EFFECTS OF HOLDING TANK ODOR CONTROL CHEMICALS ON AEROBIC WASTEWATER TREATMENT

by

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(ABSTRACT)

Three odor control chemicals and formaldehyde were tested for detrimental affects on activated sludge using bench-scale bioreactors. Slug fed and continuous flow bioreactors were monitored for changes in suspended solids, specific oxygen uptake rate, sludge settling and compaction, and effluent COD. The biodegradability of dyes and the generation of foam was also measured.

Formaldehyde and the formaldehyde-based odor control chemical "Aqua-Kem" damaged the ability of activated sludge to treat wastewater. They resulted in deceased suspended solids concentrations and increased effluent COD. Formaldehyde hinders the utilization of normal wastewater substrate by activated sludge. The dye in "Aqua-Kem" is not biodegradable, and surfactants in the chemical generate foam.

The dimethylimino polymer-based liquid odor control chemical "D-Odor-It" was as detrimental to activated

sludge as "Aqua-Kem" and formaldehyde. "D-Odor-It" also may generate foam, but the dye is biodegradable.

The solid paraformaldehyde-based chemical "Dri-Kem" appeared to be beneficial to activated sludge. The chemical resulted in increased suspended solids and decreased effluent COD. "Dri-Kem" contains non-biodegradable dye, but does not create foam.

The difference between "Dri-Kem" and "Aqua-Kem" is attributed to the polymerized (solid) versus non-polymerized (liquid) form of formaldehyde in each and the lower solubility of paraformaldehyde.

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INTRODUCTION

State and federal regulations at present permit the dumping of wastewater holding tank contents from boats directly into receiving waters. In the future, boat owners will be required to store the wastes in tanks until they can be emptied at a wastewater receiving and/or treatment facility at a marina or resort. Such regulations already exist in some areas of the Tidewater section of Virginia, but are poorly enforced. With the new regulations under consideration, stricter enforcement will be implemented by the state and the Coast Guard.

Most boat owners, like most recreational vehicle owners with onboard toilets, add chemicals to the flush water in the holding tanks to control offensive odors. The chemicals are intended to prevent the formation of odors caused by the degradation of sewage before it can be removed from the tank.

The chemicals commonly contain an active disinfectant such as formaldehyde, along with dyes and perfumes. Ideally the odor control chemicals would be toxic to the microorganisms that generate offensive odors in holding tanks, but would be biodegradable upon dilution in the natural environment or in a wastewater treatment plant.

In order to assess the impact of the new discharge regulations on marina or resort treatment facilities, the Virginia Department of Health initiated a study to determine the effects of commonly used odor control chemicals on aerobic bacteria in an activated sludge wastewater treatment plant. Such information will help in the determination of specific limits or maximum concentration levels of odor control chemicals allowable in holding tanks.

When the new laws prohibiting the dumping of holding tank contents directly into receiving waters go into effect, the boat owners will be required to hold the wastewater for treatment. The most frequently used wastewater treatment systems at marinas and resorts are package wastewater treatment plants with relatively small capacity. The effluent from these plants is usually released directly into the nearby lake, river, or bay.

If the state requires marina and resort owners with wastewater treatment systems to accept wastewater from boaters, then both the state and the marina owners need to be assured that the treatment system will not be damaged by the chemically dosed sewage. The system owners will not want their treatment plant to be in violation of effluent standards, especially if the plant is also accepting wastewater from an adjacent restaurant or residential community. Likewise, the authorities do not want the system to fail and result in the discharge of untreated sewage.

The purpose of this research was to determine what detrimental effects, if any, the addition of odor control chemicals would have on the treatment of wastewater by the activated sludge process. Laboratory bench scale bioreactors were dosed with odor control chemicals and the results monitored. Additional laboratory tests were conducted to measure the effects of the chemicals on activated sludge settling characteristics and on foam generation.

LITERATURE REVIEW

Recreational Vehicle Wastewater

A limited amount of research has been conducted on the characteristics and treatability of wastewater in the holding tanks of recreational vehicles. Brown (1) characterized wastewater from on-road recreational vehicles (Table 1) and discussed the possible treatment techniques that may be used for wastewater generated by camping vehicles and trailers. The study discussed the use of activated sludge to treat the wastewater, but focused mainly on the impact of the chemicals on drainage fields and lagoons.

On-road recreational vehicle wastewater is about fourteen times stronger than municipal waste (1). The characterization of the wastewater held by camping vehicles may be assumed to be about the same as that held aboard boats, because the sewage systems and odor control chemicals used are identical.

Brown (1) also performed a survey to determine the most common types of odor control chemicals used by on-road recreational vehicle owners. His survey determined that formaldehyde and formaldehyde-based chemicals are the most commonly used odor control chemicals in wastewater

TABLE 1. Characterization of holding tank wastewater from on-road recreational vehicles (1).

BOD_5	3100 mg/L
COD	8230 mg/L
TSS	3120 mg/L
VSS	2640 mg/L
Formaldehyde	170 mg/L

holding tanks (Table 1), with other less commonly used chemicals including copper compounds and house-hold soaps.

Marine Sanitation Regulations

Federal Regulations

Federal regulations regarding the design, construction, and testing of on-board boat toilets and wastewater treatment systems or marine sanitation devices are described in Title 33 of the Code of Federal Regulations, Part 159 (2).

The federal regulations are administered by the Coast Guard and are aimed at meeting the standards of the Environmental Protection Agency, section 312 of the Federal Water Pollution Control Act. The EPA intends to eventually eliminate the discharge of all untreated sewage from marine vessels into the waters of the United States. At present, the Environmental Protection Agency has not proposed ambient water quality criteria or effluent quality standards for waters or effluents containing formaldehyde, paraformaldehyde, or ethylene dichloride polymer.

The Coast Guard handles the certification, specification, and inspection of the types of marine sanitation devices, and enforces compliance with the laws. The odor control chemicals tested in this study are designed to be used in a Type I recirculating toilet and holding tank system used solely for the storage of sewage and flushwater.

Virginia Regulations

The Virginia state legislature has given the State Water Control Board and the Virginia Health Department the authority to adopt and promulgate all regulations and minimum requirements considered necessary requiring adequate sewage facilities at marinas and other places where boats are moored (3, 4). The State Water Control Board has also been directed to adopt regulations controlling the discharge of sewage and wastes from boats on all of Virginia's navigable and non-navigable waters (5).

The Commonwealth has ordered that no direct discharge of untreated or treated sewage is to be allowed in Virginia waters. Especially with regard to human waste, all wastewater is to be retained in holding tanks or self-contained toilets until it can be pumped or carried ashore for treatment (6).

Toxicity Testing and Activated Sludge

The general principles of toxicity testing and shock loading of activated sludge with chemicals are well established. Gaudy and Gaudy (7) provide a general overview of the theory and techniques for evaluating shock loading by pH, temperature, and toxic chemicals. Eckenfelder (8) presents a brief description of toxicity testing and tabulates some toxicity data for some priority pollutants and industrial chemicals. The toxicity and degradability of several chemical compounds of environmental and industrial interest, such as pentachlorophenol (9), have been examined using activated sludge.

Degradability of Formaldehyde Using Activated Sludge

Some research on the degradability of formaldehyde by activated sludge has been conducted in Asia and Europe. Sakagami and others (10, 11) have examined the degradation of commercial disinfectants by aerobic and anaerobic microorganisms acclimated to 8-hydroxyquinoline. Bacteria acclimated to 8-hydroxyquinoline were also found capable of degrading paraformaldehyde (10).

Leonova and Teteryatnik (12) discuss the use of adapted sludge microbes, particularly *Pseudomonas* species, for the removal of formaldehyde from antibiotic manufacturing process wastewater.

Acclimated bacteria were used by Behren and Hannes (13) to degrade formaldehyde with glucose to bicarbonate and glauconate. In pilot plant studies, Canals (14) used activated sludge to treat wastewater containing 0.2% formaldehyde. No toxic effects for formaldehyde above 15 ppm were observed in activated sludge. Canals concluded that at low concentrations formaldehyde was a limiting substrate, and at high concentrations it is an inhibitor.

Canals (15) has also proposed a treatment system to treat wastewater containing formaldehyde and pentaerythritol by activated sludge. The system is capable of reducing formaldehyde concentrations from 600-2000 ppm to 0-15 ppm.

Batch and continuous feed activated sludge experiments have been conducted for a standard wastewater containing different organic pollutants, including formaldehyde, by Ognean and Xin (16). They conclude that batch treatment provides faster degradation of organics, results in a better settling sludge, and reduces the size of the treatment facilities needed.

Jobst and Botzenhart (17) examined wastewaters in the sewers of the Bonn University hospitals for disinfectants, and the effects of the disinfectants on the rate of biodegradation of the hospital wastewater relative to conventional sewage. Formaldehyde was found in six of 67 samples, and when diluted in the main sewers was not found to have an adverse affect on the biodegradability of the wastewater.

Formaldehyde Toxicity

Formaldehyde toxicity testing has been conducted in several countries overseas. Klecka and others (18) evaluated the OCED (Organization for Economic Cooperation and Development) Activated Sludge Respiration Inhibition Rate test to measure the toxicity of a variety of organic and inorganic compounds. The test is an oxygen consumption rate test in activated sludge, similar to the specific oxygen uptake rate (SOUR) test used in this study.

Ishii and others (19) tested certain chemicals for effects on the oxygen uptake rate in activated sludge, also integrating the mortality rate of protozoa into their measure of toxicity.

Larson and Schaeffer (20) describe a method for determination of the toxicity of chemicals to activated sludge by measuring the inhibition of glucose uptake by the microorganisms.

Lin and others (21) have attempted to quantify the biological effects of formaldehyde-polluted waters on living organisms by using the frequency of root cell micronucleation and the rate of kill of seawater larvae. By testing very low concentrations of formaldehyde (maximum of 0.36% formaldehyde) in fresh and seawater, they concluded that the root cells of V. faba and the larvae of H. pulcherrimus are suitable species for formaldehyde toxicity testing.

Microbial Kinetics and Formaldehyde

The microbiological kinetics and enzyme activity of formaldehyde biodegradation has received some attention in Europe. Bonastre and others (22, 23) have used microorganisms adapted to formaldehyde as their only carbon and energy source to conclude that the biodegradation of formaldehyde is a complex process. They noted the presence of pH changes and sudden growth near the end of degradation as indicators of the complexity of the process. Bonastre and others (23) have also concluded that formaldehyde degradation may be described by the Vavilin equation relating the degradation rate to the initial substrate concentration.

Marison and Attwood (24) concluded that the oxidation of formaldehyde to formate in microorganisms is induced by enzymes involved in the methenyl-THF pathway during growth on methanol or methylamine.

Summary

The federal government and the Commonwealth of Virginia are in the process of proposing regulations which will prohibit the dumping of untreated wastewater from boats into our rivers, bays, and oceans. The regulations will be required to protect the aquatic environments, and will need to be enforceable by the Coast Guard and the state.

Most of the testing of the effects of formaldehyde on activated sludge has been conducted in Europe and Asia. These experiments have shown that the microorganisms of activated sludge may acclimate to low concentrations of formaldehyde and use it as a carbon and an energy source. The microbial kinetics of the utilization process appear to be rather complex. Higher concentrations, or shock loads, are more likely to exhibit toxic or inhibitory effects on the microbes.

Formaldehyde has been found to be toxic to aquatic flora and fauna, and methods of measuring this toxicity have been described.

What has not been previously investigated is how odor control chemicals containing disinfectants such as formaldehyde, paraformaldehyde, and polymers, along with additional chemicals, dyes, and perfumes affect activated

sludge. Also of interest is how quickly an activated sludge bioreactor can recover from a shock load of these odor control chemicals.

METHODS AND MATERIALS

The following chapter introduces the methods and materials used to evaluate the effects of odor control chemicals on the treatability of wastewater using aerobic activated sludge. The chemicals tested and then the experiments used to evaluate the chemicals are described.

Experimental Goals and Procedures

The goal of the research is to determine the detrimental effects, if any, the use of commercial odor control chemicals have on the treatment of recreational vehicle wastewater using the activated sludge process. Toward this end, bench-scale activated sludge bioreactors were operated in slug fed and continuous flow modes with three commercial odor control chemicals and reagent grade formaldehyde added to the influent. The bioreactors were monitored for changes in total suspended solids, solids settling rate and compaction, effluent COD concentrations, specific oxygen uptake rate, and the volume of foam generated upon aeration.

Odor Control Chemicals Tested

Three commercially available odor control chemicals were tested, "Aqua-Kem," "D-Odor-It," and "Dri-Kem." In addition, reagent grade formaldehyde solution was used as a test chemical.

"Aqua-Kem" is a liquid odor control additive containing formaldehyde, methyl alcohol, dye, and perfume. "Aqua-Kem" is manufactured by the Thetford Corporation (Ann Arbor, Michigan).

Laboratory reagent grade formaldehyde (37% wt/wt) produced by Fisher Scientific (Fair Lawn, New Jersey) was also tested. The formaldehyde solution also contains 10 to 15% methyl alcohol as a preservative to prevent polymerization. Formaldehyde was tested to determine if this chemical alone could account for the detrimental effects observed using the formaldehyde-based odor control chemicals in preliminary studies.

The chemical "D-Odor-It" is a water based odor control chemical containing demethyliminio ethylene dicholoride polymer as the active ingredient. "D-Odor-It" is produced by Land and Sea Products, Inc. (Grand Rapids, Michigan). The ingredients of "D-Odor-It" as listed by the manufacturer are given in Table 2. Similar compositional information for "Aqua-Kem" and "Dri-Kem" was not provided by their manufacturer, the Thetford Corporation.

TABLE 2. Composition of "D-Odor-It," a liquid polymer-based odor control chemical, as supplied by the manufacturer, Land and Sea Products, Inc. (Grand Rapids, Michigan).

Dimethyliminο ethylene dichloride polymer	1.5%
Substituted carbamate	1.0%
Aromatic sulfonate salt	1.0%
Chelator	1.0%
Fragrance	0.7%
Nonionic surfactant	3.7%
Blue dye	0.03%
Water	91.07%

"Dri-Kem" is a solid odor control chemical containing paraformaldehyde, a dry polymerized form of formaldehyde,with dye and perfume added. Like "Aqua-Kem," "Dri-Kem" is manufactured by the Thetford Corporation (Ann Arbor, Michigan).

Bioreactor Set-Up

Bench scale aerobic activated sludge bioreactor experiments were conducted in two parts. In the first set of experiments slug fed bioreactors were used, and in the second set, continuously flow stirred tank reactors (CFSTR's) were used.

The slug fed experiments were run first to determine optimal operational parameters for the bench-scale bioreactors, and to determine the time needed to acclimate municipal activated sludge to the bactopeptone feed. The slug fed experiments were preliminary experiments performed in preparation for the continuous flow stirred tank reactor tests which more accurately simulate a packaged wastewater treatment plant.

All of the bioreactors had volumes of nine liters. The bioreactors were initially filled with activated sludge from the Blacksburg, Virginia municipal wastewater treatment plant. Feed to the activated sludge was supplied as bactopeptone dissolved in tap water to give an approximate concentration of 500 milligrams of COD per liter per day.

The slug fed reactors were fed 500 milligrams of COD per liter per day as bactopeptone once every twenty four hours. After activated sludge was wasted, the feed was added in the replacement water, along with an additional ten to fifteen milliliters of water to make up for evaporation losses. A sludge age of 12 days was maintained in the batch bioreactors by wasting one twelfth of the contents each day.

For the CFSTR systems, the water and feed mixture of 500 milligrams of COD per liter per day was drip supplied to the reactors at a rate of nine liters per day to give a hydraulic retention time of one day. Sludge was wasted by pulling the clarifier baffle from the bioreactor and completely mixing the contents, then wasting enough of the contents to give a sludge age of 12 days.

All bioreactors were aerated and mixed with forced air supplied thorough a diffuser stone. All experiments were conducted at a constant temperature of 20°C.

Dosing of Bioreactors with Odor Control Chemicals

During dosing, the odor control chemicals were added to the bactopeptone feed solution. The doses of the odor control chemicals and formaldehyde used during the slug fed and CFSTR experiments are listed in Table 3. These concentrations were selected based on batch oxygen uptake tests of unacclimated activated sludge. At these dosing levels, specific oxygen uptake rates were reduced. Since recovery rates were of interest, these doses seemed appropriate to induce changes in the bioreactors so that dosing and subsequent recovery could be evaluated.

During the slug fed bioreactor experiments, "Aqua-Kem" and "Dri-Kem" were added in concentrations equal to 20% of the manufacturer's recommended dosage for self-contained toilets, or 0.31 milliliters and 150 milligrams per liter, respectively.

The formaldehyde solution was added to the slug fed bioreactor to give a concentration of 0.30 milliliters per liter. The dose was intended to approximate the dose of formaldehyde contained in "Aqua-Kem." In this way, the direct effects of formaldehyde on activated sludge could be observed and compared to a similar dose of formaldehyde-based "Aqua-Kem."

"D-Odor-It" was added to the slug fed bioreactor at 5% of the manufacturer's recommended dose, 0.16 milliliters per liter.

TABLE 3. Doses of odor control chemicals used in slug fed and continuously flow activated sludge experiments.

Odor Control Chemical	Experiment Feeding	Percent of Manufacturer's Recommended Dose	Concentration, ml/L or mg/L
"Aqua-Kem"	Slug	20	0.31 ml/L
	Continuous	100	1.56 ml/L
Formaldehyde Solution	Slug		0.30 ml/L
	Continuous		1.50 ml/L
"Dri-Kem"	Slug	20	150 mg/L
	Continuous	100	750 mg/L
"D-Odor-It"	Slug	5	0.16 ml/L
	Continuous	50	1.56 ml/L

During the CFSTR experiments, "Aqua-Kem" and "Dri-Kem" were added in doses equal to 100% of the manufacturer's recommended dose. The recommended dose of "Aqua-Kem" is 1.56 milliliter of "Aqua-Kem" per liter of wastewater. The recommended dose of "Dri-Kem" is 750 milligrams of "Dri-Kem" per liter of wastewater.

Formaldehyde solution was added to the continuously-fed bioreactor to give a concentration of 150 milliliters of formaldehyde per liter of activated sludge.

One half of the recommended dose of "D-Odor-It" was used in the continuously-fed tests, 1.56 milliliters per liter.

Bioreactor Operation and Chemical Testing

The slug fed and CFSTR bioreactors were each operated in three stages. The experiments were designed to simulate the response of a stable packaged wastewater treatment systems that may receive wastewater with heavy odor control chemical loads when its use by boaters would be great, such as during a summer weekend or holiday, and then a sudden drop in the chemical load when the heavy use period would be over.

The first stage was to acclimate the activated sludge from the Blacksburg municipal wastewater plant to the bactopeptone feed. During the stabilization period, the bioreactors were fed only bactopeptone. The acclimation period lasted at least two weeks, or until the bioreactor appeared to be at steady state. The tests used to determine steady state (MLSS, MLVSS, and SOUR) are described in the next section.

The second stage consisted of dosing the activated sludge bioreactors with odor control chemicals in the concentrations previously described. During dosing, the bioreactors were fed the same amount of bactopeptone, but with odor control chemicals added to the feed. The dosing period lasted for two days for the continuously fed experiments, and for six days in the batch experiments.

The third and final stage of the experiments involved feeding only bactopeptone substrate without odor control chemicals. This period is intended to represent the end of heavy chemical loading to the reactor at the end of a weekend or holiday, and the rate of recovery was observed. The recovery stage was monitored for a period of seven to ten days.

Bioreactor Activated Sludge Analyses

The following analyses were performed on the activated sludge and effluent to monitor the stability and performance of the bioreactors.

Total Suspended Solids

Total suspended solids in the mixed liquor were measured by the method given in Section 209C, Total Suspended Solids Dried at 103-105°C, Standard Methods for the Examination of Water and Wastewater (25). Volatile suspended solids in the mixed liquor were measured according to Section 209D, Fixed and Volatile Solids Ignited at 550°C, Standard Methods for the Examination of Water and Wastewater (25).

Specific Oxygen Uptake Rate

Specific oxygen uptake rate test (SOUR) measures the rate at which activated sludge uses dissolved oxygen relative to the concentration of biological solids in the mixed liquor. It is generally thought (26, 27) that toxic chemicals that poison microorganisms will result in a decrease in the specific oxygen uptake rate.

To measure SOUR, 300 milliliters of activated sludge was taken from the bioreactor and placed in a bottle. A dissolved oxygen probe was inserted in the neck of the bottle, sealing the sludge from the atmosphere. A YSI Model 57 Oxygen Meter (Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio) was used to measure dissolved oxygen in the activated sludge.

Dissolved oxygen readings were taken five and fifteen minutes after the bottle was sealed. The specific oxygen uptake rate of activated sludge was then calculated as follows:

$$\text{SOUR}\ \frac{(\text{mg/L*min})}{(\text{mg/L})} = \frac{(O_2)_5 - (O_2)_{15}}{10\ \text{minutes} * \text{MLSS}}$$

where $(O_2)_5$ = dissolved oxygen concentration after 5 minutes

$(O_2)_{15}$ = dissolved oxygen concentration after 15 minutes

MLSS = total suspended solids concentration of the mixed liquor.

Sludge Settling

Activated sludge must settle well if a high quality effluent is to be achieved. A poorly settling sludge will result in an effluent high in suspended solids and COD.

The sludge volume index (SVI) test was used as the measure of sludge settleability. The procedure used for determining SVI is described in Section 213C, Standard Methods for the Examination of Water and Wastewater (25).

The SVI does not have a firm theoretical basis, yet is commonly used in the operation of wastewater treatment plants (28).

To test if the odor control chemicals had an affect on the ability of the sludge to settle and compact, the chemicals were added to sludge taken from the Blacksburg, Virginia municipal wastewater treatment plant. For these batch experiments, the sludge was concentrated to a solids concentration of about 3300 mg suspended solids per liter, and the MLSS was measured for each test. The sludge was aerated and mixed by air forced through a diffuser stone, and used within 8 hours of collection.

The sludge volume index was measured during the continuous feed experiments to test if addition of the odor control chemicals would have an effect on the ability of activated sludge to settle and compact.

Effluent COD

The effluent COD was measure according to the procedure described in Section 508B, Oxygen Demand (Chemical)/ Closed Reflux, Titrimetric Method, Standard Methods for the Examination of Water and Wastewater (25).

Color or Dye Removal Experiments

All three odor control chemicals tested contain blue dye. The presence of blue dye in activated sludge after dosing with the chemicals was determined by measuring the optical absorbance of the activated sludge at 630 nanometers.

A wavelength of 630 nanometers was determined to be the optimum wavelength to detect the presence of the blue dyes with minimum interference from the dark yellow to brown color of the undosed activated sludge.

Optical absorbance measurements were taken on activated sludge samples of approximately 50 milliliters. The samples were filtered through a 0.45 micron glass microfiber filter (Whatman #934-AH filter). The filtered samples were measured for optical absorbance using a Bausch and Lomb Spectronic 20 spectrometer with the spectrometer calibrated daily to zero absorbance using distilled water.

Foam Volume Measurements

Surfactants contained in the liquid odor control chemicals, "Aqua-Kem" and "D-Odor-It", were found to generate large volumes of foam when added to aerated activated sludge bioreactors.

To measure foam volume, one liter of tap water was poured into the bottom of a glass cylinder 40 centimeters tall and 17 centimeters in diameter. The water was aerated using 2 cubic feet of air per hour forced through a diffuser stone. Specific doses of the liquid odor control chemicals were added, and the height of the foam generated inside the cylinder was measured with a ruler.

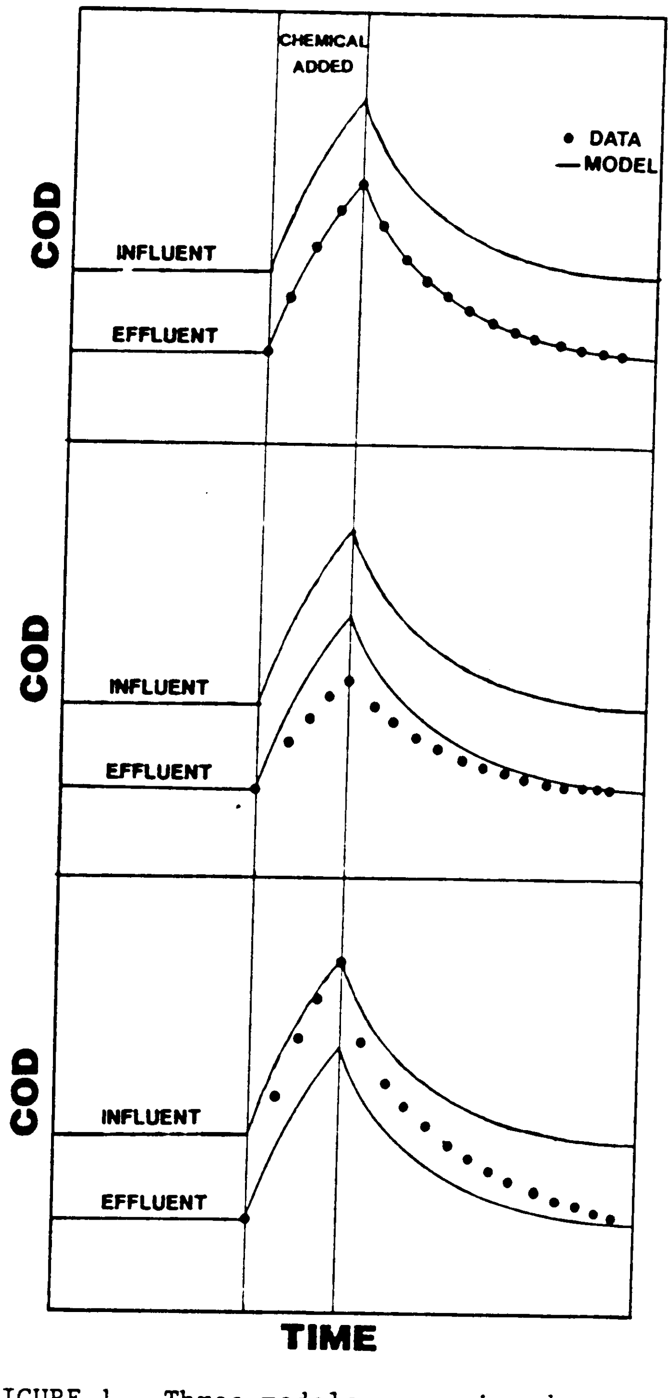
The volume of foam in the glass cylinder was then calculated.

Accumulation-Flushing Reactor Analysis

The CFSTR bioreactors were analyzed for the effects of the odor control chemicals on substrate removal by using calculated reactor accumulation-dilution analysis for a completely mixed reactor. Calculated curves are constructed to illustrate the results that should occur if the odor control chemicals are not biodegradable and do not interfere with the utilization of bactopeptone by activated sludge. This analysis assumes that the dosing chemicals would accumulate in the bioreactors, bactopeptone utilization would not be affected, and the chemicals would be flushed out of the reactor when dosing ceased.

The calculated accumulation-flushing curves are then compared to actual results as measured by effluent COD concentration to determine whether the odor control chemicals are biodegradable and whether or not they interfere with the degradation of bactopeptone (Fig 1).

The equation used to model the accumulation of non-reactive chemical in a continuous-flow, completely mixed reactor is as follows (29):



A) Dosing chemical is not degraded and does not interfere with bactopeptone utilization.

B) Dosing chemical is partially biodegraded.

C) One example of how dosing chemical may resist degradation and inhibit bactopeptone utilization.

FIGURE 1. Three models comparing data measurements with calculated accumulation-flushing curves to interpret chemical degradability and interference with bactopeptone utilization.

$$\frac{C}{C_o} = 1 - e^{-t/t_o}$$

where: C_o = influent COD

C = actual COD in reactor

t = time

t_o = hydraulic retention time.

The equation for modeling the flushing of a substance out of the reactor is (29):

$$\frac{C}{C_o} = e^{-t/t_o}$$

where the variables are defined the same as above.

RESULTS

In this chapter, results are presented for the tests performed using activated sludge dosed with "Aqua-Kem," formaldehyde, "D-Odor-It," and "Dri-Kem," first for the slug fed experiments and then for the continuous flow (CFSTR) experiments. Also described are experiments used to examine the biodegradability of the dyes in the odor control chemicals, and the generation of foam by the liquid chemicals. Data used to construct all of the displayed figures are tabulated in the Appendix.

Slug Fed Bioreactor Experiments

This section presents the results of experiments performed using slug fed activated sludge bioreactors. The results are summarized in Table 4, after which the specific results are discussed. The results listed in Table 4 are generalized because the batch bioreactor experiments were preliminary tests in preparation for the continuous flow stirred tank reactor (CFSTR) experiments, and because the slug fed bioreactors were not at apparent steady state with respect to suspended solids concentrations.

Data for the slug fed bioreactor experiments were collected over time of operation, with the time divided

TABLE 4. Generalized results of odor control chemicals and formaldehyde on slug fed activated sludge bioreactors.

Odor Control Chemical	Change of MLSS*	Change of SOUR	Change of SVI	Change of Effluent COD
"Aqua-Kem"	decrease	large increase	none	increase
Formaldehyde Solution	none detected	large increase	none	increase
"D-Odor-It"	none detected	increase	none	gradual increase
"Dri-Kem"	increase	none	none	gradual increase

* qualified by apparent lack of stability with respect to suspended solids concentrations during experiments.

into a stabilization phase of 7 to 8 days of no dosing, a dosing phase of 6 days when chemical was added to the bioreactor, and a recovery phase of 4 or 5 days, again with no chemical dosing. The bioreactors did not always fully recover within the recorded period after dosing stopped.

Suspended Solids

The slug fed bioreactor experiments were initiated with extremely high total suspended solids concentrations (2500 to 1200 mg/L), requiring longer lengths of time to stabilize than specific oxygen uptake rate, effluent COD concentrations, and sludge volume index. Because the slug fed tests were mainly preliminary experiments, the experiments were begun before complete stabilization of total suspended solids concentrations was reached. The suspended solids concentrations were observed for trends of solids loss during dosing rather than for quantitative losses or gains of suspended solids.

Both the mixed liquor total suspended solids (MLSS) and volatile suspended solids (MLVSS) were measured in the bioreactors. Mixed liquor volatile suspended solids (MLVSS) concentrations were less than mixed liquor suspended solids (MLSS) concentrations by about 100 mg/L for all four chemicals tested in slug fed activated sludge. Stabilized total suspended solids (MLSS) concentrations is about 1000 to 800 milligrams per liter for bioreactors fed 500 milligrams per liter per day of COD as bactopeptone.

The suspended solids concentrations in the bioreactors dosed with "Aqua-Kem," (fig. 2), formaldehyde (fig. 3), and "D-Odor-It," (fig. 4) were declining prior to dosing and continued to decline after dosing. The rate of decline for "Aqua-Kem" increased from about 110 mg/L per day before dosing to about 150 mg/L per day during dosing. The rate of decline of the suspended solids in the bioreactor dosed with formaldehyde solution and for "D-Odor-It" remained about the same before and after dosing.

In contrast, dosing with "Dri-Kem," (fig. 5) resulted in a near constant suspended solids concentrations in the activated sludge during and after dosing. The solids concentrations had been declining before "Dri-Kem" was added, but increased slightly as a result of adding "Dri-Kem."

Specific Oxygen Uptake Rate

Specific oxygen uptake rate (SOUR) measurements were taken to monitor for shock and toxic effects of the odor control chemicals to activated sludge.

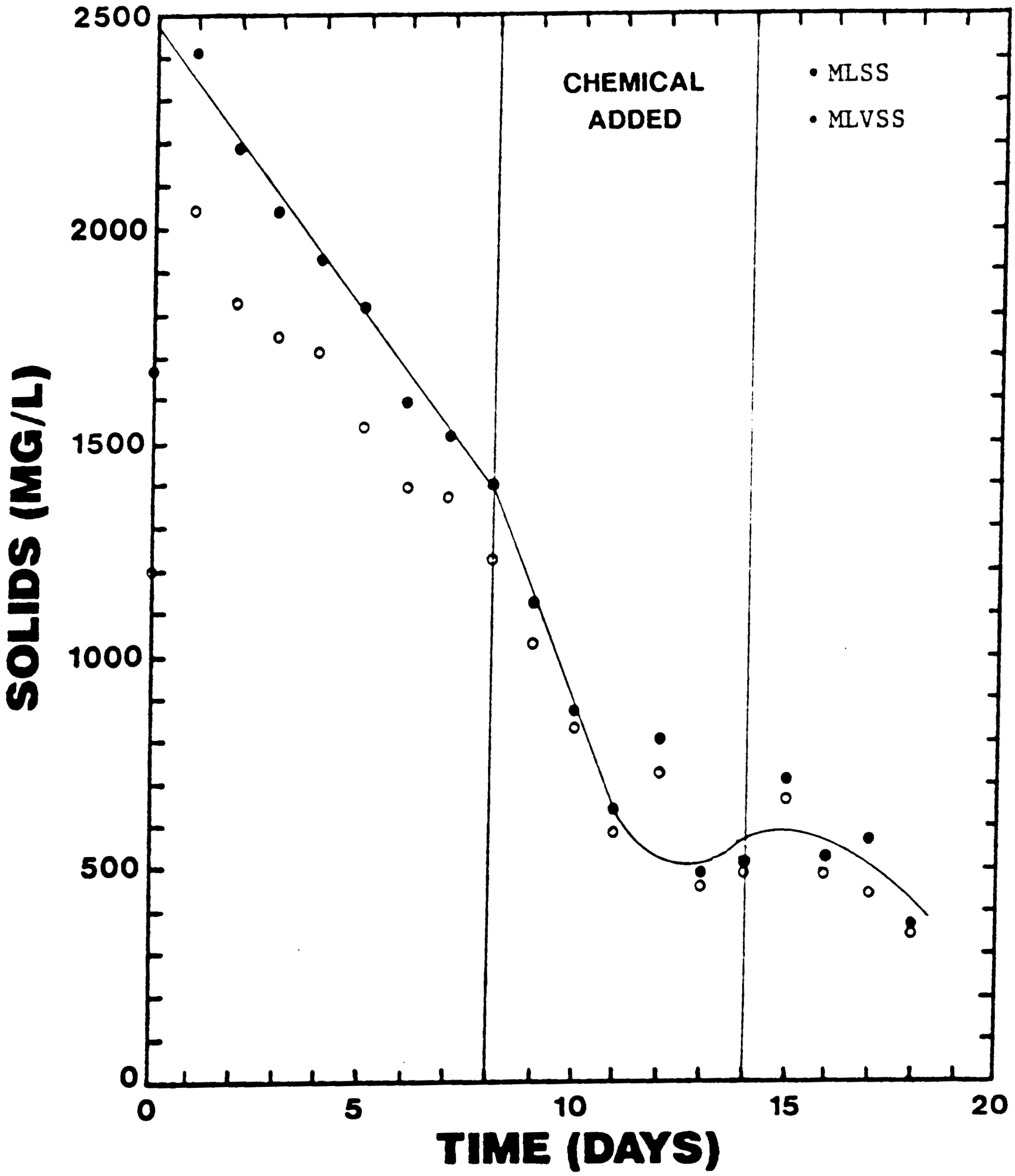


FIGURE 2. Variation of total suspended solids (MLSS) over time for batch bioreactor dosed with "Aqua-Kem."

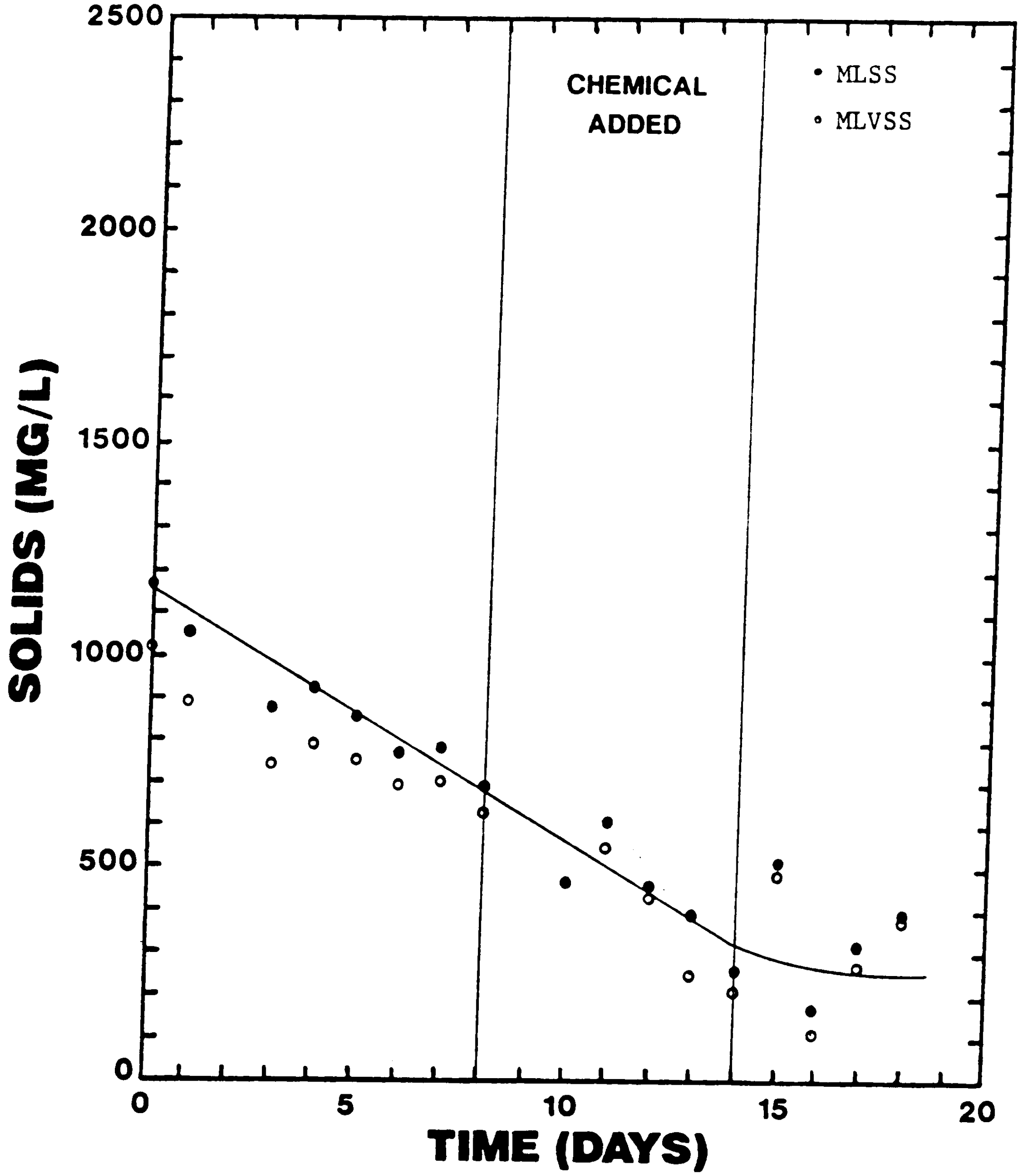


FIGURE 3. Variation of total suspended solids (MLSS) over time for batch bioreactor dosed with formaldehyde solution.

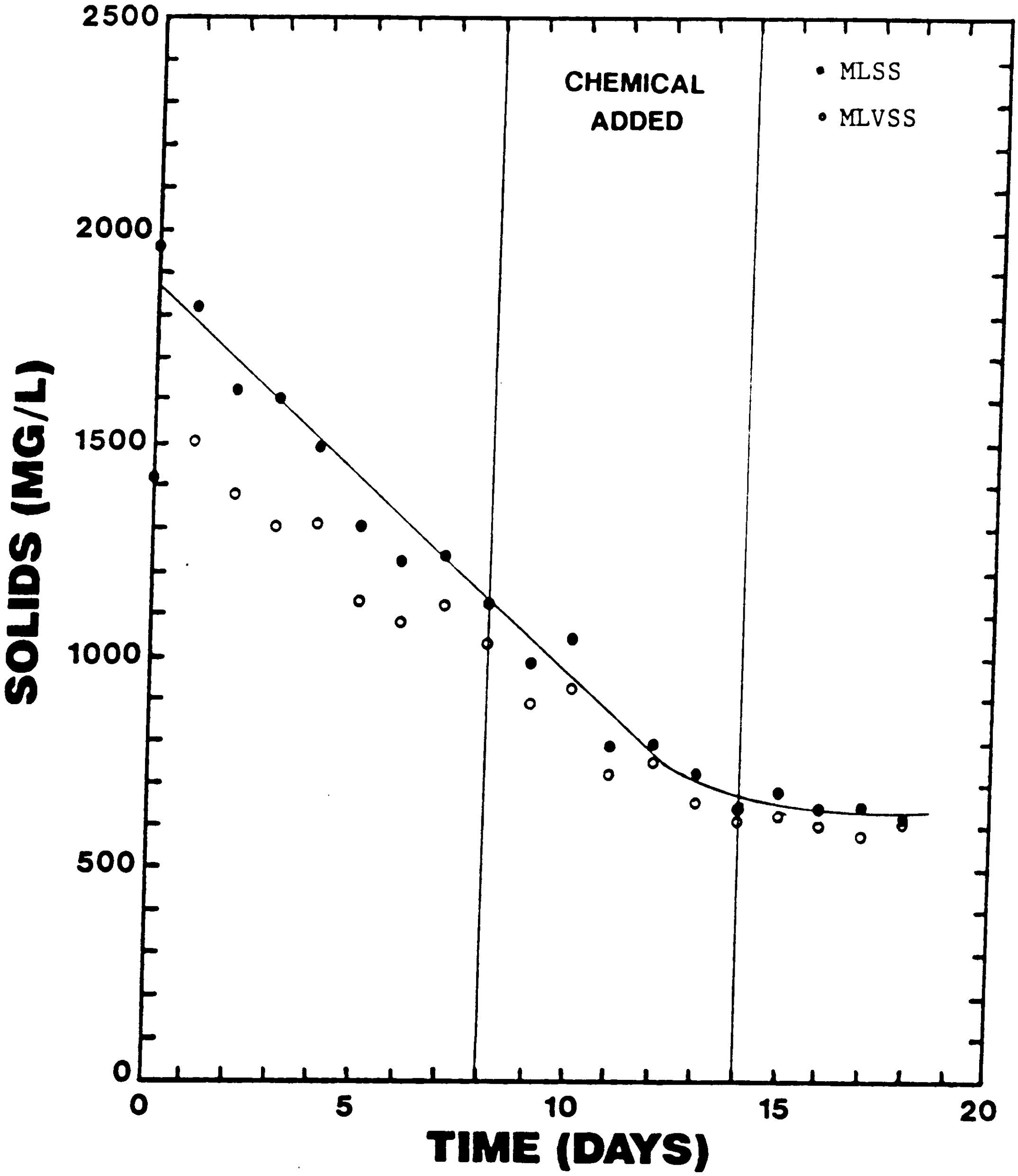


FIGURE 4. Variation of total suspended solids (MLSS) over time for batch bioreactor dosed with "D-Odor-It."

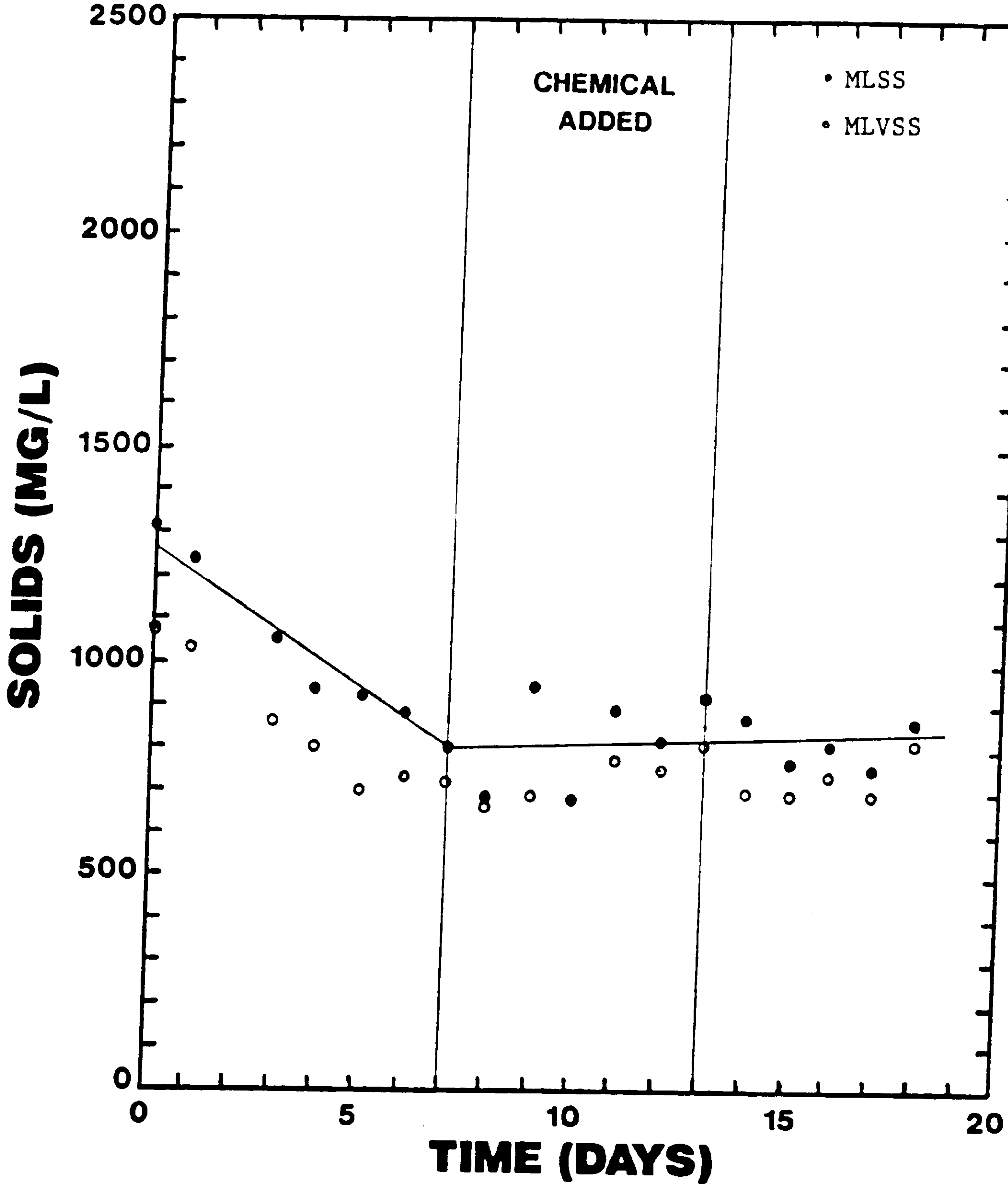


FIGURE 5. Variation of total suspended solids (MLSS) over time for bioreactor dosed with "Dri-Kem."

The specific oxygen uptake rate (SOUR) measurements for the slug fed activated sludge dosed with "Aqua-Kem" (fig. 6) showed a five-fold increase in the uptake rate over the pre-dosing rate. After three days of dosing, the rate started to gradually decline and continued to decline throughout the remainder of the dosing phase. However, the rate did not return to the pre-dosing rate as dosing continued. The uptake rates during the following recovery phase were generally erratic and above the pre-dosing rates.

The formaldehyde solution when added to activated sludge also caused the specific oxygen uptake rate to increase three or four days after application (fig. 7). Generally, uptake rates increased during dosing, and began to decline again a couple days after dosing was stopped.

Activated sludge dosed with "D-Odor-It" (fig. 8) resulted in relatively minor increases in the oxygen uptake rate. The rate increased by a factor of about two, but returned to near normal while chemical doses were still being added. The rates measured during the recovery phase were only slightly elevated above the pre-dosing rates.

The addition of "Dri-Kem" (fig. 9) to slug fed activated sludge appears to have made only slight decreases and increases in the specific oxygen uptake

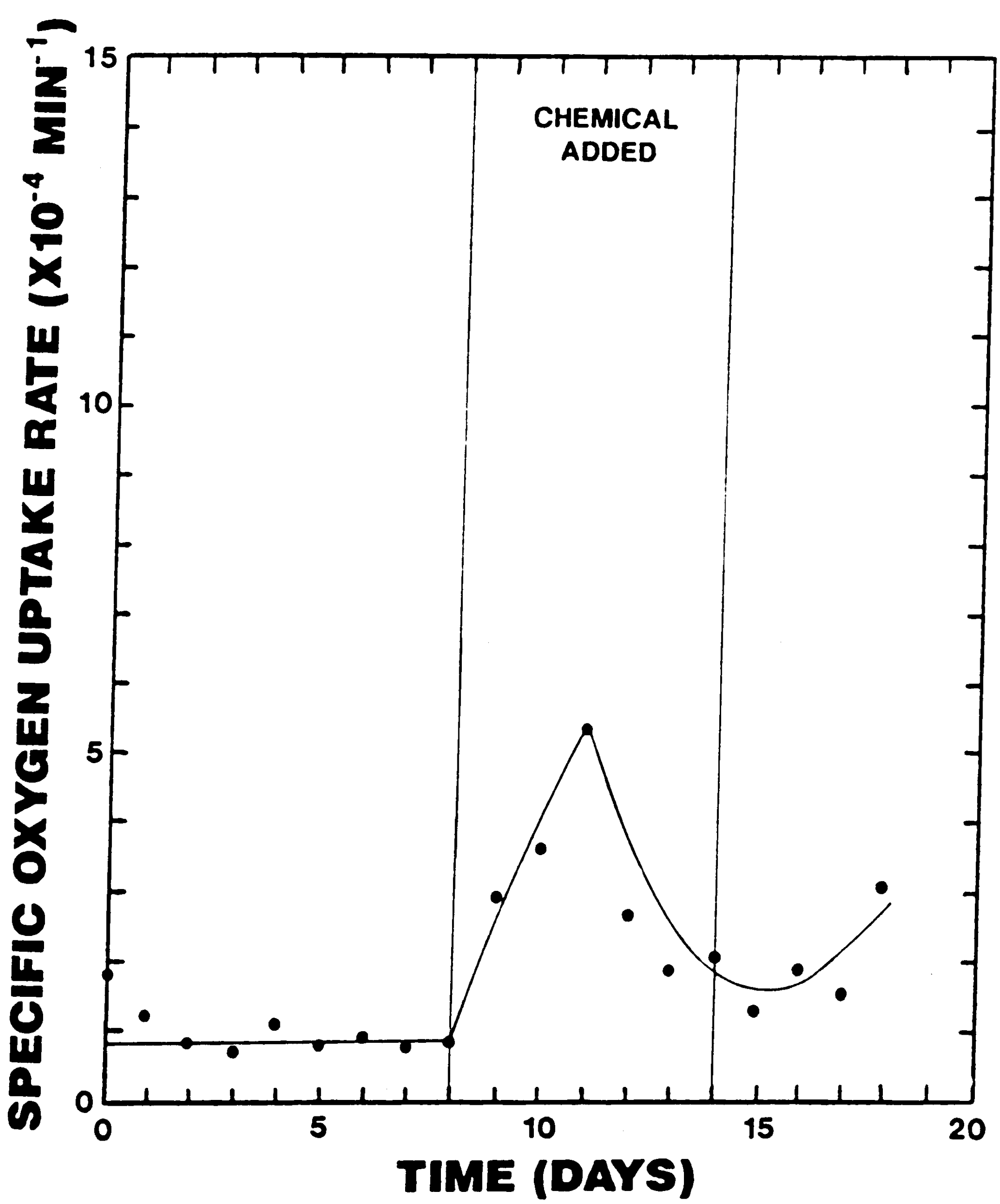


FIGURE 6. Variation of specific oxygen uptake rate (SOUR) over time for batch bioreactor dosed with "Aqua-Kem."

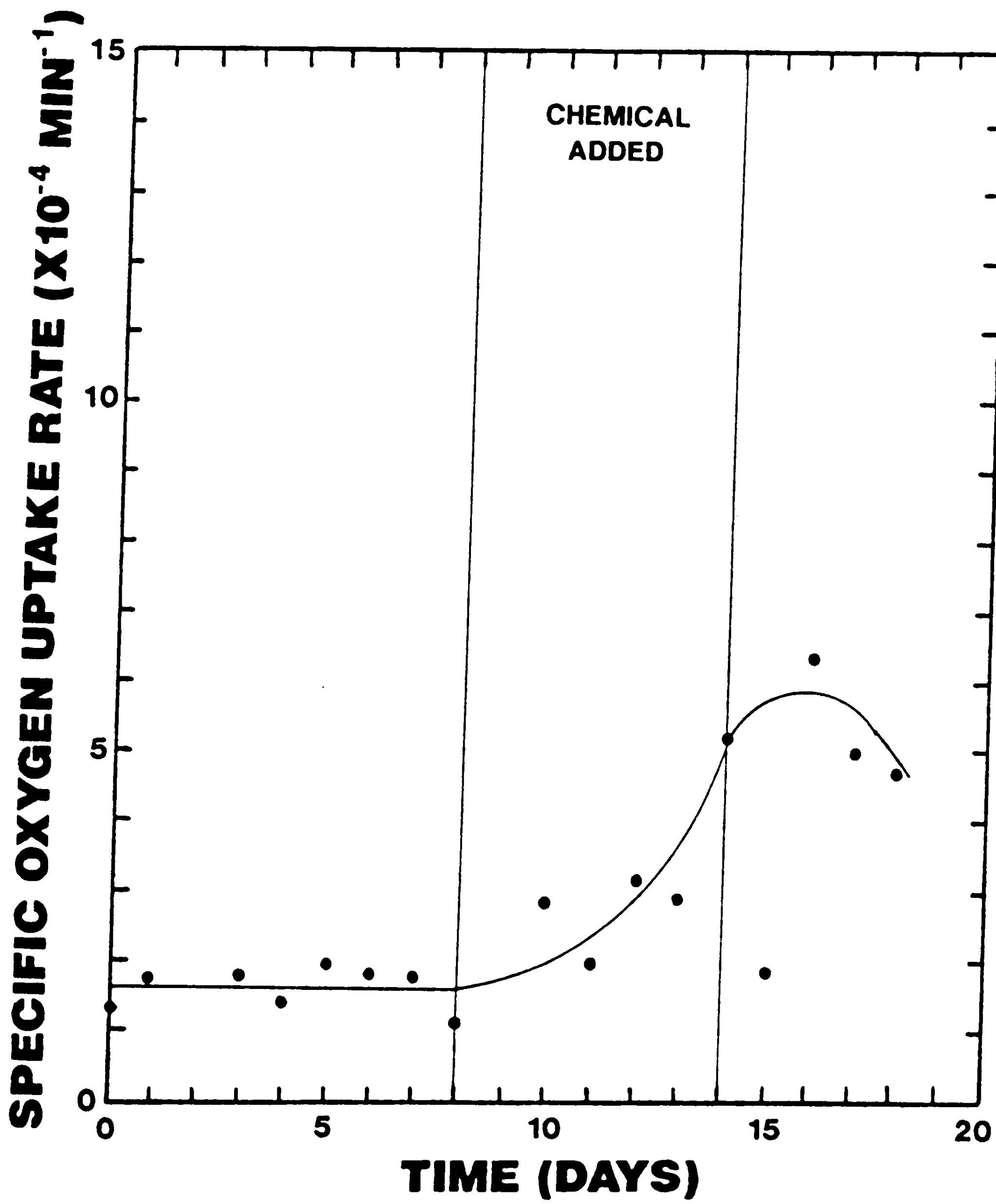


FIGURE 7. Variation of specific oxygen uptake rate (SOUR) over time for batch bioreactor dosed with formaldehyde solution.

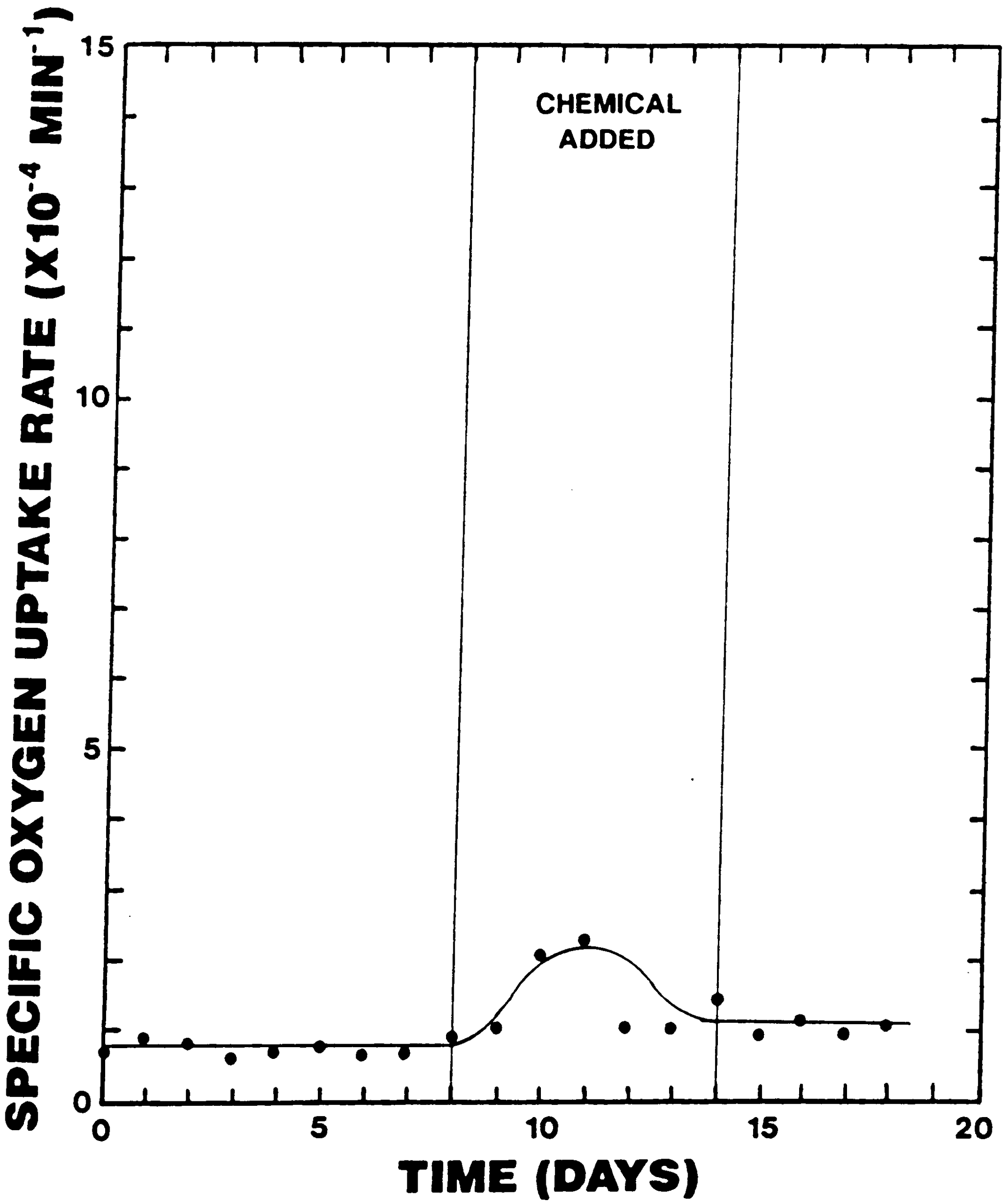


FIGURE 8. Variation of specific oxygen uptake rate (SOUR) over time for batch bioreactor dosed with "D-Odor-It."

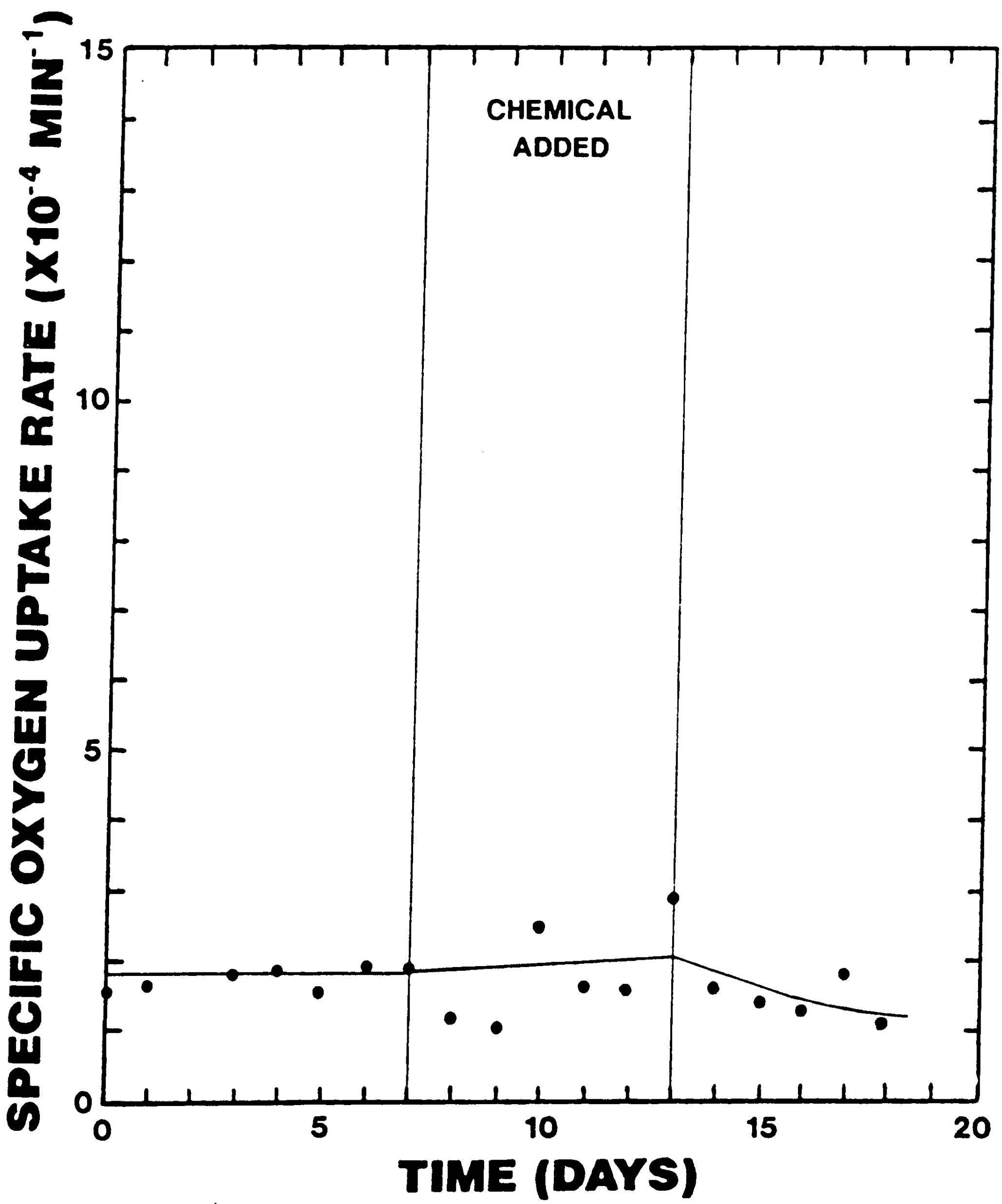


FIGURE 9. Variation of specific oxygen uptake rate (SOUR) over time for batch bioreactor dosed with "Dri-Kem."

rate. The post-dosing uptake rate was only slightly lower than the pre-dosing rate.

Settling Rate Versus Dose of Chemical

Experiments were performed to measure the change of sludge volume index (SVI) as a function of the slug dose of odor control chemical. Contact time between the sludge and the odor control chemicals was approximately 15 minutes before the 30 minutes before starting the SVI test.

The sludge volume index varied between approximately 150 and 220 over the range of doses for all odor control chemicals (fig. 10). No apparent dose or chemically related pattern emerged from the tests.

COD Removal

The concentration of COD in the effluent of the slug fed bioreactors was measured over time of operation. The influent COD was also measured during the stabilization, dosing, and recovery phases and is represented by the dashed line labeled "influent" in the following figures. The increase in influent COD during dosing is due to COD contained in the odor control chemicals.

With the beginning of slug dosing with "Aqua-Kem" (fig. 11), the COD concentration in the effluent increased

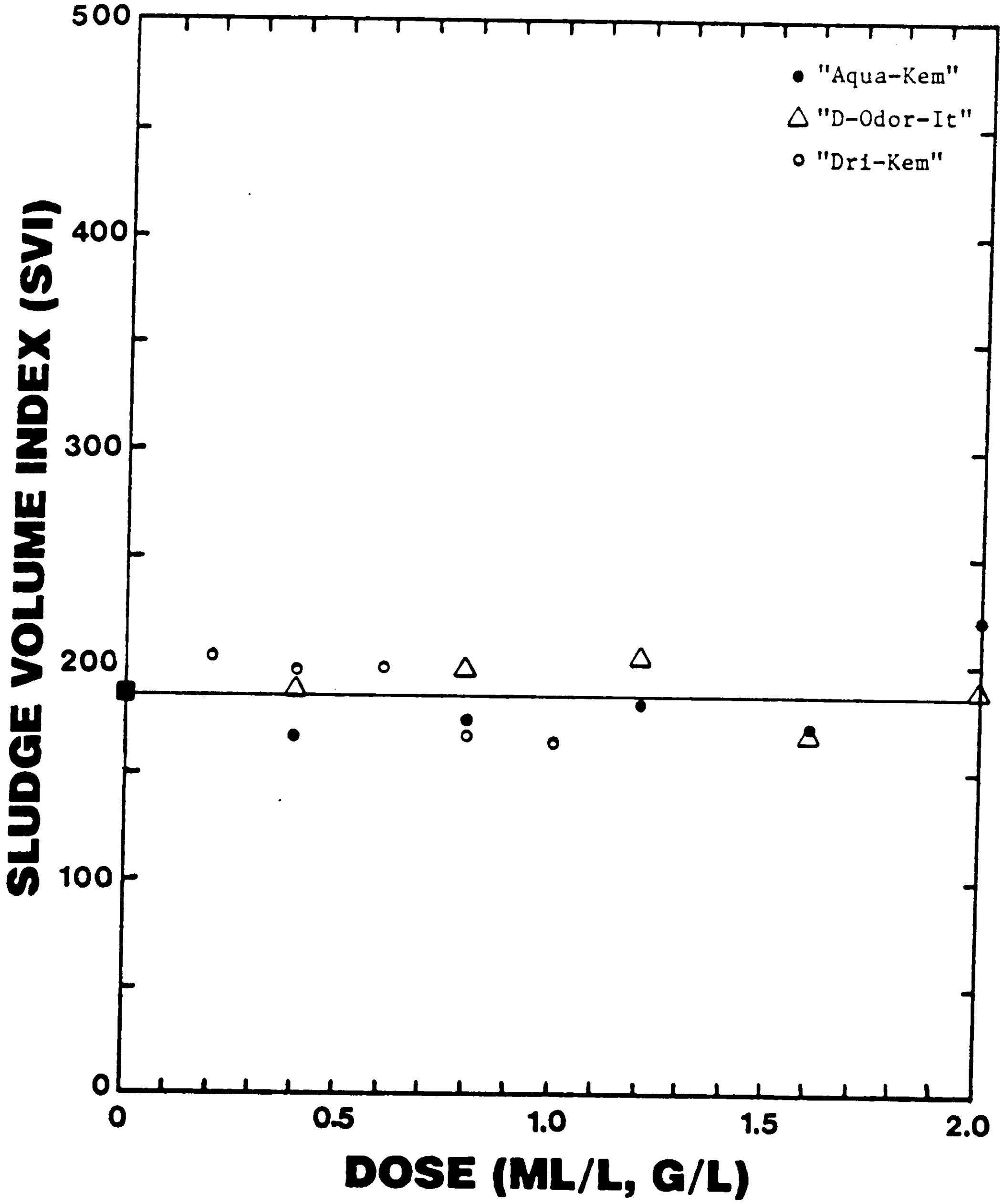


FIGURE 10. Variation of sludge volume index (SVI) versus dose of three odor control chemicals.

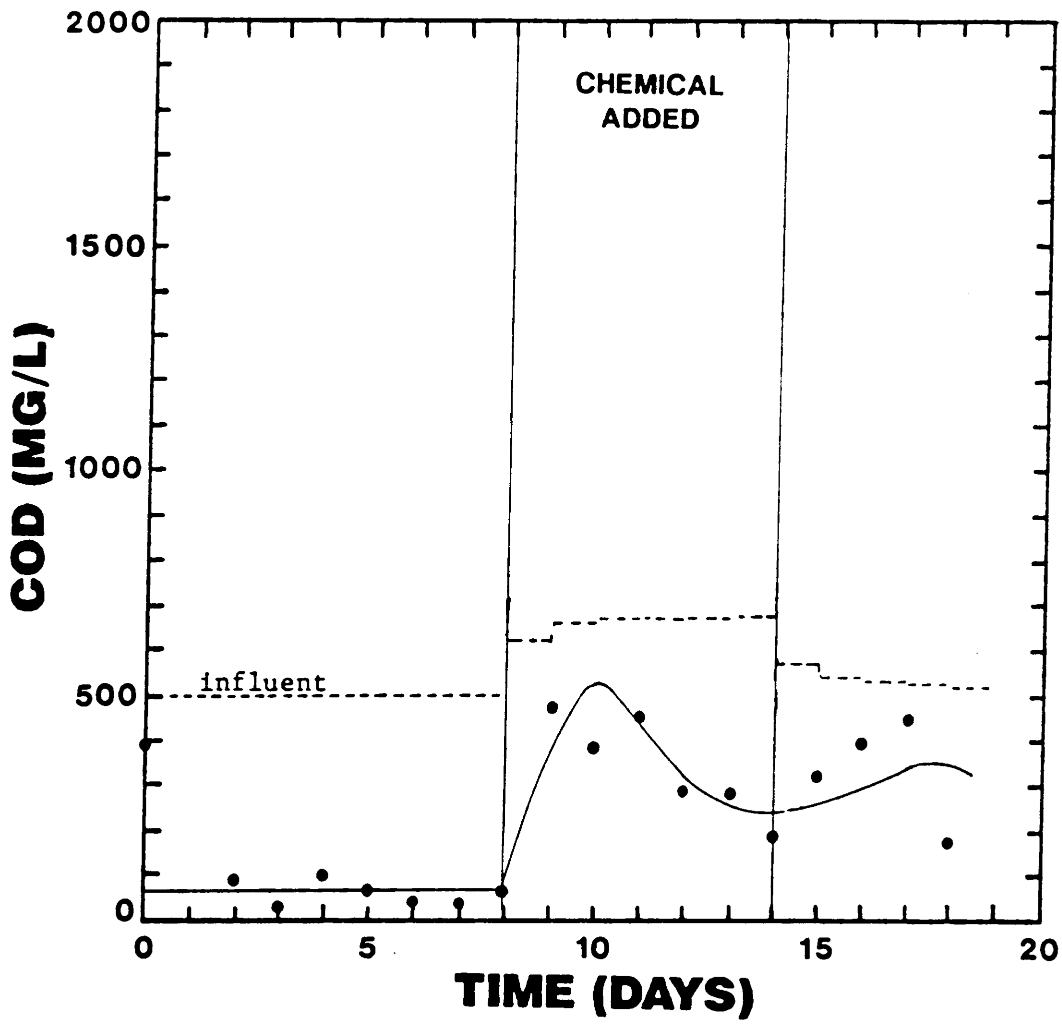


FIGURE 11. Variation in effluent COD concentration over time for batch bioreactor dosed with "Aqua-Kem."

by a factor of 8 after one day. The effluent COD concentration then gradually decreased during the remainder of the period. Effluent COD concentrations during the subsequent recovery phase began to increase again to as high as 450 mg/L. Only on the fourth day of recovery did the COD removal begin to improve.

Formaldehyde dosing of the bioreactors resulted in a large increase in effluent COD concentration during the six day dosing phase (fig. 12). The effluent COD concentration increased through the dosing phase from 133 mg/L to a maximum value of 825 mg/L by the end of the six day dosing phase. On day 14, the effluent COD measurement indicated that less COD was being fed into the reactor than was measured in the effluent. During the first three or four days of the recovery period, effluent COD was declining but continued to exceeded influent COD.

The effluent COD concentration as a result of slug dosing with "D-Odor-It" (fig. 13) gradually increased from the pre-dosing concentration, to about double the pre-dosing concentration at the end of the six day dosing phase. The concentration declined rapidly to approximately the pre-dosing concentration after only two days of recovery.

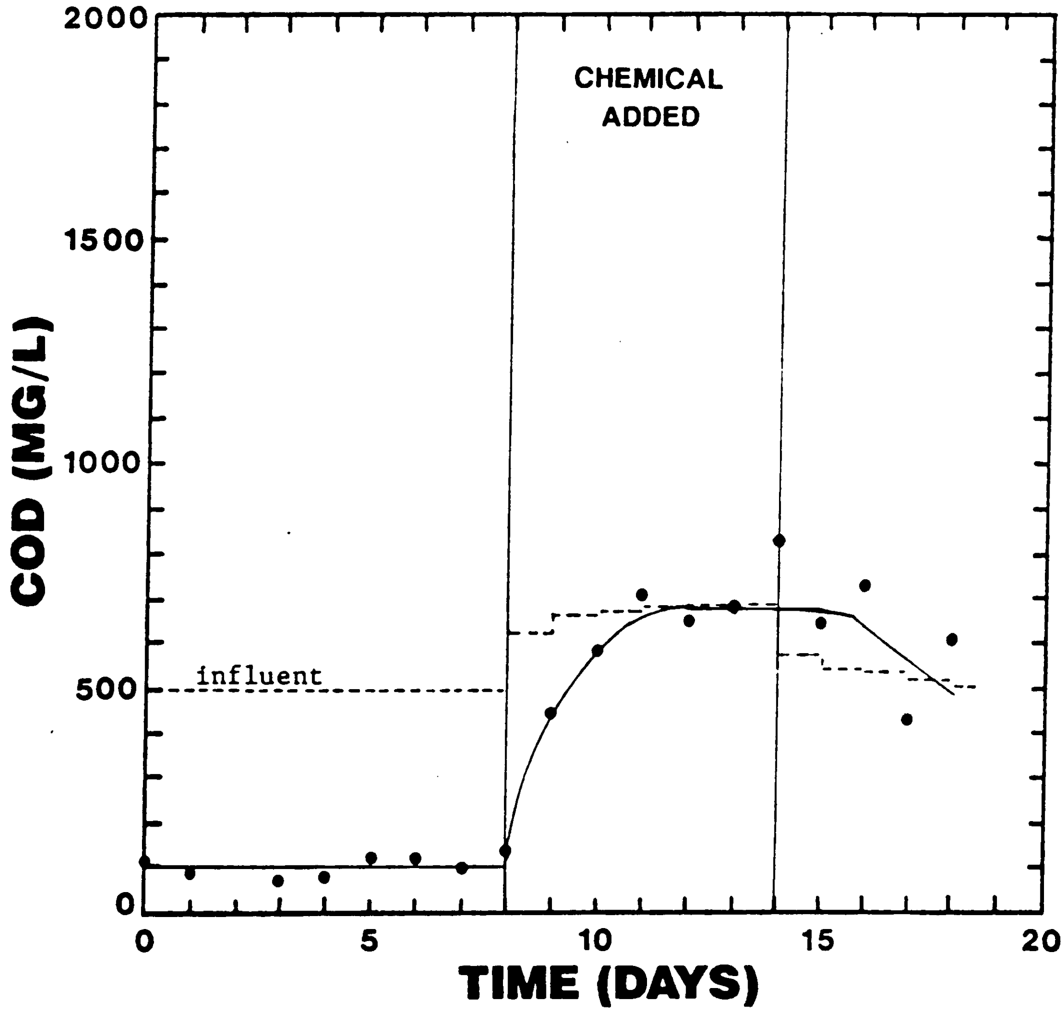


FIGURE 12. Variation in effluent COD concentration over time for batch bioreactor dosed with formaldehdyde solution.

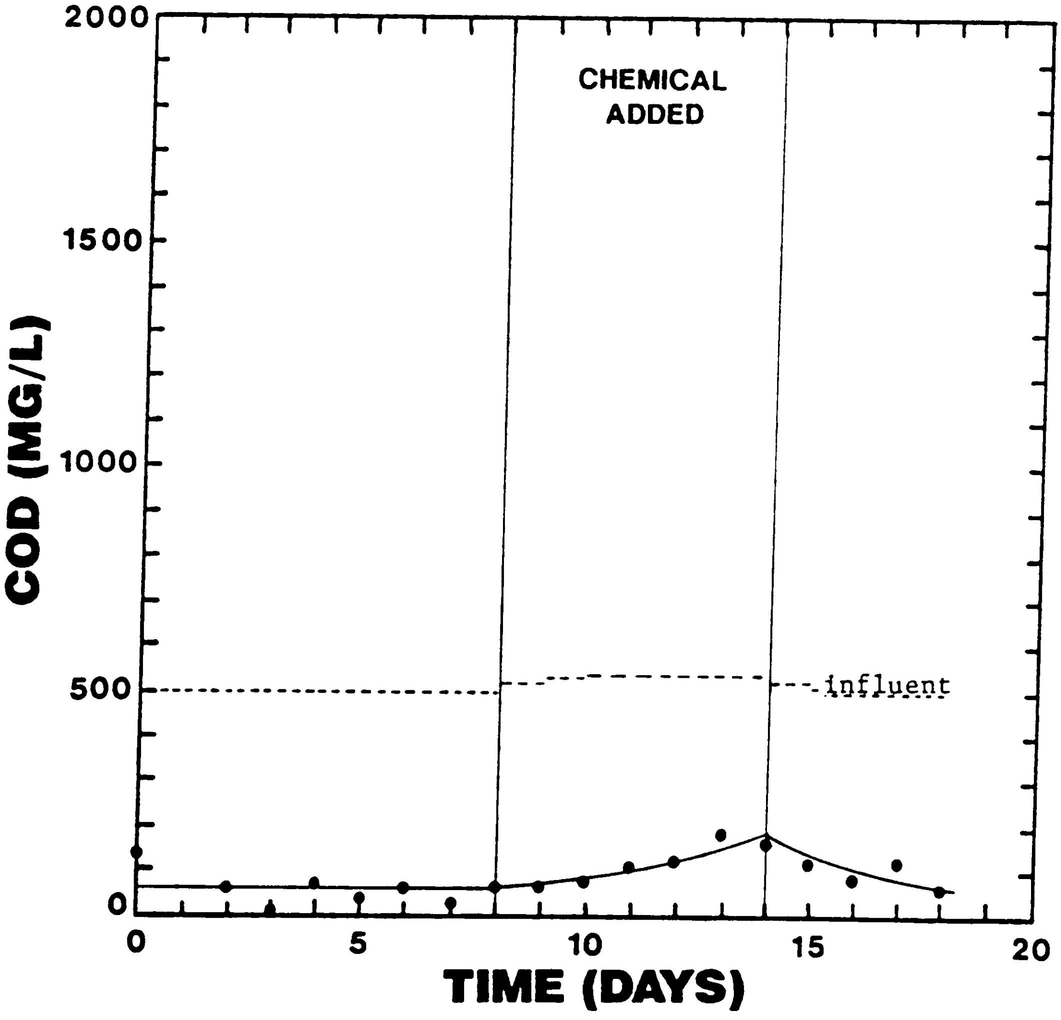


FIGURE 13. Variation in effluent COD concentration over time for batch bioreactor dosed with "D-Odor-It."

The pattern of changes in effluent COD of the bioreactor slug dosed with "Dri-Kem" (fig. 14) appear similar to that of the bioreactor dosed with "D-Odor-It." The effluent COD in the bioreactor dosed with "Dri-Kem" increased gradually by about a factor of two after six days of batch dosing. Effluent levels during recovery declined rapidly to approximately the pre-dosing concentration.

Continuous Flow Bioreactor Experiments

At the conclusion of the slug fed bioreactor experiments, continuous flow (CFSTR) experiments were initiated. The CFSTR experiments were intended to explore the responses that could be expected from a typical packaged wastewater treatment plant during a weekend of heavy use at a marina or resort community. Most packaged wastewater treatment plants at highway rest stops and marinas are continuous-flow systems.

The results of the continuous flow bioreactor experiments are summarized in Table 5. Description of specific results of the experiments follows Table 5.

Data for continuous-flow bioreactor or CFSTR experiments were collected over time of operation, with the time divided into a stabilization phase of 6 to 10 days, a dosing phase of 2 days, and a recovery phase of 7

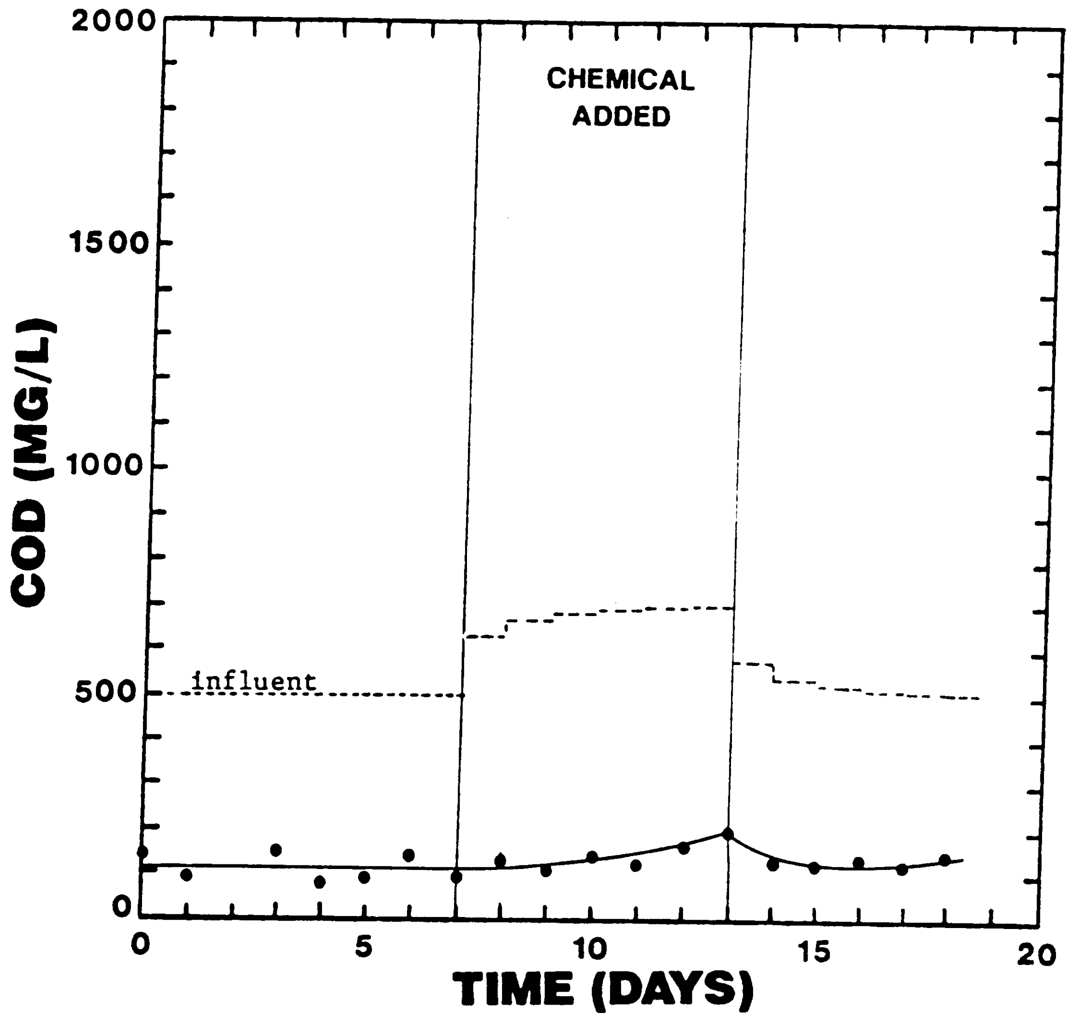


FIGURE 14. Variation in effluent COD concentration over time for batch bioreactor dosed with "Dri-Kem."

TABLE 5. Average initial conditions and changes after dosing in continuously-flow bioreactors dosed with three odor control chemicals and formaldehyde solution.

Test or Parameter	Odor Control Chemical			
	"Aqua-Kem"	Formaldehyde Solution	"D-Odor-It"	"Dri-Kem"
MLSS (mg/L)	990	940	620	540
MLVSS (mg/L)	880	890	590	500
Food / Biomass	0.505	0.532	0.806	0.926
Chemical / Biomass	0.002	0.002	0.003	1.210
SOUR (min^{-1})	2.07	1.53	2.61	3.84
SVI	976	906	1089	263
Effluent COD (mg/L)	47	43	82	130
Change of MLSS (mg/L)	-400	-350	-400	+300
Change of SOUR (min^{-1})	+6X	+12X	+7X	+0.5X
Change of SVI	-400	+400	-1300	-100
Change of Effluent COD (mg/L)	+1000	+1100	+500	-100

Suspended Solids

The mixed liquor volatile suspended solids (MLVSS) concentrations for all of the chemicals, before, during, and after dosing, are generally 20 to 30 mg/L less than the mixed liquor suspended solids (MLSS) concentrations.

During the two days of chemical dosing, the suspended solids concentrations decreased by almost one half in the bioreactor dosed with the "Aqua-Kem" (fig. 15), decreased by about one third in formaldehyde dosed bioreactor (fig.16), and decreased by greater than one half in the "D-Odor-It" dosed bioreactor (fig. 17).

The decreases in suspended solids occurred immediately upon dosing with the odor control chemicals, and continued for two or three days past the dosing period. After several days after dosing, the concentrations then began to gradually increase, but after a total of ten days of recovery, the solids concentrations in all three of the dosed bioreactors were not at the original levels that existed prior to dosing.

The solids concentrations in activated sludge dosed with "Dri-Kem" (fig. 18) differed from the other dosed systems in that the concentrations increased during dosing and remained elevated for seven days after dosing. The

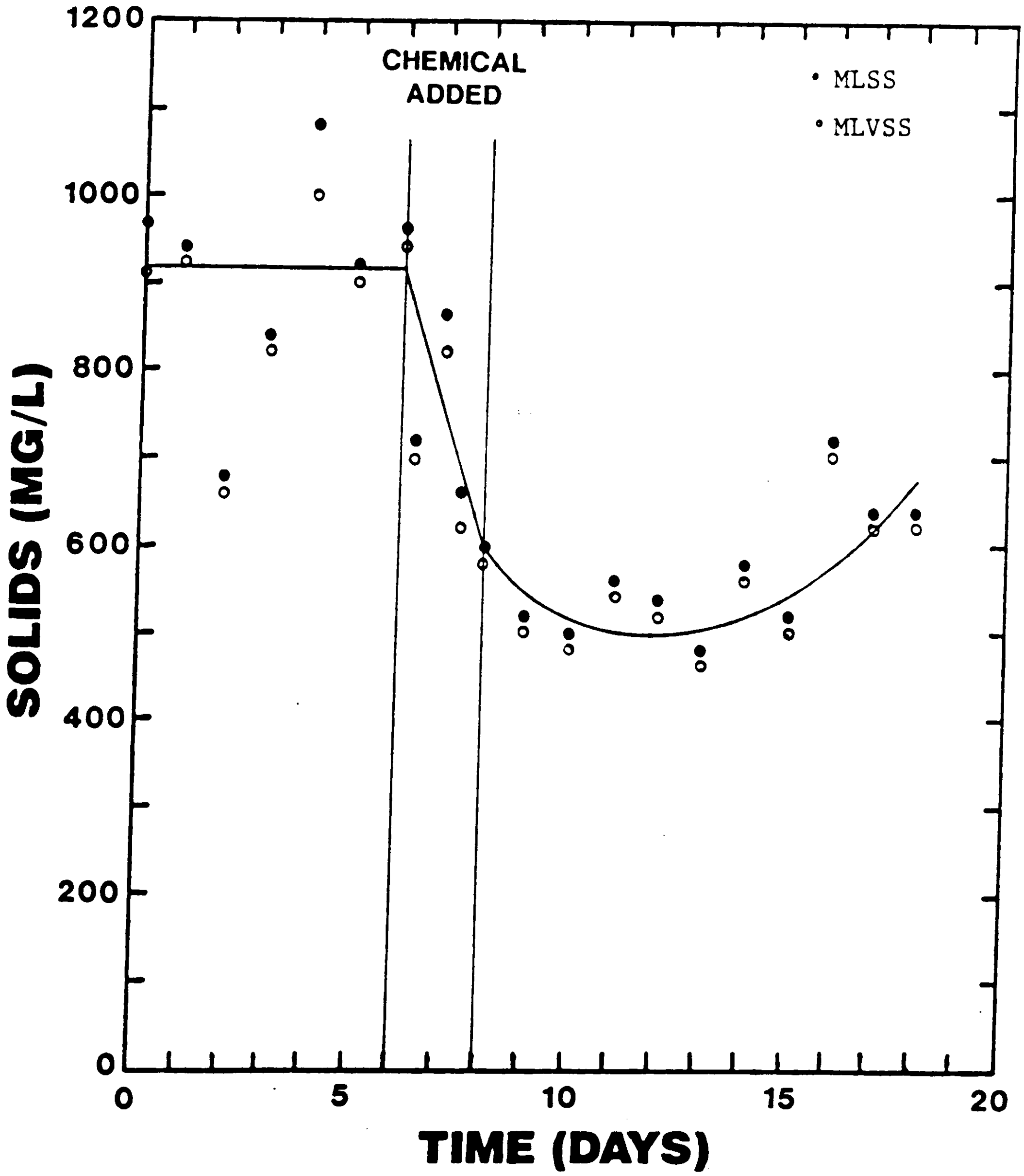


FIGURE 15. Variation in total suspended solids (MLSS) over time for continuous flow stirred tank bioreactor dosed with "Aqua-Kem."

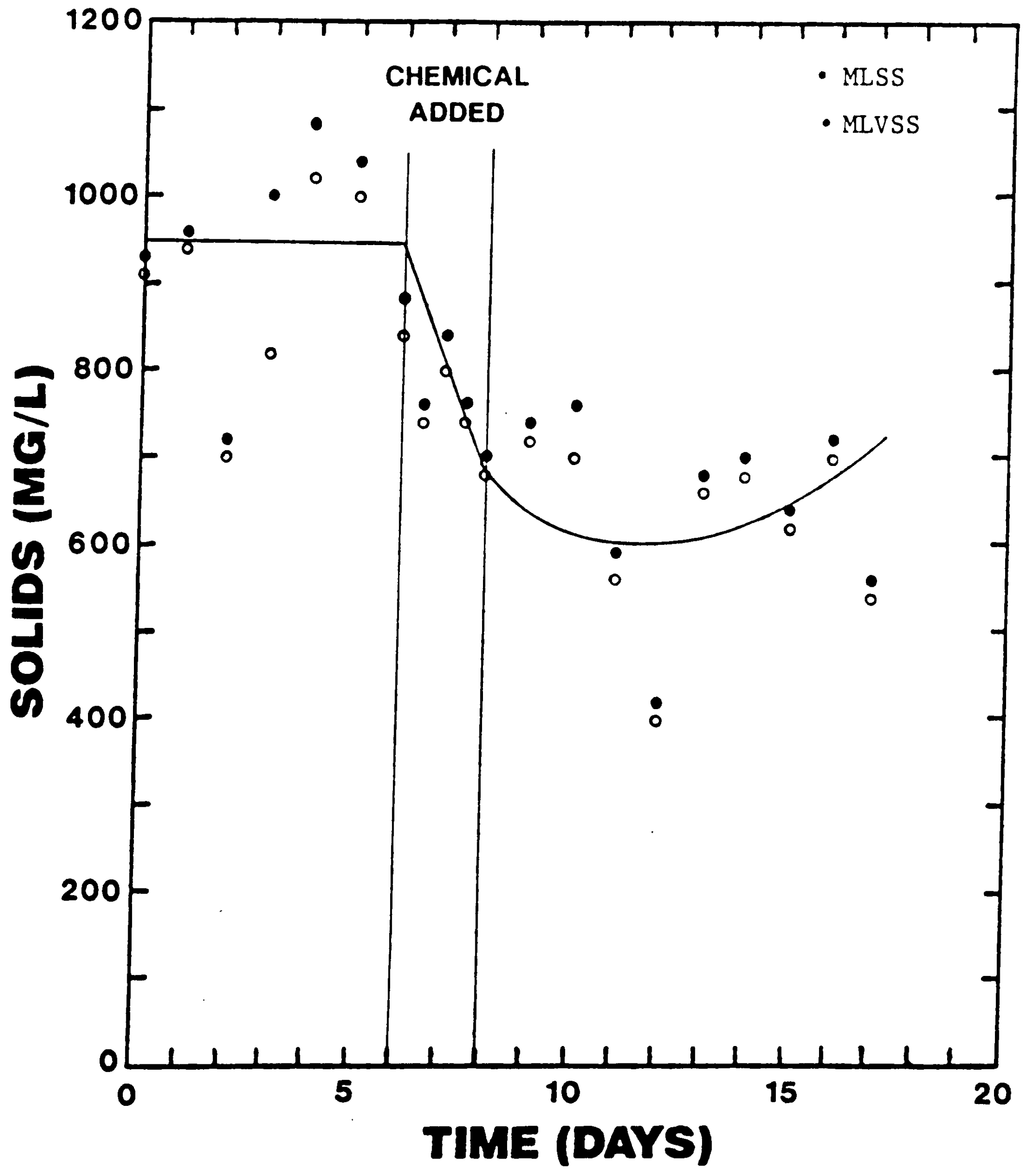


FIGURE 16. Variation in total suspended solids (MLSS) over time for continuous flow stirred tank bioreactor dosed with formaldehyde solution.

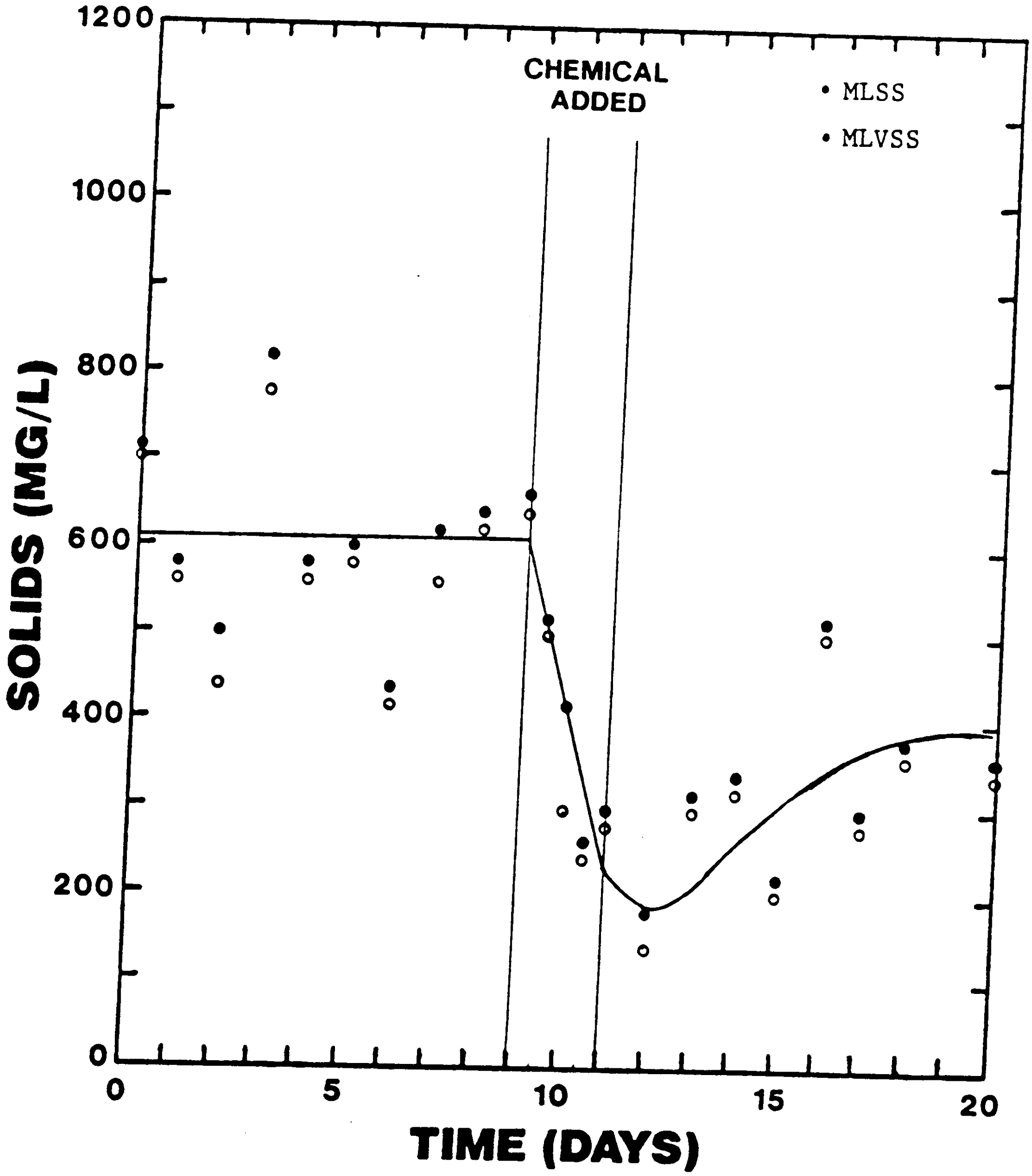


FIGURE 17. Variation in total suspended solids (MLSS) over time for continuous flow stirred tank bioreactor dosed with "D-Odor-It."

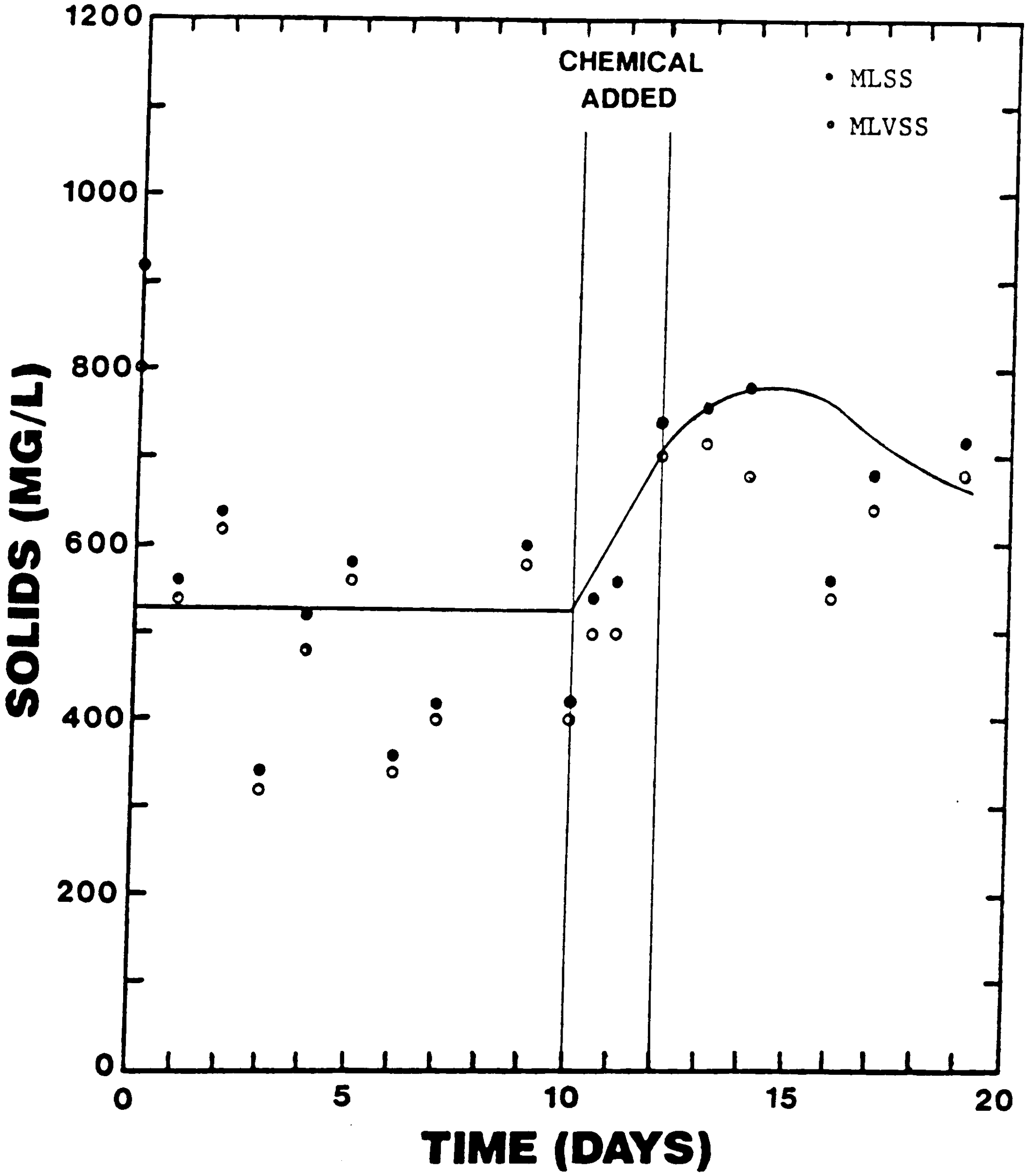


FIGURE 18. Variation in total suspended solids (MLSS) over time for continuous flow stirred tank bioreactor dosed wiht "Dri-Kem."

solids concentrations peaked after dosing at about 280 mg/l higher than the levels before dosing.

Specific Oxygen Uptake Rate

In response to dosing with "Aqua-Kem," the bioreactor showed a specific oxygen uptake rate (SOUR) decrease of about 50% after 12 to 24 hours of chemical dosing (fig. 19). During the second day of dosing, the uptake rates increased by about 6 fold over the base-level rate, or about five times the pre-dosing rate. The uptake rate did not decline until after dosing and returned to the original level within one day.

Activated sludge dosed with the formaldehyde solution reacted by showing a two-thirds drop in SOUR 12 hours after dosing was initiated (fig. 20). The rate then began to rise after one day of dosing, and peaked at about 12 times more than the pre-dosing rate. The peak rate occurred 36 hours after dosing started and declined during the last half day of dosing and after dosing stopped. The SOUR was near normal one day after dosing ceased.

For both "Aqua-Kem" and formaldehyde, the SOUR returned to near the pre-dosing rates after one day, but was slightly elevated and more erratic over the recovery period than before dosing began.

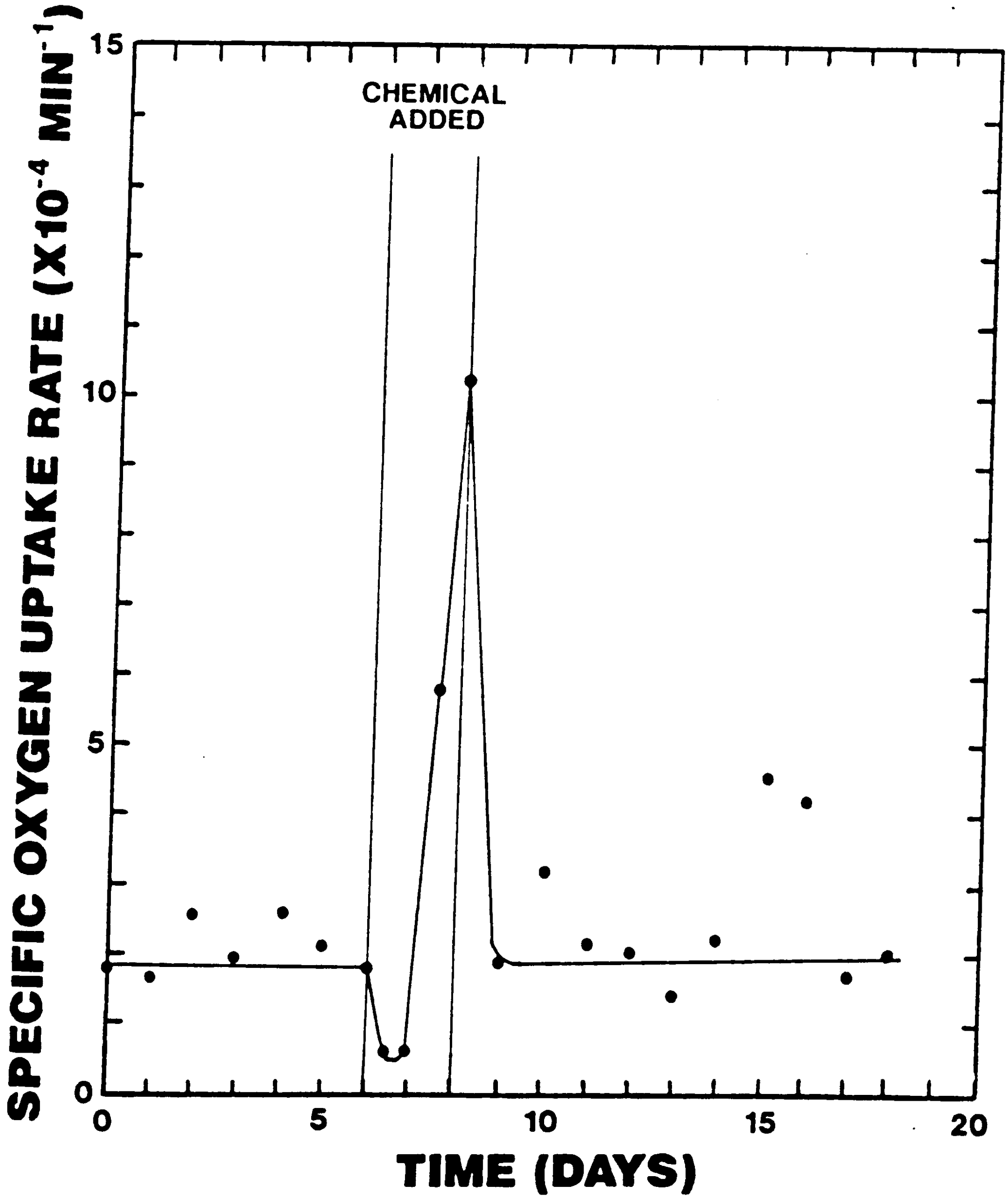


FIGURE 19. Variation in specific oxygen uptake rate (SOUR) over time for a continuous flow stirred tank bioreactor dosed with "Aqua-Kem."

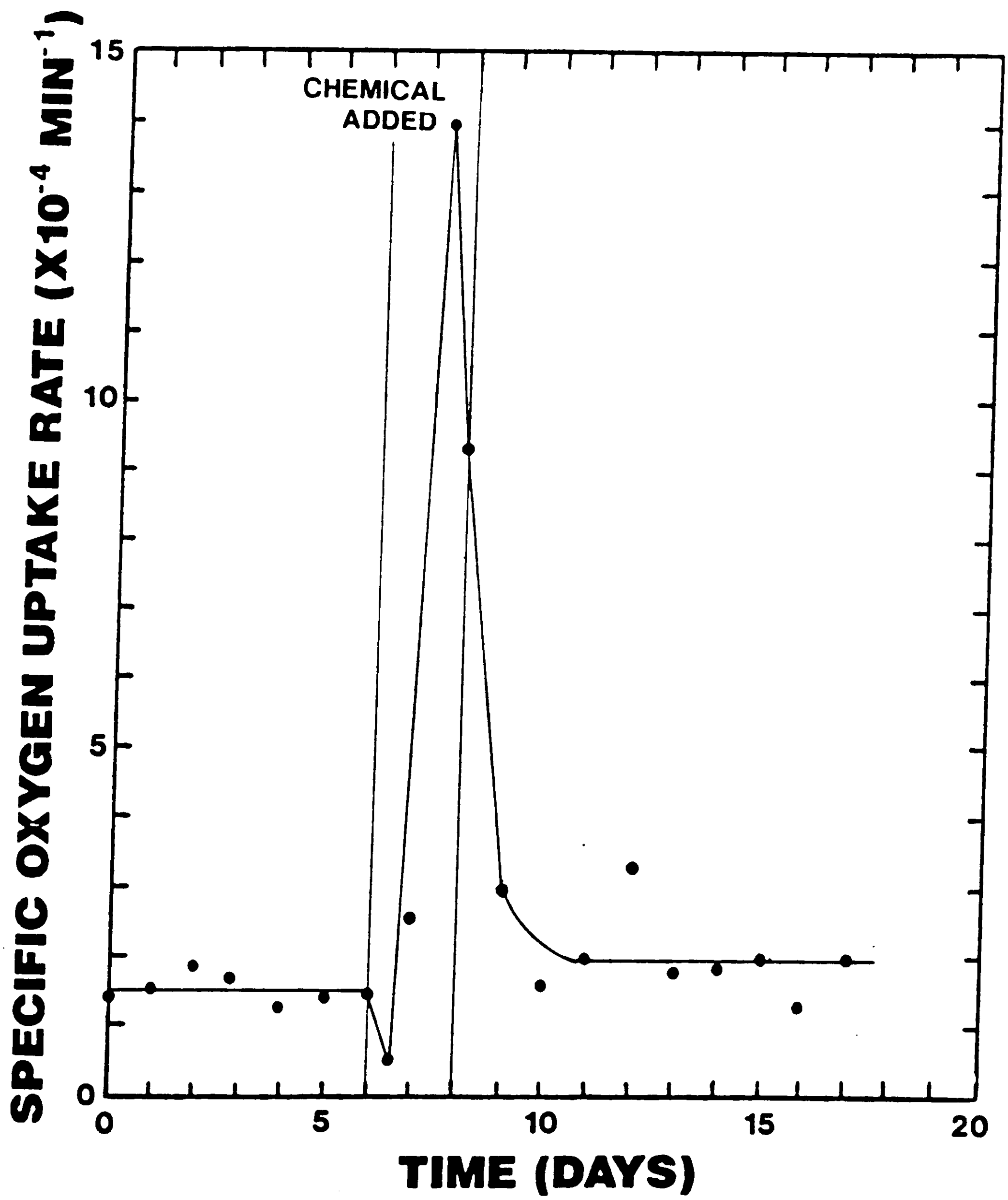


FIGURE 20. Variation in specific oxygen uptake rate (SOUR) over time for a continuous flow stirred tank bioreactor dosed with formaldehyde solution.

In activated sludge dosed with "D-Odor-It" (fig. 21), the SOUR increased sharply as a result of dosing with "D-Odor-It," and continued to increase to a maximum rate about 7 times the pre-dosing rate. About two days after dosing was stopped, SOUR for "D-Odor-It" declined to a low value of about 3.3. Rates eight days after dosing were erratic and generally increasing.

In contrast, the specific oxygen uptake rate for the "Dri-Kem" experiments (fig. 22) decreased by about one half after 12 hours of dosing. Even though the rate was rising during the stabilization phase, SOUR declined when dosing was initiated. The uptake rate declined to a low value of about 2.1 three days later. The uptake rates five days after dosing were only slightly lower than the pre-dosing rate.

Settling Rate

The sludge volume index (SVI) for the continuously fed activated sludge in the bioreactor dosed with "Aqua-Kem" (fig. 23) varied over time, but averaged approximately 1000 before and during dosing. The index decreased by about one half several days after dosing was stopped, but subsequently increased to approximately the pre-dosing level.

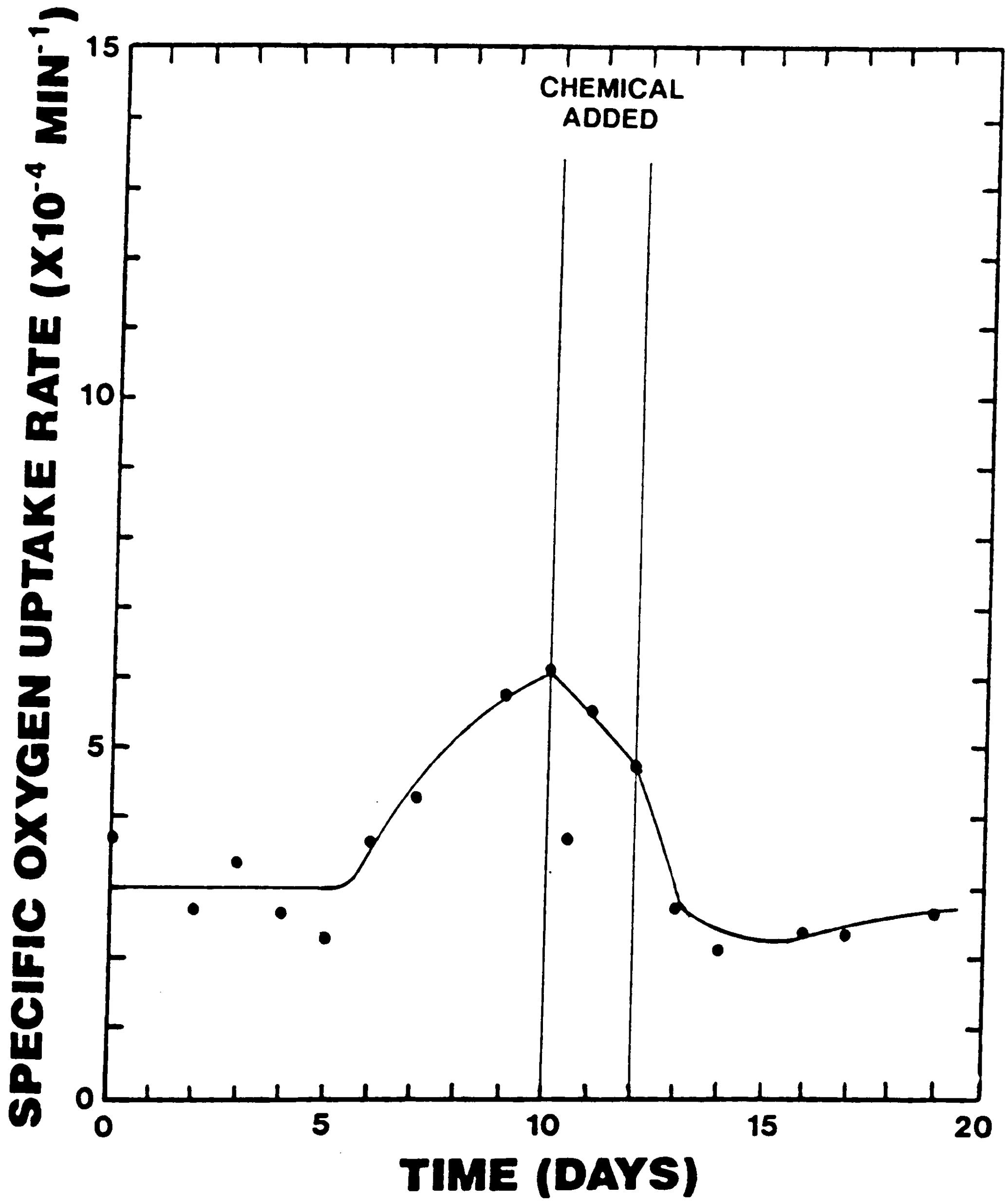


FIGURE 21. Variation in specific oxygen uptake rate (SOUR) over time for a continuous flow stirred tank bioreactor dosed with "Dri-Kem."

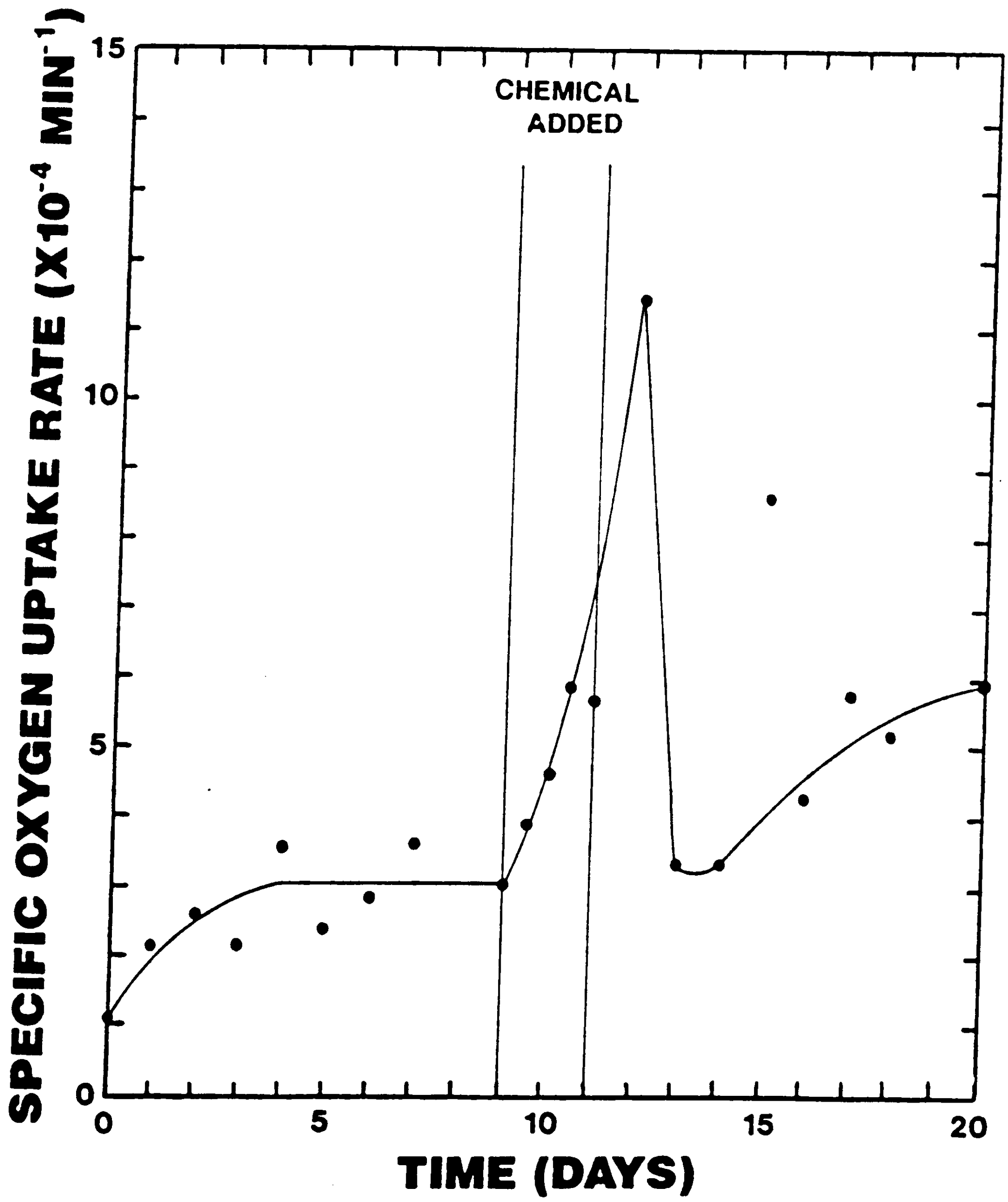


FIGURE 22. Variation in specific oxygen uptake rate (SOUR) over time for a continuous flow stirred tank bioreactor dosed with "D-Odor-It."

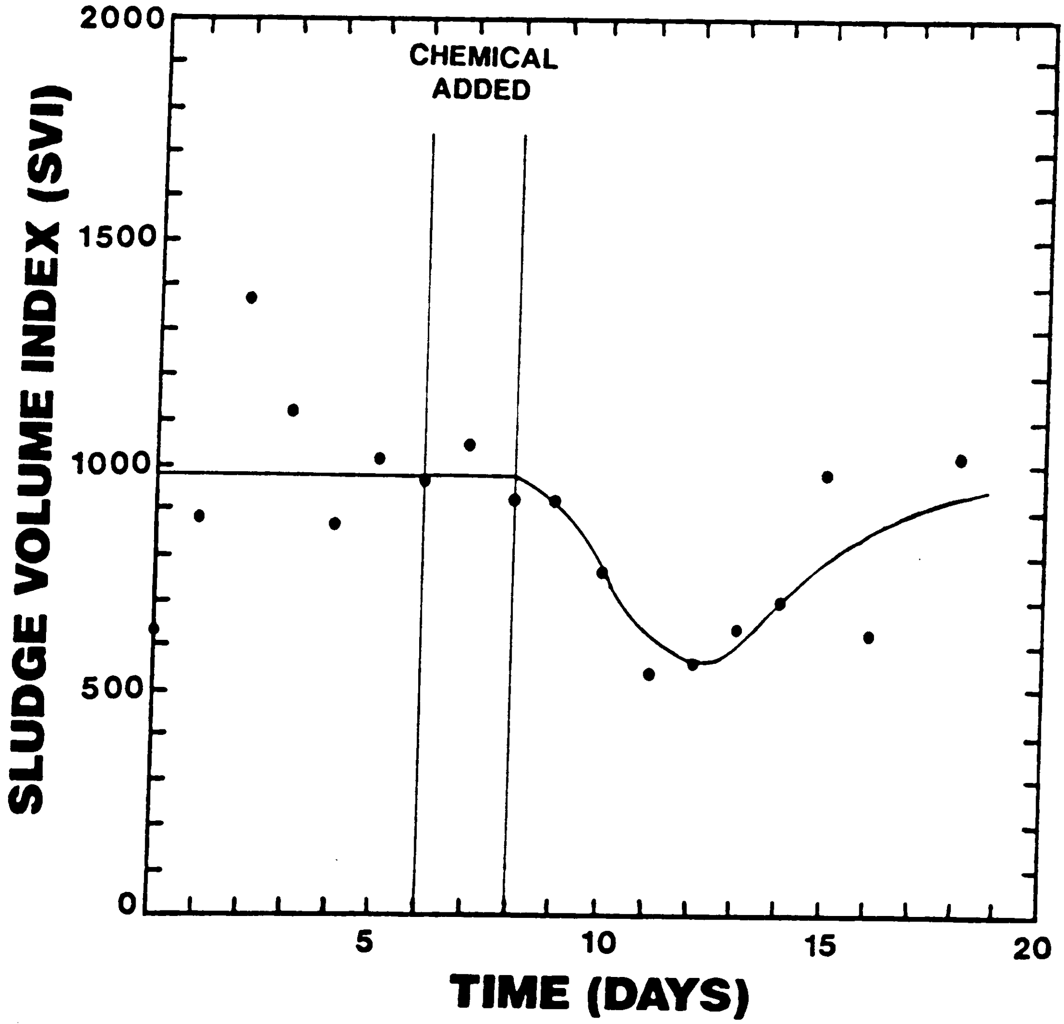


FIGURE 23. Variation in sludge volume index (SVI) over time for a continuous flow stirred tank bioreactor dosed with "Aqua-Kem."

The sludge volume index for activated sludge dosed with formaldehyde solution (fig. 24) was declining before dosing began, but sharply increased during the dosing phase. The index then steadily declined over the next ten days after dosing was stopped and appeared to stabilize at about 550.

Activated sludge dosed with "D-Odor-It" (fig. 25) showed erratic SVI changes throughout the experiment, before, during, and after dosing. In general, the index was increasing before dosing, dropped rapidly during dosing and began to slowly increase after dosing.

The activated sludge in the bioreactor dosed with "Dri-Kem" (fig. 26) exhibited almost no change in SVI as a result of dosing. The index then increased sharply to a maximum value of about 1200 seven days after dosing was stopped.

COD Removal

The effluent COD concentration in the continuously fed activated sludge bioreactor dosed with "Aqua-Kem" (fig. 27) rose by about 1000 mg/L after 36 hours of dosing. The COD concentration started to decline by the end of two days of dosing and continued to decline after seven days of no dosing.

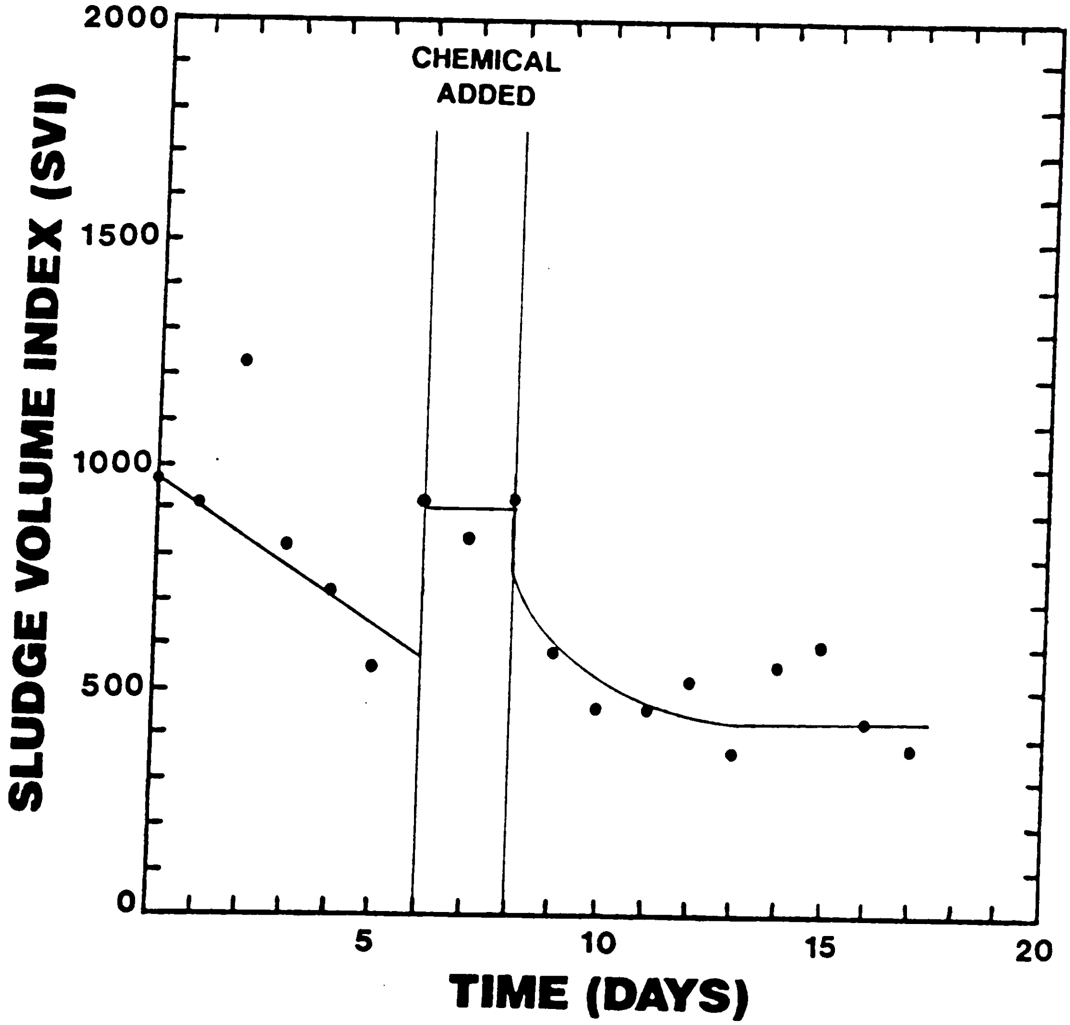


FIGURE 24. Variation in sludge volume index (SVI) over time in a continuous flow stirred tank bioreactor dosed with formaldehyde solution.

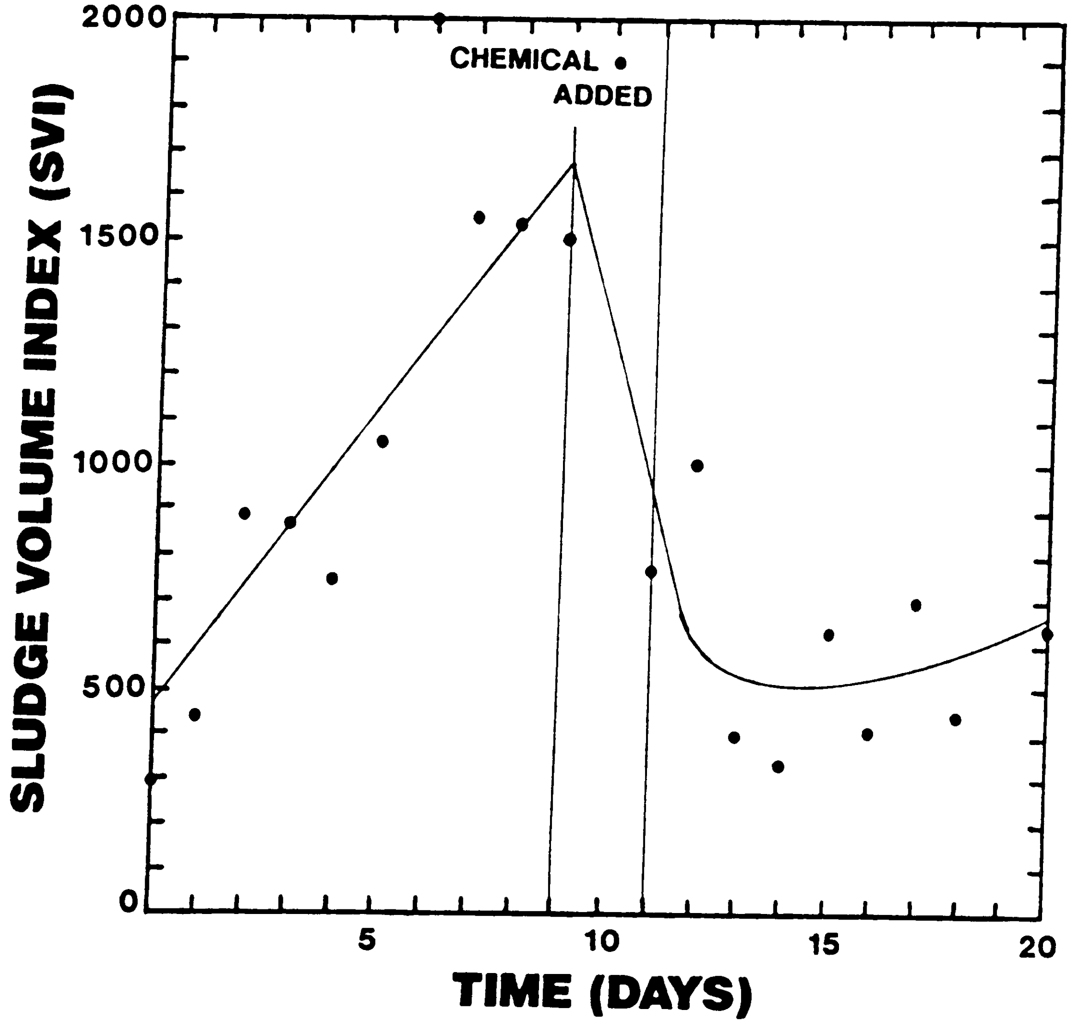


FIGURE 25. Variation in sludge volume index (SVI) over time for a continuous flow stirred tank bioreactor dosed with "D-Odor-It."

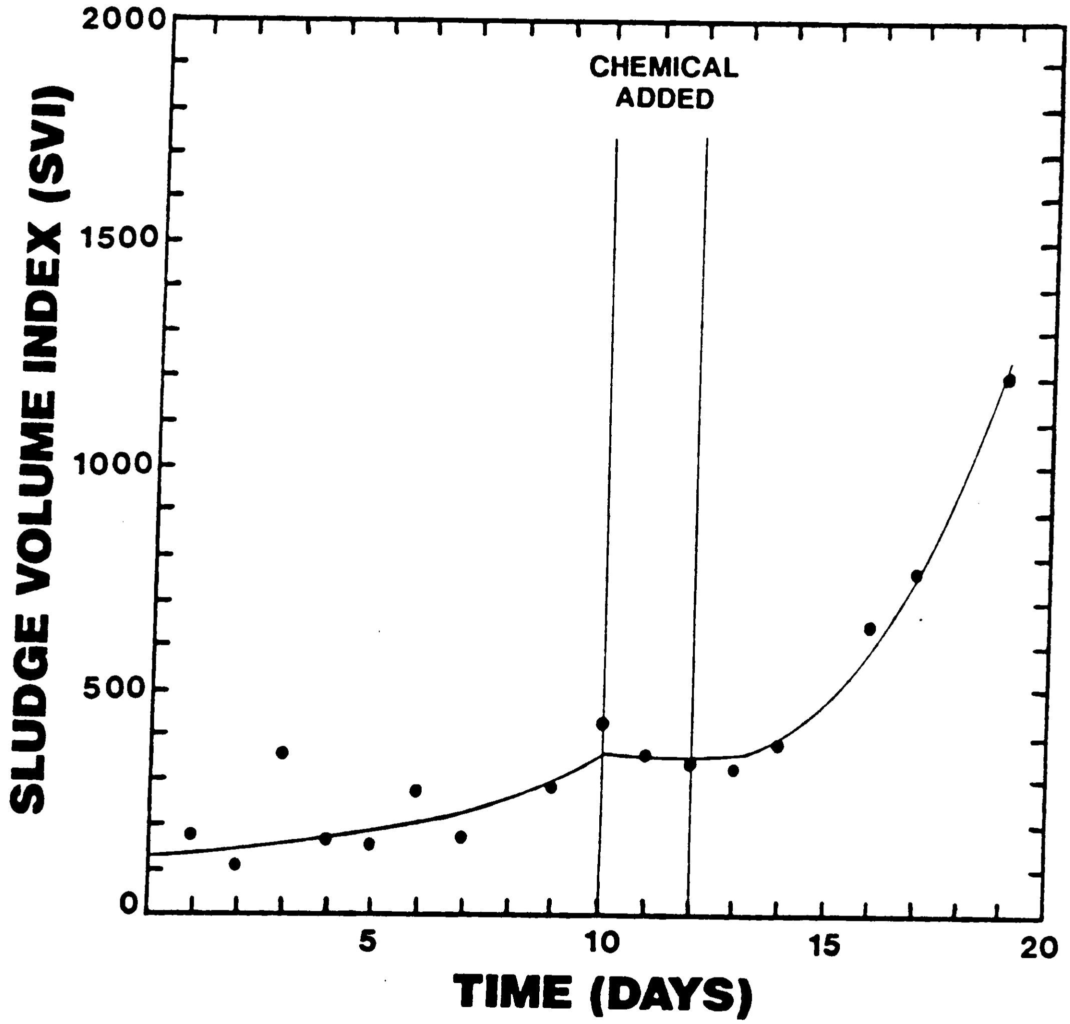


FIGURE 26. Variation of sludge volume index (SVI) over time in a continuous flow stirred tank bioreactor dosed with "Dri-Kem."

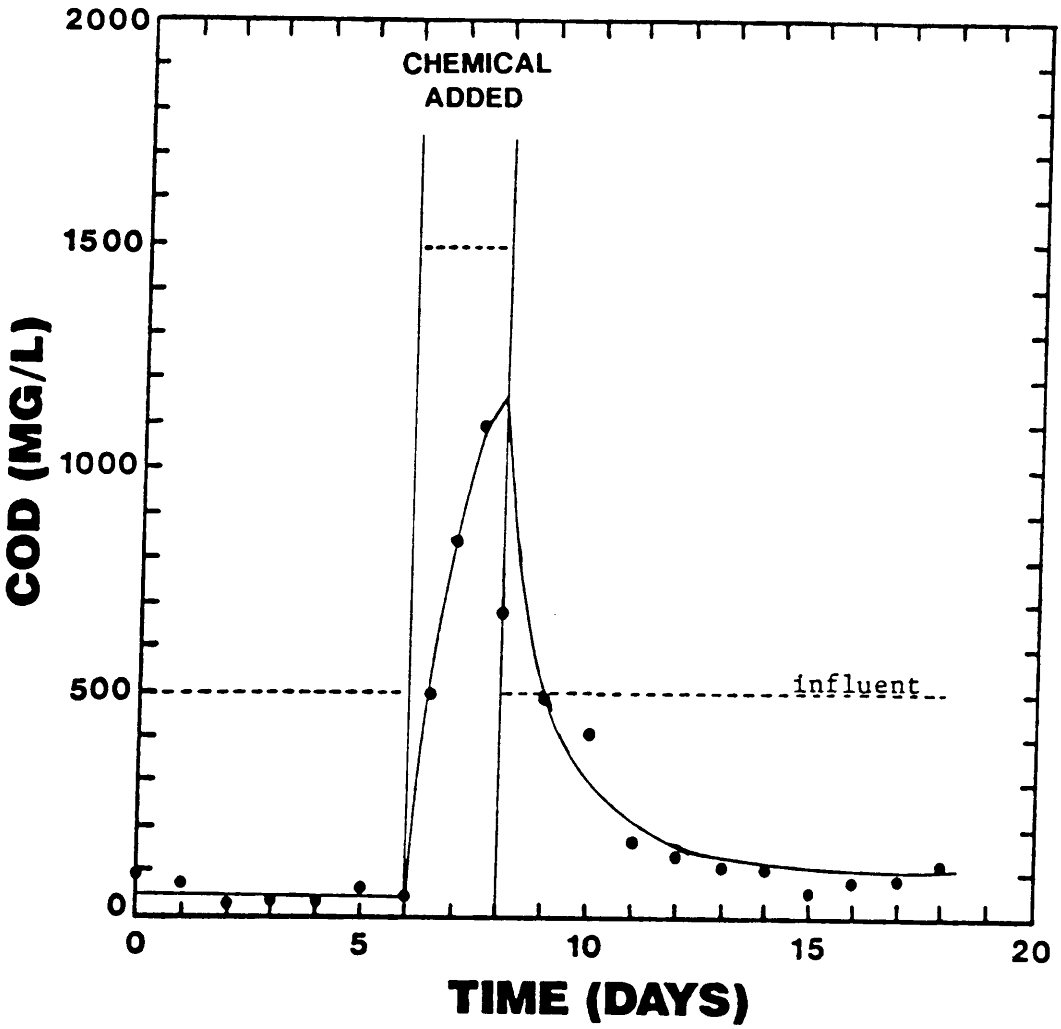


FIGURE 27. Variation in effluent COD concentration over time in a continuous flow stirred tank bioreactor dosed with "Aqua-Kem."

Formaldehyde added to activated sludge (fig. 28) also resulted in an increased effluent COD concentration by about 1100 mg/L. The COD concentration began to decline after two days of dosing, similarly as occurred with "Aqua-Kem," and continued declining for nine days after dosing stopped.

The effluent COD for the continuously fed activated sludge dosed with "D-Odor-It" (fig. 29) increased over the dosing period. The COD concentration then decreased rapidly during the last day of dosing and into the recovery phase.

In contrast to the other odor control chemicals and formaldehyde solution, the COD concentration in the effluent in activated sludge dosed with "Dri-Kem" (fig. 30) dropped by about 100 mg/L after one day of dosing. The Effluent COD began to rise again after two days of dosing, but not up to the pre-dosing base-level concentration. The effluent COD concentration returned to near pre-dosing base-level about seven days after dosing stopped.

Dye or Color Removal

Because blue dyes in some of the odor control chemicals appeared to accumulate in the bioreactors, batch experiments were conducted to attempt to measure the

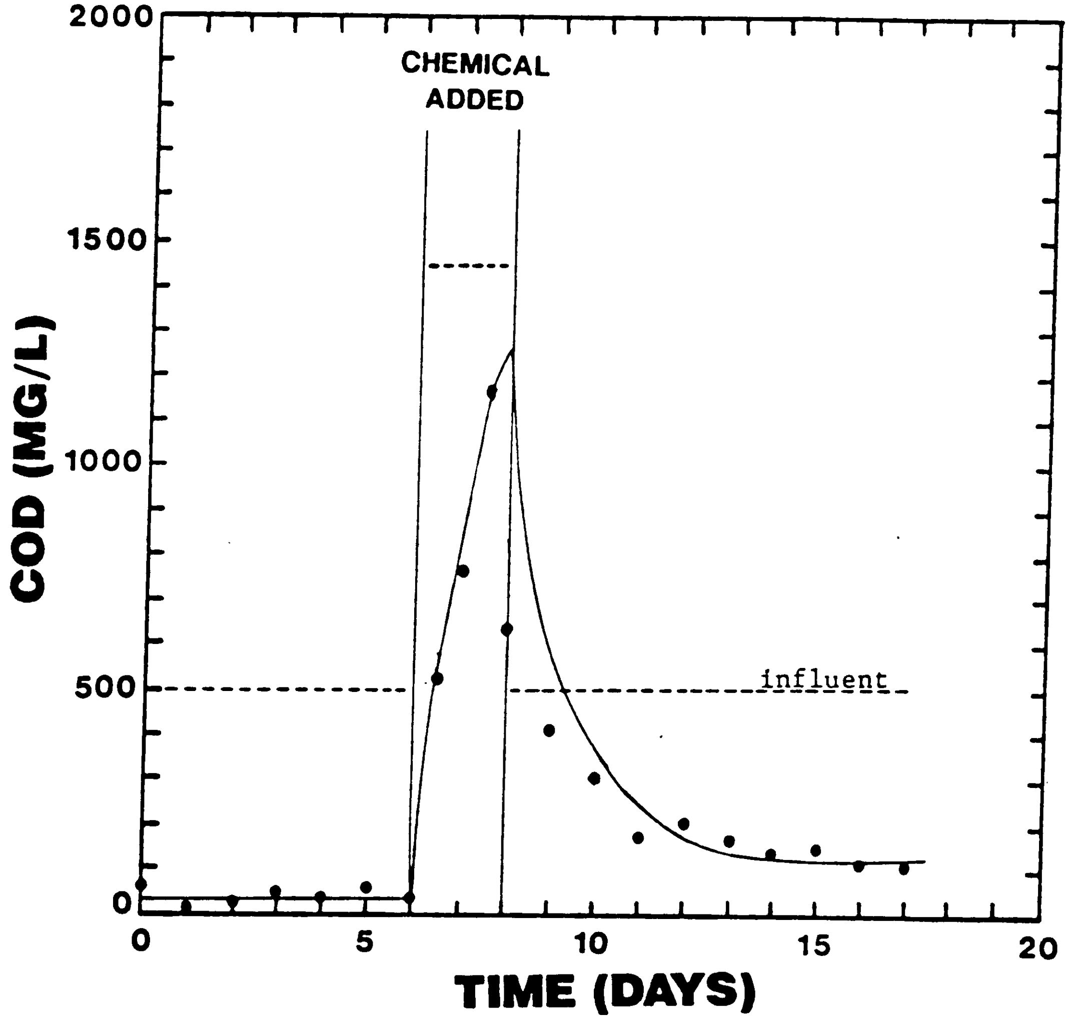


FIGURE 28. Variation in effluent COD concentration over time in a continuous flow stirred tank bioreactor dosed with formaldehyde solution.

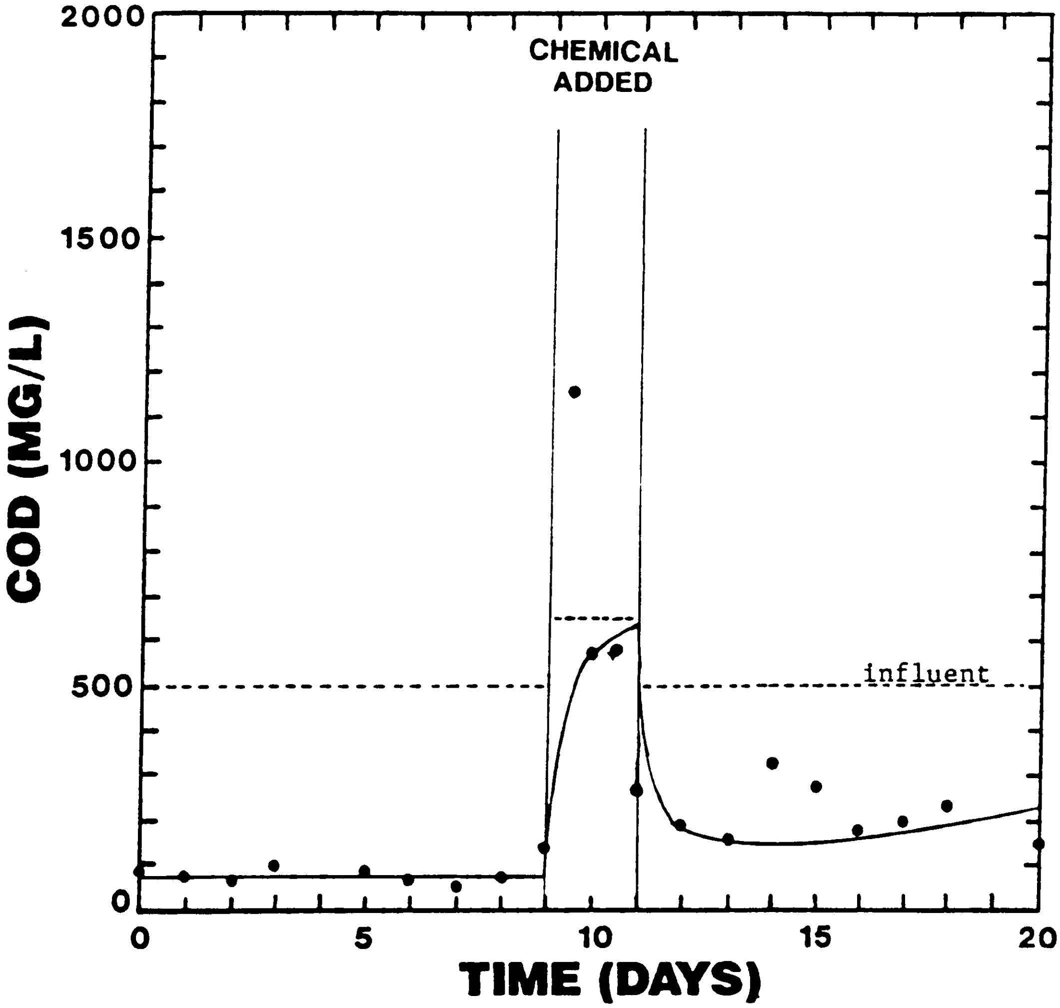


FIGURE 29. Variation in effluent COD concentration over time for a continuous flow stirred tank bioreactor dosed with "D-Odor-It."

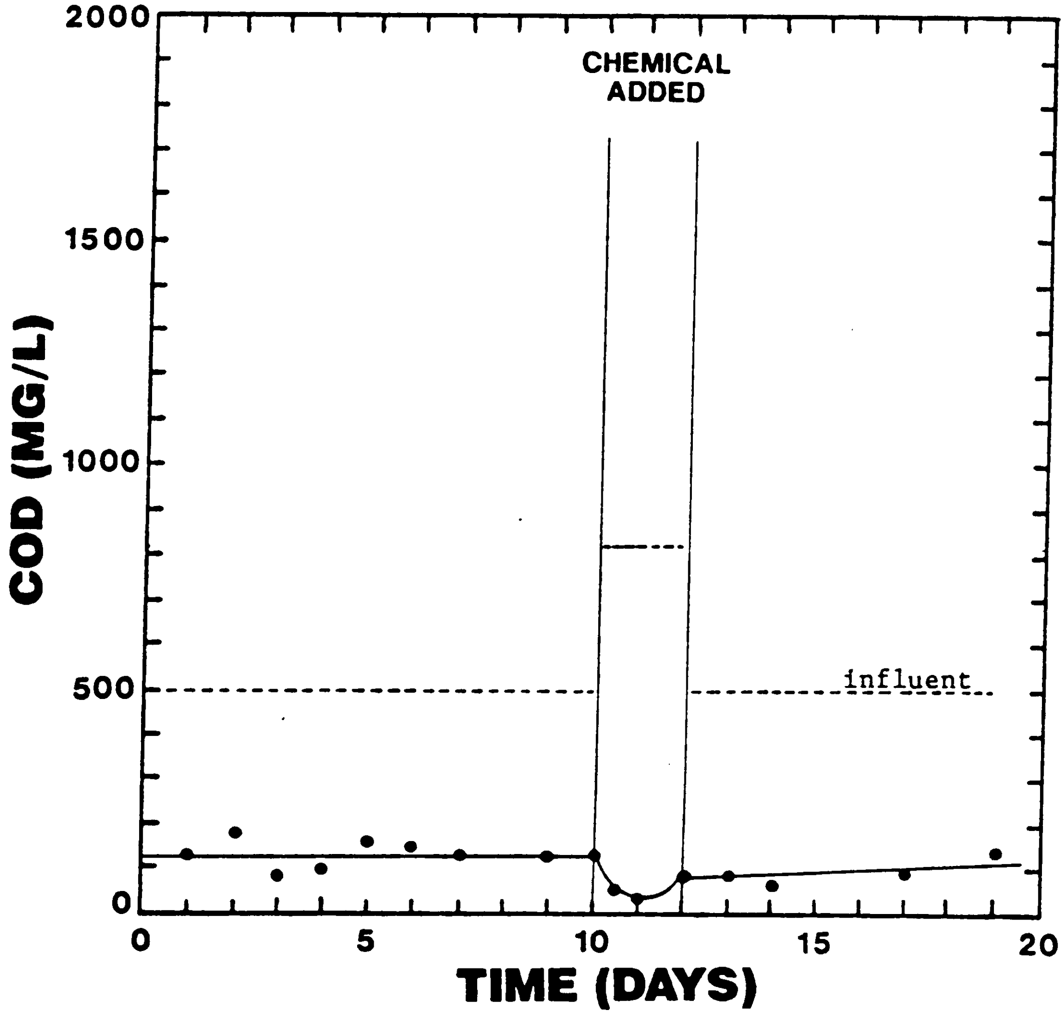


FIGURE 30. Variation in effluent COD concentration over time in a continuous flow stirred tank bioreactor dosed with "Dri-Kem."

efficiency of activated sludge in removing the dyes. Measurements of wavelength versus optical absorbance were conducted to determine the optimum wavelength that should be used to measure optical absorbance of the dyes. Over the range from 400 and 700 nanometers, 630 nanometers was determined to be the optimum wavelength (fig. 31) in order to measure the presence or intensity of the blue dye in the three odor control chemicals with minimum interference from the dark yellow to brown color of the undosed activated sludge. All of the following results were measured using a wavelength of 630 nanometers.

The optical absorbance of the activated sludge dosed with "Aqua-Kem" increased gradually during the dosing period (fig. 32). The peak absorbance after six days of dosing is 0.377. Five days after dosing, the absorbance was reduced to 0.174 in a pattern which indicated that the dye was being flushed from the system.

The color of the effluent produced by the bioreactor batch fed "Aqua-Kem" was dark blue to blue-green, about the same color as the mixed liquor in the bioreactor.

The addition of "D-Odor-It" (fig. 33) to activated sludge resulted in a smaller increase of optical absorbance. A peak value of 0.105 was obtained on the sixth day of chemical dosing. The absorbance returned

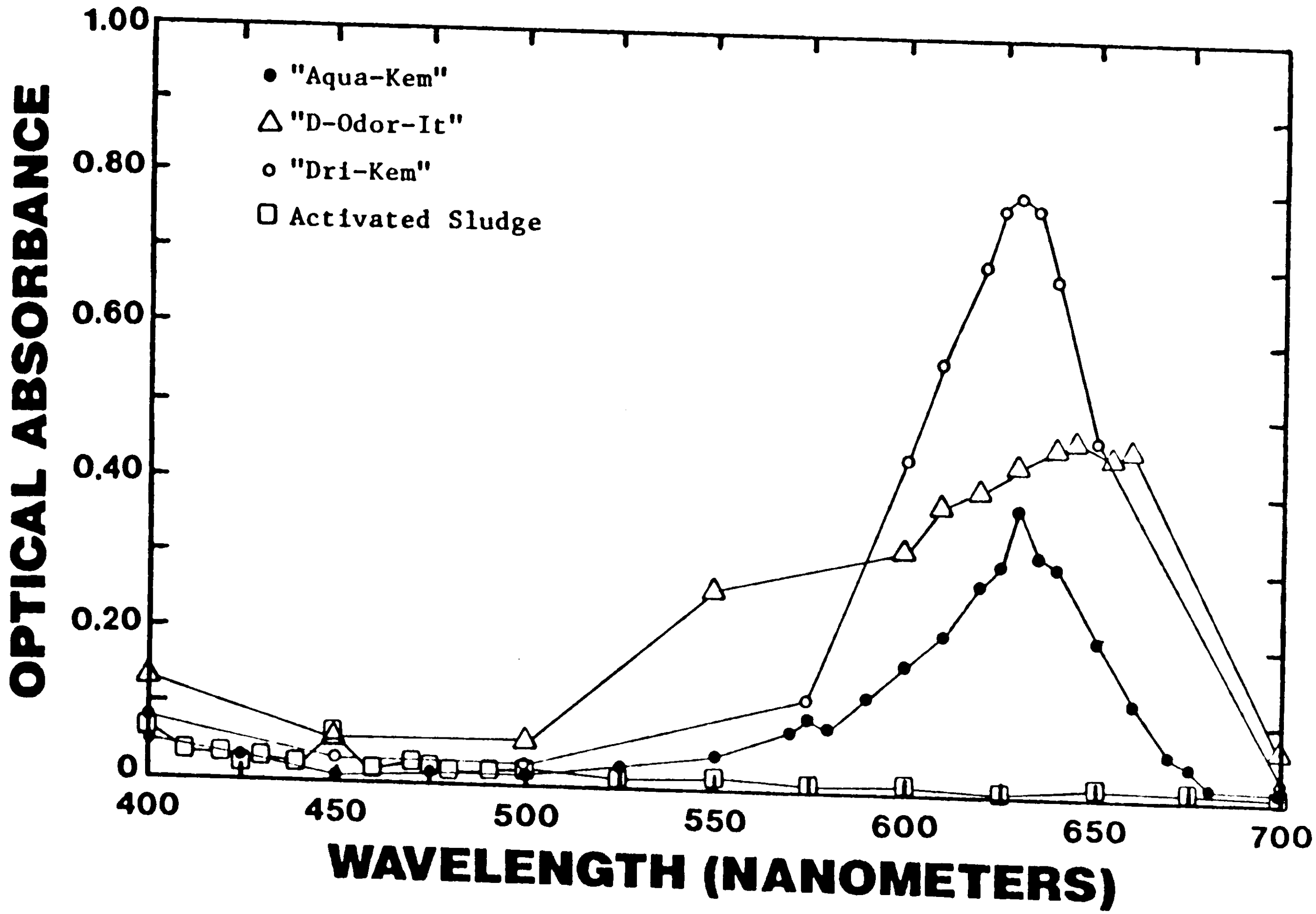


FIGURE 31. Change of optical absorbance with wavelength for dyes in three odor control chemicals and activated sludge.

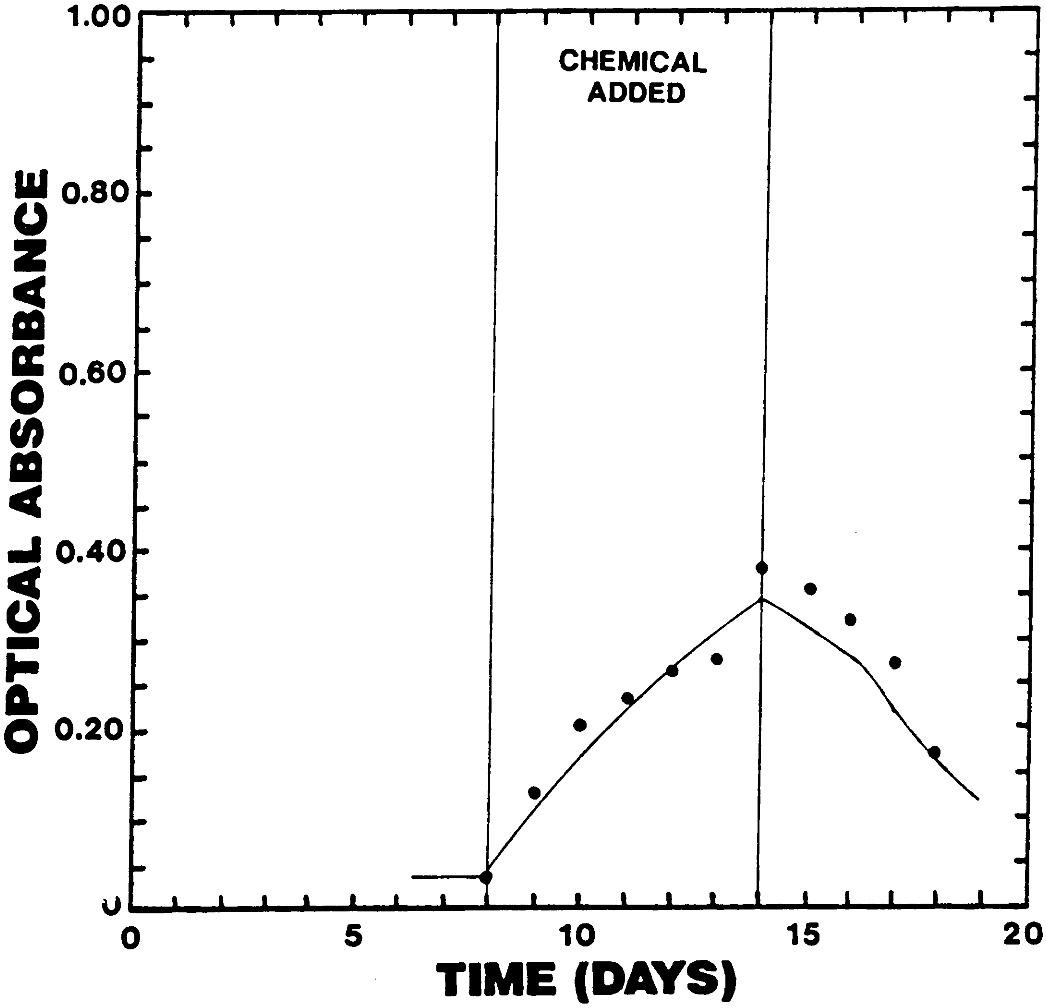


FIGURE 32. Change of optical absorbance for filtered effluent from batch bioreactor dosed with "Aqua-Kem."

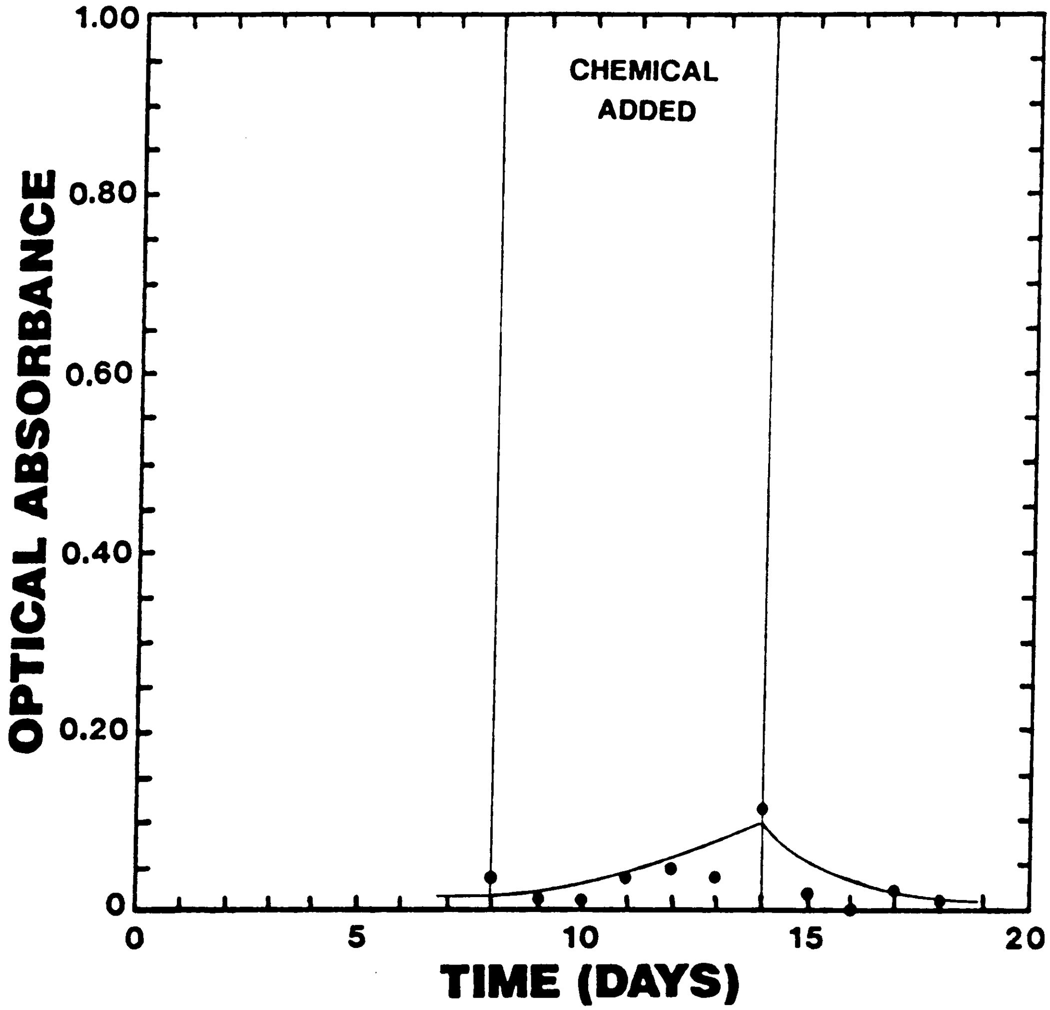


FIGURE 33. Change of optical absorbance over time for filtered effluent from batch reactor dosed with "D-Odor-It."

approximately to the pre-dosing absorbance level only one day after dosing was stopped.

In contrast to "Aqua-Kem," the bioreactor batch fed "D-Odor-It" contained a clear to lightly yellow colored effluent. The activated sludge turned only slightly darker brown than what had been its original color before dosing.

"Dri-Kem" (fig. 34) also gradual increased in optical absorbance during six days of chemical dosing. Peak absorbance, 0.161, was reached at the end of the six day dosing phase. The absorbance gradually declined for five days after dosing stopped.

Foam Generation Measurements

During the aerated bioreactor experiments, the liquid odor control chemicals "Aqua-Kem" and "D-Odor-It" were discovered to cause large volumes of white foam resembling soap suds. The two liquid odor control chemicals were batch tested to quantify the volume of foam generated upon aeration versus dose for the liquid odor control chemicals.

"Aqua-Kem" began to generate foam when added to tap water at a concentration of 0.4 ml/L (fig. 35). After 2.0 ml/L was added, more that 2000 cubic centimeters of foam were produced.

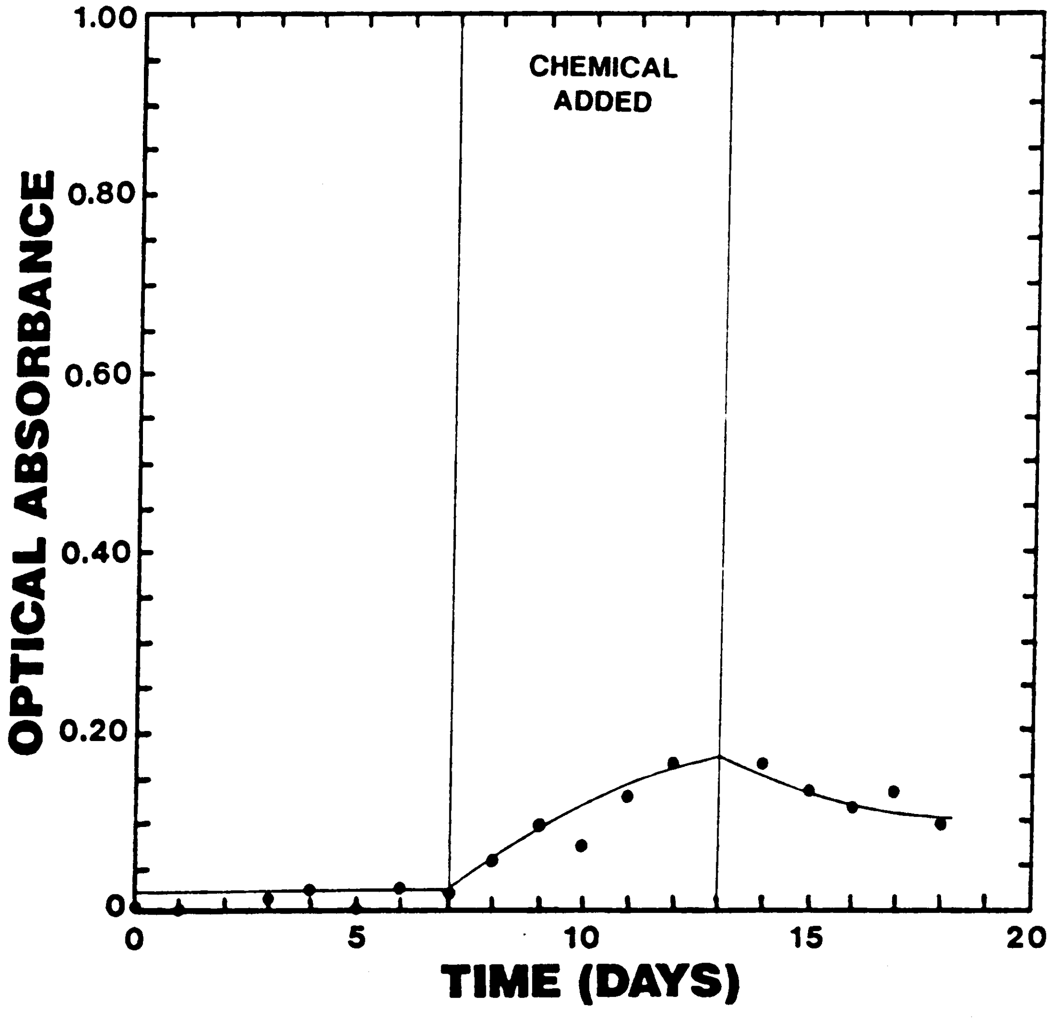


FIGURE 34. Change of optical absorbance for filtered effluent from batch bioreactor dosed with "Dri-Kem."

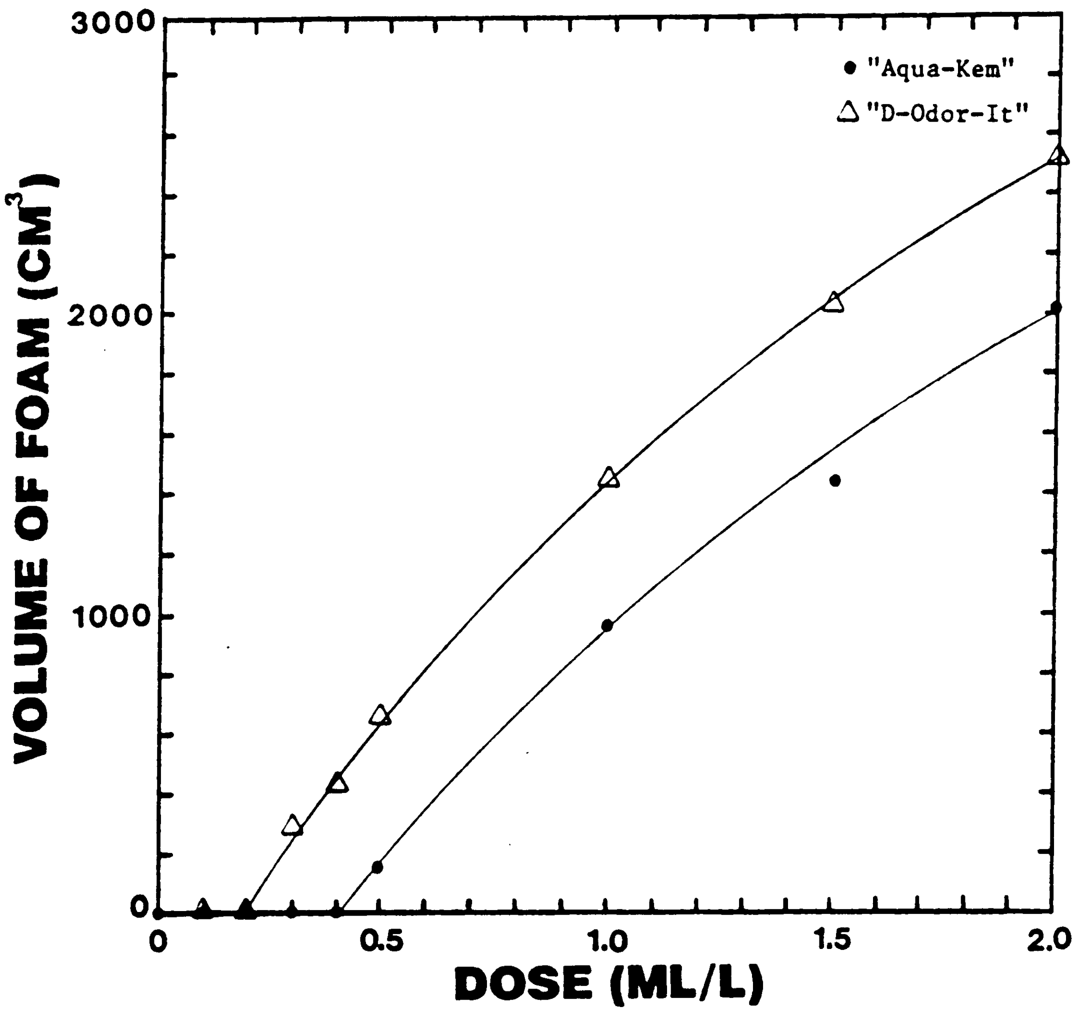


FIGURE 35. Volume of foam generated versus dose for two liquid odor control chemicals.

After 0.2 ml/L of "D-Odor-It" was added to tap water, foam generation started (fig. 35). More that 2500 cubic centimeters of foam were produced when 2.0 ml/L of "D-Odor-It" was added to water and aerated.

DISCUSSION

This chapter discusses the effects the three odor control chemicals and formaldehyde solution had on activated sludge in the slug fed and continuous flow bioreactor experiments.

"Aqua-Kem"

In both the slug fed and continuous flow bioreactor experiments, "Aqua-Kem" caused an immediate shock effect to the bioreactors as indicated by the sudden drop of suspended solids, rapid rise in specific oxygen uptake rate, and rapid rise in effluent COD concentration. The deterioration of performance, particularly denoted by the rise in effluent COD indicated that the addition of "Aqua-Kem" in concentrations from 20 to 100 percent of the manufacturer's recommended dose can damage the effectiveness of a bioreactor to treat wastewater.

The rise in specific oxygen uptake rate suggests that at least some of the components of "Aqua-Kem" may be biodegradable. However, the sharp increase in SOUR was accompanied by an equally sharp increase in effluent COD concentration, suggesting that the readily degradable components are only a minor fraction of the total components present in "Aqua-Kem."

"Aqua-Kem" when added to and later withdrawn from an activated sludge bioreactor does not appear to be readily biodegradable. The dose of "Aqua-Kem" contributed a significant amount of additional COD to the influent which tended to accumulate and inhibit bactopeptone utilization in the continuous flow bioreactor during dosing (fig. 36). The decrease in effluent COD after dosing approximately matched the slope of the flushing curve, indicating that the reduction in effluent COD during the recovery period was due to hydraulic washing-out of "Aqua-Kem" and not due to biodegradation.

The addition of "Aqua-Kem" appears to have hindered the biodegradation of bactopeptone to which the activated sludge was acclimated. Particularly after dosing stopped, the effluent COD concentration remained elevated and did not return to pre-dosing levels. Activated sludge may be capable of acclimating to "Aqua-Kem" dosed influent, but more than two days are needed for acclimation by a continuous flow bioreactor, and even more time is needed by a batch operated bioreactor.

The ability of the sludge to settle and compact after dosing with "Aqua-Kem" changed relatively slowly after dosing, and did not appear to be damaged. The results suggest that "Aqua-Kem" may have no effect or a beneficial

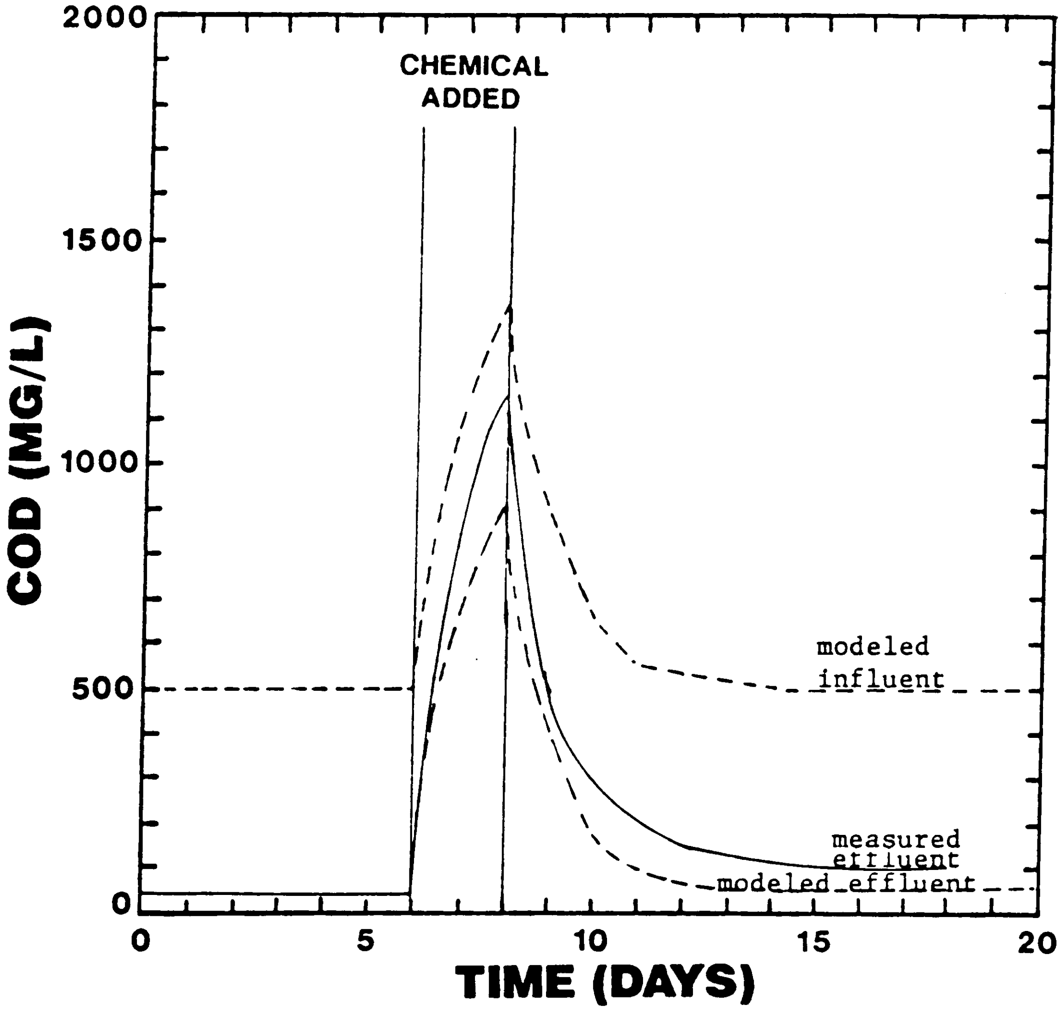


FIGURE 36. Theoretical reactor analysis applied to continuous flow bioreactor dosed with "Aqua-Kem."

effect on the settling characteristics of activated sludge. The blue dye used to make "Aqua-Kem" did not appear to be biodegradable in an aerobic bioreactor. The dye tended to remain in the batch operated bioreactor after dosing, suggesting that the removal of dye was due to the wasting of sludge. In this regard, the dye may be used as a tracer for the presence of this odor control chemical in the treatment system.

The production of foam from surfactants in "Aqua-Kem" constituted a real operational and stability problem to aerated bioreactors. Doses of "Aqua-Kem" as small as 0.2 ml per liter of water, only 13% of the manufacturer's recommended dose, initiated the generation of white foam. The microbial floc of the activated sludge tended to adhere to the foam and to be carried up and out of the bioreactor. Loss of some of the suspended solids in the batch and continuously flow experiments was due to suspended solids being lifted out of the bioreactor and deposited on the outside of the tank.

Formaldehyde Solution

The results obtained from the batch and continuous flow bioreactors dosed with formaldehyde solution correlate very closely with the results discussed above for "Aqua-Kem." This is to be expected since formaldehyde is a major constituent of "Aqua-Kem."

Activated sludge dosed with formaldehyde solution experienced a decline in suspended solids, an increase in specific oxygen uptake rate, and a sharp rise in effluent COD concentration. After dosing with formaldehyde, the suspended solids concentrations decreased in a manner and magnitude similar to the declines experienced by the bioreactors dosed with "Aqua-Kem."

Some portion of formaldehyde solution, probably methanol, appears to be biodegradable as demonstrated by the increase in SOUR. However as noted for "Aqua-Kem" above, the increase in SOUR is accompanied by an equally sharp increase in effluent COD concentration. The rise in specific oxygen uptake rate may also be due to the blocking of synthesis within the microbial cells rather than by biodegradation of the formaldehyde solution.

The addition of formaldehyde to the influent inhibited the ability of the reactor to remove influent COD. The comparison of recorded effluent COD loading and subsequent flushing (fig. 37) suggests that COD was accumulating and then being flushed from the bioreactor during the recovery phase rather than being metabolized by microorganisms. During the dosing phase the increase in effluent COD suggests that all metabolism was nearing

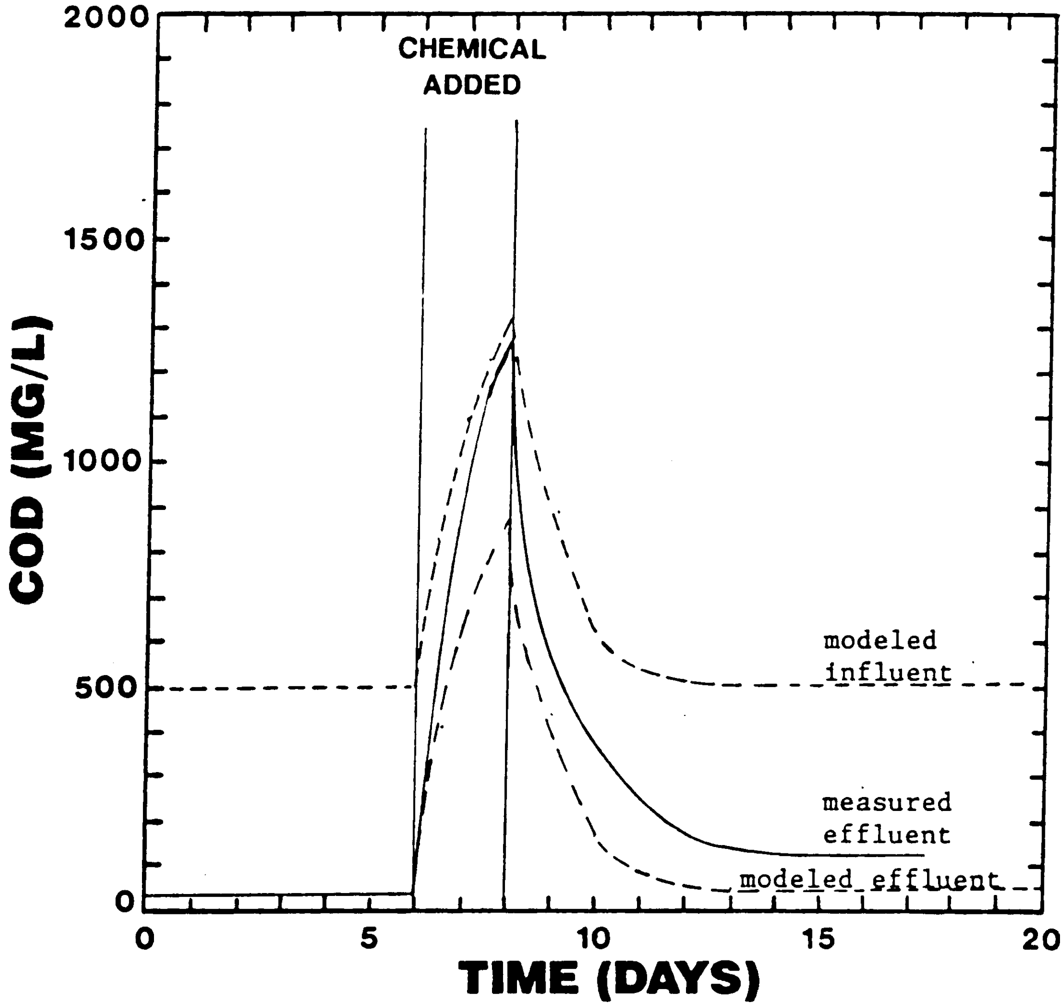


FIG. 37. Accumulation-flushing reactor analysis applied to continuous-flow bioreactor dosed with formaldehyde.

total inhibition. Recovery was evident, however, indication that after dosing a new microbial culture would not be needed.

The "Aqua-Kem" and formaldehyde solutions strongly suggest that formaldehyde is the source of the decline in bioreactor performance after dosing with "Aqua-Kem."

"D-Odor-It"

The results of dosing with "D-Odor-It" shared many similarities to the results of dosing with "Aqua-Kem" and formaldehyde. Suspended solids concentrations dropped sharply, specific oxygen uptake increased during dosing and remained elevated afterward, and effectiveness of the sludge to remove influent COD dropped sharply and almost immediately. The ability of the bioreactor to remove COD in the influent was inhibited by the addition of "D-Odor-It" (fig. 38).

The changes in solids concentrations and specific oxygen uptake rate measured during the continuous flow experiments suggest that the use of "D-Odor-It" may be more damaging to an activated sludge bioreactor than "Aqua-Kem" or formaldehyde. While "Aqua-Kem" was added at 100 percent of the manufacturer's recommended dosage in the continuous flow experiments, "D-Odor-It" was added at only 50 percent, yet its detrimental effects to activated

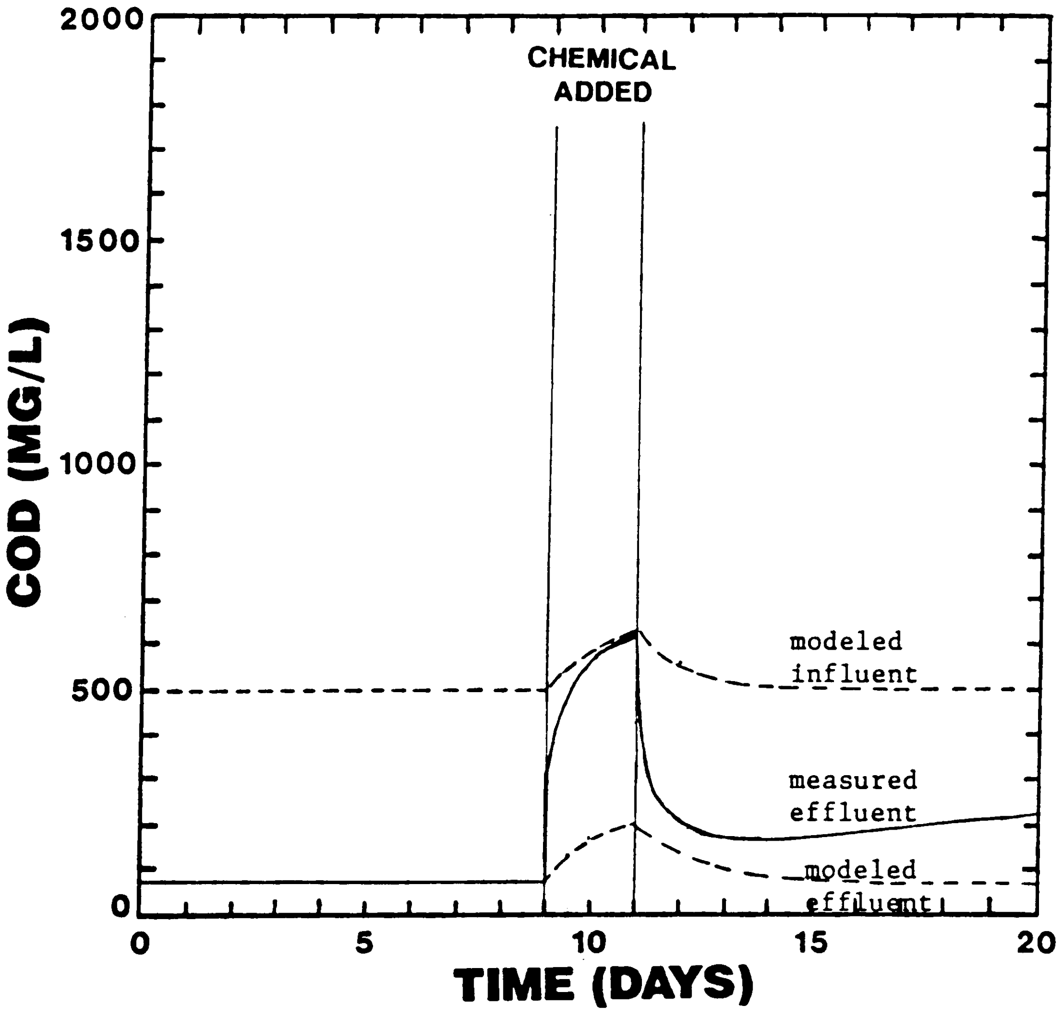


FIGURE 38. Theoretical reactor analysis applied to continuous flow bioreactor dosed with "D-Odor-It."

sludge were more severe. Only sludge settling and compaction showed indications of improvement as a result of dosing with "D-Odor-It."

In contrast to the blue dyes contained in "Aqua-Kem" and "Dri-Kem," the blue dye in "D-Odor-It" appears to accumulated slowly in the batch activated sludge reactor and appears to have to have been partially biodegradable. The optical absorbance remained low through most of the dosing period, and tended to rise near the end of dosing after the viability of the activated sludge had been damaged after several days of dosing. The color of the effluent after dosing with "D-Odor-It" was about the same color as the effluent produced by the bioreactor before dosing.

Like "Aqua-Kem," the liquid odor control chemical contains surfactants that created foam upon aeration. The foam had a strong tendency to carry suspended solids out of the reactor. As a result of this foaming, microorganisms needed to purify the wastewater will be removed from the bioreactor and effluent quality will suffer. The loading of odor control chemicals containing surfactants into bioreactor must be carefully watched to see that the critical concentration leading to foam generation does not occur.

"Dri-Kem"

Overall, the results of adding "Dri-Kem" to activated sludge were not as detrimental to the ability of the sludge to remove COD. A contributing factor may have been that less COD is contained in "Dri-Kem" than in the same percentage of manufacturer's recommended dose of "Aqua-Kem" or "D-Odor-It."

In contrast to the results obtained from dosing activated sludge with the other two odor control chemicals and formaldehyde solution, dosing with "Dri-Kem" appears to have improved the ability of the sludge to treat the influent. Suspended solids concentrations increased and the ability of the sludge to remove influent COD appears to have increased (fig. 39). The specific oxygen uptake rate increased, but not as sharply or as high as the increased measured using the three other chemicals. This is to be expected since the COD in "Dri-Kem" is lower than in "Aqua-Kem" and "D-Odor-It."

During continuous flow dosing of the bioreactor with "Dri-Kem," the sludge volume index declined only slightly during the two days of dosing, and appeared to have risen rapidly two days into the recovery period. The rise of the sludge volume index during recovery may have been an indication of the instability of the bioreactor as a

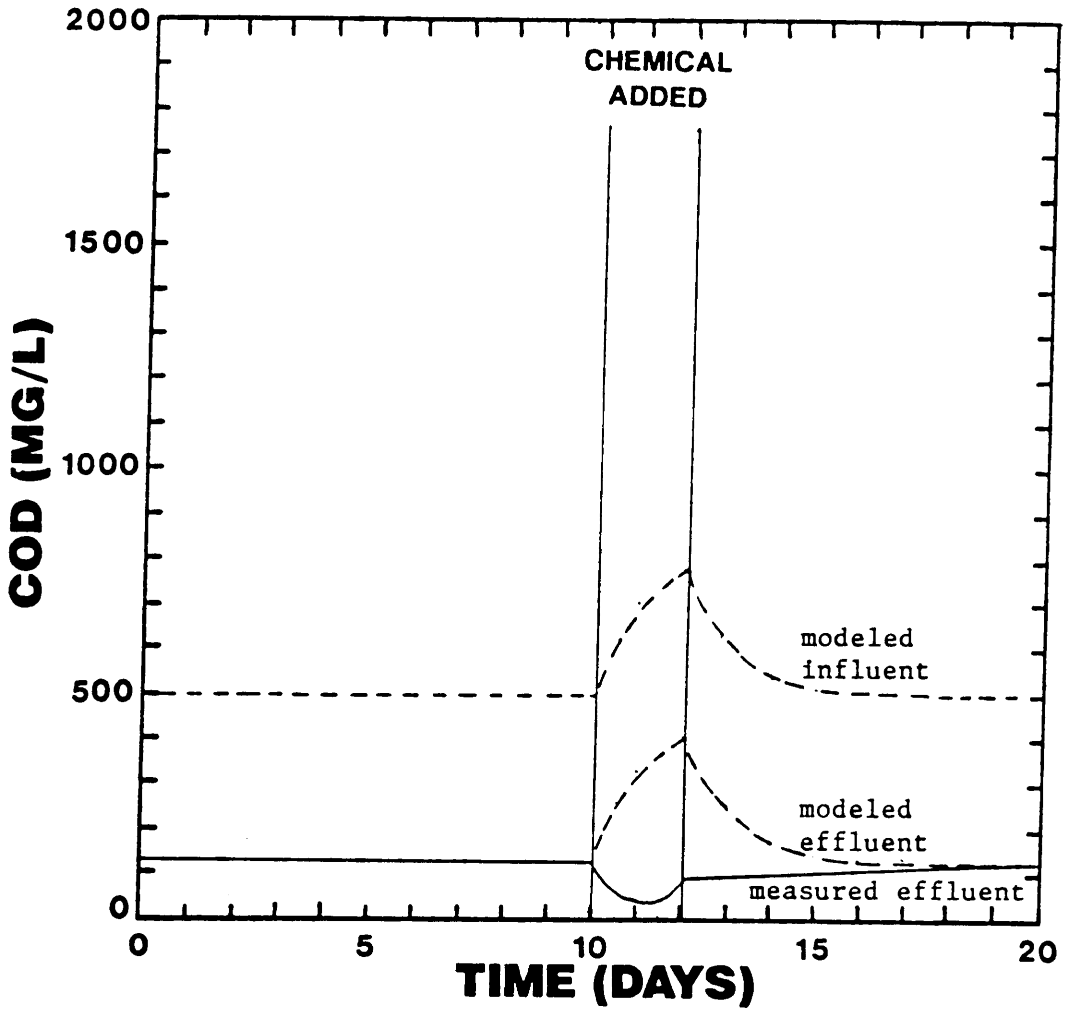


FIGURE 39. Theoretical reactor analysis applied to continuous flow bioreactor dosed with "Dri-Kem."

result of being shock loaded with "Dri-Kem," then being shocked again by having the "Dri-Kem" withdrawn. The increased sludge volume index may also have been due to hindered settling because of the higher concentration of suspended solids produced by an increase in biodegradable feed, and may not have been as severe a settling problems as it appeared.

The blue dye contained in "Dri-Kem" accumulated in the batch fed bioreactor and did not appear to biodegrade. The color disappeared in the blue effluent and in the wasted activated sludge at about the same rate in which it was added during dosing.

Discussion of Formaldehyde Solubility and Its Importance to "Aqua-Kem" and "Dri-Kem"

The main reason for the differences in the responses of the bioreactors to equivalent doses of "Aqua-Kem" and "Dri-Kem" may have been due to the chemical state of formaldehyde present in each. Paraformaldehyde is a solid, polymerized form of formaldehyde, which is supposed to dissolve easily in water (30). Therefore, one might expect the bioreactors to react similarly to "Aqua-Kem" and "Dri-Kem."

However, when "Dri-Kem" was added, the paraformaldehyde granules did not dissolve completely in

Solid grains of paraformaldehyde were present in the of bottom the batch dosed bioreactors five days after dosing was stopped. The temperature at which all experiments were conducted, 20°C, may have been too low for paraformaldehyde to dissolve completely in activated sludge.

Microorganism in activated sludge can acclimate to low concentrations of formaldehyde (9, 10, 11, 13, 14, and 24), and are poisoned by large concentrations of formaldehyde (18, 20, and 24). If the solubility of paraformaldehyde in activated sludge was low, then less formaldehyde is going into solution when "Dri-Kem" is added to the bioreactor. The microorganisms may be able to better adapt to "Dri-Kem" than to "Aqua-Kem" because the shock load of formaldehyde experienced by the microbes immediately after dosing is less than the shock when liquid formaldehyde solution is added in the form of "Aqua-Kem."

Discussion of Shock Loading and Microbial Population Shifts

One explanation for the changes seen during and after dosing of activated sludge with the odor control chemicals and formaldehyde may be that a shift had occurred in the microbial population present in the sludge. This new population may have been more capable of surviving the shocks of loading and withdrawing the chemicals, but did not appear as capable of removing influent substrate and did not settle as readily as the microbes present before dosing. The result was that effluent quality suffered as a result of the shock loading and withdrawl.

SUMMARY AND CONCLUSIONS

The following conclusions may be drawn as a result of the slug fed and continuous flow bioreactor experiments conducted using the three odor control chemicals and formaldehyde solution. These conclusions are summarized in Table 6.

"Aqua-Kem"

The addition of the liquid odor control chemical "Aqua-Kem" severely damages the microbial suspended solids concentration in bioreactors. The damaging component contained in "Aqua-Kem" is concluded to be formaldehyde. The ability of the activated sludge to settle is not adversely affected, but the ability of the bioreactor to remove influent COD is strongly inhibited and oxygen requirements increase.

Activated sludge does not appear as dose sensitive to "Aqua-Kem" as it does to the duration of the application of the chemical and the length of recovery time. Repeated applications and withdrawls of wastewater containing "Aqua-Kem" greatly increase the likelihood that the bioreactor will fail.

TABLE 6. Summary of the effects of odor control chemicals and formaldehyde solution on activated sludge.

	"Aqua-Kem"	Formaldehyde Solution	"D-Odor-It"	"Dri-Kem"
Suspended Solids:	Large Decrease	Large Decrease	Decrease	Increase
Oxygen Required:	Large Increase	Large Increase	Large Increase	About Same
Settling & Compaction :	Not Affected	Not Affected	Not Affected	Possibly Hindered
COD Removal:	Greatly Hindered	Greatly Hindered	Greatly Hindered	About Same
Dye Degradable:	No	Does Not Apply	Yes	No
Foaming Problems:	Potentially Significant	None	Potentially Significant	None

The blue dye used in "Aqua-Kem" is not biodegradable, and foam generated by surfactants contained in "Aqua-Kem" may cause suspended solids loss and operational problems.

Formaldehyde Solution

The least acceptable chemical tested using the activated sludge system was formaldehyde. The microbial suspended solids concentrations were severely reduced, oxygen uptake rates increased dramatically, and the ability of the activated sludge to remove COD was nearly eliminated. Activated sludge is capable of acclimating to continuously applied low doses of formaldehyde, but repeated application and withdrawl of formaldehyde greatly increases the tendency of the bioreactor, whether continuously fed or batch fed, to fail.

"D-Odor-It"

The adverse affects of chemical dosing will also occur with the use of "D-Odor-It." Those effects include a decline of microbial suspended solids, an increase in oxygen uptake, and an immediate and sharp increase in effluent COD. Like formaldehyde, "D-Odor-It" appears to hinder the utilization of the substrate to which the activated sludge was acclimated. Foaming problems may be caused by the surfactants contained in the liquid odor control chemical.

One advantage of "D-Odor-It" is that the blue dye contained in it is degradable by activated sludge.

"Dri-Kem"

The inclusion of "Dri-Kem" in wastewater causes fewer problems for treating wastewater than the other two odor control chemicals or formaldehyde solution.

In treating a wastewater containing "Dri-Kem," the microbial solids concentration increased, oxygen requirements are not negatively affected, and the COD concentration of the effluent is improved. Drawbacks of treating wastewater containing "Dri-Kem" are that the ability of the activated sludge to settle and compact may be hindered, and that the blue dye contained in "Dri-Kem" is not biodegradable.

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APPENDIX

Table A-1. Data for bioreactor slug fed bactopeptone and dosed with 20%, 0.31 ml/L, of manufacturer's recommended dose of "Aqua-Kem."

Day	Type Feed	Phase	MLSS, mg/L	MLVSS, mg/L	SOUR, $X10^{-4}$ min^{-1}	Optical Absorbance
0	B	S	1670	1200	1.08	
1	B	S	2410	2040	1.20	
2	B	S	2190	1830	0.86	
3	B	S	2040	1750	0.75	
4	B	S	1930	1710	1.12	
5	B	S	1820	1540	0.82	
6	B	S	1580	1390	0.89	
7	B	S	1510	1370	0.81	
8	B+AK	D	1400	1220	0.87	0.032
9	B+AK	D	1130	1030	2.93	0.128
10	B+AK	D	870	830	3.66	0.201
11	B+AK	D	640	580	5.34	0.236
12	B+AK	D	800	720	2.69	0.260
13	B+AK	D	490	460	1.90	0.276
14	B	R	560	540	2.05	0.377
15	B	R	710	660	1.31	0.357
16	B	R	520	480	1.92	0.319
17	B	R	570	440	1.58	0.268
18	B	R	360	340	3.06	0.174

B - Bactopeptone
AK - "Aqua-Kem"

S - Stabilization phase.
D - Dose phase.
R - Recovery phase.

Table A-2. Influent and effluent COD data for bioreactor slug fed bactopeptone and dosed with 20%, 0.31 ml/L, of manufacturer's recommended dose of "Aqua-Kem."

Day	Feed Type	Phase	Influent COD, ml/L	Effluent COD, mg/L
0	B	S	500	394
1	B	S	500	
2	B	S	500	96
3	B	S	500	32
4	B	S	500	100
5	B	S	500	65
6	B	S	500	41
7	B	S	500	41
8	B+AK	D	700	57
9	B+AK	D	700	475
10	B+AK	D	700	380
11	B+AK	D	700	452
12	B+AK	D	700	282
13	B+AK	D	700	281
14	B	R	500	188
15	B	R	500	322
16	B	R	500	390
17	B	R	500	449
18	B	R	500	177

B - Bactopeptone
AK - "Aqua-Kem"

S - Stabilization phase.
D - Dose phase.
R - Recovery phase.

Table A-3. Data for bioreactor slug fed bactopeptone and dosed with 0.31 ml/L of formaldehyde solution.

Day	Type Feed	Phase	MLSS, mg/L	MLVSS, mg/L	SOUR, $X10^{-4}$ min^{-1}	Optical Absorbance
0	B	S	1170	1020	1.29	
1	B	S	1050	890	1.76	
2	B	S				
3	B	S	870	740	1.84	
4	B	S	920	790	1.43	
5	B	S	850	750	1.98	
6	B	S	770	690	1.82	
7	B	S	780	700	1.76	
8	B+F	D	690	630	1.10	
9	B+F	D				
10	B+F	D	460		2.83	
11	B+F	D	600	540	2.00	
12	B+F	D	460	440	3.20	
13	B+F	D	380	240	2.89	
14	B	R	260	210	5.19	
15	B	R	510	480	1.88	
16	B	R	170	110	6.35	
17	B	R	320	240	5.00	
18	B	R	390	380	4.74	

B - Bactopeptone
F - Formaldehyde solution

S - Stabilization phase.
D - Dose phase.
R - Recovery phase.

Table A-4. Influent and effluent COD data for bioreactor slug fed bactopeptone and dosed with 0.30 ml/L of formaldehyde solution.

Day	Feed Type	Phase	Influent COD, ml/L	Effluent COD, mg/L
0	B	S	500	105
1	B	S	500	81
2	B	S	500	
3	B	S	500	70
4	B	S	500	78
5	B	S	500	120
6	B	S	500	116
7	B	S	500	97
8	B+F	D	685	133
9	B+F	D	685	441
10	B+F	D	685	588
11	B+F	D	685	707
12	B+F	D	685	653
13	B+F	D	685	685
14	B	R	500	825
15	B	R	500	647
16	B	R	500	723
17	B	R	500	423
18	B	R	500	607

B - Bactopeptone
F - Formaldehyde solution

S - Stabilization phase.
D - Dose phase.
R - Recovery phase.

Table A-5. Data for bioreactor slug fed bactopeptone and dosed with 10%, 0.16 ml/L, of manufacturer's recommended dose of "D-Odor-It."

Day	Type Feed	Phase	MLSS, mg/L	MLVSS, mg/L	SOUR, $X10^{-4}$ min^{-1}	Optical Absorbance
0	B	S	1960	1650	0.72	
1	B	S	1820	1500	0.88	
2	B	S	1620	1380	0.80	
3	B	S	1600	1300	0.60	
4	B	S	1490	1310	0.71	
5	B	S	1300	1130	0.72	
6	B	S	1220	1080	0.69	
7	B	S	1240	1120	0.66	
8	B+DOI	D	1120	1030	0.88	0.032
9	B+DOI	D	980	890	1.02	0.009
10	B+DOI	D	1040	970	2.04	0.009
11	B+DOI	D	790	720	2.34	0.032
12	B+DOI	D	790	750	1.04	0.041
13	B+DOI	D	730	660	1.00	0.036
14	B	R	640	620	1.45	0.105
15	B	R	680	630	0.96	0.013
16	B	R	640	600	1.13	0.000
17	B	R	650	580	0.98	0.018
18	B	R	620	600	1.08	0.010

B - Bactopeptone
DOI - "D-Odor-It"

S - Stabilization phase.
D - Dose phase.
R - Recovery phase.

Table A-6. Influent and effluent COD data for bioreactor slug fed bactopeptone and dosed with 10%, 0.16 ml/L, of manufacturer's recommended dose of "D-Odor-It."

Day	Feed Type	Phase	Influent COD, ml/L	Effluent COD, mg/L
0	B	S	500	138
1	B	S	500	
2	B	S	500	56
3	B	S	500	15
4	B	S	500	73
5	B	S	500	44
6	B	S	500	54
7	B	S	500	35
8	B+DOI	D	515	67
9	B+DOI	D	515	60
10	B+DOI	D	515	78
11	B+DOI	D	515	103
12	B+DOI	D	515	122
13	B+DOI	D	515	183
14	B	R	500	165
15	B	R	500	112
16	B	R	500	75
17	B	R	500	119
18	B	R	500	61

B - Bactopeptone
B+DOI - "D-Odor-It"

S - Stabilization phase.
D - Dose phase.
R - Recovery phase.

Table A-7. Data for bioreactor slug fed bactopeptone and dosed with 20%, 150 mg/L, of manufacturer's recommended dose of "Dri-Kem."

Day	Type Feed	Phase	MLSS, mg/L	MLVSS, mg/L	SOUR, X10^{-4} min^{-1}	Optical Absorbance
0	B	S	1310	1080	1.54	0.004
1	B	S	1230	1030	1.66	0.000
2	B	S				
3	B	S	1050	860	1.79	0.018
4	B	S	940	800	1.88	0.027
5	B	S	920	780	1.57	0.000
6	B	S	880	740	1.97	0.027
7	B+DK	D	800	720	1.93	0.018
8	B+DK	D	690	670	1.22	0.056
9	B+DK	D	940	680	1.01	0.092
10	B+DK	D	680		2.47	0.071
11	B+DK	D	890	770	1.67	0.125
12	B+DK	D	820	750	1.62	0.161
13	B	R	910	800	2.89	
14	B	R	870	700	1.59	0.161
15	B	R	760	690	1.44	0.131
16	B	R	810	740	1.28	0.114
17	B	R	750	690	1.80	0.137
18	B	R	860	810	1.09	0.097

B - Bactopeptone
DK - "Dri-Kem"

S - Stabilization phase.
D - Dose phase.
R - Recovery phase.

Table A-8. Influent and effluent COD data for bioreactor slug fed bactopeptone and dosed with 20%, 150 mg/L, of manufacturer's recommended dose of "Dri-Kem."

Day	Feed Type	Phase	Influent COD, ml/L	Effluent COD, mg/L
0	B	S	500	138
1	B	S	500	91
2	B	S	500	
3	B	S	500	152
4	B	S	500	83
5	B	S	500	65
6	B	S	500	139
7	B+DK	D	700	94
8	B+DK	D	700	133
9	B+DK	D	700	106
10	B+DK	D	700	141
11	B+DK	D	700	129
12	B+DK	D	700	161
13	B	R	500	200
14	B	R	500	128
15	B	R	500	121
16	B	R	500	132
17	B	R	500	121
18	B	R	500	149

B - Bactopeptone
AK - "Aqua-Kem"

S - Stabilization phase.
D - Dose phase.
R - Recovery phase.

TABLE A-9. Bioreactor data for activated sludge bioreactor continuously fed bactopeptone and dosed with 100%, 1.56 ml/L, of manufacturer's recommended dose of "Aqua-Kem."

Day	Type Feed	Phase	MLSS, mg/L	MLVSS, mg/L	SOUR, X10^{-4} min^{-1}	SVI
0	B	S	970	910	1.77	639
1	B	S	940	920	1.69	883
2	B	S	680	660	2.56	1368
3	B	S	840	820	1.97	1119
4	B	S	1080	1000	2.62	861
5	B	S	920	900	2.10	1011
6	B	S	960	940	1.79	969
6.5	B+AK	D	720	700	0.61	
7	B+AK	D	860	820	0.62	1047
7.5	B+AK	D	660	620	5.79	
8	B+AK	D	600	580	10.23	917
9	B	R	520	500	1.87	920
0	B	R	500	480	3.24	760
1	B	R	560	540	2.18	536
12	B	R	540	520	2.07	556
13	B	R	480	460	1.40	635
14	B	R	580	560	2.24	698
15	B	R	520	500	4.56	980
16	B	R	720	700	4.22	625
17	B	R	640	620	1.72	
18	B	R	640	620	2.03	1016

B - Bactopeptone
AK - "Aqua-Kem"

S - Stabilization
D - Dosing
R - Recovery

TABLE A-10. Influent and effluent COD data for activated sludge bioreactor continuously fed bactopeptone and dosed with 100%, 1.56 ml/L, of manufacturer's recommended dose of "Aqua-Kem."

Day	Type Feed	Phase	Influent COD, mg/L	Effluent COD, mg/L
0	B	S	500	43
1	B	S	500	76
2	B	S	500	28
3	B	S	500	35
4	B	S	500	33
5	B	S	500	69
6	B	S	500	46
6.5	B+AK	D	1485	494
7	B+AK	D	1485	837
7.5	B+AK	D	1485	1094
8	B+AK	D	1485	676
9	B	R	500	486
10	B	R	500	407
11	B	R	500	167
12	B	R	500	134
13	B	R	500	108
14	B	R	500	106
15	B	R	500	55
16	B	R	500	80
17	B	R	500	81
18	B	R	500	112

B - Bactopeptone
AK - "Aqua-Kem"

S - Stabilization
D - Dosing
R - Recovery

TABLE A-11. Bioreactor data for activated sludge bioreactor continuously fed bactopeptone and dosed with 1.50 ml/L of formaldehyde solution.

Day	Type Feed	Phase	MLSS, mg/L	MLVSS, mg/L	SOUR, $X10^{-4}\ min^{-1}$	SVI
0	B	S	930	910	1.38	978
1	B	S	960	940	1.56	917
2	B	S	720	700	1.86	1236
3	B	S	1000	820	1.70	820
4	B	S	1080	1020	1.29	718
5	B	S	1040	1000	1.41	755
6	B	S	880	840	1.49	920
6.5	B+F	D	760	740	0.53	
7	B+F	D	840	800	2.54	845
7.5	B+F	D	760	740	13.95	
8	B+F	D	700	680	9.14	929
9	B	R	740	720	2.96	581
10	B	R	760	700	1.58	460
11	B	R	580	560	1.98	466
12	B	R	420	400	3.29	524
13	B	R	680	660	1.76	368
14	B	R	700	680	1.84	557
15	B	R	640	620	1.98	602
16	B	R	720	700	1.33	431
17	B	R	560	540	2.00	375

B - Bactopeptone
F - Formaldehyde solution

S - Stabilization
D - Dosing
R - Recovery

TABLE A-12. Influent and effluent COD data for activated sludge reactor continuously fed bactopeptone and dosed with 1.50 ml/L of formaldehyde solution.

Day	Type Feed	Phase	Influent COD, mg/L	Effluent COD, mg/L
0	B	S	500	63
1	B	S	500	23
2	B	S	500	34
3	B	S	500	50
4	B	S	500	33
5	B	S	500	66
6	B	S	500	32
6.5	B+AK	D	1445	521
7	B+AK	D	1445	760
7.5	B+AK	D	1445	1160
8	B+AK	D	1445	628
9	B	R	500	406
10	B	R	500	308
11	B	R	500	175
12	B	R	500	204
13	B	R	500	169
14	B	R	500	134
15	B	R	500	150
16	B	R	500	128
17	B	R	500	109

B - Bactopeptone
F - Formaldehyde solution

S - Stabilization
D - Dosing
R - Recovery

TABLE A-13. Bioreactor data for activated sludge reactor continuously fed bactopeptone and dosed with 50%, 1.56 ml/L, of manufacturer's recommended dose of "D-Odor-It."

Day	Type Feed	Phase	MLSS, mg/L	MLVSS, mg/L	SOUR, $X10^{-4}$ min^{-1}	SVI
0	B	S	710	700	1.03	296
1	B	S	580	560	2.15	448
2	B	S	500	440	2.62	890
3	B	S	820	780	2.17	863
4	B	S	580	560	3.59	741
5	B	S	600	580	2.40	1050
6	B	S	440	420	2.89	2000
7	B	S	620	560	3.63	1556
8	B	S	640	620		1547
9	B	S	660	640	3.03	1500
9.5	B+DOI	D	520	500	3.90	
10	B+DOI	D	420	300	4.64	1905
10.5	B+DOI	D	260	240	5.90	
11	B+DOI	D	300	280	5.67	767
12	B	R	160	140	11.44	1000
13	B	R	320	300	3.31	400
14	B	R	340	320	3.38	335
15	B	R	220	200	8.55	636
16	B	R	520	500	4.27	404
17	B	R	300	280	5.77	700
18	B	R	380	360	5.21	447
19	B	R				
20	B	R	360	340	5.97	639

B - Bactopeptone
DOI - "D-Odor-It"

S - Stabilization
D - Dosing
R - Recovery

TABLE A-14. Influent and effluent COD data for activated sludge bioreactor continuously fed bactopeptone and dosed with 50%, 1.56 ml/L, of manufacturer's recommended dose of "D-Odor-It."

Day	Type Feed	Phase	Influent COD, mg/L	Effluent COD, mg/L
0	B	S	500	86
1	B	S	500	74
2	B	S	500	68
3	B	S	500	95
4	B	S	500	
5	B	S	500	87
6	B	S	500	68
7	B	S	500	51
8	B	S	500	69
9	B	S	500	138
9.5	B+DOI	D	643	1154
10	B+DOI	D	643	562
10.5	B+DOI	D	643	574
11	B+DOI	D	643	285
12	B	R	500	184
13	B	R	500	155
14	B	R	500	322
15	B	R	500	273
16	B	R	500	173
17	B	R	500	192
18	B	R	500	234
19	B	R	500	
20	B	R	500	142

B - Bactopeptone
DOI - "D-Odor-It"

S - Stabilization
D - Dosing
R - Recovery

TABLE A-15. Bioreactor data for activated sludge reactor continuously fed bactopeptone and dosed with 100%, 750 mg/L, of manufacturer's recommended dose of "Dri-Kem."

Day	Type Feed	Phase	MLSS, mg/L	MLVSS, mg/L	SOUR, $X10^{-4}$ min^{-1}	SVI
0	B	S	920	800	3.70	
1	B	S	560	540		179
2	B	S	640	620	2.72	109
3	B	S	340	320	3.38	353
4	B	S	520	480	2.69	163
5	B	S	580	560	2.28	155
6	B	S	360	340	3.67	278
7	B	S	420	400	4.31	175
8	B	S				
9	B	S	600	580	5.77	283
10	B	S	420	400	6.07	429
10.5	B+DK	D	540	500	3.70	
11	B+DK	D	560	500	5.52	357
12	B+DK	D	740	700	4.71	331
13	B	R	760	720	2.74	329
14	B	R	780	680	2.14	385
15	B	R				
16	B	R	560	540	2.38	643
17	B	R	680	640	2.31	765
18	B	R				
19	B	R	720	680	2.64	1208

B - Bactopeptone
DK - "Dri-Kem"

S - Stabilization
D - Dosing
R - Recovery

TABLE A-16. Influent and effluent COD data for activated sludge bioreactor continuously fed bactopeptone and dosed with 100%, 750 mg/L, of manufacturer's recommended dose of "Dri-Kem."

Day	Type Feed	Phase	Influent COD, mg/L	Effluent COD, mg/L
0	B	S	500	
1	B	S	500	126
2	B	S	500	171
3	B	S	500	82
4	B	S	500	91
5	B	S	500	156
6	B	S	500	149
7	B	S	500	129
8	B	S	500	
9	B	S	500	129
10	B	S	500	133
10.5	B+DK	D	818	46
11	B+DK	D	818	25
12	B+DK	D	818	80
13	B	R	500	82
14	B	R	500	63
15	B	R	500	
16	B	R	500	
17	B	R	500	94
18	B	R	500	
19	B	R	500	142

B - Bactopeptone
DK - "Dri-Kem"

S - Stabilization
D - Dosing
R - Recovery

TABLE A-17. Results of batch tests measuring sludge settling rate and compaction (sludge volume index, SVI) versus doses of the three odor control chemicals.

Odor Control Chemical	Dose, ml/l or mg/L	Percent MRD	30 Minute Settled Volume, ml	MLSS, mg/L	SVI
"Aqua-Kem"	0.0 ml	0	762	3150	217
	0.4	26	600	3560	168
	0.8	51	580	3360	173
	1.2	77	600	3300	181
	1.6	103	560	3300	170
	2.0	128	690	3120	221
"Dri-Kem"	0 mg	0	490	3200	153
	200	27	670	3300	203
	400	53	630	3200	197
	600	80	600	3000	200
	800	107	565	3400	166
	1000	134	490	3000	163
"D-Odor-It"	0.0 ml	0	625	3100	202
	0.4	13	620	3320	187
	0.8	26	630	3200	197
	1.2	38	620	3070	202
	1.6	51	580	3500	166
	2.0	64	587	3133	187

MRD - Manufacturer's recommended dose

TABLE A-18. Optical absorbance versus wavelength data used to determine optimum wavelength for measurement of presence of dyes from odor control chemicals.

Wavelength, nanometers	Optical Absorbance			
	"Aqua-Kem"	"Dri-Kem"	"D-Odor-It"	Activated Sludge
400	0.051	0.081	0.131	0.027
410				0.036
420				0.036
425	0.036			0.027
430				0.032
440				0.027
450	0.011	0.030	0.060	0.032
460				0.022
470				0.027
475	0.013			0.022
480				0.022
490				0.022
500	0.013	0.027	0.060	0.022
525	0.027			0.013
550	0.046		0.261	0.013
570	0.076			
575	0.092	0.125		0.004
580	0.086			
590	0.125			
600	0.164	0.444	0.319	0.009
610	0.208	0.569	0.377	
620	0.276	0.699	0.403	
625	0.301	0.770		0.004
630	0.380	0.783	0.432	
635	0.317	0.770		
640	0.301	0.678	0.456	
645			0.469	
650	0.208	0.469	0.481	0.013
655			0.444	
660	0.125		0.456	
670	0.060			
675	0.043			0.009
680	0.032			
700	0.014	0.018	0.071	0.009

TABLE A-19. Foam generation measurements, data for foam volume versus dose of liquid odor control chemical. Temperature = 20°C, air flow = 2 cubic feet per hour.

Odor Control Chemical	Dose, ml/L	Percent MRD	Height, cm	Volume, cm^3
"Aqua-Kem"	0.0	0	0	0
	0.1	6	0	0
	0.2	13	0	0
	0.3	19	0	0
	0.4	26	0	0
	0.5	32	2	145
	1.0	64	13	939
	1.5	76	20	1445
	2.0	128	28	2023
"D-Odor-It"	0.1	3	0	0
	0.2	6	0	0
	0.3	10	4	289
	0.4	13	6	434
	0.5	16	9	650
	1.3	32	20	1445
	1.5	48	28	2023
	2.0	64	35	2529

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