THE IMPACT OF DISPOSING HOUSEHOLD CLEANING PRODUCTS IN WASTEWATER TREATMENT SYSTEMS

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SECTION 1

EXECUTIVE SUMMARY

Biological wastewater treatment can be impaired by inhibitory concentrations of chemicals are in the influent wastewater. The concern has been expressed that household cleaning products can reach these inhibitory concentrations and, therefore, should be disposed by means other than down-the-drain. The objective of this paper is examine the validity of this concern by reviewing the relevant biological characteristics of wastewater treatment, predicting maximum concentrations of household cleaning products in wastewater, and listing the laboratory procedures used to determine the safety of substances to wastewater treatment microorganisms.

Publicly Owned Wastewater Treatment Works (POTW) accept community-wide household wastewater along with commercial (and often some industrial) wastewater. POTW are generally designed to accept 100 gallons of wastewater per resident per day and their capacity is measured in millions of gallons per day (MGD). In this situation, occasional cleaning product disposal by a small percentage of households would be attenuated by dilution. Product ingredient concentrations in POTW influent wastewater tend to equilibrate around an average concentration that can be predicted from the total volume of products sold in the serviced district.

Approximately 20-25% of US households use on-site septic tank systems to treat their wastewater. In septic tanks dilution of disposed cleaning products is initially limited to the volume of the septic tank itself, although the short hydraulic retention time (HRT) of 24-48 hours will wash out contaminated water in a matter of days. Because of limited dilution and the potential for increased sludge carry over from damaged septic tanks to clog drainage fields, the scenario of short-term toxicity to septic tank microorganisms due to cleaning product disposal appears to present the highest risk.

Toxicity to wastewater treatment microorganisms is conservatively assayed in the laboratory by standard tests examining microbial activities such as consumption of oxygen, production of anaerobic gases, and/or removal of a readily biodegradable reference compound.

These types of tests are considered to be conservative because inhibition of these activities does not necessarily translate into wastewater treatment failure or sludge carryover from septic tanks. However, if the concentration of the test substance is maintained below the No Observed Effect Concentration (NOEC) in these screening level tests, this is powerful evidence that no toxicity will occur in the wastewater treatment process. In special cases, wastewater treatment simulators or laboratory-scale septic tanks may be used to determine the impact of a test substance on unit process operation.

There are relatively few published studies examining the impact of disposing household chemicals in septic tanks. Four case studies examining the impact of household chemicals with anti-microbial properties on septic tank microorganisms are reviewed as part of this work. Case studies support the idea that these household chemicals can be disposed in whole-package quantities with little or no observed effect on microbial activity and septic tank operation.

SECTION 2

INTRODUCTION

Living microorganisms are key to biological wastewater treatment processes. As with any living system, wastewater treatment organisms require food and favorable environmental conditions. Optimization of these conditions for wastewater treatment microorganisms will result in efficient waste removal. A biologically adverse environment could be created by releases of toxic concentrations of substances into influent water. This may result in the inhibition of microorganisms possibly resulting in wastewater treatment interference or failure. In severe cases of bacterial loss, the wastewater treatment units may need to be restarted with new inoculum or the microorganisms may require a significant period of recovery to rebuild populations. In any case, the wastewater treatment capability of the system may be compromised for a period of time. Frequent upsets or chronic inhibition due to low levels of toxicity may lead to long term poor performance of wastewater treatment units.

The majority of failures in publicly owned treatment works (POTW) are caused by mechanical failures, hydraulic deficiencies, lack of maintenance, and interference by undesired microorganisms. When upsets are caused by toxicity, the cause is usually large slug doses of chemicals from industrial sources (Hänel 1988). The concern has been raised that household cleaning products may cause toxic upsets to wastewater treatment microorganisms in POTW and household septic tanks, especially in cases where whole containers of product are disposed by pouring down the drain.

The purpose of this literature review is to evaluate the impact of disposing cleaning products down the drain on wastewater treatment processes. First, wastewater treatment processes will be reviewed briefly to provide a background. Patterns of cleaning product disposal will be discussed, especially in terms of dilution, to identify the wastewater treatment process most likely to be impacted by cleaning product disposal. Finally, case studies using "worst case" assumptions will be reviewed to determine whether disposal of cleaning products have been found to upset wastewater treatment biological processes.

SECTION 3

WASTEWATER TREATMENT SYSTEMS

As of 1992, 75.5% of the United States population is connected to publicly owned wastewater treatment works (US Bureau of the Census, 1993). The remaining population utilizes on-site treatment such as septic tanks, cesspools, chemical toilets, or no treatment at all. The following sections briefly describe treatment processes in order to provide a context for the disposal of cleaning product ingredients.

3.1 Publicly Owned Wastewater Treatment Works (POTW)

POTW are facilities designed to treat wastewater on a community level. Typically, these systems are designed to treated 100 gallons per day per capita of the serviced customers (Benefield and Randall, 1980). For example, for a moderate sized facility designed for a population of 60,000 people, the minimum capacity would be 6 million gallons per day (MGD).. Wastewater comes from a multitude of residential, institutional, commercial and industrial sources.

POTW treatment processes are generally divided into three categories: primary, secondary, and tertiary. Primary treatment refers to a series of initial treatment steps subjected to the wastewater entering the plant. The first step in primary treatment consists of coarse screening to remove large objects and a grit chamber where the flow is slowed sufficiently to settle dense particles such as sand and gravel. A primary clarifier is next, which is a large quiescent tank where suspended solids that settle to the bottom as sludge and grease that floats to the surface are removed. Effluent from the primary clarifier exits though overflows and is conveyed to secondary treatment. In the past, many plants would chlorinate this effluent and discharge without further treatment. Modern wastewater engineering practices and water quality regulations have made this latter practice unusual.

The primary goal of secondary treatment is the removal of biochemical oxygen demand (BOD) and the oxidation of ammonium (NH_4^+). These goals are accomplished using aerobic biological treatment, most commonly in the activated sludge or trickling filter configurations. The following description of aerobic biological treatment is from a paper by Rittmann (1987). The most common methods of aerobic treatment are the activated-sludge and the trickling filter processes. Although each performs the same oxidation reactions and accumulates similar microorganisms, they differ in the manner in which cells are retained. In the activated-sludge process, microorganisms must accumulate into relatively large aggregates, called flocs. Because they are much larger and more dense than single bacterial cells, the flocs can settle out in a quiescent settler after they exit the aeration tank. After settling, most of the settled cell mass is collected and some of the cell mass is returned to the aeration tank to allow reproduction and subsequent regeneration of healthy microorganisms for the biological treatment process. In trickling filter systems, the cell mass is retained directly in the filter; it is attached to fixed, solid surfaces. This attached cell mass is called a biofilm. Organic contaminants and NH_4^+ removal, oxygen use, new cell mass growth, and biofilm retention all occur in the trickling filter. The wastewater moves from the trickling filter to a settler to improve the quality of the effluents, but the settler is not used for the return of cell mass.

The effluent from secondary treatment is commonly released to a receiving water. However, more stringent treatment may occasionally be required. In this case, advanced secondary or tertiary treatment may be applied. Advanced secondary or tertiary treatment may employ further biological processes or include one or more physical/chemical steps including the chemical precipitation, ion exchange, mechanical filtration, carbon adsorption, ozonation, ultraviolet disinfection, chlorination, or other processes. The end product of tertiary treatment is a high quality potable or near potable water.

One of the major byproducts of biological wastewater treatment is sludge. The major sources of sludge are: settled and floating materials from primary clarifiers, waste activated sludge from settling basins, and sloughed sludge from trickling filters. Sludge handling and disposal represents a major part of the wastewater treatment process. A variety of options are available for sludge disposal, for example they may be anaerobically digested, landfilled, applied to agricultural land, incinerated, or dried and used as fertilizer. These steps may be used alone or in combination.

The advantages of pretreating sludge by anaerobic digestion are the further biodegradation of adsorbed contaminants, reduced sludge mass, destruction of pathogens, destruction of plant seeds, and reduction of nuisance odors. The following discussion of sludge and anaerobic digestion is summarized from Benefield and Randall (1980). Primary sludge produced during the treatment of municipal wastewater consists primarily of solid particles of a predominately organic nature, whereas secondary sludge consists primarily of excess biomass generated as a result of organic removal in the biological process. Raw sludges of both types are composed mainly of water with a solids content of 0.5 to 5.0% depending upon the origin of the solids and the method of removal. The end products of anaerobic sludge digestion are methane, carbon dioxide, and new bacterial cells created by strictly anaerobic bacteria. The digested sludge can then be disposed by the means mentioned earlier. The supernatant is generally high in nutrients due to organic materials solubilized from the sludge. This liquid may be sent back through the aerobic system for treatment.

3.2 Septic Tanks

The large majority of on-site wastewater treatment systems are septic tank systems (EPA 1987). In contrast to POTW's, most septic tank systems receive wastewater from single-family residences, although some are designed for multiple dwelling residences and commercial business. Septic tank systems gained widespread usage in the United States during the 1940's and 1950's in both rural and suburban settings. Septic tank design and construction is regulated according to state specifications. Minimum septic tank capacities are summarized on a state-by-state basis in Table 1. In summary, 28 states require the minimum usable septic tank volume to be in the range of 750-900 gallons. A total of 18 states require a minimum of 1000 gallons. Three states are regulated on a county or district basis. One state (Louisiana) allows a minimum 500 gallon septic tank for one-bedroom dwellings, but even in that case, the typical septic tank would be expected to be larger since the primary design criteria for septic tank volume is 2.5 times the estimated daily flow.

A large amount of effort was expended during the 1950's on research to refine the design and management of septic systems. Most of the techniques learned during this period have stood the test of time and, except for the introduction of plastic tanks, there have been few additional modifications. Several of the historic references on septic tanks have been included in this paper in order to illustrate how long some of these practices have been known. The following sections include general information about septic tanks taken from these sources: Mackenzie 1950, Weibel, et al. 1954, Canter and Knox 1986, and deVilliers 1987.

Table 1. Summary of state regulations on minimum septic tank capacities[a].

State	Minimum Volume[b] (gallons)	Additional volume (gallons/bedroom)	State	Minimum Volume[b] (gallons)	Additional volume (gallons/bedroom)
Alabama	750	250	Montana	750	250
Alaska	1000	250	Nebraska	1000	250
Arizona	960	300	Nevada	1000	250
Arkansas	750	250	New Hampshire	1000	250
California[c]	---	---	New Jersey	1000	250
Colorado	750	250	New Mexico	750	250
Connecticut	1000	250	New York	1000	250
Delaware	1000	250	North Carolina	900	250
Florida	900	add 1.5 X estimated additional daily flow	North Dakota	1000	200-300
Georgia[c]	---	---	Ohio	1000	250-300
Hawaii	750	250	Oklahoma	1000	250
Idaho	900	250	Oregon	1000	250
Illinois	750	250	Pennsylvania	900	add 3.5 X estimated additional daily flow
Indiana	750	250	Rhode Island	1000	250
Iowa	750	250	South Carolina	890	250
Kansas	750	250	South Dakota	1000	250
Kentucky	750	250	Tennessee	750	250
Louisiana[d]	500	2.5 X estimated total daily flow	Texas	750	250
Maine	750	250	Utah	750	250
Maryland	750	250	Vermont	1000	1.5 X estimated total daily flow
Massachusetts	1000	1.5 X estimated total daily flow	Virginia	750	200-300
Michigan[b]	---	---	Washington	750	250
Minnesota	750	250	West Virginia	750	250
Mississippi	750	250	Wisconsin	750	225
Missouri	1000	250	Wyoming	1000	250

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[a] State regulations compiled by the National Small Flows Clearinghouse (1994).

[b] Minimum volumes may be based on 1, 1-2, 1-3, or 1-4 bedroom dwellings before additional volume is triggered, depending on state.

[c] Regulations are based on county-by-county or district-by-district basis.

[d] Minimum volume of 500 gallons in Louisiana is for 1 bedroom dwelling only. The primary design factor is 2.5 X estimated daily flow.

A septic tank system is typically composed of two unit processes: 1) the septic tank; 2) the absorption field. Both processes must work properly for the septic system to adequately treat household waste water.

The primary purpose of a septic tank is to separate solids from the wastewater. The decreased solids loading to the tile field results in an extended tile field life. The septic tank is made of concrete, brick, or reinforced plastic. Steel tanks had been used historically, but have gone out of favor due to corrosion problems. Plastic tanks are currently the most popular because of their light weight and resistance to corrosion. The septic tank is designed to hold household wastewater for a hydraulic retention time (HRT) of at least 24 hours. A septic tank may have one, two, or more compartments connected in series by submerged openings. The advantage of compartmentalization is that it reduces solids carryover into the absorption field during peak flows. This is most important for multi-household septic systems since a large amount of household wastewater flow (45%) usually occurs within a peak four-hour period (de Villiers 1987). The inlet to a septic tank is designed to dissipate energy from the flowing water by having a reduced slope (1-2% maximum) for at least 10 meters prior to the septic tank. To further reduce the disturbance of the liquid within the septic tank, the inlet tube discharges below the liquid level in the septic tank.

Wastewater entering the septic tank separates into three distinct layers according to relative density. The top layer is a floating scum composed primarily of biosolids, fats, oils and grease. The bottom layer contains sludge and any other settled materials. The middle layer is composed of relatively clarified water. Effluent is drained from the middle layer into the absorption field by a submerged outlet tube. The septic tank must be vented to the surface to reduce the accumulation of gases produced during anaerobic biological processes.

Limited biological treatment also occurs in the septic tank by anoxic/anaerobic processes. Treatment of the aqueous phase is limited due to a short HRT. The rate of sludge build-up is more rapid than digestion; therefore, it is necessary to remove sludge and scum by pumping the tank out every few years to prevent solids from accumulation to the point where they begin to carry over into the absorption field. However, digestion of solids can significantly reduce the rate of sludge build-up (Truesdale and Mann, 1968), effectively extending the periods between sludge removal. Failure to routinely remove sludge may result in the carryover of solids and possible clogging and failure of the absorption field.

An absorption field is typically an area of soil containing a system of perforated drain pipes (also called tiles) usually surrounded by gravel to improve water dispersion. The pipes must be located below the frost line, but in a biologically active aerobic zone. The absorption field receives the effluent from the septic tank and distributes it into the soil. Normal soil microorganisms and physical/chemical processes treat the water. Site selection is very important for absorption fields. Soils exhibiting low permeability, shallow soils over restrictive layers, high water tables, etc. are unsuitable for typical absorption fields and site-specific alternative systems may be necessary.

Assuming that a septic system is designed and installed properly (tank is proper size, soil drainage conditions are good, etc.), the most common failure of septic systems is clogging of the absorption field (Mitchell 1976). This failure is quickly recognized by the homeowner due to back up of sewage or gurgling of pipes in the house, ponding of wastewater and/or unusually lush vegetative growth in the yard near the septic system. Decreases in soil permeability have been shown to be directly proportional to the suspended solids of the septic tank effluent (Mackenzie 1950). The most common cause of high suspended solids in septic tank effluent is failure to routinely pump out excess sludge from the septic tank. Failed absorption fields may need to be reinstated, often (at high cost) in another location. Since septic tanks are primarily designed for solids separation, chemical induced reduction of anaerobic respiration will have little effect on wastewater treatment and may not reasonably be expected to cause direct failure of the system. Chemicals concentrated in the sludge layer can reduce the digestion rate, causing more rapid sludge accumulation. Reduced sludge digestion necessitates more frequent clean-outs or a greater risk of absorption field clogging.

In the short term, harsh chemical slug loading can disrupt the settling process or cause sludge bulking, leading to rapid clogging of the drainage field. This phenomenon has been reported in some old literature to occur from large doses of caustic septic tank additives such as sodium hydroxide (Mackenzie 1950). According to one report, the addition of 25 pounds of sodium hydroxide caused previously granulated sludge to bulk into the consistency of heavy motor oil (Weibel et al. 1954). Reports of septic tank failure due to such extreme measures should not be confused with the disposal of relatively minute amounts of ingredients in household cleaning products.

3.3 Concentrations of Product Ingredients in Wastewater

Consumer products are not composed of single chemicals. Household cleaning products are generally formulations of active ingredients, a carrier (such as water), and additives which improve mixing and application or otherwise enhance the chemical performance. Following disposal, each component of these mixtures pursues its individual fate in the environment. Since certain household cleaning products are designed to have anti-microbial properties, the active ingredients providing these properties would logically present the greatest risk of inhibiting residential wastewater treatment biological processes.

The microbial toxicity of cleaning product ingredients should be evaluated in the context of typical and worst case exposure concentrations under normal use and disposal practices. Some cleaning products, such as hand dish washing detergents, will enter the disposal system on a daily basis in small quantities. Others will follow disposal of washwaters on a weekly basis. Pouring an entire package of a cleaning product down the drain represents the worst case scenario.

In the case of POTWs, overall fluctuations in concentrations due to routine household use and disposal would be expected to be dampened by the presence of many POTW users. Because of the damping effect that occurs in POTWs, the disposal of a single container of household cleaning product under a worst case scenario would not impact the operation of the treatment works.

A simple mathematical method to predict the wastewater concentrations of consumer product ingredients was developed by Holman (1981). This method uses general assumptions about per capita product and water usage to provide an estimate of average product ingredient concentration in wastewater. This estimate is considered to be conservative since it assumes that all of the product is disposed down the drain and none is consumed during use or disposed by other routes. The concentration of a product ingredient in municipal wastewater can be estimated by the following equation:

$$C_{mw} = \frac{X * P}{Y * Q} \qquad [1]$$

Where: C_{mw} = concentration of product ingredient in municipal wastewater (mg/L).

X = quantity of product marketed (mg/day)

P = product ingredient fraction in product (% by weight ÷ 100)

Y = population of market area (number of people)

Q = per capita wastewater flow rate (L/day).

The quantities X and P are available to the manufacturers of the products and Y is available through census data. The quantity Q is variable according to geographic region and water use patterns. For estimation purposes, the per capita flow of 400 L/day is generally used for United States estimates (Cowan *et al.* 1992). More precise flow data may be obtained for specific wastewater treatment plants by consulting their records.

The general product ingredient category of surfactants may be used as a general example to illustrate the application of equation 1. Surfactants are key ingredients in almost all cleaning product applications including laundry detergents, dishwashing detergents and drying and antispotting products, and hard surface cleaners. Over 1 billion kilograms (9.8 million tons) of total non-soap surfactants were sold in the United States for use in household cleaning product formulations in 1992 (United States International Trade Commission 1994). No other single group of cleaning product ingredients would be expected to exceed the concentration of surfactants in average household wastewater. Assuming the 1992 United States population of 260 million people produces wastewater at a rate of 400 L/day per capita, the average concentration of total surfactants calculated by equation 1 is 26 mg surfactant per liter of wastewater. This is a conservative calculation since some surfactant may biodegrade in sewers and some are used in products which are not typically disposed down the drain, such as automotive or agricultural cleaning products. The result of this calculation is consistent with the high end of the ranges of surfactant concentration in residential community wastewater reported in reviews by Swisher (1987) and Srinivasarao *et al.* (1992).

In cases of on-site wastewater treatment, such as septic tanks, the lack of dilution from other households precludes dampening of high concentrations during periods of peak usage or disposal events. The dampening in this case is due only to the wastewater coming from other uses in the household. Maximum ingredient concentrations due to disposal of unused product into septic tanks can be more directly calculated. For example, if a liquid cleaning product contains 10% (w/v) of an ingredient, disposal of one gallon into a 1000 gallon septic tank would lead to a maximum concentration of the ingredient of 100 mg/L in the aqueous phase, assuming the septic tank is completely mixed. Subsequent household water use would dilute and flush out this material creating lower concentrations. This type of disposal into a septic tank can reasonably be expected to represent the worst case scenario in terms of concentrations of cleaning product ingredients in a wastewater treatment system.

3.4 Patterns of Disposal

In order to understand the frequency of this worst-case scenario the question remains: how often are cleaning products disposed without usage? In order to answer this question, SDA (NPD Group, Inc., 1995) recently commissioned a market research group to survey 20,000 randomly selected US households. The following points from the summary of findings of the study are relevant to this report:

- Among the 13,697 returned surveys (68.5%):
    - ◊ 8% reported disposing at least one unused cleaning product within the past 3 months.
    - ◊ 23% reported using septic systems.
    - ◊ There was no difference in disposal patterns between those who used septic systems and those who used sewer systems.

- Among the 8% who reported disposing products:
  - ◊ The average number of products disposed over the three month period was 2.43.
  - ◊ 67% disposed of product by leaving it in the container and placing it in the trash, 10% were poured down the drain. No other single disposal pathway accounted for more than 1% of disposal.
  - ◊ Liquids in bottles were the most frequently disposed products overall (40%) and were also the most frequent product to be poured down the drain. Solids, aerosols and gels were generally disposed in the container and placed in the trash.

The survey did not attempt to estimate the percent of the product remaining in the container when disposed, but it does point out that down-the-drain disposal is performed infrequently. This is particularly true for higher volume products which tend to be used up rather than dumped out (NPD Group, Inc., 1995). Nonetheless, cleaning products are occasionally poured down the drain, therefore, manufacturers routinely address the impact of cleaning products on wastewater treatment systems. Section 4 briefly describes the major methods used for this purpose.

SECTION 4

REVIEW OF METHODS TO MEASURE TOXICITY TO WASTEWATER TREATMENT MICROORGANISMS

The objective of wastewater treatment microbial toxicity tests is to determine the concentration at which a compound impairs the ability of the microorganisms to treat wastewater. If this concentration is greater than the expected exposure concentrations, then the compound is not expected to have a negative impact on the activity of wastewater treatment microorganisms. In general, there are three major categories of testing approaches: effects on respiration (or gas production from anaerobic microorganisms); effects on removal of other compounds; and effects on performance during wastewater treatment simulations. These effects can be examined in both aerobic and anaerobic systems.

4.1 Consumption of Oxygen

4.11 OECD 209

The only test currently specifically addressing wastewater treatment microorganism toxicity in US or European regulatory guidelines is OECD procedure number 209: "Activated sludge, respiration inhibition test" (OECD 1984). This test is designed as a simple screening tool to assess the impact of a chemical on the overall respiration rate of activated sludge.

A solution containing an excess of nutrients is added to a beaker with microbial inoculum and various volumes of test substance stock solution. The microbial inoculum (seed) is activated sludge from a municipal facility treating primarily domestic wastewater. Controls without test substance are used in the test design to measure the background activity of the sludge. An inhibitor of respiration (3,5-dichlorophenol) is included as a negative control to assess sludge sensitivity to chemical inhibition. The 50% inhibition concentration of the standard inhibitor must be within a specified range in order for the test to be considered valid.

Each mixture of sludge, nutrient solution, test solution, and dilution water is aerated for a set period of time (usually 3 hours). The set-up of each vessel is offset over time so that data can be collected after the precise incubation time. At the appropriate time for each vessel, the rate of dissolved oxygen (DO) consumption is measured. The "inhibitory effect" is defined by comparison to duplicate controls using the following equation:

$$1 - \frac{2R_s}{R_{c1} + R_{c2}} \times 100 = \textit{percent inhibition}$$

where:

R_S = oxygen consumption rate (mg/O_2/L/Hour) at tested concentration of test substance

R_{C1} = oxygen consumption rate (mg/O_2/L/Hour), control 1

R_{C2} = oxygen consumption rate (mg/O_2/L/Hour), control 2

The percent inhibition is plotted as a function of test substance concentration. The 50% inhibition concentration is determined from the resulting graph.

OECD 209 provides a measure of the overall impact of a chemical on a high strength inoculum such as would be encountered in activated sludge mixed liquor. This high concentration of sludge could buffer toxicity by adsorption of the test compound onto sludge solids. The high overall respiration rate of a variety of species consuming the abundant carbon could also mask some toxicity to individual species. The inhibition that is masked in this test could potentially become important in biodegradation tests using more dilute inoculum.

4.12 BOD$_m$

A test somewhat similar to the OECD test has been presented by Marks (1973). This test is a variation of the classic biochemical oxygen demand (BOD) test and is known as the BOD microbial toxicity test or BOD$_m$. In the BOD$_m$ test a relatively dilute seed is prepared from domestic activated sludge. The seed is defined as 5 mL of a sludge culture that is fed daily with domestic sewage and whose "oxygen consumption rate is in the range of 1 to 3 mg/liter/h." The seed is combined with a series of volumes of a test substance stock solution (or mixed waste stream of interest) in standard BOD bottles with a single concentration of a reference compound (glucose). The remaining volume in the BOD bottles is filled with dilution water and aerated to saturate the water with oxygen. The concentration of glucose is designed to be sufficient for the microorganisms to deplete one-half of the dissolved oxygen (DO) present in the mixture if no inhibition is encountered. Each BOD bottle is incubated at 20°C for three days without further aeration. The DO is then measured in each bottle and plotted as a function of test substance concentration. The lowest concentration of test substance that causes a reduction in the oxygen consumption rate compared to a control is defined as the "threshold inhibition level." Concentrations of the test substance below the threshold are considered to be acceptable for wastewater treatment systems. A higher concentration of sludge is suggested if data are needed within a time frame shorter than 3 days.

4.13 Other Respirometric Methods

Numerous variations on methods measuring the impacts of chemicals on oxygen consumption have been published as biodegradation tests (Swisher 1987). Many oxygen consumption tests utilize respirometers. A respirometer is a device that continuously monitors oxygen consumption and/or carbon dioxide generation in a test vessel. Respirometers can be used to measure real-time effects of substances on biological respiration in a continuously aerated system (Eckenfelder 1980). Unfortunately, respirometric tests using sophisticated apparatus have historically been expensive relative to standard BOD systems and require significant skill on the part of the analyst. Recent technical advances in respirometers and computerization are leading to wider usage of these instruments in BOD and biodegradation applications (Mahendraker and Viraraghavan 1995).

4.2 Production of Anaerobic Gases

Anaerobic biological treatment is a major unit process in wastewater treatment throughout the world, primarily in the form of sludge digesters and household septic tanks. Since appreciable quantities of oxygen are not consumed (or present) in anaerobic systems, respiration tests based on dissolved oxygen are not applicable. In the place of oxygen consumption, gas production volume is the most common measurement of anaerobic activity. The validity of gas production as an indicator of anaerobic activity is contingent on the presence of an active methane producing (methanogenic) consortium of bacteria. The test system must be completely protected from exposure to oxygen, which is toxic to anaerobic bacteria producing methane. Oxygen contamination in the test system can also lead to negative gas pressure due to absorption of oxygen into the test liquid. Examples of procedures used to evaluate anaerobic gas production are provided later in this paper as part of case studies reported by Yang *et al.* (1979) and Vaishnav and McCabe (1996).

4.3 Removal of a Reference Compound

An alternative to respiration measurements is measuring the effect of a chemical on the removal of a reference compound. The matrix containing the test chemical and a microbial seed (usually activated sludge, but anaerobic inoculum such as septage can be used to assess anaerobic systems) is analyzed for the reference compound after a defined exposure period. The test compound may be one that is known to be biodegradable or chosen to address specific concerns.

A general test for inhibition of activated sludge using removal of ^{14}C-glucose is described by Larson and Schaeffer (1982). These authors recognized that respiration measurements could have limitations such as being non-specific, relatively time consuming, difficult to interpret for biodegradable compounds, and potentially misleading by masking modes of toxicity such as uncoupling of oxidative phosphorylation. The suggested alternative to respiration measurements is removal of ^{14}C-glucose from solution following the exposure of activated sludge to a potential toxicant for 15 minutes.

The sludge is obtained from a POTW receiving primarily domestic wastewater, aerated, and used within two hours of collection. Aliquots of the sludge are placed in open beakers on a rotary shaking table with various concentrations of test substance stock solutions. After a 5 minute equilibration period, an aliquot of ^{14}C-glucose solution is added to each mixture. Equilibration is continued for an additional 15 minutes, then terminated by the addition of hydrochloric acid. Samples of each mixture are filtered and assayed for ^{14}C activity by liquid scintillation counting (LSC) and the percent removal of the ^{14}C-glucose is calculated.

An initial range finding test is followed by a definitive test with a narrower range of concentrations. The concentration of chemical inhibiting glucose removal by 50% (IC_{50}) is calculated and normalized to the control response by using an empirical non-linear regression model.

4.4 Wastewater Treatment Simulation

Laboratory-scale wastewater treatment simulations performed to determine the treatability of a test substance can also provide important information on the longer term impact of chemicals in wastewater treatment. Simulation tests such as continuous activated sludge (CAS), porous pot (ASTM, draft method), and coupled units (OECD 303A, 1984), can provide insight into potential problems that can occur at wastewater treatment facilities. Simulation tests assessing the impact of cleaning product ingredients on septic tanks have been reported in literature (Pearson *et al.*, 1991; Holman and Hopping, 1980; Truesdale and Mann, 1968). Potential operating problems can include sustained foaming, accumulation of the test substance on solid surfaces, etc. These factors are generally included as subjective "visible adverse effects" along with quantitative measurements of general unit performance such as chemical oxygen demand (COD) removal, total suspended solids (TSS) removal, etc. Unfortunately, in order to determine the toxic concentration of a test substance, the concentration must be increased until the unit fails, a procedure usually avoided during costly treatability tests. Therefore, failure concentrations are not usually identified (except by accident), but at least safe operation at the nominal concentration can be demonstrated.

SECTION 5

CASE STUDIES RELEVANT TO SEPTIC TANK MICROORGANISMS

It is generally recognized that normal use levels of household cleaning agents and disinfectants do not impair septic tank function (Gross 1987, Truesdale and Mann 1968). There have been few studies in the published research literature specifically examining the impact of disposing quantities of household chemicals on wastewater treatment systems, although the procedures listed in Section 4 are commonly conducted by manufacturers to provide data for safety assurance of new or reformulated products.

5.1 Yang *et al.* 1979

In a report entitled "Recovery of Anaerobic Digestion after Exposure to Toxicants" Yang *et al.* (1979) provide a detailed literature review on previously published data relating toxicity of various chemicals to anaerobic wastewater treatment microorganisms. The authors also performed their own experiments examining the toxicity of over 30 chemicals representing heavy metals, inorganics, various organic chemicals common to industry, and antibiotics. This study was undertaken to test the previously widely held perception that methane fermentation cannot tolerate chronic or slug doses of toxicants. Two types of assays were used: an "anaerobic toxicity assay (ATA)" and an anaerobic filter assay. The ATA was designed as a short term test to determine the impact of single doses of chemical into an unacclimated system. The anaerobic filter assay was used in a continuous flow mode that allowed long term operation and acclimation by microorganisms.

The inoculum sludge for each test was originally sampled from a municipal digester, then maintained in a laboratory digester for an extended period (years) with acetic acid as a sole source of carbon. In the ATA test, fifty mL of this sludge was anaerobically added to a serum vial, followed by 2000 mg/L of acetate as acetic acid or 8,000 or 16,000 mg/L of acetate as calcium acetate. Test substances were added at various concentrations to the bottles and gas production was measured and compared to controls without test substances added. This method bears some similarity to the anaerobic biodegradation screening test listed by the USEPA (1994).

The anaerobic filter assay was a flow-through system in which a feed solution was passed through a packed bed of 1 cm diameter gravel in a plexiglass tube. The feed solution was a nutrient salt solution containing acetate at 2000 mg/L or 3300 mg/L. The feed solution inflow rate approximated a one day hydraulic retention time. Gas production and COD removal were measured over time from each filter unit.

Under an ATA test using unacclimated sludge (Figure 1), 25 mg/L of an anionic surfactant (Trade name "WXN", produced by American Cyanamid Corporation) reduced gas production to about 80% of the control. At 50 mg/L, the gas production rate gradually declined for the first 10 days then subsequently increased. At 100 mg/L, the initial gas production rate was about 20% of the control. Subsequently, it decreased and later showed acclimation after 20 days. Gas production ceased after 10 days at 12% of the control volume in the system with 250 mg/L of anionic surfactant. Note that in this ATA system, the mixed liquor suspended solids (MLSS) were measured at 600 mg/L, significantly lower than typical anaerobic digesters where solids typically range on the order of 1-5% (w/v) which is equivalent to 10,000-50,000 mg/L. The low MLSS level could have exhibited toxicity at lower chemical concentrations than would be seen in actual systems. In the anaerobic filter system, continuous additions of 15 and 30 mg/L of the anionic surfactant did not produce sustained inhibition (Figure 2). However, 60 mg/L for 28 days produced a gradual decrease in gas production until the surfactant additions were stopped (Figure 2). Gas production remained ~50-60% of the earlier maximum levels until beginning to improve approximately 30 days after the last surfactant addition. The study was terminated before complete recovery was evident.

The test systems used by Yang *et al.* (1979) were not exactly representative of the operational parameters of real-world septic tanks; however, this work provides an early example of the use of gas production techniques to examine toxicity to methanogens and documents the ability of these microorganisms to acclimate and recover from loading of chemicals in toxic concentrations.

5.2 Vaishnav and McCabe (1996)

Inhibition of anaerobic gas production from cellulose degradation is used by Vaishnav and McCabe (1996) to assess safety of cleaning products to anaerobic microorganisms. In this procedure, various concentrations of the test compound are added to incubation vessels (250 mL flasks) containing constant amounts of anaerobic digester sludge, cellulose, and a synthetic sewage feed mixture. The vessel is sealed and the headspace is connected by tubing to a second vessel containing water. Water displacement into a third vessel is measured and used as an indicator of anaerobic respiration. The concentration of test substance inhibiting anaerobic respiration by 50% over a 96 hour exposure period (EC_{50}) is calculated, along with the No Observed Effect Concentration (NOEC). Sodium chloride is used as a reference compound.

Using the NOEC value derived from these test procedures and worst case scenario of disposing an entire full-container of a granular all-fabric bleach and a general purpose cleaner (trade names withheld at manufacturer's request) directly into a 750 gallon septic tank, Vaishnav and McCabe calculated whether the product concentration in the septic tank would exceed the NOEC. As Table 2 describes, the worst case predicted septic tank concentrations of neither product exceeds the NOEC. Therefore, it is unlikely that disposing an entire container of either product will cause harm to septic tank microbes.

Table 2. Impact of two cleaning products on gas production by anaerobic sludge. (Vaishnav and McCabe, 1996).

Product	NOEC	Worst Case Concentration
Granular all-fabric bleach[a]	625 mg/L	356 mg/L
General purpose cleaner[b]	10,000 mg/L	750 mg/L

[a] Assumes 64 oz. container.
[b] Assumes 1 gallon container.

5.3 Gross (1987)

In a report presenting data on the impact of disposal of household cleaning products on septic tanks, Gross (1987) examined chlorine bleach, Lysol® (a disinfectant), and Drano® (a drain opener), which are products that they identified as materials of concern. They suspected these common household products had the potential to harm septic tank operation due to their anti-microbial properties.

The first step in this study was to establish the concentration of each product required to "kill all of the bacteria." One liter samples of septic tank effluent were subjected to interaction with various concentrations of the chemicals. They were allowed to interact for about one hour and then analyzed for total coliforms following standard procedures. The statement "kill all of the bacteria" is used in quotes because this study only considered coliforms, which are naturally present within digestive tracts and are used as indicators of fecal contamination. These bacteria would be expected to be only minor members of the septic tank consortium and would not be expected to significantly contribute to the wastewater treatment performance of the septic tank.

Furthermore, because these bacteria are not natural inhabitants of the environment outside of the digestive tract, coliforms are not acclimated to the conditions and chemical fluctuations of the septic tank and would be expected to be much more sensitive to chemical upset. The concentrations required to eliminate coliforms in effluent samples were 1.85 mL/L for chlorine bleach, 5 mL/L for Lysol, and 3 mg/L of Drano.

Four septic tanks were used in a field study to assess the impact of these levels of the products on septic tank operation. The volumes of these tanks were 400 and 375 gallons, for septic tanks C, and D, respectively. Prior to the field test, the tanks were pumped out and then operated for two weeks to allow return to normal operation. The cleaning products were injected into the tanks by flushing down the toilet. Samples of septic tanks liquid were taken from the tanks periodically and tested for coliforms until the coliform population was found to reach pre-dosing levels. When the concentrations of bleach, Lysol, and Drano equivalent to those determined in the first part of the experiment were flushed into tanks C an D, coliform populations were temporarily reduced, but populations to approximate pre-dosing levels within 60 hours (Table 3). The pH, BOD_5, and total suspended solids of septic tank effluents were not impacted by the chemical treatments (data not shown).

The conclusion of this report was once-per-week slug loads at the concentrations used would cause little harm to the septic tank's bacteriologic action since the longest recovery time is 60 hours.

Table 3. Results of field study on impact of cleaning products on septic tank coliforms. (Gross 1987)

Product	Dose	Septic Tank C (400 Gallons) Recovery Time (Hours)	Septic Tank C (400 Gallons) Coliforms (Colonies/100 mL)	Septic Tank D (375 Gallons) Recovery Time (Hours)	Septic Tank D (375 Gallons) Coliforms (Colonies/100 mL)
Liquid Bleach	2 Gallons	0	68E5	0	48E5
		4	0	4	0
		8	0	8	0
		11	19E0	11	6E1
		22	32E2	22	43E2
		26	86E2	26	92E2
		31	29E3	31	18E3
		43	99E4	43	19E5
		48	26E5	48	31E5
		52	42E5	52	42E5
Lysol	2 Gallons	0	6.7E5	0	3.8E5
		4	0	5	<10,000
		12	1E2	24	<10,000
		26	1.6E3	29	0.8E5
		32	2.9E3	48	3.2E5
		39	2.1E4		
		50	2.3E5		
		56	3.8E5		
Drano	10 grams	0	4.2E5	0	5.8E5
		1	7E2	2	9E2
		5	0	5	0
		12	3E2	8	6E2
		23	2.1E5	24	2.2E3
		26	2.7	27	1.1E4
		29	2.4E5	30	2E5
		47	3.2E5		

5.4 Bookland *et al.* (1992)

Four materials were tested by the glucose removal method (Section 4.3) in septage collected from the blanket zone of a functioning septic tank. These four chemicals were chosen as representative of high volume ingredients in cleaning products which could exhibit antibacterial properties: linear alkylbenzene sulfonate (LAS), an anionic surfactant; ethanol, an organic solvent; sodium hypochlorite, a bleach; and DODMAC, a cationic surfactant. The results of this study are reported in Table 3 as HA_{50} (heterotrophic activity reduced by 50% as measured by a 50% reduction in glucose uptake) and as the NOEC (concentration having no effect on glucose uptake). Note that the glucose removal method is conservative because it measures a specific activity and not lethality of the microorganisms.

These data were used to calculate the maximum ingredient concentration (ICmax) that can be disposed into a septic system that would not be expected to cause an adverse effect in a 750 gallon septic tank (See Section 3.2 for discussion of septic tank volumes):

ICmax = NOEC (mg/L) x 3.785 L/gallon x 750 gallons per tank

The maximum amount of product (Pmax) that can be safely disposed is calculated by:

Pmax = ICmax/PICmax (mg/L)

where PICmax is the maximum product ingredient concentration.

For example, if ethanol is used in cleaning products at a maximum concentration of 5% NOEC (weight/weight), its NOEC would be converted to a Pmax as follows:

ICmax = 10,000 mg/L ethanol (NOEC) x 3.785 L/gallon x 750 gallons/tank = 28,388 g ethanol/tank

Pmax = 28,388 g/tank x 100 mL product/5 g ethanol x 1 L/1000 mL x 1 gal./3.785 L = 150 gal.

Therefore, up to 150 gallons of product containing 5% ethanol can be added to a 750 gallon septic tank without adversely affecting heterotrophic activity.

Similar calculations illustrate that up to 4.5 gallons of anionic surfactant product containing 30% LAS, 4.3 gallons of bleach containing 5% sodium hypochlorite, and 2.5 gallons of cationic surfactant product containing 30% DODMAC can be added to a 750 gallon septic tank without adversely affecting heterotrophic activity (Table 3).

Table 4. Summary of septic tank safety data based on glucose removal. (Bookland *et al.*, 1992).

Test Material	HA_{50} (mg/L)	NOEC (mg/L)	NOEC Equivalent Amount of Product in 750 Gallon. Septic Tank (Pmax)
Sodium Hypochlorite	475	288	4.5 gallons[a]
LAS	6,750	1,820	150 gallons[b]
Ethanol	80,000	10,000	4.3 gallons[c]
DODMAC	>1000	>1000	2.5 gallons[d]

[a] Assumes 30% LAS.
[b] Assumes 5% ethanol.
[c] Assumes 5% sodium hypochlorite.
[d] Assumes 30% DODMAC.

5.5 Summary of Case Studies

These case studies support several statements related to down-the-drain disposal of cleaning products in septic systems:

1. Septic tanks are robust in tolerating chemical exposure due to disposal of household cleaning products, even those designed as disinfectants.
2. Rapid hydraulic turnover minimizes the exposure of microorganisms to high concentrations of chemicals due to one-time slug loads. This aids in the rapid recovery of microorganisms even if temporarily adverse biological conditions are experienced in the tank.
3. Quantities of cleaning products required to inhibit septic tank activity are larger than single packages, sometimes much larger. This is observed even when using conservative "no effect" indices of glucose uptake or toxicity to coliforms in septic effluent.

SECTION 6

SUMMARY AND CONCLUSIONS

Due to the huge amount of dilution in POTW, disposing single household quantities of cleaning products that are normally mixed with water will not impact their concentration in POTW influent. Approximately 25% of households in the US use on-site waste treatment, most commonly configured as septic tank/absorption field systems. In this case, dilution is limited to the volume of the septic tank and subsequent household water usage. It is generally accepted that normal usage concentrations of unused cleaning products do not create problems in septic tanks, but it is possible to temporarily elevate product concentrations in septic tanks by pouring an entire package down-the drain. A recent survey shows that disposing unused cleaning down-the-drain is an infrequent practice. The worst case scenario of product disposal in wastewater treatment is the disposal of a completely unused package of product in a minimum size septic tank. If a product does not impact waste treatment under this scenario, it may be assumed to be safe for other common use and disposal scenarios.

A variety of testing methods are available to assess the safety of disposing unused household cleaning products in wastewater treatment systems. These tests range from small scale screening tests examining single endpoints such as respiration or gas production, to large pilot-scale systems evaluating the impact of the chemicals on wastewater treatment performance and operational parameters. Two common screening tests applied to septic tank microorganisms evaluate the impact of substances on gas production and glucose uptake, respectively. Both of these screening tests provide highly conservative indices, since they measure impact on specific metabolic activities rather than the overall function of the septic tank, which tend to be more robust.

Available data have shown that disposal of household quantities of cleaning products such as drain openers, bleach, and detergents do not interfere with septic tank function. Screening tests indicate that disposal of whole packages of these products result in maximum concentrations in septic tanks that are well within the no-effect concentrations for gas production and glucose uptake. This literature review did not reveal any case studies or reports of septic tank failure following disposal of cleaning products. In general normal dilution appears to adequately provide safety for operation of biological waste treatment following the disposal of cleaning products. This appears to be true even under the worst case scenario of disposing whole packages of products into relatively small septic tanks.

SECTION 7

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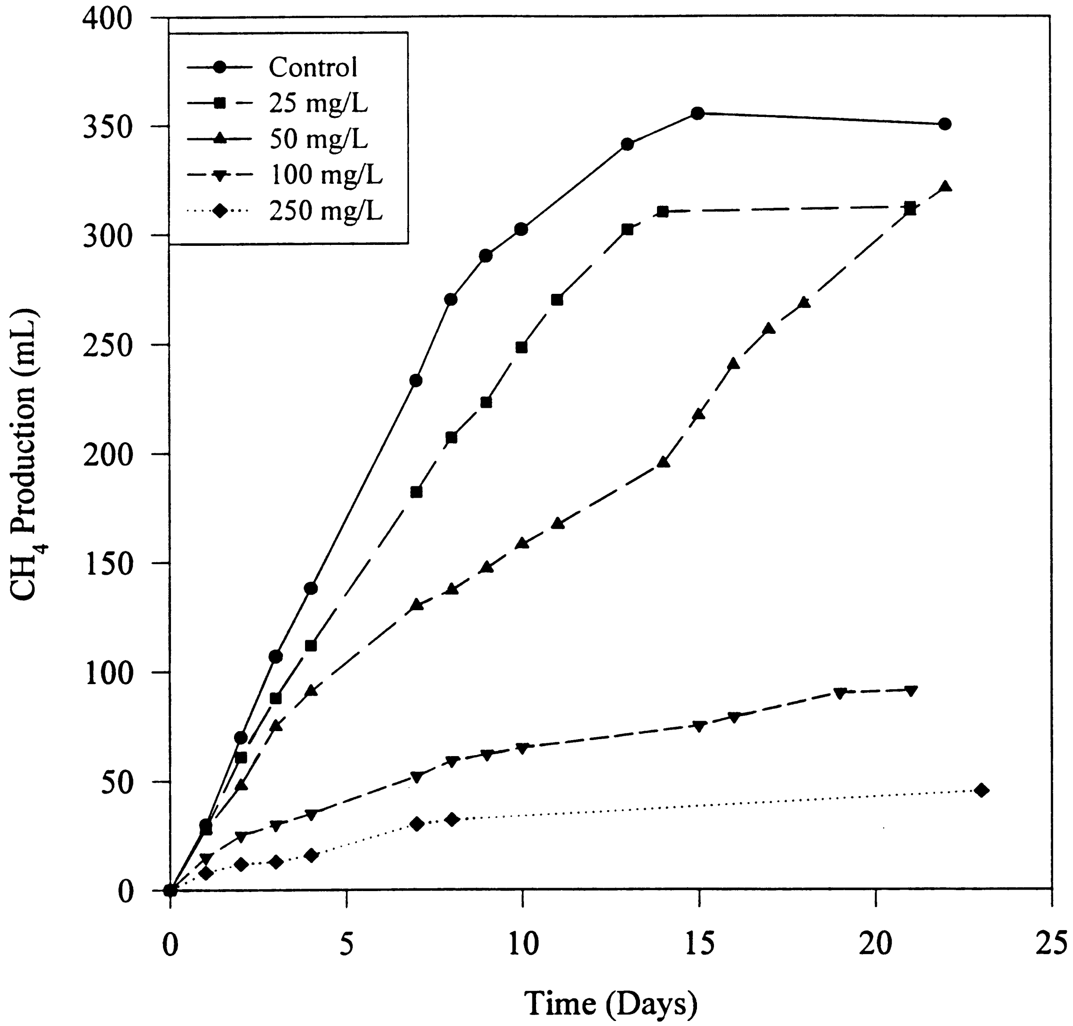

Figure 1. Response of unacclimated methanogens to an anionic surfactant. (From Yang, *et al.* 1979).

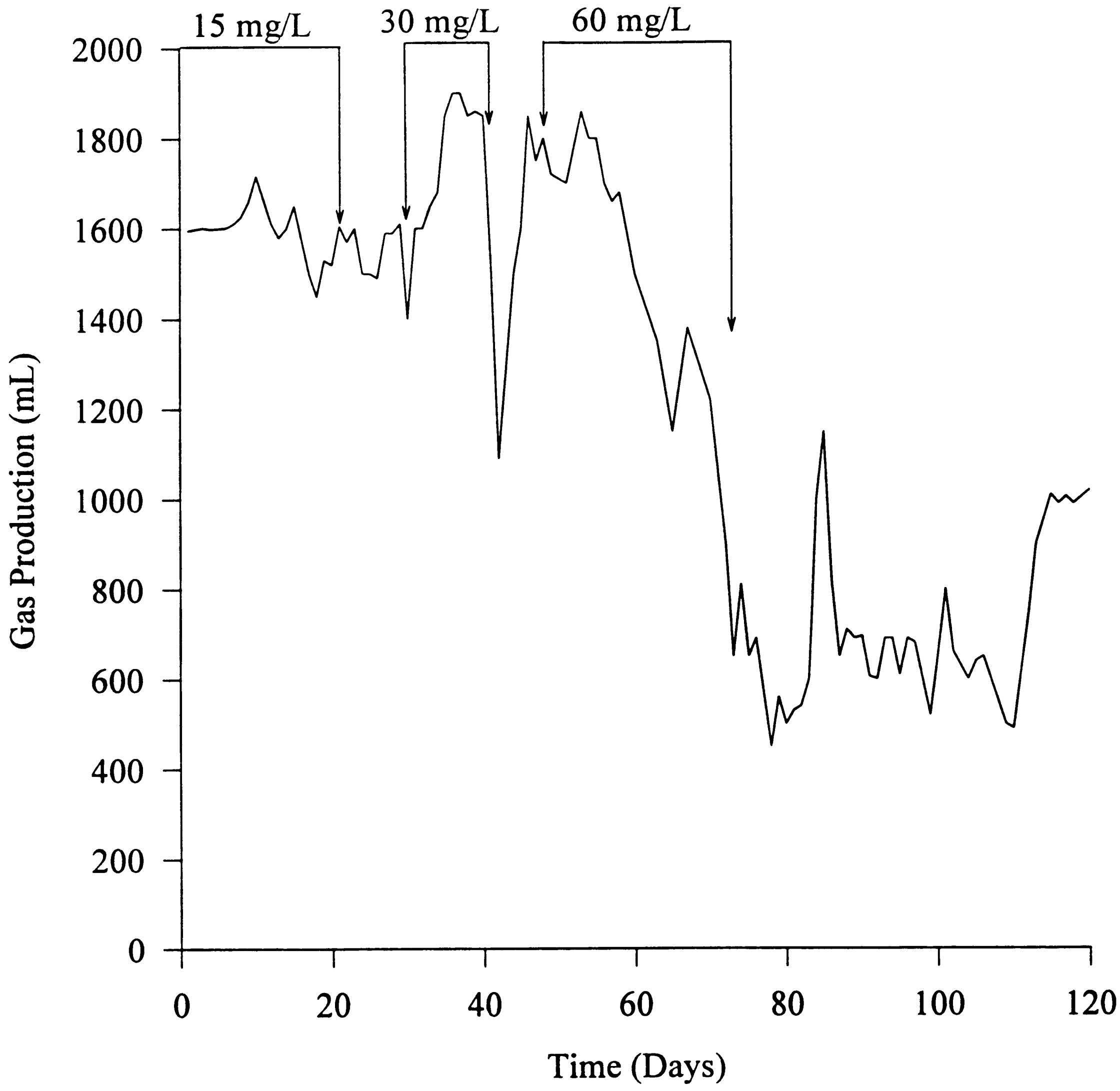

Figure 2. Response of anaerobic filter to an anionic surfactant.
(From Yang, *et al.* 1979)