C. STATISTICAL RESULTS OF WASTE CHARACTERIZATION DATA

Category 6. Houseboats on Saltwater[a]

Wastewater Parameter	Minimum Value	Maximum Value	Value Range	Arithmatic Mean	Weighted Arithmatic Mean[(b)]	Standard Deviation[(c)]	95-Percent Confidence Limits[(d)]
SS (mg/1)	430	7,360	6,930	3,240	3,180	1,300	5,780 580
VSS (mg/1)	310	5,840	5,530	2,570	2,530	1,050	3,630 1,430
TS (%)	0.55	2.90	2.35	1.43	1.57	0.37	2.31 0.83
TVS (%)	0.36	0.89	0.53	0.62	0.62	0.06	0.74 0.50
TOC (mg/1)	850	5,140	4,290	2,440	2,280	600	3,480 1,080
SOC (mg/1)	750	3,200	2,450	1,550	1,360	310	1,980 740
BOD_5 (mg/1)	1,070	5,640	4,570	2,400	2,310	610	3,530 1,090
COD (mg/1)	3,370	17,200	13,830	7,040	6,680	2,020	10,720 2,640
T-N (mg/1)	880	3,050	2,170	1,890	1,890	300	2,490 1,290
NH_3-N (mg/1)	105	2,450	2,345	1,300	1,370	350	2,070 670
T-PO_4 (mg/1)	72	1,130	1,058	580	520	145	810 230
Zinc (mg/1)	0.0	449	449	120	127	70	267 0
Conductivity (MHO)	3,500	40,000	36,500	13,300	15,800	6,470	28,740 2,860
pH	5.5	8.9	3.4	7.8	7.8	0.54	8.9 6.7
Coliform (MPN/100 ml)	45	7.0×10^9	7.0×10^9	2.3×10^9	1.6×10^9	1.3×10^9	4.2×10^9 0

(a) Sample Details: Total - 5.

(b) Mean value after weighting each sample according to total volume of waste present at time of sampling.

(c) Root-mean-square of the deviations of the weighted measured values from the true value.

(d) Value range that is 95-percent confident to contain the true mean value.

APPENDIX D

ACTIVATED SLUDGE MATERIAL BALANCE EQUATIONS

Cell yeild coefficient, biodegradability factor, cell retention time, and aerobic stabilization rate* are dynamic parameters describing "fill and draw" activated sludge systems. Their definitions and calculations are given by the following equations.

Cell Yield Coefficient, Ky: Empirical constant that represents the sludge that is formed by conversion of BOD_5 to cellular solids.

$$\Delta MLVSS = Ky\ (\Delta BOD_5) - (MLVSS)(C)(k_e) \qquad (1)$$

$$Ky = \left[\frac{\Delta MLVSS}{\Delta BOD_5}\right] + \left[\frac{\Delta MLVSS}{\Delta BOD_5}\right](C)(k_e) \qquad (2)$$

where Ky = cell yield coefficient

$\Delta MLVSS$ = average change in MLVSS per unit time, day^{-1}

ΔBOD_5 = average removal of BOD_5 per unit time, day^{-1}

MLVSS = average total mass of volatile solids in system, gm

C = biodegradability factor

k_e = endogenous respiration rate, day^{-1}

Biodegradability Factor, C: The portion of activated sludge mass that is biodegradable.. C is not constant for all sludges but varies inversely with sludge age.

$$C = \frac{(MLVSS)_o - (MLVSS)_n}{(MLVSS)_o} \qquad (3)$$

*Theory and equations derived by M. Floyd Hobbs, FMC Corporation, San Jose, California, 1973. Unpublished work.

where C = biodegradability factor

$(MLVSS)_o$ = initial mass of volatile suspended solids, gm

$(MLVSS)_n$ = nonbiodegradable volatile solids as determined by aerobic stabilization, gm

Cell Retention Time, Θ_C: Average residence time of activated sludge in the system.

$$\Theta_c = \frac{(MLVSS)}{(MLVSS)_w + (MLVSS)_e} \qquad (4)$$

where Θ_c = cell retention time, day

MLVSS = average total mass of volatile solids in system, gm

$MLVSS_w$ = average mass of volatile solids wasted per unit time, gm day^{-1}

$MLVSS_e$ = average mass of volatile solids in effluent per unit time, gm day^{-1}

Aerobic Stabilization Rate, R: Rate of reduction in sludge mass per unit time due to biological oxidation of biodegradable sludge components.

Aerobic stabilization or aerobic reduction of biomass is based on endogenous respiration of the bacterial mass. This phenomenon occurs during all phases of bacterial growth and only becomes predominant when the carbonaceous nutrient level in the environment is insufficient to support the living biological mass. Under these conditions, cell death and lysing exceeds cell growth. Consequently, bacteria utilize stored food within their cells or biological solids obtained by lysing of other bacteria that have died. In this manner, the cell mass is reduced to material that, in essence, is nonbiodegradable. Thus, aerobic stabilization is the reduction in sludge mass caused by the biological oxidation of sludge of reduced concentration that is not readily oxidized by bacteria.

This phenomenon can be expressed mathematically by the following equation:

$$R = k_e m = -\left[\frac{dm}{dt}\right] \qquad (5)$$

where R = aerobic stabilization rate, gm day^{-1}

k_e = endogenous respiration rate, day^{-1}

m = total biodegradable sludge mass, gm

$\frac{dm}{dt}$ = change in biodegradable cell mass per unit time, gm $days^{-}$

Rearranging and integrating this equation gives:

$$R = -k_e t = \ln \frac{M_t}{M_o} \qquad (6)$$

where M_t = total biodegradable cell mass at given time, t, gm

M_o = initial biodegradable cell mass at zero time, gm

t = time, day

The biodegradable mass present at a given time is approximately equivalent to the difference between the total mixed liquor volatile suspended solids and the mass of stabilized or nonbiodegradable volatile solids. This is expressed as follows:

$$M_t = (MLVSS)_t - (MLVSS)_n \qquad (7)$$

where $(MLVSS)_n$ = total mass of nonbiodegradable matter, gm

Substitution of Equation 7 into Equation 6 gives the following expression in common log form:

$$R = -k_e t = 2.303 \log \frac{(MLVSS)_t - (MLVSS)_n}{(MLVSS)_o - (MLVSS)_n} \qquad (8)$$

Equation 4 expresses aerobic stabilization rate in measurable quantities.

The half-life time ($T_{½}$) required to reduce by 50 percent any given quantity of biodegradable sludge mass can be calculated by the following expression:

$$T_{½} = \frac{0.693}{k_e}$$

The above expressions appear to be applicable for the design of batch homogeneous reactors or continuous plug-flow reactors such as longitudinal flow baffled or tubular reactors.

Appendix E. RESULTS OF LAKE MEAD FIELD TESTING

RUN NUMBER	1		2		3		4		5		6		7		8	
RUN DATE	8-22		8-23		8-27		8-29		8-31		9-3		9-4		9-5	
ANALYICAL DATA	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
SS (mg/1)	955	20	1,500	34	1,035	133	1,160	73	1,010	52	800	10	655	58	360	25
VSS (mg/1	690	6	1,075	12	595	34	670	23	525	18	420	4	405	23	240	13
TS (%)	0.24	0.43	0.31	0.43	0.26	0.55	0.23	0.41	0.24	0.37	0.24	0.39	0.25	0.47	0.24	0.44
TVS (%)	0.11	0.17	0.16	0.16	0.10	0.12	0.11	0.14	0.09	0.13	0.10	0.10	0.10	0.17	0.10	0.16
TOC (mg/1)	530	16	700	15	455	14	595	18	350	18	250	14	460	36	410	41
SOC (mg/1)	160	12	148	14	172	11	112	11	110	11	95	13	136	33	150	40
BOD_5 (mg/1)	515	18	1,630	3	440	26	1,480	9	---	---	680	2	276	26	216	5
COD (mg/1)	1,875	41	2,500	47	1,960	49	1,960	60	---	---	1,110	50	1,490	110	2,430	79
T-N (mg/1)	348	316	330	258	360	190	275	260	312	252	302	260	360	295	375	320
NH_3-N (mg/1)	318	303	265	252	290	185	212	---	253	241	256	250	300	280	320	305
T-PO_4 (mg/1)	98	N.D.	120	1	147	1	131	14	152	5	90	N.D.	104	3	94	1
pH	8.4	4.4	8.8	4.3	8.2	4.4	8.2	4.2	8.2	4.3	8.1	4.8	8.0	4.2	8.2	4.5
Conductivity (MHO)	3,500	4,800	3,000	4,100	3,500	7,000	2,500	4,000	2,750	3,800	2,800	4,000	3,500	5,000	3,600	5,000
Zinc (mg/1)	46	6	96	9.2	36	13	33	14	50	28	43	25	---	---	---	---
Formaldehyde (mg/1)	---	---	8.7	3.3	2.6	0.8	---	---	---	---	27	2.1	---	---	5.7	3.7
Turbidity (JTU)	160	10	175	15	175	65	120	27	110	12	100	7.2	250	19	240	3
Coliform (MPN/100 ml)	---	< 3	---	< 3	23×10^7	3	---	5	---	< 3	---	10	---	3	62×10^8	< 3
Cake TS (%)	---		32.6		32.1		---		---		32.3		---		31.4	
Cake TVS (%)	---		12.7		11.4		---		---		10.4		---		8.9	
Cake Zinc (mg/gm)	---		5.42		1.53		---		---		1.06		---		---	
Cake BOD_5 (mg/gm)	---		102		---		---		---		84		---		---	
Cake Coliform (MPN/100 ml)	---		---		20		---		---		340		---		200	
PROCESS DATA																
Waste Volume (1)	1,590		871		946		980		1,500		1,514		985		1,250	
Process Rate (1/min)	4.21		3.40		3.52		3.03		4.09		3.82		3.94		3.28	
HTH (kgm)	1.74		0.93		1.25		1.10		0.92		0.80		1.08		0.94	
Alum (kgm)	2.18		1.73		1.32		2.36		1.82		2.27		2.04		3.06	
$NaHSO_4$ (kgm)	2.90		1.45		0.95		0.95		1		2.60		1.14		2.04	
Dry Chemical (kgm)	20.6		10.9		8.20		9.69		12.76		11.92		6.71		11.20	
NaOH (kgm)	---		---		---		---		---		---		---		---	
NaOCl (kgm)	---		---		---		---		---		---		---		---	
Power (KWH/hr)	8.1		10.7		6.6		5.3		6.3		6		5		4.6	

Appendix E. RESULTS OF LAKE MEAD FIELD TESTING

RUN NUMBER	9		10		11		12		13		14		15		16	
RUN DATE	9-6		9-7		9-10		9-11		9-12		9-13		9-17		9-18	
ANALYICAL DATA	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
SS (mg/1)	2,120	58	2,580	69	1,500	41	1,620	79	1,120	68	1,580	55	1,320	67	860	81
VSS (mg/1	1,710	31	1,890	25	980		1,110	20	645	19	705	15	630	19	470	24
TS (%)	0.39	0.45	0.42	0.49	0.23	0.38	0.28	0.51	0.29	0.49	0.32	0.60	0.30	0.79	0.25	0.76
TVS (%)	0.26	0.16	0.28	0.15	0.10	0.12	0.14	0.16	0.12	0.17	0.13	0.20	0.13	0.27	0.10	0.24
TOC (mg/1)	800	31	860		670	30	865	29	560	50	500	33	670	86	525	79
SOC (mg/1)	124	19	116	15	115	15	128	26	164	44	142	31	198	78	230	77
BOD_5 (mg/1)	1,080	63	945	2	350	22	450	30	2,070	78	1,565	83	1,770	170	2,350	166
COD (mg/1)	3,900	110	4,380	65	3,030	117	3,400	110	2,220	126	2,030	119	2,340	310	1,930	290
T-N (mg/1)	790	230	232	N.D.	280	205	280	155	390	270	410	250	430	260	440	310
NH_3-N (mg/1)	480	230	224	N.D.	230	200	225	150	320	260	345	240	355	240	375	290
T-PO_4 (mg/1)	115	2	76	9	134	2	150	7	160	2	480	5	420	13	240	11
pH	7.7	4.2	8.1	9.9	7.7	4.4	7.7	4.0	8.4	4.8	8.4	4.5	8.2	4.5	8.3	4.2
Conductivity (MHO)	3,500	5,300		5,200	3,400	3,900	3,400	4,900	2,800	4,400	2,600	4,600	3,000	5,200	4,200	7,200
Zinc (mg/1)	---	---	---	---	---	---	26	22	---	---	56	53	53	24	---	---
Formaldehyde (mg/1)	---	---	---	---	---	---	1.8	0.7	---	---	8.5	1.4		2.7	---	---
Turbidity (JTU)	120	17	600	27	140	14	120	25	140	52	100	24	120	37	120	19
Coliform (MPN/100 ml)	---	<3	---	3	---	---	50 x 10^7	3	---	<3	---	3	---	3	---	---
Cake TS (%)	---		30.8		---		31.7		---		33.5		---		32.4	
Cake TVS (%)	---		11.5		---		10.2		---		12.9		---		11.3	
Cake Zinc (mg/gm)	---		---		---		0.24		---		0.36		---		---	
Cake BOD_5 (mg/gm)	---		105		---		28		---		---		---		---	
Cake Coliform(MPN/100 ml)	---		20		---		47		---		45		---		45	
PROCESS DATA																
Waste Volume (1)	1,250		910		984		1,665		1,190		960		908		1,514	
Process Rate (1/min)	4.63		3.94		4.20		4.16		3.48		3.90		4.54		4.16	
HTH (kgm)	1.36		1.10		1.02		1.36		1.22		1.05		1.30		1.50	
Alum (kgm)	2.27		2.81		1.82		7.72		3.20		1.91		2.72		4.54	
$NaHSO_4$ (kgm)	0.91		0.50		0.23		0.45		0.41		0.22		0.68		2.45	
Dry Chemical (kgm)	9		10.20		7.45		14.90		13.50		11.92		9.70		13.41	
NaOH (kgm)	---		0.77		---		---		---		---		---		---	
NaOCl (kgm)	---		3.89		---		---		---		---		---		---	
Power (KWH/hr)	6.7		5.4		5.4		6		5.8		4.7		5.9		6.2	

Appendix E. RESULTS OF LAKE MEAD FIELD TESTING

RUN NUMBER / RUN DATE	17 9-19		18 9-20		19 9-24		20 9-25		21 9-26		22 9-27		23 9-29		24 9-30	
ANALYTICAL DATA	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
SS (mg/l)	1,075	113	670	28	7,420	27	5,200	20	5,700	47	2,720	11	2,170	30	1,690	21
VSS (mg/l	595	33	360	8	5,320	12	4,230	12	4,320	18		3	1,760	4	1,365	4
TS (%)	0.30	0.73	0.29	0.55	0.66	0.43	0.81	0.44	0.86	0.41	0.41	0.70	0.49	0.67	0.34	0.54
TVS (%)	0.11	0.24	0.11	0.17	0.49	0.11	0.62	0.13	0.66	0.13	0.31	0.09	0.32	0.06	0.19	0.07
TOC (mg/l)	500	51	410	26	950	15	1,590	17	1,425	33	650	12	950	70	840	38
SOC (mg/l)	198	50	96	23	160	11	116	7	152	12	65	8		58	124	35
BOD_5 (mg/l)	2,450	90	1,480	30	3,650	6	4,010	36	3,625	13	3,700	7	1,490	35	610	66
COD (mg/l)	1,800	200	1,740	106	15,090	102	14,100	102	18,600	103	13,800	50	8,690	174	2,750	123
T-N (mg/l)	445	305	480	240	270	114	225	114	260	115	81	2	265	65	280	105
NH_3-N (mg/l)	380	285	405	230	152	109	133	109	148	106	38	N.D.	212	52	235	
T-PO_4 (mg/l)	750	11	910	3	550	7	225	5	320	3	50	3	124	2	133	N.D.
pH	8.4	4.2	8.7	4.2	7.8	4.2	7.5	4.3	7.7	4.4	7.3	8.9	8	11	7.9	10.5
Conductivity (MHO)	4,300	7,200	3,900	6,200		4,200	2,400	4,200	2,250	4,400	1,340	8,200	2,950	8,000	3,200	5,800
Zinc (mg/l)	38	18	---	---	---	---	---	---	---	---	---	---	---	---	38.2	1.2
Formaldehyde (mg/l)	8.2	2.8	---	---	---	---	---	---	---	---	---	---	---	---	8.6	1.2
Turbidity (JTU)	120	22	120	10	---	12	150	11	150	17	120	10	200	10	140	8.7
Coliform (MPN/100 ml)	---	<3	---	---	23 x 10^5	3	---	<3	---	<3	---	---	---	3	---	---
Cake TS (%)	27.5		---		---		32.3		---		31.3		---		29.8	
Cake TVS (%)	10.1		---		---		11.1		---		10.5		---		9.4	
Cake Zinc (mg/gm)	1.20		---		---		---		---		---		---		---	
Cake BOD_5 (mg/gm)	78		---		---		93		---		94		---		55	
Cake Coliform (MPN/100 ml)	<45		---		---		30		---		10		---		60	
PROCESS DATA																
Waste Volume (l)	1,192		1,010		1,363		1,290		1,100		1,249		890		1,550	
Process Rate (l/min)	4.54		4.42		4.54		4.84		4.52		3.88		3.71		3.89	
HTH (kgm)	1.02		0.95		1.32		1.09		1.10		1.55		0.57		1.09	
Alum (kgm)	3.41		1.36		4.50		3.63		3.20		3.68		2.72		3.63	
$NaHSO_4$ (kgm)	2.72		1.45		3.25		1.45		1.15		1.02		0.91		1.82	
Dry Chemical (kgm)	14.54		11.92		16.21		11.92		10.80		15.64		11.80		14.50	
NaOH (kgm)	---		---		---		---		---		1.07		0.61		1.06	
NaOCl (kgm)	---		---		---		---		---		3.80		2.03		3.53	
Power (KWH/hr)	3		3.3		6		3.8		4.8		5.2		4.8		6	

Appendix E. RESULTS OF LAKE MEAD FIELD TESTING

RUN NUMBER	25		26		27		28		29		30		31		32	
RUN DATE	10-2		10-3		10-5		10-8		10-10		10-11		10-12		10-13	
ANALYICAL DATA	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
SS (mg/1)	1,055	10	885	19	935	5	825	18	3,085	39	2,730	11	2,510	21	2,710	13
VSS (mg/1	710	1	605	1	630	1	665	5	2,590	12	2,380	2	2,290	3	2,420	3
TS (%)	0.32	0.47	0.25	0.82	0.29	1.16	0.28	1.44	0.57	1.50	0.44	1.33	0.43	1.30	0.40	1.41
TVS (%)	0.16	0.11	0.11	0.13	0.12	0.21	0.12	0.14	0.38	0.13	0.29	0.11		0.14	0.22	0.15
TOC (mg/1)	680	46	490	18	510	15	500	128	990	53	980	21	1,580	22	850	43
SOC (mg/1)	126	32	112	15	136	14	235	124	380	51	110	20	116	18	130	38
BOD_5 (mg/1)	1,410	38	790	3	300	2	850	---	1,810	53	1,670	29	2,320	12	1,760	145
COD (mg/1)	2,140	172	2,540	38	1,450	69	3,380	410	3,890	290	4,010	312	5,510	275	3,880	320
T-N (mg/1)	325	235	310	163	250	62	310	129	310	129	265	71	250	22	280	80
NH_3-N (mg/1)	265	215	255	153	194	57	260	127	240	117	225	66	195	15	245	71
T-PO_4 (mg/1)	160	1	43	N.D.	160	1	81	N.D.	175	N.D.	74	0.7	100	0.5	80	1
pH	8.5	9.2	8.6	5.3	9	3.3	8.4	10	7.7	10	7.9	9.4	8.2	3.2	7.9	9.8
Conductivity (MHO)	3,400	5,500	3,300	9,500	3,000	12,800	3,500	17,000	3,100	18,000	3,100	15,500	2,100	15,000	3,100	16,000
Zinc (mg/1)	52	1	17.6	12	13	11.6	60	1.3	64	1.5	38	1.3	30	6.3	42	1.5
Formaldehyde (mg/1)	9.7	3.3	7.3	3.6	6.3	2.3	10.3	4.8	12.7	2.9	9.2	1.6	17.5	3.1	9.4	3.3
Turbidity (JTU)	280	10	250	10	120	5.7	140	5.4	140	5	150	5	225	8	200	7
Coliform (MPN/100 ml)	---	<3	---	---	60×10^7	<3	---	---	---	5	---	---	35×10^8	<3	---	---
Cake TS (%)	34.6		---		32.4		33.1		31.6		---		34.0		30.3	
Cake TVS (%)	10.2		---		11.8		8.9		9.8		---		11.6		10.2	
Cake Zinc (mg/gm)	2.11		---		0.10		2.10		2.05		---		0.89		1.25	
Cake BOD_5 (mg/gm)	31		---		12		16		20		---		34		26	
Cake Coliform(MPN/100 ml)	60		---		<30		<45		60		---		60		45	
PROCESS DATA																
Waste Volume (1)	1,363		1,022		1,590		1,098		1,136		1,514		1,287		980	
Process Rate (1/min)	4.54		4.25		3.85		4.54		4.92		3.90		3.57		3.91	
HTH (kgm)	0.95		0.82		2.86		1.23		1.10		2.72		2.26		0.75	
Alum (kgm)	2.72		4.09				5.45		3.63		7.26		7.15		3.74	
$NaHSO_4$ (kgm)	1.82		1.14		1.36		0.45		0.50		0.42		0.30		0.45	
Dry Chemical (kgm)	14.5		11.18		17.90		10.43		8.94		11.92		14.70		9.30	
NaOH (kgm)	0.87		0.87		1.36		1.03		0.87		1.04		1.10		0.84	
NaOCl (kgm)	2.91		2.91		4.53		3.44		2.91		3.45		3.67		2.80	
Power (KWH/hr)	5.4				5.3		4.6		4		3.3		5		4.7	

Appendix E. RESULTS OF LAKE MEAD FIELD TESTING

RUN NUMBER / RUN DATE	33 10-14		34 10-15		35 10-16											
ANALYTICAL DATA	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
SS (mg/l)	2,470	17	2,340	13	2,770	38										
VSS (mg/l	1,930	5	1,670	4	2,425	12										
TS (%)	0.41	1.40	0.39	1.37	0.40	1.42										
TVS (%)	0.21	0.24	0.22	0.13	0.25	0.13										
TOC (mg/l)	1,240	46	700	100	1,470	59										
SOC (mg/l)	152	42	148	94	155	53										
BOD_5 (mg/l)	1,250	110	1,150	153	1,380	105										
COD (mg/l)	4,300	400	3,460	3.4	5,800	540										
T-N (mg/l)	300	75	330	8	300	117										
NH_3-N (mg/l)	250	65	270	44	245	90										
T-PO_4 (mg/l)	150	1.2	40	0.5	80	0.5										
pH	8	10.2	8.2	5.6	8.1	10										
Conductivity (MHO)	3,200	15,000	3,000	16,000	3,000	17,000										
Zinc (mg/l)	65	2	51	1.5	40	1.9										
Formaldehyde (mg/l)	11.4	3.3	4.1	1	11.2	2.6										
Turbidity (JTU)	250	7.5	200	6	125	5										
Coliform (MPN/100 ml)	---	---	72×10^6	<3	---	---										
Cake TS (%)	32		30.2		29.8											
Cake TVS (%)	11		10.8		9.7											
Cake Zinc (mg/gm)	2.31		1.02		1.50											
Cake BOD_5 (mg/gm)	34		48		41											
Cake Coliform (MPN/100 ml)	30		60		45											
PROCESS DATA																
Waste Volume (l)	890		908		1,510											
Process Rate (l/min)	3.82		4.92		4.05											
HTH (kgm)	1.90		1.77		2.45											
Alum (kgm)	4.30		4.54		7.26											
$NaHSO_4$ (kgm)	0.65		0.50		0.45											
Dry Chemical (kgm)	7.20		6.71		20.41											
NaOH (kgm)	0.76		0.62		1.03											
NaOCl (kgm)	2.53		2.07		3.44											
Power (KWH/hr)	5.8		5.3		6.1											

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-670/2-74-056	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE DEVELOPMENT OF ON-SHORE TREATMENT SYSTEM FOR SEWAGE FROM WATERCRAFT RETENTION SYSTEM		5. REPORT DATE July 1974; Issuing Date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) James H. Robbins and Arthur C. Green		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS FMC Corporation, Advanced Products Division, San Jose, California 95108		10. PROGRAM ELEMENT NO. 1BB038/ROAP 21-BBU/TASK 03
		11. CONTRACT/GRANT NO. 68-32-0220
12. SPONSORING AGENCY NAME AND ADDRESS National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A two-phase program developed and demonstrated a new method for on-shore treatment of sewage from recreational watercraft. Phase I characterized wastes and chemical additives associated with recirculating/retention systems. Statistical analysis determined probable ranges of waste characteristics as a function of watercraft type and location. Typical wastes had suspended solids and biochemical oxygen demand of 2000 mg/l. Respirometer studies evaluated toxicity of additives to activated sludge. Treatability of chemical/sewage mixtures was determined from pilot-scale activated sludge plant operations. Cell yield coefficients were calculated. Photomicrographs recorded physical changes to activated sludge. Concentrations greater than 20 mg/l zinc or 120 mg/l formaldehyde caused adverse effects to the activated sludge process. Phase II field tested full-scale physical-chemical treatment equipment operating on watercraft wastes. Average removal efficiencies for suspended solids, biochemical and chemical oxygen demand, phosphate, and zinc were greater than 90 percent. Effluent coliform was less than 10 MPN/100 ml. Discharge solids were nonodorous and innocuous. Postchlorination increased total-nitrogen removal from 30 to 70 percent. Operating costs were determined.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Waste treatment, Sewage treatment, *Zinc, *Formaldehyde, Toxicity, Operating costs	*Physical-chemical sewage treatment, *Marine sewage treatment, *Holding tank, *Chemical additives, Recreational watercraft sewage, Pump out wastes, Post chlorination	13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 124
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

☆ U S. GOVERNMENT PRINTING OFFICE. 1974-757-584/5330 Region No. 5-11