THE REDUCTION OF EFFLUENT LOADING BY A LABORATORY SEPTIC TANK AND ITS RESULTANT EFFECT ON AN INDIVIDUAL LABORATORY SEWAGE LAGOON

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SEWAGE LAGOON

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CHAPTER I

INTRODUCTION

Individual sewage lagoons have been utilized by the Indian Health Service for over 10 years as an alternative waste disposal system for domestic sewage at rural Indian homes. Since the approval of Public Law 86-121 on July 31, 1959, the Indian Health Service has had the responsibility to provide "domestic and community water supplies and facilities, drainage facilities, and sewage and waste disposal facilities, together with necessary appurtenances and fixtures, for Indian homes, community and lands" (1) (Appendix, p. 78). In fulfilling the intent of this law the Indian Health Service has constructed individual water supply and waste disposal facilities for scattered Indian homes throughout the United States. Until recently, septic tanks and drainfields (soil absorption trenches) were usually installed for waste disposal at individual rural homes. In many areas, however, it was found that the soil was not suitable for a subsurface waste disposal system. As a result, individual sewage lagoons have been utilized for individual home waste disposal where subsurface disposal is not feasible due to inadequate percolation rates and sufficient land area is available for separation from the home and water supply.

Most individual sewage lagoon systems have included the use of a 1000 gallon septic tank which purpose has been to allow the settling of solids and remove grease and scum. The septic tank is then followed by a 4-inch PVC sewer service line, usually 300 feet long, that serves as an outfall line to the lagoon. The lagoon is sized according to local rainfall, evaporation, and estimated water usuage. Each lagoon is designed based on an operating level of three to five feet and to be total retention (that is influent flow=net evaporation, and there is no effluent). A typical lagoon in western Oklahoma for a family of four persons would have a surface area of 60 feet by 60 feet (0.08 acres) and operate on a depth of five feet.

The operating objectives of an individual sewage lagoon differ considerably from most industrial and municipal lagoons. Because there is no effluent flow the critical measure as to the proper operation of the lagoon is to prevent it from becoming a nuisance, and of lesser importance is the BOD reduction in the lagoon. To prevent the lagoon from becoming a nuisance, the dissolved oxygen (DO) must not be allowed to decrease to the point where anaerobic bacteria predominate, nor must the lagoon be allowed to overflow.

The operating characteristics of the individual sewage lagoon are dependent on several factors. Some of these factors are included in the design of the lagoon, such as volume, depth, surface area, and the hydraulic and organic loading of the lagoon. Natural forces that directly influence the operation of the lagoon include seasonal and daily variations in temperature, sunlight, winds, rainfall and evaporation patterns. All of the factors can play a role in the overall operation of the sewage lagoon.

Most of the research that has been done pertaining to sewage lagoons has been concerned primarily with developing rational design equations or evaluating the operation of industrial or municipal sewage lagoons. Little experimental work has been done on individual home sewage lagoons. As a result, this study was undertaken to ascertain the effects of various hydraulic and organic loadings on individual sewage lagoons and to determine whether the septic tank is required for the proper operation of the lagoon.

Laboratory scale individual sewage lagoons were operated under batch flow and diurnal light/dark conditions with a near constant room temperature. One lagoon was preceded by a model septic tank while the other lagoon was subject to the raw synthetic waste. The hydraulic loading on the 17 liter individual lagoons was varied from 0.2 liter per day and the quality of the waste water from the liquid was analyzed in terms of dissolved oxygen, pH, temperature, suspended solids concentration, and total COD. A heterogenous bacteria and algae population was maintained throughout the study.

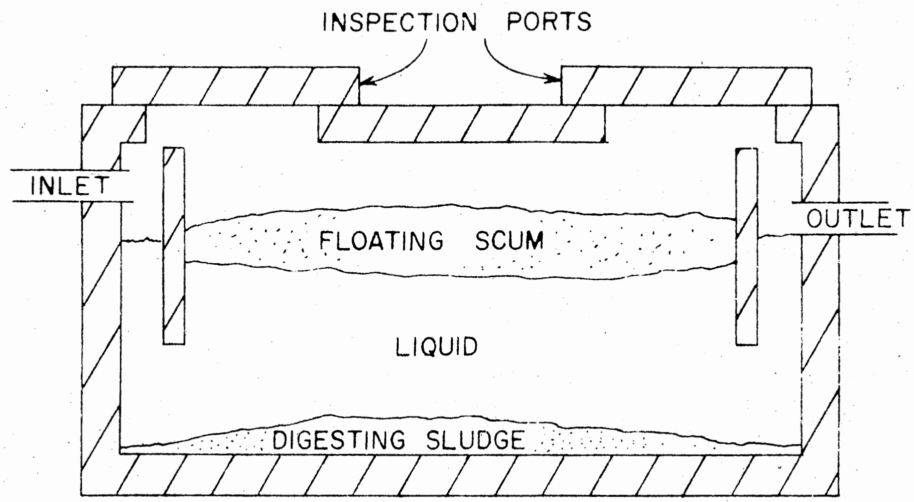
CHAPTER II

LITERATURE RESEARCH

Septic Tanks-General Considerations

Approximately one-third of the over 60 million households in this country are located in areas where community sewage disposal systems are not available. These homes that must rely on individual household waste treatment have different needs than those connected to central waste collection systems. If the individual system does not properly operate, it can directly affect the homeowner, such as by unpleasant odors, plumbing that won't function, or raw waste near his home. One of the first waste disposal systems put into operation was the septic tank soil absorption which was patented by Mouras and Moigno in 1881 (2). Although this system is still the most popular sewage disposal method for rural homes today, other systems have been developed but met with limited success. These include utilizing aeration tanks, grinders, and other patented processes. Where soil conditions are not suitable for the use of a septic tank soil absorption system the Indian Health Service has utilized a combination septic tank-individual total retention lagoon as a means of waste disposal. Septic tanks have been generally included in all waste disposal systems that have been developed for individual homes to date.

Septic tanks have been installed in individual waste disposal systems to provide three functions: 1) removal of solids; 2) biological treatment, and 3) sludge and scum storage (3). Septic tanks are usually constructed of precast reinforced concrete, although some tanks have been constructed of concrete blocks or poured in place. The volume



Source: J. Bailey and H. Wallman, "A Survey of Household Waste Treatment Systems," Jour. Water Pollution Control Federation (1971).

Figure 1. Typical Septic Tank Design

of septic tanks ranges from 500 gallons to 1250 gallons for precast home tanks with 1000 gallon tanks being the most commonly utilized by the Indian Health Service. Figure 1 shows a typical septic tank design (2). Most Health Departments throughout the United States require that the length:width ratio for septic tanks not exceed 3:1 (4). Minimum depth is usually 48 inches. Tanks are always provided with inlet and outlet baffling. Additional baffling is sometimes used within the tank (3).

Septic Tanks-Operational Characteristics

Few investigations have been made into the nature and removal efficiencies of individual household septic tanks. Schwartz and Bendixon, using municipal wastes, reported COD concentrations of 207 mg/l in effluent from a septic tank (5). Vivaraghavan and Warnock reported an average COD concentration of 568 mg/l, an average BOD concentration of 280 mg/l, TSS concentration of 176 mg/l, and a pH of 6.90 for the Septic tank effluent from an individual household (6). This information was incidental to both of these studies, therefore they did not report influent flows or give removal efficiencies.

One of the most comprehensive studies of a single septic tank was done by Vivaraghavan (7) on a large household utilizing a 1250 gallon septic tank. Average removal efficiencies over the study period were 45% removal of COD, 46% removal of BOD, and 18% removal of TSS. The average pH was 6.90. Average effluent values were 165 mg/l TSS, 280 mg/l BOD, and 550 mg/l COD. A study done by Lawrence (8), however, indicated that this high a removal efficiency may not always be possible. Studying two household septic tank systems, his study showed suspended solids removal of 35-44%, total solids of 4-8%, and BOD removal of only 7-15%. The pH values of 7.2 and 7.5 were also different from previous studies. He also reported a settleable solids reduction of 85% and 91% for the two systems.

Ludwig (9) examined septic tank performances under surge flow conditions and reported settleable solids removal efficiencies of 94.5% and suspended solids removal of 84.1% for a standard 800 gallon rectangular tank using fresh municipal sewage.

Ludwig (4) also examined removal efficiencies under uniform flow conditions and reported removal efficiencies as high as 80% and 91% for settleable solids. He also showed that these removal efficiencies decreased to 65% for suspended solids and 81.5% for settleable solids when a heavy sludge accumulation was in the tank. As in his other studies he used 800 gallon rectangular tanks and fresh municipal sludge.

Bailey and Wallman (2) stated that typical treatment parameters used in experimental septic tank studies at the Sanitary Engineering Center at the University of California were 50% removal of BOD, COD removal of 48.4%, and suspended solids removal of 73%. This system was preceded by a rock filter which probably contributed to the overall removal efficiency.

Proprietary products are frequently marketed which are claimed to improve operation of the septic tank. Some of these, especially those that are for "cleaning" septic tanks, contain sodium hydroxide or potassium hydroxide that may cause sludge bulking and an increase in alkalinity and actually interfere with proper operation of the septic tank (3). For normal household septic tanks no chemical additives are normally required for proper operation.

Lagoons - General Considerations

During the late forties several State Health Departments in the Midwest became interested in the use of lagoons as an acceptable method of treating municipal sewage (10). One of the earliest lagoons was installed at Maddock, North Dakota in 1948. Since that time, the lagoon concept has been utilized for a wide variety of treatment problems and many different variations have been developed. Previous literature on the history, development and application of lagoons to waste water treatment has already been thoroughly investigated by other authors (10-19) and therefore has not been included in this report.

Although waste stabilization lagoons are usually classified as aerobic, anaerobic, or facultative, it is usually found that most waste stabilization ponds, unless artificially mixed or otherwise influenced, will develop into a facultative system (20). Aerobic conditions will occur at the surface and sometimes throughout the entire depth of the lagoon while settleable organic debris will usually result in anaerobic conditions at or near the bottom of the lagoon.

Vennes (21) has reported that a series of lagoon cells will result in the best reductions in organic loading and enteric microorganisms. Most states recommend an operating depth of three to five feet with a minimum depth of two feet (22). Ten State Standards (23) has recommended that primary cells be loaded at a maximum of 0.5 lb. BOD/1000 sq. ft. (21.8 lbs. BOD/acre/day) or on a population basis 100 capita/acre. Prior to construction of municipal lagoons, soil tests are usually made to predict possible seepage, and if necessary, use liners, such as clay, bentonite, plastic, to reduce seepage.

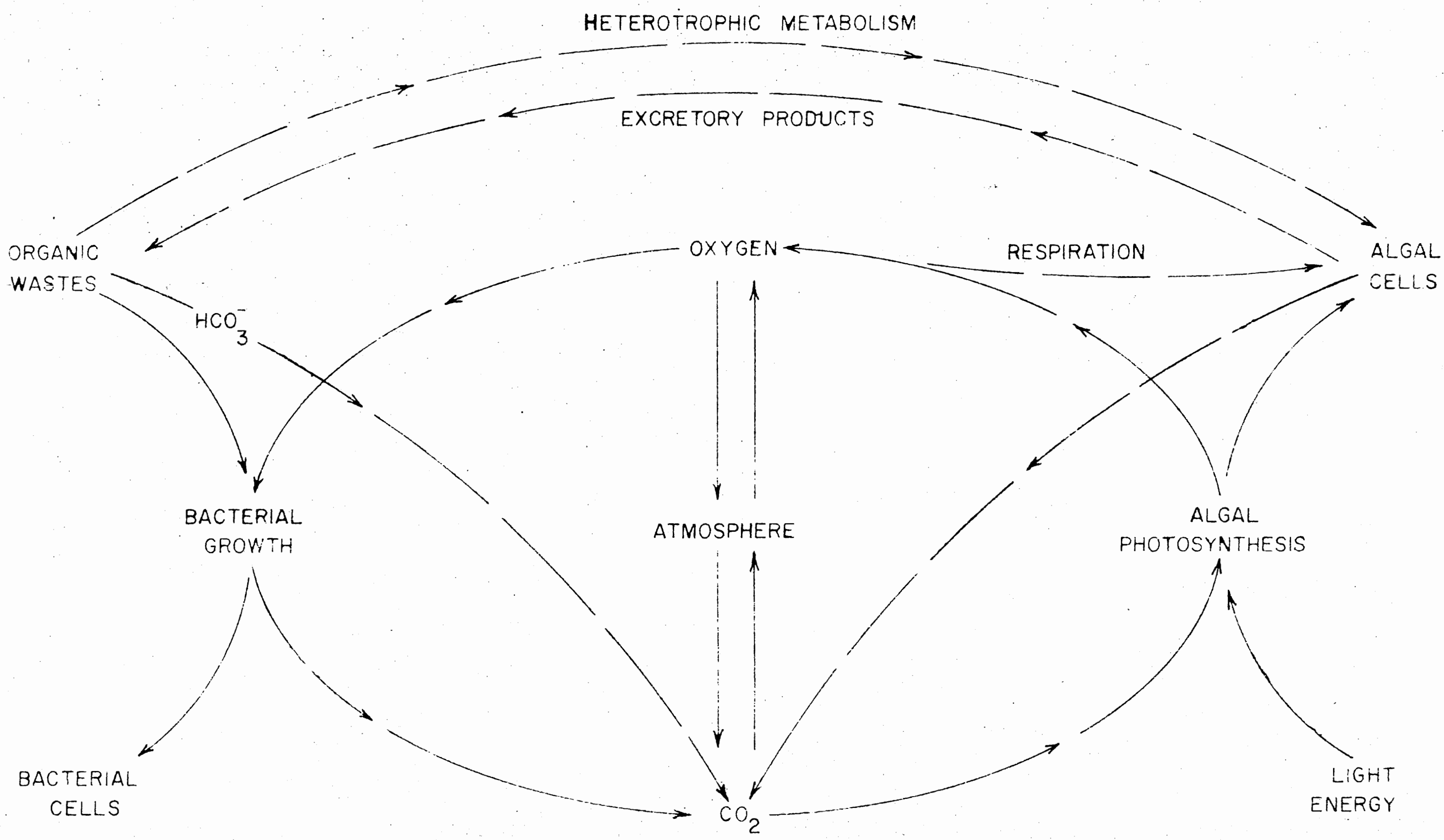
Factors that must be considered in the location of all lagoons, be they municipal, industrial, or individual household, includes distance to the nearest habitation, wind direction, location of nearby wells or other water supplies, and avoidance of surface runoff problems (22). Because of the tendency of warm sewage lagoons to attract wildlife and domestic livestock, especially during the winter (24), adequate measures, such as fencing, must be taken to prevent access to the lagoon.

The Indian Health Service has designed its lagoons for individual homes on the basis of hydraulic and organic loading (Appendix, p. 93). These lagoons are located away from the house so as not to create a nuisance, and are fenced to prevent access to the lagoon. Design guidelines of Indian Health Service lagoons have generally been based on Ten State Standards criteria (23).

Microbial and Algal Activity Within Lagoons

An understanding of microbial and algal physiology is important when studying the operation and performance of sewage lagoons. Of all the organisms in lagoons, the role of algae has been most extensively studied. It has been generally accepted that algae which are usually autotrophs, but may function as heterotrophs, contribute most of the oxygen utilized by heterotrophic bacteria in the oxidation of organic substrate (21).

Figure 2 shows the basic interrelationship that occurs between bacteria and algae in a waste stabilization lagoon (25). This interrelationship of microbial species is essential for the proper operation of any waste stabilization lagoon. Oswald et al. (26), reported that when sewage first enters a lagoon, bacteria is already at work. As such, bacteria will produce rapidly before algal populations appear in significant numbers. In a series of lagoons which approximate plug flow this results in cyclic growth with phases where bacterial growth predominates, and alternately algal growth predominates. Total retention lagoons force a symbiosis where algae supply the oxygen demand of the bacteria from photosynthesis and the bacteria supply



Source: H. C. Glaus, "The Effects of Temperature on the Response of a Laboratory Waste Stabilization Pond." Unpublished Masters Report, Okla. State Univ., Stillwater, Okla. (1971).

Figure 2. The Major Ecosystem Existing in an Aerobic Waste Stabilization Pond.

algae with necessary nutrients from sewage decomposition. Competition for nutrients and antibiotic activity tend to disrupt the symbiotic relationship. Both Fitzgerald and Rohlich (19) and Caldwell (27) have reported the lowering of bacterial counts, in particular E. coli, by the action of oxidation lagoons. This reduction is generally attributed to the liberation of chlorellin by algae which has an effect on bacteria similar to antibiotics such as penicillin.

Considerable work has been done on the biochemical actions that occur in sewage lagoons which will only be briefly mentioned in this report. McKinney (28) described the use of combined oxygen by micro-organisms in biological systems. Vennes (21) reported various biochemical reactions that occur in sewage lagoons. One of the most extensive studies was by Amin and Ganapati (29) who studied changes in bacterial populations in the soluble organic constituents, in the physiochemical and biological conditions including algae and protozoa, along with the interrelationships existing among them in laboratory lagoon studies.

Little, if any, work has been done towards identifying specific bacteria in sewage lagoons. Amin and Ganapati (29) identified most bacteria as belonging to starch hydrolyzing and tributyrin hydrolyzers with lesser amounts of gelatin liquifiers. They also reported significant amounts of nitrate reducers, ammonia oxidizers, and nitrogen fixers, and only small amounts of acid producers.

Some of the genus algae that have been utilized in laboratory studies and found to be present most frequently in oxidation lagoons includes, but not limited to, Euglena (30), Scenedismus (31), and Chlorella (19). Major qualitative and quantitative variations will occur as seasonal variations in the climate. Besides climatic variations affecting the dominant species, other factors include changes in organic content or pH of the lagoon.

Amin and Ganapati (32) have reported that a viscous scum develops, frequently within the first few days, on the surface of lagooned waste water. This had been reported as a temporary accumulation of dead and live algal cells (31), however, recent investigations (32) has shown the scum to consist of hundreds of zoogloeae of different shapes and sizes.

The importance of algae to oxygen production cannot be over emphasized. Oxygen production and carbon dioxide reductions by algae during periods of light can exceed by twenty times the reverse reaction during darkness (20). Hermann and Gloyna (33) noted, however, that if algal densities are too low, oxygen production will not be sufficient to satisfy any more than a small fraction of the BOD.

Gloyna (20) examined illumination, temperature, and nutrients as the key factors that influence algae growth. Light is essential in the conversion of carbon dioxide to oxygen by algae. Hermann and Gloyna (33) have reported that high intensity light is not an absolute requirement for successful waste treatment including laboratory work where light-intensity was only 500 foot-candles and algal densities were low. Oswald et al. (26) using synthetic sewage and studying the effect of light intensity on Euglena gracilis found that the algal population did not develop well until the light intensity reached 1200-2400 foot-candles. However, this resulted in a severe reduction in chlorophyll production. This study has also indicated that algal population, chlorophyll content, assimilatory quotient, and cell age are relatively independent of temperature when operating near the optimum temperature. Gloyna (20) reported that optimum oxygen production is maintained at approximately 20° C with rates approximately doubling for each 10° C rise. Gloyna (20) also stressed the importance of proper nutrients being available, in particular, the importance of nitrogen, phosphorus, and trace elements. Pipes (34) reported that algae of the type commonly present in stabilization lagoons have been cultured on media with pH values in the range of 3.0 to 11.0 without any detectable inhibition of photosynthesis. High pH values have not been found to directly affect algae growth, but usually have an indirect effect, such as carbon dioxide availability or inhibition of bacterial oxidation. Marais (35) has reported that mixing is a critical factor for algal growth under all environmental conditions. Many types of algae, such as the species Euglena rostifera will, if near the surface, form cysts to protect themselves from the warming effect of radiation. His studies have shown low periods of algal growth when there has been a lack of mixing.

Considerable research has been done to develop methods for removing algal growth from lagoon effluents (16). This study is concerned primarily with total waste water retention and therefore removal of algae from the waste water was not further studied.

Factors Affecting Lagoon Performance

Illumination and Duration

Light is important in that it is the driving force in the process of photosynthesis by algae in the lagoon. Previous discussion concerning the relationship of light to photosynthesis and algal growth indicated that oxygen production during periods of light can exceed oxygen consumed during periods of respiration by a factor of twenty (20). Glaus (25), in his investigation, reported that the optimum light intensity for algal growth under normal conditions is close to 400 foot-candles and cited Oswald (36) as showing that the ratio of light hours to dark hours was optimum at 0.5. Oswald et al. (26) showed that the optimum light intensity for "natural sewage" was from 400-1200 foot-candles, and for synthetic sewage it was 1200-2400 foot-candles to obtain optimum algal growth. It was also noted that chlorophyll production dropped rapidly in the range of 100-400 foot-candles. They concluded that a low loading rate (long detention period) at a low lighting intensity is as effective as a high lighting intensity for short retention periods.

pH and Carbon Dioxide

The carbon dioxide concentration in a sewage lagoon is dependent on bacterial decomposition of waste organic material, alkalinity, pH, temperature, and algal uptake. Glaus (25), in his investigation, reported that as algae utilized available CO_2 the pH of a stabilization pond will usually increase, sometimes to values as high as 11.0. High pH has been shown to have a definite detrimental effect on the growth and metabolism of microorganisms and therefore BOD removal in the lagoon will decrease (25) (34) (36).

Oswald (36) reported that by artificially increasing the CO_2 in a lagoon pH increases were less variable. Pipes (34) attempted to control pond pH by adjusting influent pH and by loading the pond during light hours only. Loading the pond during daylight hours was not effective, however, controlling the influent pH did help to prevent high pH levels from being reached, even though it did not eliminate the rapid changes that occur. This was not as important to overall BOD removal in conventional lagoons as it was in achieving high BOD removals in high-rate type stabilization ponds.

Investigations by Keefer and Meisal (37) on pH effects on activated sludge has shown similar results to lagoons where BOD reduction was best at pH 7.0-7.5 with a significant decrease in bacterial activity at pH 10.0.

Temperature

Gloyna (19, p. 398) has stated that "temperature is of paramount importance in the design and performance of waste stabilization ponds." Optimum temperature for biological action has been found to occur at 20° C with the lower limit generally accepted as 4° C with no activity (stagnation) occurring below 3.5° C (38) and an upper limit of 35° C. Gloyna (20) has stated that chemical reaction rates approximately double for each 10° C increase in temperature (van't Hoff's theory) (20) which substantiates Ferguson's (40) statement that "the rate of algal growth roughly doubles with every 20° F rise in water temperature between 32° F and 90° F". Neither author gave any supportive data.

Most investigators have generally accepted the van't Hoff rule and the theories of Arrhenius' (41)(42) developed therefrom. Arrhenius' relations were developed to describe chemical reactions but have also been shown to be applicable to enzymatic reactions that occur in biological systems (33) (43). The van't Hoff rule is also known as the Q_{10} relationship which has been defined as the ratio of the reaction rate at a particular temperature to the rate at 10 C° lower (42). Although the Q_{10} ratio is commonly assumed to be 2, it can vary considerably because of such factors as pH, light intensity and duration, cultures and algal species present (25).

Algal growth has been shown to be relatively independent of temperatures near the optimum growth temperature, however, bacterial growth and BOD removal have been influenced by slight temperature changes (26). Glaus (25) noted that temperatures which gave higher algal yields also had an increase in soluble COD in the effluent. He also noted that temperatures above 30° C or below 15° C inhibited microbial activity as measured by the dissolved oxygen parameter.

Brock (44) noted the following facts concerning temperature effects on microorganisms:

(1) Organisms will grow at any low temperature at which liquid water still exists.

(2) Many organisms that spend their entire lives at temperatures less than 10° C still often show temperature optimum for growth of around 20-25° C.

(3) The highest temperature at which living organisms are found is affected by pH and other environmental factors and in most favorable conditions is in the range of 85-88° C at which bacteria but not algae are found.

(4) The upper temperature limit for algae is 73° C.

Mixing

Marais (35) has investigated the importance of mixing to lagoon operations. His investigations of a five foot deep lagoon have shown that without mixing, stratification occurs, with insufficient dissolved oxygen at the greater depths. He reported that microbial organisms that lack motility will be adversely affected during periods when mixing does not occur, such as the case of Euglena algae which, unable to move away from intense illumination, will form cysts, and as a result, BOD and/or COD removal efficiencies will decrease.

Phosphorus

Phosphorus is one of the major nutrient elements required by algae for growth, and in particular, energy transformation. Domestic waste waters have been found to contain sufficient amounts of phosphorus to support algal and bacteria growth (19) (25). Because of the concern of the role of phosphorus in algal growth and eutrophication of lakes and rivers, extensive investigations have been made into the relation of phosphorus and phosphorus compounds to algal growth and need not be repeated in this study (25) (40) (43) (45) (46) (47).

The Theory and Relationship of Organic and Hydraulic Loading to Lagoon Performance

General Operating Experience

Fitzgerald and Rohlich (19) reviewed literature on sewage lagoons up to 1958 and reported that average raw sewage influent had a BOD_5 of 199 mg/l and lagoon effluent was 21 mg/l for an average reduction of 89%. However, these average values represent a wide variety of lagoons.

Most studies that have been done on actual sewage treatment lagoons have involved municipal treatment lagoons. Towne et al. (12)

reported treatment accomplished on a single cell for five communities in North Dakota and South Dakota. BOD removal was greater in the summer (average of 90.0%) than in the winter (average of 75.5%), however, one system had better removal in winter (96.2%) than summer (87.0%). One community with three cells in series and operating on total retention had removal exceeding 99%. Organic and hydraulic loading for the communities was not reported, so the relationship of removal to surface loading could not be determined.

Neel and Hopkins (48) investigated the adaptation of a lagoon for the city of Kearney, Nebraska. The lagoon provided BOD reductions comparable to conventional secondary treatment. BOD removal ranged from 32-90% in the winter, however, sewage frequently bypassed the lagoon, and it was not possible to accurately relate BOD removal to loading.

Thirmurthi (49) reported the following removal efficiencies and related them to organic loading and detention time for various municipal lagoons:

TABLE I

BOD REMOVAL VS ORGANIC LOAD AND DETENTION TIME (48)

Location	Description	BOD Removal	Organic Load lbs./acre/day	Detention Days	Temp.
Fayetteville, AR	Primary Cell	87.2%	20	87	17° C
Herzliya, Israel	Primary Cell	81.1%	172	13	27° C
Spooner, WS	Aug., 1958	97.2%	9	246	24° C
	Dec., 1957	90.0%	24	195	1° C
	Aug., 1958	93.4%	23.5	160	25° C

Sudweeks (13) reported data on the operation of various municipal lagoons in Utah. The BOD loading on primary cells reported ranged from 18 lbs./acre/day to 55 lbs./acre/day, however, these were all multiple cell lagoons.

Meron et al. (50), studying quality changes as related to detention time for two-cell lagoons in Israel observed that the highest rate of BOD reduction occurred during the first few days of activity and decreased with time. It was noted that prolonged detention time usually resulted in a reduction in the algal cell and mass concentration attributable to the age of the algae and limiting amounts of available carbonaceous material. A pronounced shift in carbonate equilibrium caused an increase in pH from 7.5 to 8.06 after 26 days. Liquid losses after 26 days were 18% evaporation and 12% seepage. Neither of these values were related to relative humidity or soil conditions.

Lyman et al. (51) reported the following operating characteristics for lagoons for small towns in Kansas:

TABLE II

OPERATING CHARACTERISTICS FOR VARIOUS LAGOONS IN KANSAS (51)

Location	Description	BOD lbs./acre/day	BOD Removal	COD Removal	pH	DO
Overbrook	Primary Cell	48	91.5%	78.9%*	7.86	3.28
	2nd Cell	28.9 (both cells)	87.3%*	64.6%*	8.98	12.37
Eskridge	Primary Cell	44.2	79.7%	60.6%	8.8	9.0
	2nd Cell	22.2 (both cells)	60.3%*	60.3%*	9.7	8.3

*In comparison to plant influent.

It is interesting to note that in both these lagoon systems additional algal growth in the second cell has actually caused an increase in BOD and COD.

Canter et al. (11) reported the results of a questionaire showing design criteria developed by various state water pollution control agencies.

TABLE III

QUESTIONAIRE RESULTS (11)

Variable (1)	Region		
	North[a] (2)	Central (3)	South (4)
Number of states	18	84	15
Organic loading in pounds of BOD_5 per acre per day			
Mean	26	33	44
Range	16.7-40(5)	17.4-80(1)	30-50(2)
Median	21	33	30
Loading, population per acre			
Mean	124	189	267
Range	100-200(7)	100-400(4)	175-300(3)
Median	100	200	295
Detention time, in days			
Mean	117	82	31
Range	30-180(11)	25-180(5)	20-45(9)
Median	125	65	31

[a]Numbers in parentheses indicate the number of states for which no value was obtained.

Operating Experience - Small Lagoons Without Pretreatment of Sewage

Very little work has been done to investigate lagoon operating characteristics for small flows such as from individual households, most of the work being done on laboratory scale models.

Hermann and Gloyna (31) using municipal sewage observed BOD removal rates ranging from 91% at a surface loading of 263 lbs./acre/day to 96% at a loading of 75 lbs./acre/day. Using a synthetic waste composed of non-fat dry milk solids, BOD removal was as high as 98% at a surface loading of 172 lbs./acre/day. Effluent pH ranged from 8.0 to 10.7 with the higher pH values usually associated with longer detention time.

Pipes (34), utilizing synthetic wastes consisting primarily of dextrose, beef extract, and tryptose in one trial and milk solids in a second trial, found that pH significantly decreased with detention time generally approaching a maximum of 10.0 while the BOD removal usually decreased with time as algal growth increased when studying lagoons illuminated at 600 foot-candles. BOD removal tended to stabilize at approximately 80% after 30 days.

Canter et al. (11) reported BOD_5 and COD removals greater than 90% and 80% respectively for loading rates up to 200 lbs. BOD_5 per acre per day. The report stated that the removals were essentially independent of the loading rate. However, in reviewing their data there were significant variations in the COD removal in relation to loading if the effluent was not contrifuged.

Operating Experience - Lagoons

With Anaerobic Pretreatment

Little or no work has been done to determine the affects of anaerobic pretreatment of sewage on the operation of a lagoon. A limited amount of data has been collected on such lagoons but its applicability to this study is of limited value.

Beard and Lawrence (52) investigated the performance of four waste stabilization ponds serving individual rural households. Each lagoon was preceded by a septic tank and designed as total retention and as such had no overflow. BOD and COD values for lagoon waste water are reported in Table IV. The study did not attempt to determine percent removal, nor did it relate BOD or COD values to hydraulic loading. Visual inspection of the ponds showed that the more heavily loaded ponds had much higher algal population.

TABLE IV

OPERATING CHARACTERISTICS FOR VARIOUS INDIVIDUAL HOUSEHOLD LAGOONS (51)

Pond No.	BOD mg/1	COD mg/1	Loading cap./acre
1	65.8	323	284
2	44.5	229	114
3	13.8	99.5	43
4	9.4	57.8	27

A study done by Vivaraghavan and Raman (53) at a tuberculosis sanatorium in Madras, India showed characteristics of raw sewage, septic tank effluent, and oxidation pond effluent for a population of approximately 650 persons. Removal efficiencies have not been reported because the authors' have only reported a range of values over a 15 month period. Detention time for the pond was approximately 20 days and the BOD design loading was 60 lbs./acre/day. General characteristics reported by the authors are shown in Table V. It is interesting to note that their preliminary studies indicated that Mycobacterium tuberculosis did not survive oxidation pond treatment.

TABLE V

CHARACTERISTICS OF RAW SEWAGE, SEPTIC TANK EFFLUENT, AND OXIDATION POND EFFLUENT

Particulars	Raw Sewage	Septic Tank Effluent	Oxidation Pond Effluent
Colour	Whitish	Black to White	Greenish
Odour	Phenolic and coal-tar sometimes	Phenolic and H_2S odour	Algal
Suspended solids (mg/1)	40-340	20-230	40-280
pH	6.6-7.6	6.9-7.6	7.5-8.1
BOD (5 days 20-C mg/1)	130-230	95-180	3.5-30.0F*

*Filtered Samples

Caldwell (27) reported the results of tests of effluent from sewage oxidation ponds in Nevada and California where primary treatment was in septic tanks. Because no information was given as to size, number, series or parallel operation of the lagoons, comparison is difficult. pH values were generally 9.0 or above although some results showed lower pH values with increased loading, such as 7.4 with a loading of 500 cap./acre, and 8.4 with a loading of 700 cap./acre. Dissolved oxygen values were generally reported to be super saturated. Five day BOD values ranged from a low of 11 mg/l at a loading of 200 cap./acre to a high of 131 mg/l at 600 cap./acre. Suspended solids concentrations varied greatly but generally increased with increased loading. Suspended solids concentrations ranged from a low of 17 mg/l at 300 cap./acre to a value of 109 mg/l at 700 cap./acre. Individual tests varied widely, sometimes exceeding these concentrations at intermediate loadings.

Esparato, California utilized a system of an anaerobic waste lagoon followed by a series of aerobic lagoons (54). Reviewing the operational data for these lagoons, it is evident that the first aerobic lagoon receiving the anaerobic waste does not effectively remove the suspended COD as the second anaerobic lagoon following, indicating that the anaerobic waste is not readily acclimated to treatment in an aerobic lagoon. Operating characteristics for the system are given in Table VI. No explanation was given regarding the apparent discrepancy between BOD_5 and COD removal.

TABLE VI

OPERATING CHARACTERISTICS FOR ESPARATO, CALIFORNIA SEWAGE DISPOSAL SYSTEM

	Raw Waste	Anaerobic Lagoon	First Aerobic Lagoon	Second Aerobic Lagoon
Loading lbs./BOD_5/acre/day	-	62.5	33.6	21.5
Detention time (days, average)	-	40	36	42
BOD_5 mg/l	203	14	7	3
COD mg/l	452	287	265	70
Suspended COD mg/l	231	207	195	9
Suspended Solids mg/l	166	90	70	6
	138	54	52	34
Average pH	8.08	8.18	8.22	9.04
DO mg/l	2.8-5.9	1.4-5.0	1.2-3.0	4.3-6.7

Purushothaman (55) conducted studies in South India utilizing an effluent from an anaerobic lagoon and found for model lagoons that BOD removal efficiency did not vary appreciably for depths ranging from two feet to five feet, nor for detention times up to only nine days. He reported removal efficiencies ranging from 75-80% for loadings ranging from 90 to 230 lbs./acre/day. It is interesting to note that dissolved oxygen levels in the five foot lagoon were equal or above saturation values for 8-10 hours each day but completely used up by algal respiration and bacterial decomposition at night.

Empirical Relationships

Numerous empirical relationships developed concerning lagoon operation have been presented in textbooks and literature. Marais and Shaw (56) reported the relationship:

$$P = \frac{750}{0.6d + 8}$$

Where d is pond depth and P is the maximum BOD in a lagoon which must not be exceeded if aerobic conditions are to be maintained.

Hermann and Gloyna (33) developed the following relationships for study pilot ponds and aquaria models:

$$P = \frac{100}{1 + 0.04\ (Y/AT)^{0.57}} \qquad \text{Pilot Ponds}$$

$$P = 100 - 0.05\ (Y/AT) \qquad \text{Aquaria Models}$$

Where P = percent BOD reduction, and Y/AT is the BOD loading in weight per unit over per unit time (lbs./BOD/acre/day). Combining these relationships with operating data for various depth lagoons the authors were able to conclude that a maximum practical loading would be 300 lbs./BOD/acre/day. These equations were only used to describe model behaviour and are not intended for use as design equations.

Popular textbooks, such as Metcalf and Eddy (57) have reported BOD removal as:

$$\frac{S}{S} = \frac{1}{1 + K\ (\frac{V}{Q})}$$

Where K = overall first order BOD_5 removal coefficient. This equation is based on completely mixed flow systems. Thirumurthi (49) has recommended that the evaluation of K should be based on a standard value of K_s which corresponds to an arbitrarily selected standard environment which is then corrected for temperature, organic load, and toxicity using the following formula: $K = K_s \; C_{Te} \; C_o \; C_{tox}$

Where K_s = standard K_s value

Where C_{Te} = temperature correction

Where C_o = loading correction

Where C_{tox} = toxicity correction

Applying these relationships to field data for waste stabilization ponds in various parts of the world the author reported variations in the field coefficient K from as low as 0.0017 to as high as 0.128 $days^{-1}$. By applying the correction factors and averaging the values for each lagoon, he found K_s to vary considerably less, from 0.042 to 0.071 $days^{-1}$. It is noted, however, that one lagoon exhibited K_s values ranging from 0.025 $days^{-1}$ to 0.079 $days^{-1}$ during different trial periods.

The attempts to develop empirical relationships to describe lagoon performance illustrate how difficult it is to predict lagoon performance considering all the environmental factors and waste characteristics that influence the resultant BOD reductions achieved in waste stabilization lagoons.

CHAPTER III

MATERIALS AND METHODS

Experimental Apparatus

Model Individual Sewage Tank

The model individual septic tank used for this study consisted of a wide mouth two-quart jar. Dimensions of the tank are as follows:

Length	11 cm
Width	9 cm
Depth	19.5 cm
Freeboard	4 cm
Surface Area	99 cm^2
Volume	1.93 liters

Model Individual Sewage Laooon

The model sewage lagoons used for this study consisted of standard rectangular glass five-gallon aquariums. Dimensions of the aquarium are as follows:

Length	36 cm
Width	21 cm
Depth	25.2 cm
Surface Area	756 cm^2
Total Volume	19.1 liters

Temperature Control

No attempt was made to control the temperature of the units. The units were generally maintained at room temperature, and subject only to variations in the room temperature.

Illumination

Illumination was provided from two 40-watt fluorescent lamps (Westinghouse Cool White brand) which were 118 cm long and situated side by side and parallel to the length of the model lagoons. The lights were located at a height of 16 cm above the surface of the lagoons. Illumination at the surface of the lagoon was 350 foot-candles as measured by General Electric Type 213 light meter. The lights were operated on a 12-hour-on/12-hour-off cycle by the use of a 24 hour timer throughout the length of the study.

Mixing

Artificial mixing was achieved by the use of a window box fan (Kel-Aire Model 7000, diameter 46 cm) set on high speed. This created surface agitation of the individual lagoons similar to that produced by a 5-10 mph breeze. The fan was operated in conjunction with the lights on a 12-hour-on/12-hour-off cycle by the use of a 24 hour timer throughout the length of the study.

Rainfall and Evaporation

Water was allowed to freely evaporate from each of the individual lagoons. Any surface scum that formed that might inhibit evaporation was not removed. To simulate rainfall, distilled water was periodically added to the model lagoons to maintain a constant water level.

Substrate Feed System

The small daily influent flow to the reactors was done daily on a batch basis. The influent flow (200-500 ml/day) was carefully measured in a graduated cylinder.

Effluent Discharge

Because the individual lagoons are designed to serve as total retention lagoons, no provisions were made for effluent discharge. A schematic diagram of the units is shown in Figure 3.

Seeding Populations

Heterogenous Microbial Seed

The heterogenous microbial seed used in this study for the model septic tank was sludge taken from the authors' septic system located near Stillwater, Oklahoma. The heterogenous microbial seed and bottom sediments for the model lagoons were liquid waste water and sediments from an actual lagoon at the home of Sam Osborne near Pawnee, Oklahoma.

Heterogenous Algal Seed

The initial algal seed was the liquid waste water described above as microbial seed. This seed never developed into a satisfactory algal growth. As a result, a second seeding population was obtained from another individual sewage lagoon located at the home of Bill Eaves,

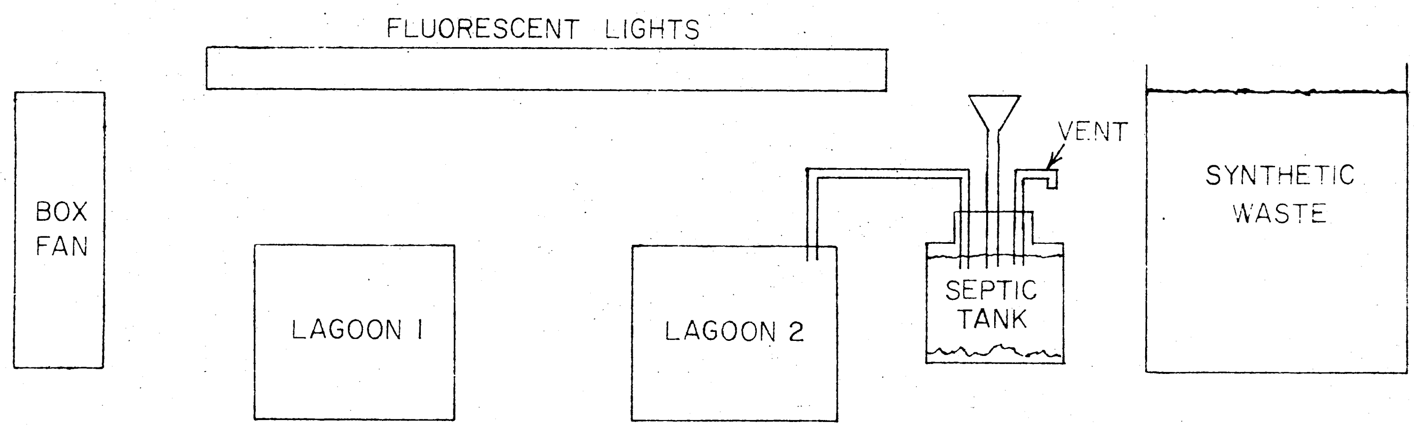


Figure 3. Schematic Diagram of Experimental Apparatus.

northwest of Pawnee, Oklahoma. Waste water from this lagoon had the appearance of "green pea soup" and was excellent as an algal seed.

No attempt was made to maintain a pure culture or a predominating species within any of the biological units.

Sludge Blanket

A bottom sludge of about 2.5 cm was provided in the bottom of the model septic tank with sludge obtained from the authors' septic system. Bottom sediments taken from the Sam Osborne lagoon were used to provide sludge in the bottom of the model lagoons. Average sediment depth was 2.7 cm in Lagoon #1, and 2.5 cm in Lagoon #2.

Organic Loading

At the initiation of the project it was necessary to determine the relationship between the model lagoon system and an actual individual lagoon system. It was decided to base the operation of the model lagoon on the Indian Health Service design guidelines as much as possible. A comparison of the model lagoon system with a typical individual lagoon system designed for a home with four persons is shown in Table VII. Based on the scale of the model sewage lagoon system to a typical installation, the hydraulic loading for the model was selected to range from 200 ml/day to 500 ml/day. The strength of the waste was maintained as closely as possible to 140% of the design waste flow strength. This provided a very comparable surface loading rate for the model lagoon system versus the typical home lagoon system at a flow rate of 200 ml/day.

Preparation of a suitable synthetic waste required several

TABLE VII

COMPARISON OF TYPICAL INDIVIDUAL LAGOON SYSTEM WITH MODEL LAGOON SYSTEM

	Typical Individual Lagoon System - 4 Persons*		Model Lagoon System	Ratio
	English Units	Metric Units	Metric Units	Model/Actual
Septic Tank	1,000 gallons	3,785 liters	1.93 liters	0.0005
Lagoon -				
Surface Area	3,600 sq. ft.	334.44 meters	756 cm^2	0.0002
Depth	5 ft.	1.52 meters	25.2 cm	0.1658
Volume	11,250 $ft.^3$	318,600 liters	19.1 liters	0.00006
Flow Rate to Experimental Lagoon - 200 ml/day				
Sewage Influent				
Flow	240 gal./day	908 liters/day	0.2 liters/day	0.0002
Strength of Waste	0.17 lbs./day/person (BOD)	567 mg/l (COD)	788 mg/l***	1.38
Surface Loading	20 lbs. BOD/acre/day	0.0022 Kg/m^2/day (COD)	0.0021 Kg/m^2/day**	0.96
Flow Rate to Experimental Lagoon - 300 ml/day				
Sewage Influent				
Flow	240 gal./day	908 liters/day	0.3 liters/day	.0003
Strength of Waste	0.17 lbs./day/person (BOD)	567 mg/l (COD)	788 mg/l***	1.38
Surface Loading	20 lbs. BOD/acre/day	0.0022 Kg/m^2/day (COD)	0.0032 Kg/m^2/day**	1.45

TABLE VII (Continued)

Typical Individual Lagoon System - 4 Persons*	English Units	Metric Units	Model Lagoon System Metric Units	Ratio Model/Actual
Flow Rate to Experimental Lagoon - 400 ml/day				
Sewage Influent				
Flow	240 gal./day	908 liters/day	0.4 liters/day	.0004
Strength of Waste	0.17 lbs./day/person (BOD)	567 mg/1 (COD)	788 mg/1***	1.38
Surface Loading	20 lbs. BOD/acre/day	0.0022 Kg/m^2/day (COD)	0.0042 Kg/m^2/day**	1.91
Flow Rate to Experimental Lagoon - 500 ml/day				
Sewage Influent				
Flow	240 gal./day	908 liters/day	0.5 liters/day	.0006
Strength of Waste	0.17 lbs./day/person (BOD)	567 mg/1 (COD)	788 mg/1***	1.38
Surface Loading	20 lbs./acre/day	0.0022 Kg/m^2/day (COD)	0.0052 Kg/m^2/day**	2.36

*Based on Indian Health Service design guidelines and BOD of a "typical" waste water is 60% of the COD.

**Does not include septic tank reduction.

***Average Waste Strength.

trials. It was desired to produce a waste having a COD of approximately 800 mg/1 and a total suspended solids concentration of 300-400 mg/1. Trial solutions were prepared by several different methods using "Friskies" brand pellet dog food. Several methods, such as pulverizing the dog food with a hammer by hand, produced excessive suspended solids while other methods, such as mixing in a blender, did not produce sufficient suspended solids. Best results were obtained by grinding the dog food in a Wiley Intermediate Mill using a #60 screen, mixing it in water, analyzing the solution for total COD and also determining the COD of the supernatant after settling was allowed to take place, and then adding distilled water and glucose to give a supernatant with a COD of 400 mg/1 and a total COD of 800 mg/1. Thus, it was necessary to prepare the synthetic waste every 2-4 days and each solution was analyzed daily. Average strength of the waste over the length of the study was a total COD of 788 mg/1 and a total suspended solids of 356 mg/1.

Since the synthetic waste was prepared on an individual basis to achieve a desired organic content of 800 mg/1 total COD, the dog food and glucose content varied throughout the length of the study. Average values for composition of the waste are given in the following table:

TABLE VIII

COMPOSITION OF SYNTHETIC WASTE

Constituent	Average Concentration
Dry Dogfood	416 mg/1
Glucose Concentrations	300 mg/1

TABLE VIII (Continued)

Constituent	Average Concentration
$(NH_4)_2SO_4$	150 mg/l
$MgSO_4 \cdot 7H_2O$	30 mg/l
$FeCl_3 \cdot 6H_2O$	0.15 mg/l
$MnSO_4 \cdot H_2O$	3.0 mg/l
K_2HPO_4	374 mg/l
$KHPO_4$	116 mg/l

Except for the dry dog food, the constituents of the waste and their concentration are based on the glucose synthetic waste commonly used in the Bioenvironmental Engineering Laboratory at Oklahoma State University.

Method of Operation

Initially each sewage lagoon was seeded with microbial and algal seeds from the sources previously mentioned. Also, the individual septic tank was seeded from an individual septic system. Sludge was added to each model lagoon from the actual lagoon to simulate actual operating conditions. The system was then fed on a batch basis until it had become acclimated to the new environmental conditions.

The individual lagoon systems were studied under five (5) different loading conditions. The feed rate to the systems was varied from 200 ml/day to 400 ml/day for the first three trials with evaporated water being replaced as rainfall. The fourth and fifth trials involved a feed rate of 500 ml/day and 200 ml/day, and evaporated water was not replaced. For flow rates of 200 ml/day and 300 ml/day the effluent was taken from the model septic tank under quiescent conditions before adding the influent flow. At flow rates of 400 ml/day and 500 ml/day the effluent was drawn off continuously as the influent was added to achieve short circuiting of the tank. Samples were taken from the septic tank effluent and the middle of each lagoon approximately every other day. Total COD, dissolved oxygen, pH, temperature, and suspended solids were determined on the samples. Samples of the raw influent flow were also taken daily and analyzed for total COD. The small amount of liquid withdrawn for sampling was not replaced, as this was comparable to losses due to pipe leakage, ground seepage, etc., that occur in most home waste water disposal systems. Flow rates were usually maintained for approximately three weeks.

Analytical Procedures

Substrate Removal

Substrate removal was determined by analyzing samples for COD as described in Standard Methods (58). Several 10 ml samples were inadvertently not diluted to 20 ml. Comparison of these values with values for properly diluted samples indicated a random error that could not be corrected. These values have been included because they do show differences in operating characteristics of the units, however, the actual value of the parameter is questionable. These values are marked by an asterisk (*) where they appear in the report.

Biological Solids

The concentration of biological solids in the effluent of the model sewage lagoons was determined by filtering a known volume through a 0.45μ Millipore filter as described in Standard Methods (58).

pH

The pH of the septic tank effluent and the individual sewage lagoons was determined by the use of a "Ovion Research Model 701" digital pH meter. The pH meter was standardized twice weekly.

Dissolved Oxygen and Temperature

Temperature and dissolved oxygen were measured using the "Weston and Stack Dissolved Oxygen Analyzer, Model No. 330". The analyzer was standardized using the azide modification of the winkler method twice weekly as described in Standard Methods (58).

CHAPTER IV

RESULTS

The results of this study are shown in Figures 4 through 15, which show the variability in dissolved oxygen, suspended solids, pH, temperature, and total Chemical Oxygen Demand for each of the five trials. Figure 14 shows the total COD remaining in each reactor versus loading and suspended solids remaining versus the loading. Figure 15 shows the percent removal of suspended solids and COD versus the hydraulic loading of the units. Average, maximum, and minimum values for each trial as well as percent removal values for each unit are given in the Appendix.

The experimental study involved the increasing of the hydraulic loading of the reactors holding the other factors that could influence the operation of the units as near constant as possible. Even though the units were located in a laboratory room where it was attempted to maintain an even temperature, temperatures did vary, as noted in the graphs. The temperature of the laboratory room, although controlled by a thermostat, did vary with outdoor temperatures causing variations in the temperatures of the units. The variations were greatest in the first trials at 200 and 300 ml/day.

Lighting was maintained constant by the use of fluorescent lights, as noted earlier, operated 12-hours-on/12-hours-off by the use of a 24-hour timer. This was done to simulate actual diurnal variations in lagoon operation as closely as possible. Although no extensive investigation was done to observe what variations occurred in the operating parameters due to darkness, some incidental observations were made in order to note general tendencies. Some of this data is shown in Figures 4 and 5 which was done during the 200 ml/day loading trial. In general, it was observed that temperature and pH decreased slightly during darkness conditions, while dissolved oxygen loads showed significant decreases, sometimes 2 mg/1. Lagoon #2 (receiving the septic effluent), with the greater algal growth, showed a greater dissolved oxygen reduction in periods of darkness than did Lagoon #1.

A fan was utilized to simulate actual wind conditions. Several samples were taken at various depths of the reactors at random intervals during the experiment to see if the reactors were completely mixed or if stratification had occurred. COD samples taken did not show any significant differences between the top and lower levels of either of the lagoons. Samples taken from the septic tank, however, showed that the upper 2/3 of the tank was constant, while as the bottom was approached, the total COD increased approximately 20%. This may have been due to hindered settling in the lower region of the septic tank.

The organic substrate concentration of the waste did vary during t the experiment between trials. This variation was nearly impossible to avoid because of the lack of uniformity in the dog food used as a synthetic waste. Percent removals for suspended solids and total COD used based on the concentrations in the raw influent flow for that particular trial and <u>not</u> on the average concentrations for the entire ex experiment.

Figures 4 and 5 indicate the effects of a loading of 200 ml/day on

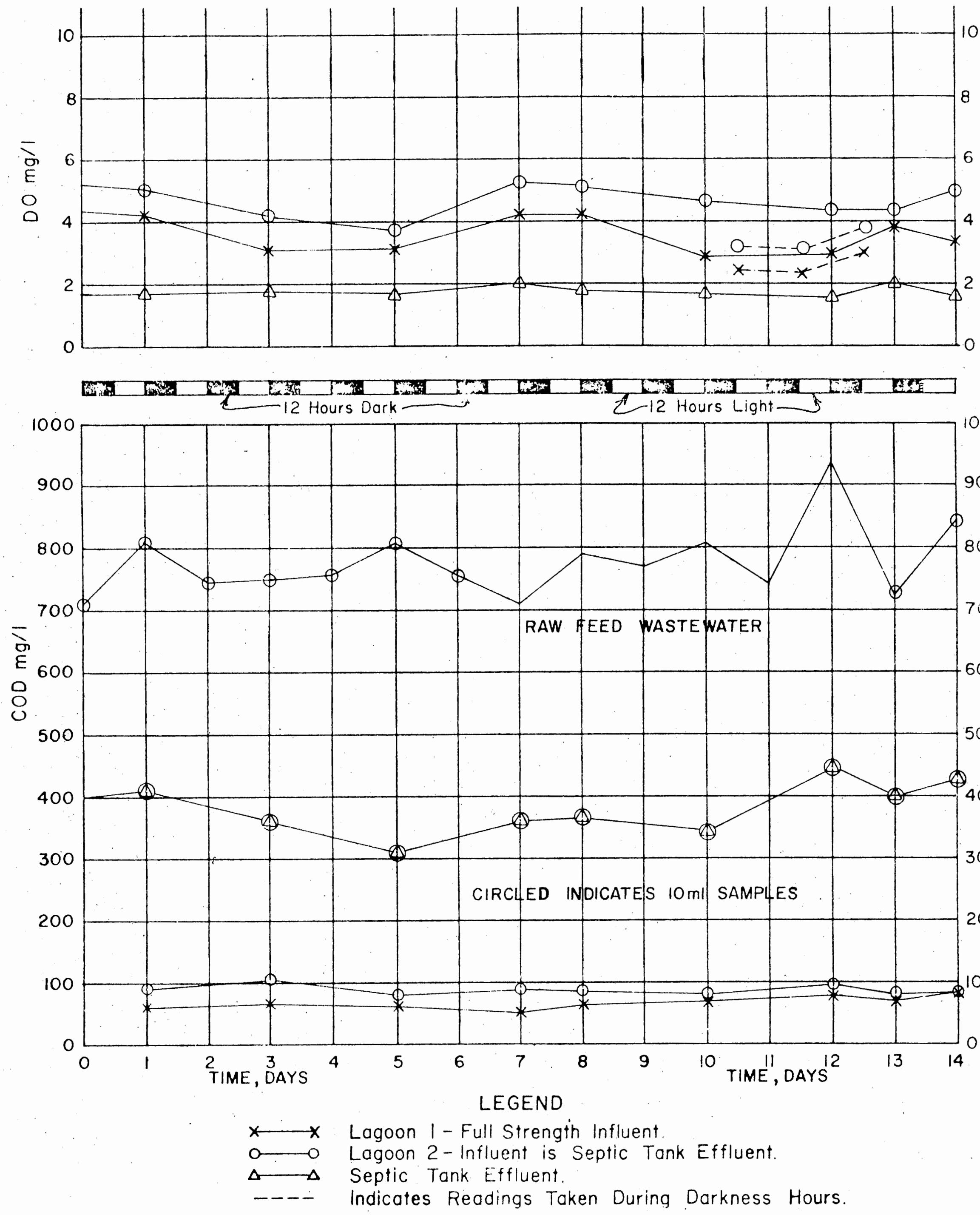


Figure 4. Dissolved Oxygen and COD Variations at 200 ml/day Hydraulic Loading, Evaporative Losses Replaced.

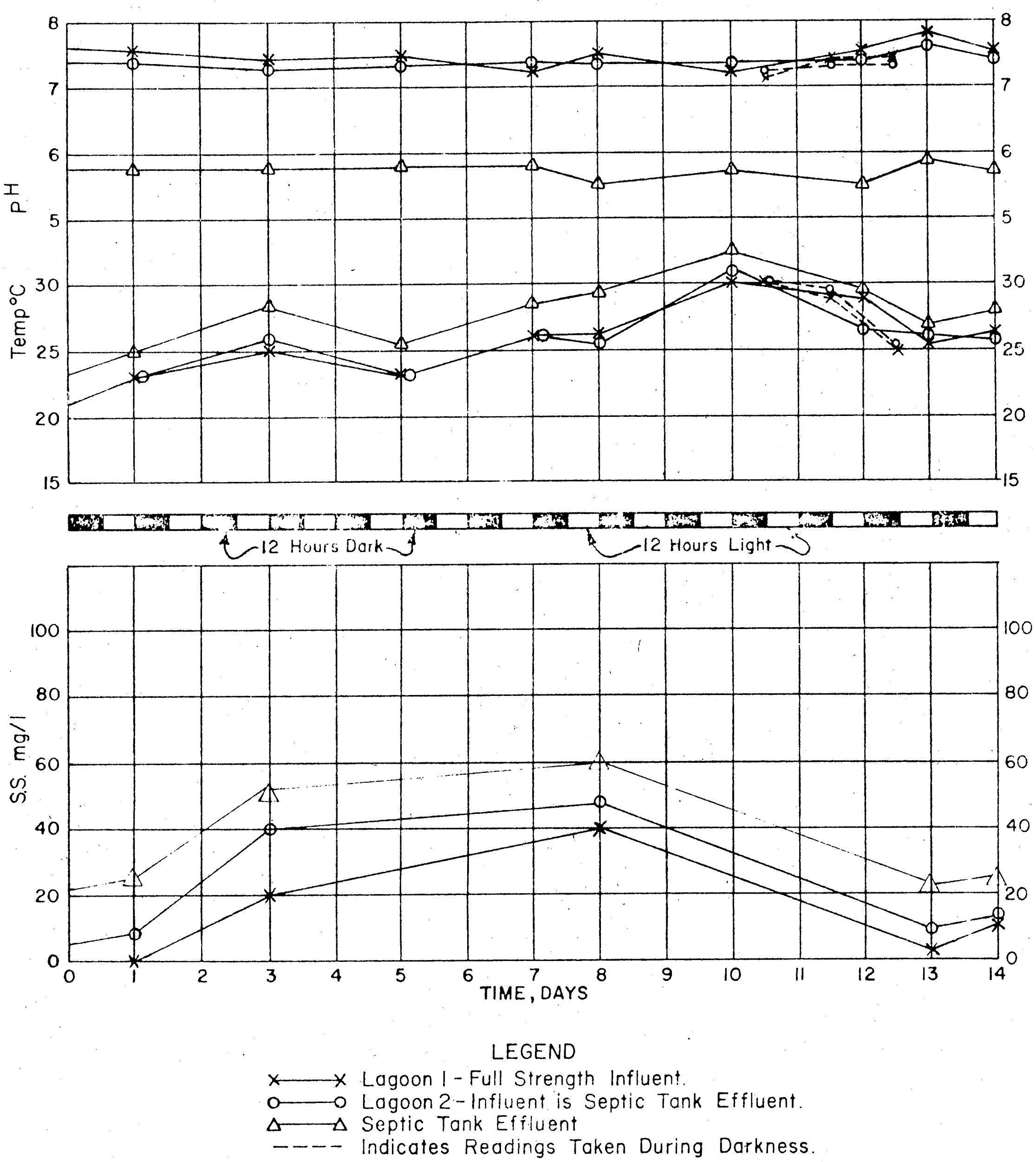


Figure 5. pH, Temperature, and Suspended Solids Variations at 200 ml/day Hydraulic Loading, Evaporative Losses Replaced.

the experimental reactors. During this trial Lagoon #1 had an average daily evaporation of 450 ml/day and Lagoon #2 was 490 ml/day. Evaporation in excess of the daily influent flow was replaced by adding distilled water to the lagoon. This was added to simulate actual design practice where individual home sewage lagoons are designed to operate at a constant level with influent plus rainfall equal to evaporation. The lesser evaporation in Lagoon #1 was likely due to a grease and scum layer which was present on the lagoon. The dissolved oxygen content of Lagoon #1 (3.5 mg/l) was considerably lower than that of Lagoon #2 (4.5 mg/l) indicating that the septic tank had reduced the loading with a correspondent decrease in the biological action, and thus, oxygen consumption in Lagoon #2. Dissolved oxygen in the septic tank was approximately 1.76 mg/l and along with the distinct "rotten egg" odor, indicated that anaerobic decomposition was occurring within the septic tank. COD samples indicated that a slightly better COD reduction was occurring in Lagoon #1 (91.7%) than in Lagoon #2 with the septic tank (88.7%). This could be contributed to less microbial activity in Lagoon #2, perhaps because the influent from the septic tank to the lagoon, having been undergoing anaerobic decay, was not readily acted upon by the aerobic microorganisms in Lagoon #2. Actual removal efficiencies for the septic tank was 51.1% and the lagoon 76.9% for a combined efficiency of 88.7%. pH differences were very slight between Lagoon #1 and #2 (7.51 for Lagoon #1 and 7.49 for Lagoon #2), while the septic tank had a low pH (5.69) attributed to anaerobic decomposition. The temperature difference (0.2° C) between the lagoons was negligible, however, the temperature of the septic tank was approximately 2° C higher. This difference was likely due to the evaporative cooling of the model lagoons by the fan. Temperatures of the reactors during this trial varied considerably with the room temperature. Suspended solids of Lagoon #2 slightly exceeded that of Lagoon #1 while the septic tank had the largest concentration of suspended solids. Once again, the increased suspended solids in Lagoon #2 was attributed to the anaerobic nature of the influent from the septic tank. Removal efficiencies for suspended solids were 95.9% for Lagoon #1, and 93.4% for the septic tank-Lagoon #2 combined system.

Figures 6 and 7 show the effects of loading of 300 ml/day on the experimental lagoons and septic tank. During this trial, Lagoon #1 had an average daily evaporation of 410 ml/day and Lagoon #2 was only slightly greater at 415 ml/day. As in the previous trial, evaporation was replaced with distilled water. Evaporation may have decreased due to the formation of a heavy grease layer on Lagoon #1 and a lesser amount of grease on Lagoon #2, however, most of the decrease in evaporation was probably due to increased atmosphere relative humidity during this trial. On two occasions an attempt was made to degrease the surface of the lagoons, however, since the film reappeared within 24-hours and showed rapid buildup, no further attempts were made to reduce or eliminate the grease layer on the lagoons. As in the previous loading, the dissolved oxygen content of Lagoon #1 (3.05 mg/l) was considerably lower than that of Lagoon #2 (4.41 mg/l) indicating that the septic tank was continuing to reduce the loading in the second lagoon and thus the microbial activity in Lagoon #2 was less than that of Lagoon #1. Dissolved oxygen levels as well as the pH at this loading showed a decrease from values in the previous trial which indicated that the increased organic load in the lagoons had resulted

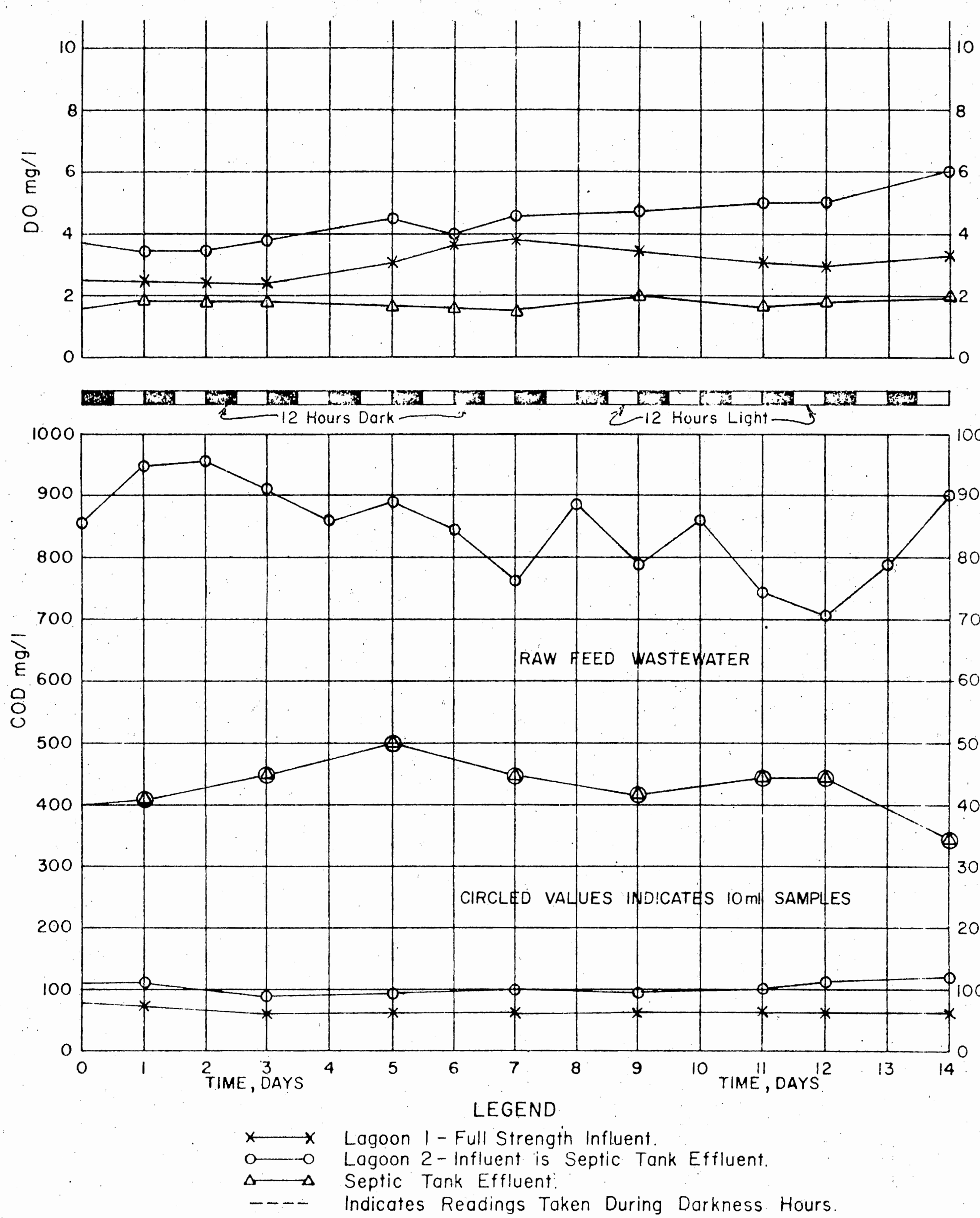


Figure 6. Dissolved Oxygen and COD Variations at 300 ml/day Hydraulic Loading, Evaporative Losses Replaced.

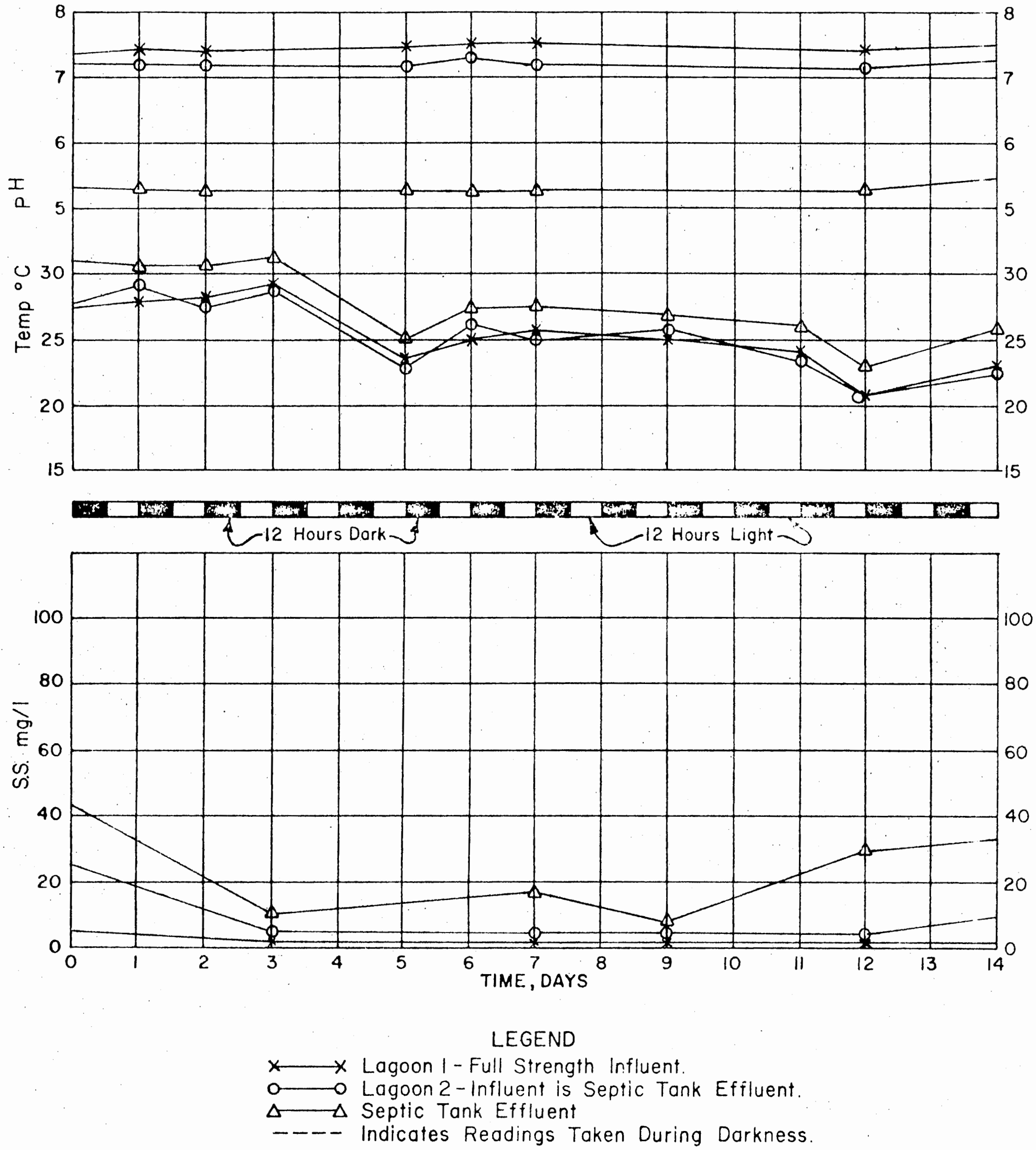


Figure 7. pH, Temperature, and Suspended Solids Variations at 300 ml/day, Evaporative Losses Replaced.

in increased microbial activity. As in the previous trial, COD samples sho showed a better COD reduction in Lagoon #1 (91.7%) than in Lagoon #2 with the septic tank (88.0%). Lagoon #1 did not show any decrease in removal efficiency while the septic tank/Lagoon #2 system showed a slight reduction from 88.7% to 88.0%. Most of this reduction occurred in the operation of the septic tank. As in the previous trial, temperature differences between the lagoons was negligible while the septic tank was approximately 1.75° C warmer. Suspended solids levels were very low at this operating level.

When the loading was increased to 400 ml/day, several interesting changes were noted in the operation of the units. During the acclimation to the increased flow rate it was visually noted that the liquid in Lagoon #1 was very clear with algal growths on the bottom and a slight amount on the sides, while Lagoon #2 had only a small algal growth on the bottom and sides but was developing a suspended algal growth. By the start of Figures 8 and 9, showing the various operating values for this trial, the sides of Lagoon #1 were thickly covered with algae while Lagoon #2 had little algal growth on the sides or bottom but instead had a dense algal growth suspended throughout the solution. This manifested itself in several ways. With the increased loading, the dissolved oxygen levels of Lagoon #1 stayed close to the previous value, whereas Lagoon #2 was sometimes supersaturated with oxygen. Evaporation during this trial was essentially the same for both lagoons, however, it increased significantly over the previous trial due to a decrease in relative humidity. Evaporation exceeding influent flow was replaced with distilled water. As in the previous trials, the percentage of total COD removed decreased with the increased loading. Lagoon

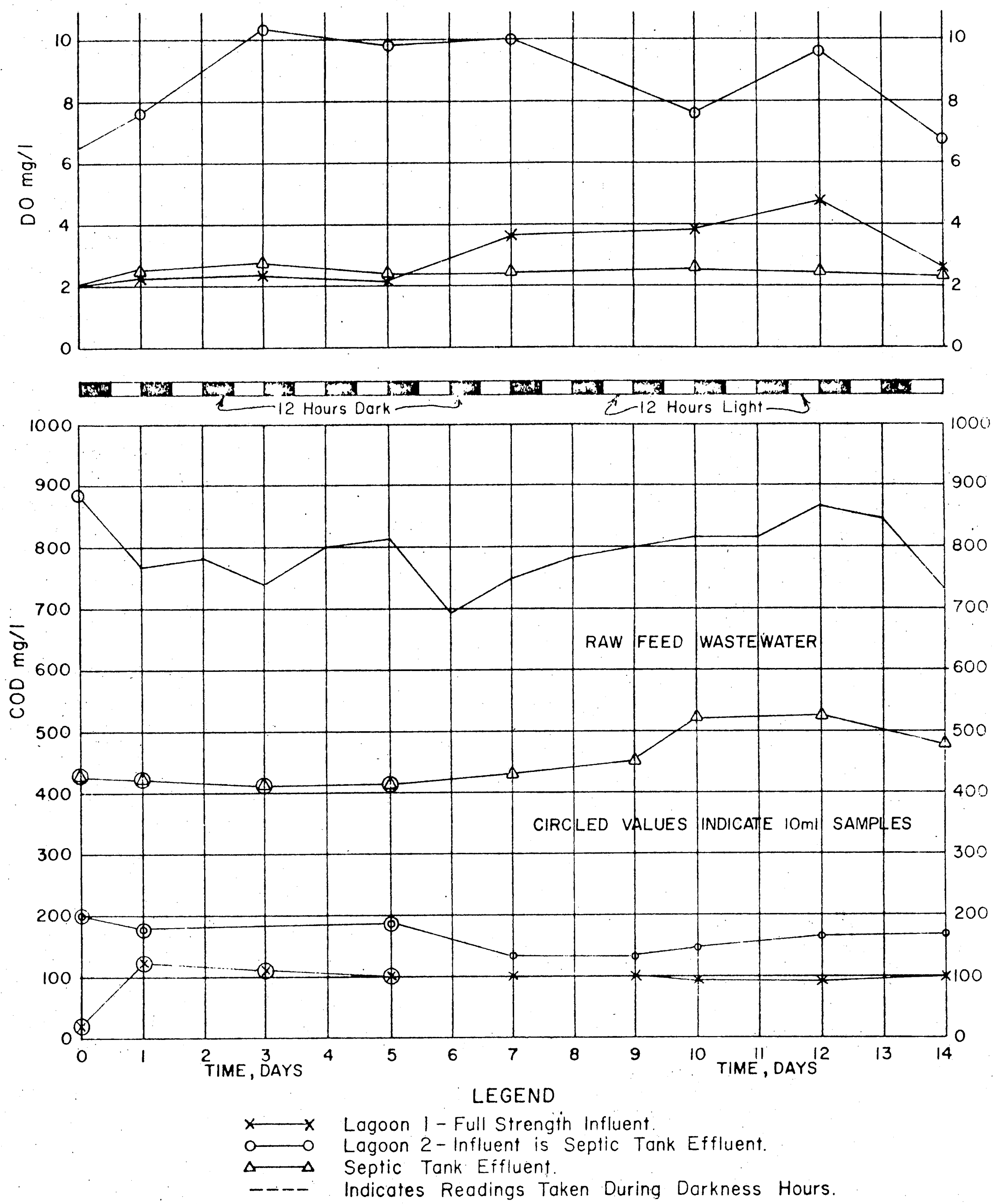


Figure 8. Dissolved Oxygen and COD Variations at 400 ml/day Hydraulic Loading, Evaporative Losses Replaced.

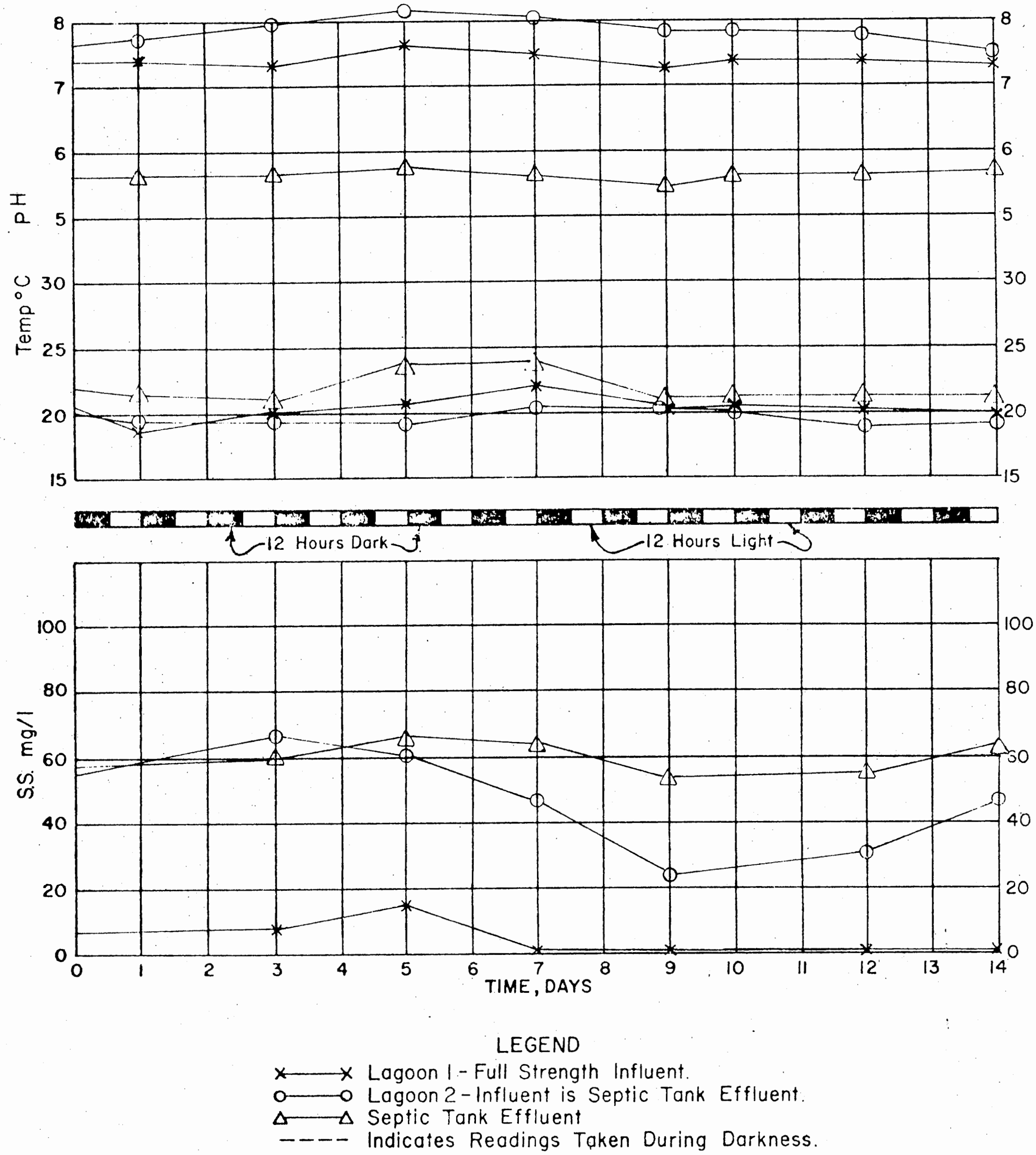


Figure 9. pH, Temperature, and Suspended Solids Variations at 400 ml/day Hydraulic Loading, Evaporative Losses Replaced.

#1 continued to have a greater percentage COD removal than the septic tank and Lagoon #2. Lagoon #1 also removed a larger percentage of the suspended solids that the other system, even though it was slightly less efficient at the higher loading. Removal of suspended solids by the septic tank decreased to 84.8%. This decrease was due to short circuiting occurring in the septic tank at the higher flow rate. Suspended solids in Lagoon #2 were only reduced 21.7%. This apparent low reduction rate was probably due to the formation of the large amount of algae suspended in the waste water of Lagoon #2. The pH differences between the lagoons was more marked in this trial as the near-anaerobic condition of Lagoon #1 resulted in a lower pH (7.44) than that of Lagoon #2 (7.88), which was affected by the increased algal growth. Room temperature was more nearly constant during this trial. As in the previous trials, temperature differences between the lagoons was negligible, while the septic tank was considerably warmer (approximately 1.5° C). COD removal efficiency for this trial were 88.4% for Lagoon #1 and 80.6% for the septic tank/Lagoon #2 system. Suspended solids removal efficiencies were 99.0% for Lagoon #1 and 88.1% for the septic tank/Lagoon #2 system.

At the highest loading studied, 500 ml/day, removal efficiencies for COD and suspended solids were even less. Figures 10 and 11 show the operating data for the fourth trial. Evaporation was approximately equal to the influent flow rate for Lagoon #1 and exceeded Lagoon #2 by approximately 25%. Excess evaporation in Lagoon #2 was not replaced. During this trial Lagoon #1 overflowed 175 ml on 12/23/77 (day 12) and 225 ml on 12/24/77 (day 13). The percent reduction in COD continued to decrease at this increased hydraulic loading, with Lagoon

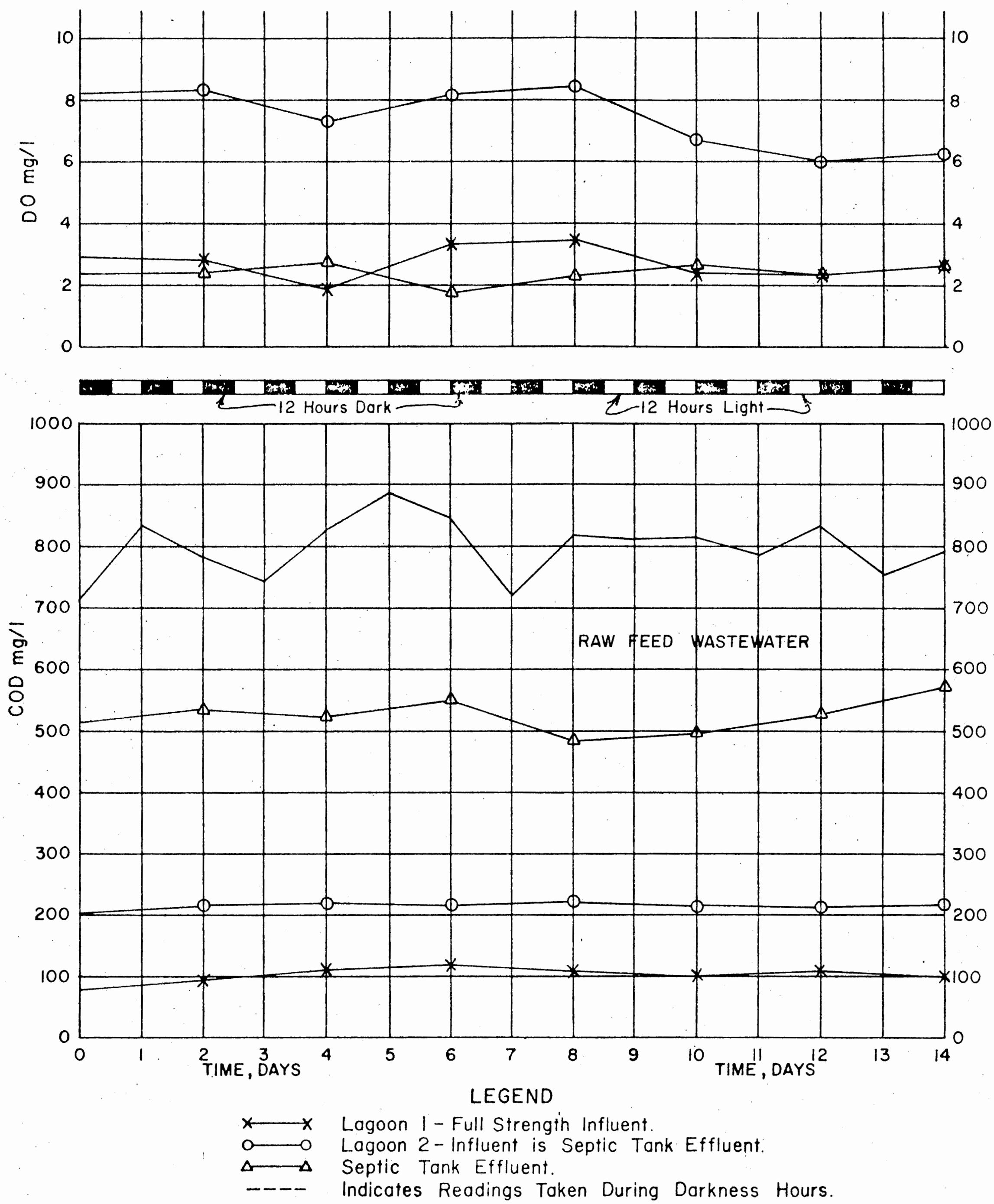


Figure 10. Dissolved Oxygen and COD Variations at 500 ml/day Hydraulic Loading, Evaporative Losses Not Replaced.

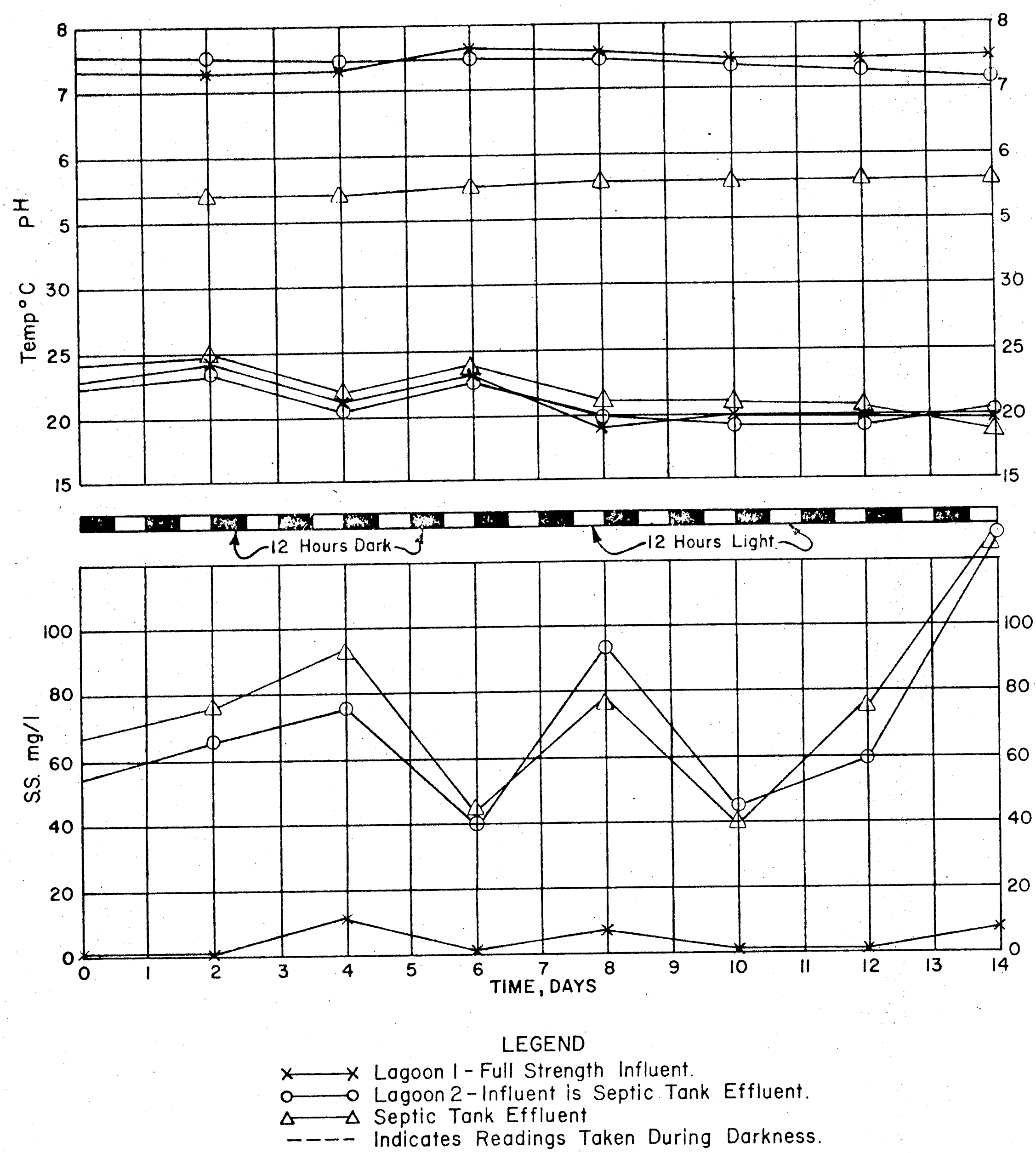


Figure 11. pH, Temperature, Suspended Solids Variation at 500 ml/day Hydraulic Loading, Evaporative Losses Not Replaced.

#1 still having a better COD removal than the septic tank/lagoon system. Conversely, the dissolved oxygen in Lagoon #2 was considerably higher than Lagoon #1 which was nearly anaerobic at this increased loading. Even though the dissolved oxygen levels of Lagoon #2 continued to be saturated, the average oxygen level was considerably lower than that in the previous trial where there was a lower hydraulic loading. COD and suspended solids removal by the septic tank continued to decrease as short circuiting of the septic tank occurred at a greater rate. Short circuiting also caused an increase in the dissolved oxygen in the effluent flow due to the affects of the larger influent flow. The pH of Lagoon #1 was slightly greater than that of Lagoon #2 at this flow while the septic tank continued to have a low pH. Again, temperature differences between the lagoons was slight, while the septic tank was somewhat warmer. Suspended solids removal continued to decrease with the increased flow rate. Most notably affected were the septic tank, where short circuiting was occurring, and Lagoon #2 due to the large algae population. COD removal efficiencies for this trial were 87.0% for Lagoon #1 and only 73% for the combined septic tank/lagoon system.

For the final trial, a loading of 200 ml/day was again utilized, however, net evaporation was not replaced. This simulated the operation of the system during drought conditions when waste water would be concentrated by excess evaporation. Average evaporation during the trial periods was 430 ml/day for Lagoon #1 and 435 ml/day for Lagoon #2. It was noted during this trial that the reduced loading on Lagoon #1 resulted in an initial decrease in the amount of grease and scum on the lagoon. This was probably due to less grease being released from the waste and existing grease on the lagoon being metabolized by microbial action to a lower equilibrium concentration. As would be expected with the decreased loadings, dissolved oxygen levels increased in the lagoons while decreasing in the septic lagoon effluent due to reduction in short circuiting. COD removal was not improved overall. By looking at Figure 12 it can be seen that COD removal decreased during the trial as the waste water became more concentrated. The pH of the lagoons and the septic tank rose when the influent flow was decreased. As in all of the previous trials temperature differences between the lagoons was slight while the septic tank was approximately 1.1° C warmer. With the elimination of short circuiting, the septic tank again was able to remove suspended solids effectively (95.4%). The removal efficience of the second lagoon also increased to 55.9%. Most of the remaining suspended solids was suspended algal growth. Figures 12 and 13 show the results of the final trial. COD removal efficiencies for this trial were 86.6% for Lagoon #1 and 74.1% for the septic tank/lagoon system. Suspended solids removal efficiencies were approximately 100% for Lagoon #1 and 89.6% for the combined septic tank/lagoon system.

Figure 14 shows the suspended solids remaining and the total COD remaining versus the loading. Figure 15 shows the percent removal suspended solids and total COD versus the hydraulic loading of the system. The figures show that COD and suspended solids removal are less affected by increased hydraulic loadings when the influent is direct to the lagoon than when it is passed through a septic tank to reduce the loading on the lagoon. On the other hand, it was noted in each of the trials that by reducing the organic loading on the lagoon a greater amount of dissolved oxygen was present and in the latter trials a better algal growth was maintained.

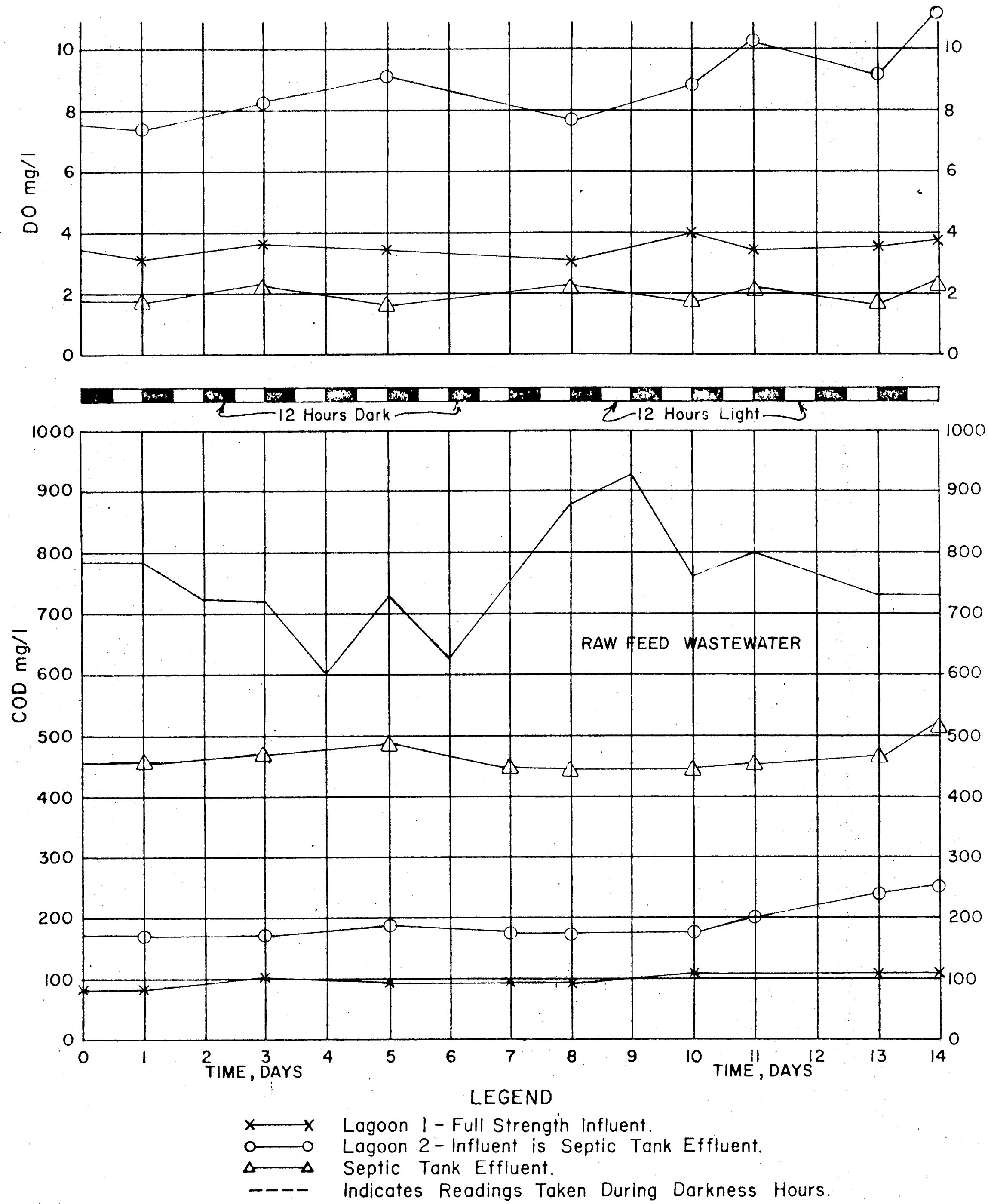


Figure 12. Dissolved Oxygen and COD Variations at 200 ml/day Hydraulic Loading, Evaporative Losses Not Replaced.

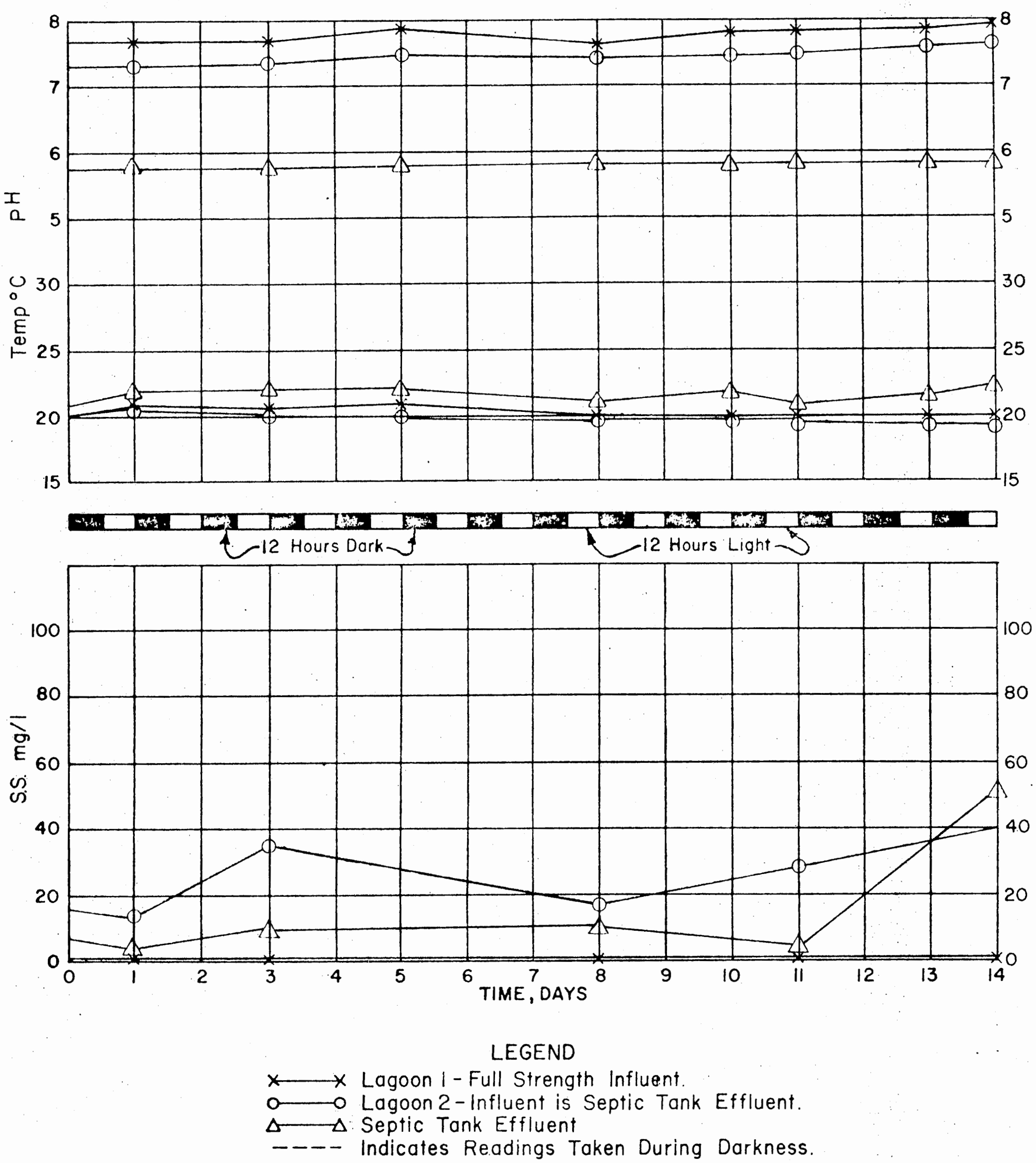


Figure 13. pH, Temperature, and Suspended Solids Variations at 200 ml/day Hydraulic Loading, Evaporation Losses not Replaced.

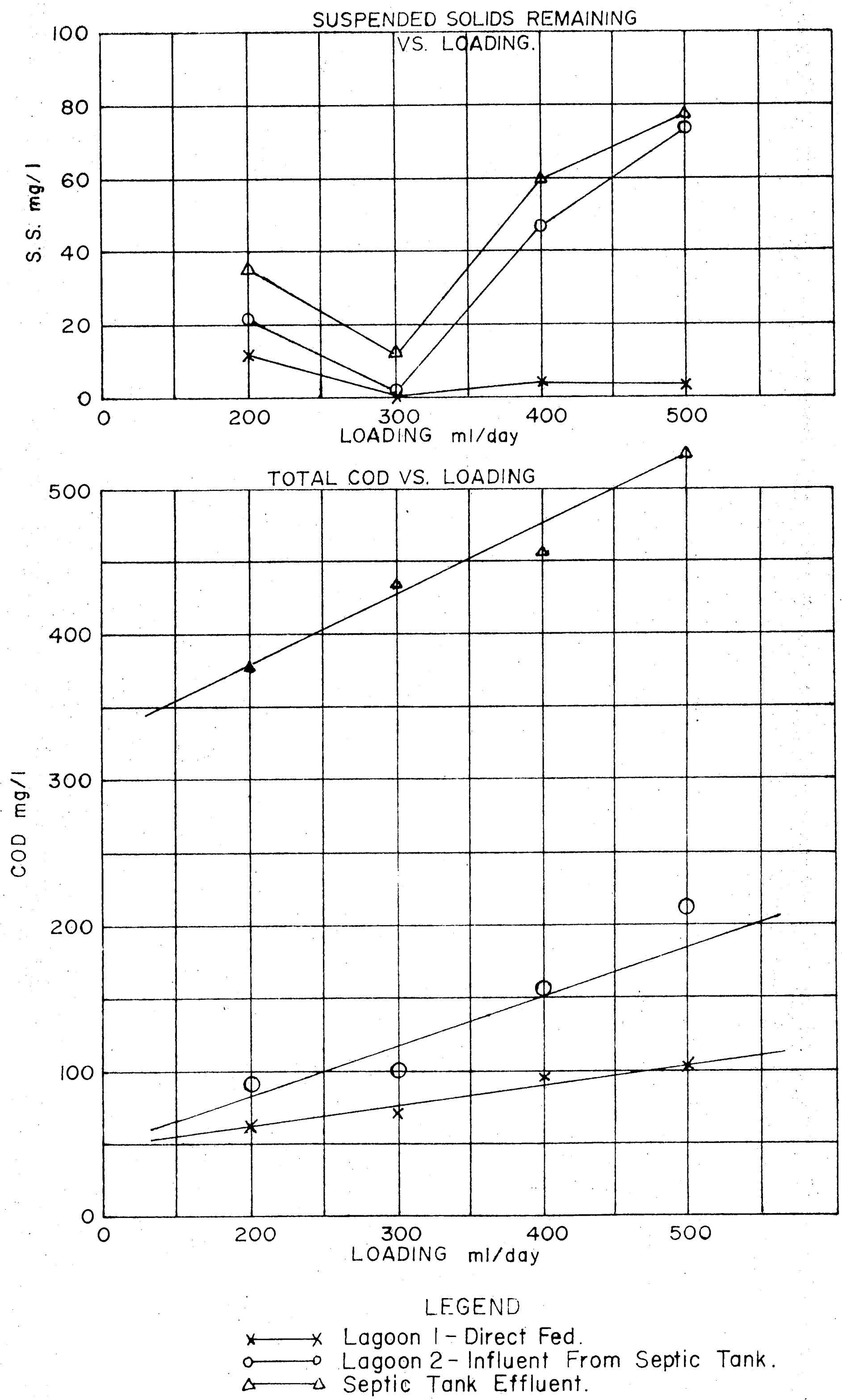


Figure 14. Suspended Solids Remaining vs Loading.

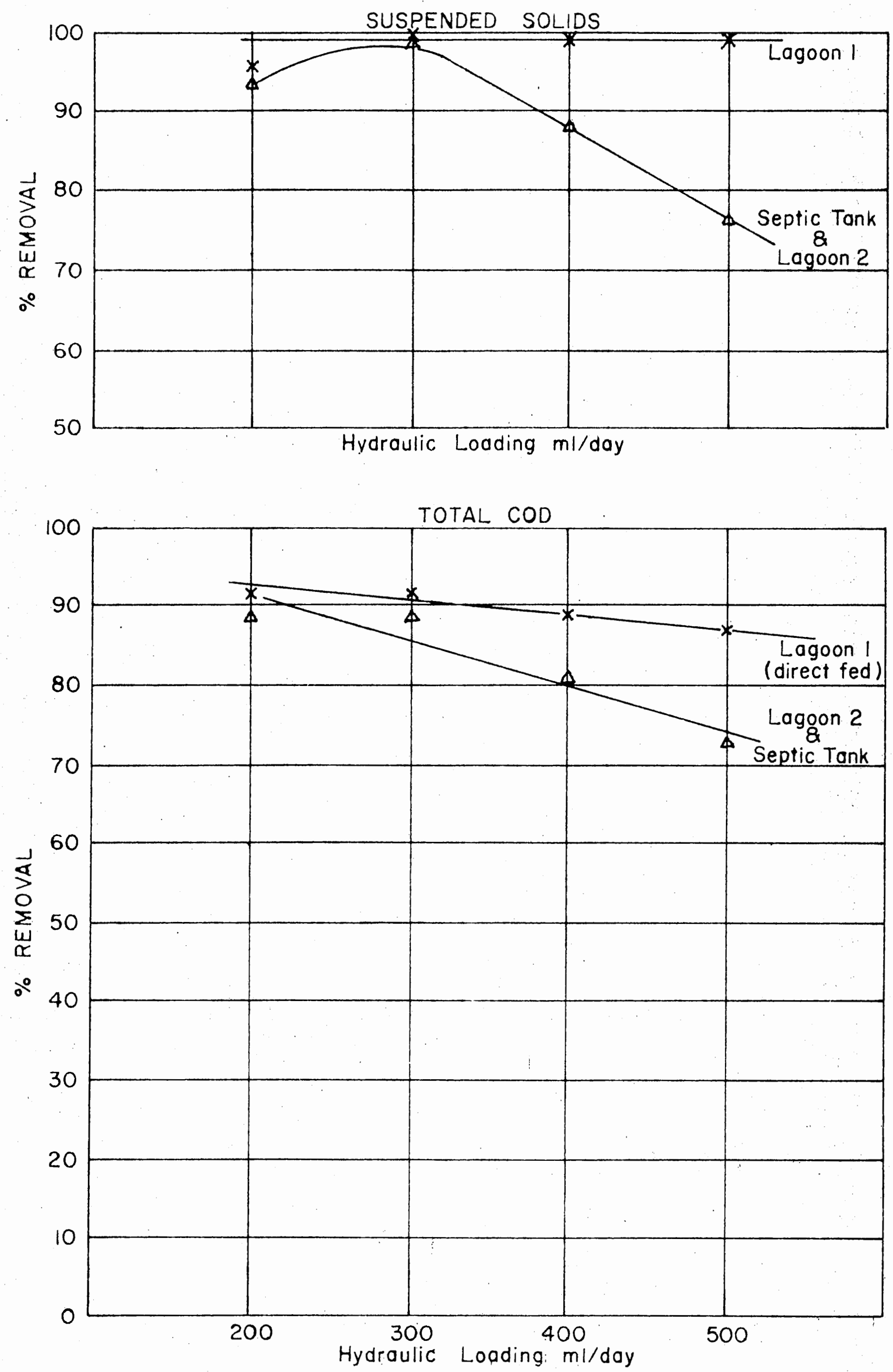


Figure 15. % Removal of Suspended Solids and COD vs Loading.

Figure 16 shows the dissolved oxygen level versus the loading. As stated earlier, this figure shows graphically the decrease in dissolved oxygen with the increased organic load placed on the lagoon. There is one exception when the change in algal growth in Lagoon #2, at the 400 ml/day loading, resulted in significantly greater dissolved oxygen levels. However, as the loading on this lagoon increased, the dissolved oxygen level continued to decrease.

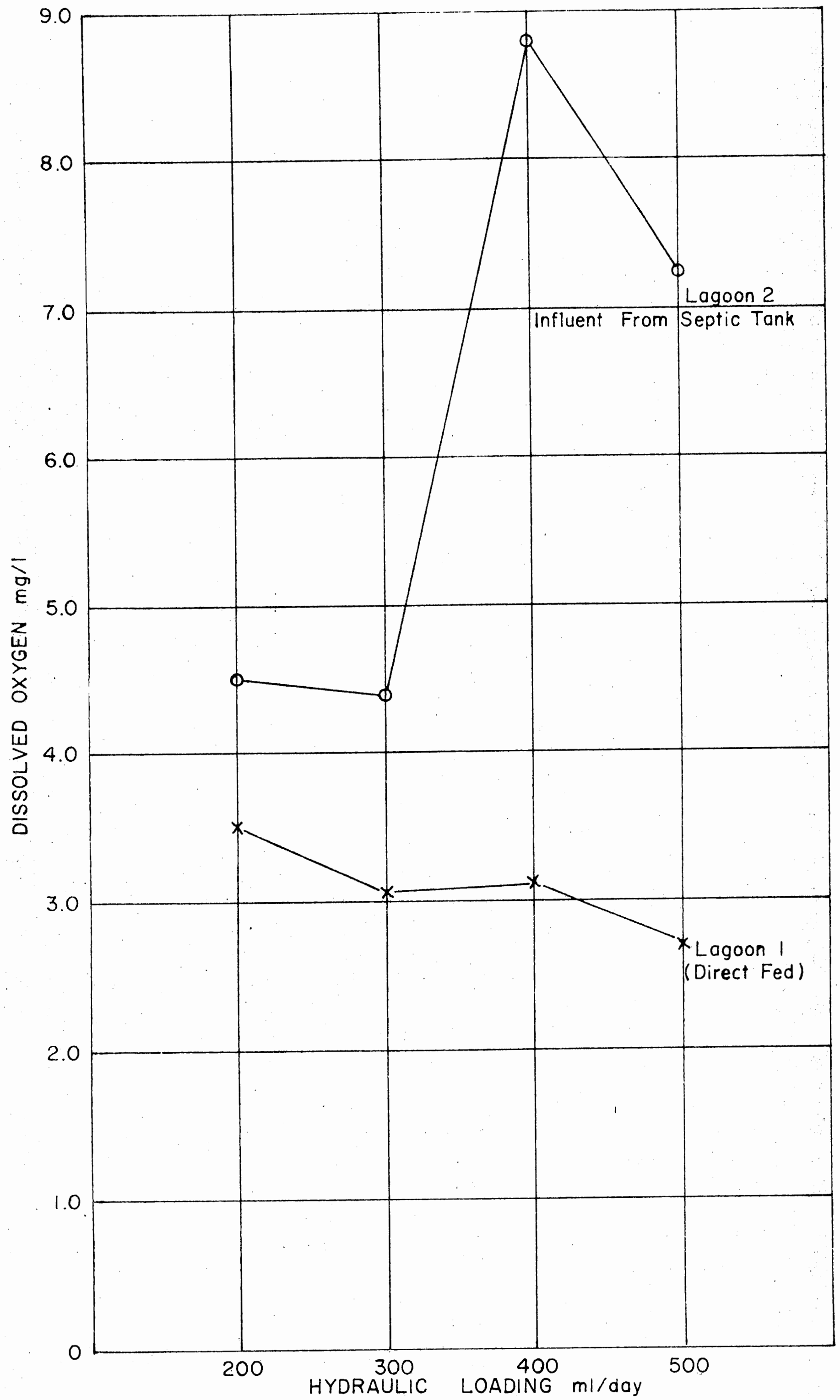


Figure 16. Dissolved Oxygen vs Loading.

CHAPTER V

DISCUSSION OF THE RESULTS

pH

The effects of pH on the results of this study were negligible. As can be seen from the literature, the operation of a lagoon is usually subject to a decrease in efficiency with the occurrance of high pH values. It appears from the pH data presented in the results that the addition of K_2HPO_4 and $KHPO_4$ in the synthetic waste was effective as a buffer system in the lagoons. Algal growth was much greater in the second lagoon than in the first lagoon and is reflected in the pH values during the trial loading of 400 ml/day in Figure 9. In most trials the pH values of the two lagoons were not significantly different, in fact, in some instances the pH of Lagoon #1 exceeded that of Lagoon #2. This difference was probably due to the low pH of the septic tank effluent influencing the pH of the lagoon.

pH values in the septic tank ranged from 5.26 to 5.80, which was lower than what was expected. Vivaragharan and Warnock (6) had reported pH values of 6.90 for effluent from individual household septic tanks. Studies (6) (7) (8) examined earlier in this report showed pH values ranging from 6.90 to 7.5. This discrepancy between field data and model data was probably due to an increased CO_2 production rate by the microbial population and the inability of the buffer system to prevent decreases in pH with increased anaerobic bacterial action. No attempt was made to explain the phosphate buffer effect on pH.

Temperature and Dissolved Oxygen

Temperatures of the model units generally varied with the room temperature of the laboratory. Highest average temperatures occurred during the 200 ml/day and 300 ml/day trials, which were in the early fall when ambiant air temperatures were most variable. At these two loadings, temperatures of the two lagoons averaged 26.2° C and 25.4° C. According to van't Hoff's theory, considerable increased algal growth would have been anticipated at this higher temperature. This is not generally substantiated by the dissolved oxygen values for the lagoon models.

Dissolved oxygen in Lagoon #1 decreased with increased organic loading. The decrease is not attributed to a decrease in temperature as the dissolved oxygen concentration for the first trial was 3.5 mg/1 (loading 200 ml/day) and the average temperature was 26.1° C, whereas the final trial, when the loading was again 200 ml/day, the average temperature was 20.3° C and the dissolved oxygen concentration was greater, 3.63 mg/1. The decrease in dissolved oxygen concentrations with increasing loadings in this lagoon is attributed to increased microbial action.

The septic tank effluent showed increasing dissolved oxygen levels with increased hydraulic load. This increase is attributed to the short circuiting of an unknown fraction of the influent which had a higher dissolved oxygen content through the tank. Model Lagoon #2, which received the septic effluent, showed a significant increase in dissolved oxygen concentration between the second (300 ml/day) and third (400 ml/day) trials. This increase was due to a sudden increase in the algal population during the acclimation period for the third trial. Taking into account this sudden increase in algal population, dissolved oxygen concentrations also decreased in Lagoon #2 with increasing organic loading. Dissolved oxygen values for Lagoon #2 were considerably higher than those of Lagoon #1, indicating a greater amount of algal activity and lesser microbial decomposition of the waste.

It was felt that temperature effects on this experiment were minimal. Investigators have generally shown algal growth to be independent of temperature near the optimum growth temperature, and Glaus (25) indicated that the reaction rate within a lagoon does not double for each 10° C rise in temperature. Decreased dissolved oxygen values with increased loading is attributed to increased bacterial metabolism rather than temperature fluctuations.

Suspended Solids

Suspended solids values during all of the trials were extremely low. Lagoon #1, receiving the raw waste water, had suspended solids values averaging 13 mg/l or less. As expected, the septic tank effluent showed increasing suspended solids values with increased loading as short circuiting occurred in the tank. Lagoon #2, receiving the septic tank effluent, had negligible suspended solids until the large algal growth occurred. Removal efficiencies for the septic tank and the model lagoons were generqlly greater than that reported in the literature.

Removal efficiencies in the model reactors was probably greater for two reasons. Visual observation of the raw influent feed solution indicated that a large portion of the solids were settleable solids. Lawrence (8) and Ludwig (9) indicated that 84% to 91% of domestic sewage is composed of settleable solids. This would mean that a large portion of the solids would readily settle out in the septic tank and model lagoons. Also, the model lagoons were comparable to quiescent settling tanks, despite the presence of the fan. The depth of the model lagoons was several times what it would have been had all the dimensions of the model been equally reduced in proportion to an actual lagoon. As a result, wave action induced by the fan was not observed to have any appreciable effect below the surface of the model lagoons and did not cause reentrainment of solids from the bottom sediments.

TABLE IX

COMPARISON OF SUSPENDED SOLIDS REMOVAL FOR MODEL SEPTIC TANK AND AS REPORTED IN LITERATURE RESEARCH

	Suspended Solids % Removal	Ref.
Model Septic Tank	76.1-96.9%	-
Field Studies-Septic Tanks	18-84.1%	1, 3, 6, 7, 8
Lagoon #1 Raw Waste Influent	95.9-100%	-
Lagoon #2 Septic Influent	3.9-100.0%	-
Lagoon #2 and Septic Tank Combined	77.0-100.0%	-
Field Studies-Lagoons	22-34%	52, 53

Substrate Removal

From the experimental data it appears that the model lagoon receiving the raw influent waste had a more effective COD removal (91.7% at 200 ml/day to 87.0% at 500 ml/day) then did the combined model septic tank-lagoon system (88.7% at 200 ml/day to 73% at 500 ml/day). This study did not attempt to discern what fraction of the COD was original substrate and how much had been converted to metabolic intermediate compounds.

It must be remembered when reviewing the results of this work that it was the total COD of the total bio mass (algae plus bacterial cells) that was measured. If the COD had been based on filtered samples, there would have been a decrease in the waste water COD corresponding to the suspended solids concentration. This statement was supported by random samples taken during the course of the experiment which showed that the COD of the filtered effluent from Lagoon #1 was essentially unchanged, while that of Lagoon #2, which had significant algal growth, had a COD reduction of about 45%. This corresponds with Rich (59) who reported that waste stabilization lagoons may reach as high as 90% BOD removal, but due to the high algal content the efficiency of the lagoon may only be 50-60% when reported as COD.

In general, removal efficiencies in this study were very comparable to that reported in the literature. Lagoon #1, receiving the raw influent, showed COD removal efficiencies from 87% to 91.7%. This is somewhat lower than Hermann and Gloyna (31) who reported BOD removal for non-centrifugal effluent averaging 74.9% for a loading of 60 lbs. BOD_5/acre/day.

The model septic tank had a COD removal efficiency ranging from 51.1% at a loading of 200 ml/day to 34.0% at a loading of 500 ml/day. This is very close to date presented by Vivaragharan (7) who reported COD removal to be 45% for an individual household septic tank, and Bailey and Wallman (2) who reported 48.4% COD removal in the study of a model septic tank. It was also noted that the performance of the lagoon following the septic tank was notably less efficient than the model control lagoon. Additional COD removal by the lagoon ranged from 76.9% at 200 ml/day loading to 59.2% at 500 ml/day. This decreased efficiency was anticipated, however, it was less than had been estimated from the literature review. Beard and Lawrence (52) investigations of household lagoons with septic tanks had much higher COD concentrations than did the model lagoon following the septic tank. This is shown in Table X.

TABLE X

COMPARISON OF LAGOON WASTE WATER COD FOR LAGOONS RECEIVING SEPTIC TANK EFFLUENT

Description	Loading Capita/acre	Average COD mg/l	Ref.
Experimental Lagoon	108	88	-
Experimental Lagoon	276	215	-
Pond 1	114	229	51
Pond 2	323	284	51

Oswald et al. (54) show a COD reduction of 8% in the first aerobic lagoon following the anaerobic lagoon. Reduction in the subsequent aerobic lagoon increased to approximately 74%. It is evident that the anaerobic condition of the waste entering the lagoon makes COD reduction more difficult. Greater COD reductions in the model lagoon than that reported for various operating experiences reported in the literature is probably due to the total retention of the waste water allowing more time for microbial action on the waste.

It is interesting to note from Figure 12 that under conditions when evaporated water was not replaced, that COD levels in the model lagoon receiving the septic tank effluent started to show significant increases after the 10th day of the trial. This indicated that under drought conditions when there is less waste water in the lagoon to dilute the influent, anaerobically conditioned waste, the capacity of the lagoon to assimilate the waste is considerably less. A slight increase in COD concentration was also noted in the lagoon receiving the raw waste water, however, it did not show the substantial increase noted in Lagoon #2.

It is interesting to look at the performance of the model lagoons in relation to some of the empirical relationships presented in the Literature Research. Marais and Shaw (56) reported the relationship:

$$P = \frac{750}{0.6\ d + 8}$$

using: $d = 25.2\ cm = 0.83\ ft.$ the maximum permissable BOD in the lagoon is:

$$P = \frac{750}{(0.6)(0.82)} + 8 = 88\ mg/l$$

assuming $COD = \frac{BOD}{0.60}$

Allowable $COD = \frac{88\ mg/l}{0.6} = 147\ mg/l$ to maintain aerobic conditions. This would predict that Lagoon #2 would have been anaerobic under trials 3 and 4 (400 ml/day and 500 ml/day) when the COD concentrations within the model lagoon were 158 mg/l and 215 mg/l, respectively.

Hermann and Gloyna (33) developed the following relationship to predict the removal in aquaria models:

$P = 100 - 0.05\ (Y/AT)$ where Y/AT = lbs. BOD/acre/day

Similar equations developed for the model lagoons based on Figure 15 percent removal versus loading are:

$P = 95.7 - 0.18\ (Y/AT)$ Lagoon #1
$(r = -0.92)$

$P = 100.9 - 0.54\ (Y/AT)$ Lagoon #2 + Septic tank system where Y/AT = lbs. BOD/acre/day and it is assumed BOD = 0.6 COD
$(r = -0.93)$

Comparing this data with the previous reference (33) it is noted that there is a portion of the substrate that will not be removed no matter how low the loading when the lagoon receives the raw influent. It is also noted at low organic loadings performance of the septic tank-lagoon system would be expected to exceed that of the direct fed lagoon. It is presumed that this would be because the anaerobic condition of the waste would have negligible effect at low loadings. A very significant difference between this study is the rate at which lagoon efficiency decreases. This would indicate that individual household waste stabilization lagoons will not operate efficiently at the high loadings reported in the literature.

Lagoon Activity

Lagoon activity is best described by examining the dissolved oxygen concentration variations under the various loadings. Waste water DO variations between light and dark periods give an indication of the overall microbial activity in the model reactors. Figure 4 shows several readings taken during the 200 ml/day loading where DO levels dropped approximately 1.5-2.0 mg/l in Lagoon #2 and less than 1 mg/l in Lagoon #1. Random measurements taken during this study showed the variation to increase to approximately 3 mg/l in Lagoon #2, while Lagoon #1 had a lesser variation, usually less than 2 mg/l. Increased DO concentrations during periods of light is due to the increased oxygen transfer at the surface and oxygen production by algal activity above that amount required by bacteria metabolizing the waste. Differenced between daylight DO values and darkness values, when the algae is not producing oxygen, is a measure of microbial activity. Dissolved oxygen variation and levels are considerably below that reported by Glaus (25). Some of the factors which probably contributed to this were lighting intensity, total retention, organic loading, and algal growth.

It is interesting to note that Lagoon #1, receiving the raw influent wqste, developed a scum layer which had a definite effect on lagoon operations. Not only did it reduce evaporation and illumination but it also hindered the exchange of oxygen and carbon dioxide at the air-water interface. As a result, DO concentrations and microbial activity were considerably lower than what would normally be expected for this lagoon. This scum layer was attributed to fats, oils, and grease in the waste. Lagoon #2 did not develop a scum problem as the septic tank effectively removed the objectionable material from the waste.

CHAPTER VI

CONCLUSION

In conclusion, it is evident that the use of the model septic tank significantly reduced the loading on the model lagoon enabling it to perform much more effectively than the lagoon receiving the raw waste water. The lagoon receiving the raw waste water showed a better COD reduction than the septic tank/lagoon system, however, during all loadings it had significantly lower dissolved oxygen concentrations and during periods of stress, i.e., loading in excess of design criteria, the lagoon approached anaerobic conditions. The lagoon/septic system had significantly more algal growth and higher dissolved oxygen concentrations. Conspicuously lacking was the scum layer which formed on the surface of the control lagoon.

It is recommended that septic tanks be utilized with all individual household lagoon disposal systems. Design of the lagoons is based on total retention of waste water, therefore, COD removal is of minor importance as no water courses will be affected. What is of paramount importance, especially to the homeowner, is that the lagoon is not a nuisance. The inclusion of the septic tank in the system can prevent this by eliminating unsightly grease and scum, promoting increased algal growth and dissolved oxygen levels, and making the system less susceptable to upset by flows in excess of the design capacity of the system.

CHAPTER VII

SUGGESTIONS FOR FUTURE STUDY

From the results of this study it is evident that additional investigation should be made in regards to the operation of waste stabilization lagoons. Some suggestions for future studies are listed below.

(1) Studies should be made to determine the effects of synthetic waste, septic tank effluent, and domestic waste on algal species predomination.

(2) Studies should be made on the effect of wind action on the reentrainment of organic matter from the bottom sediments of waste stabilization lagoons.

(3) Studies should be done to determine if it is feasible to select a facultative bacteria species that would achieve effective substrate reduction in the septic tank and lagoon with minimal acclimation.

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APPENDIX

Public Law 86-121
86th Congress, S. 56
July 31, 1959

AN ACT

73 Stat. 267.

To amend the Act of August 5, 1954 (68 Stat. 674), and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Act of August 5, 1954 (68 Stat. 674), is amended by adding at the end thereof the following new section: Indians, sanitation facilities.

"SEC. 7. (a) In carrying out his functions under this Act with respect to the provision of sanitation facilities and services, the Surgeon General is authorized— 42 USC 2001-2004. Surgeon General. Powers.

"(1) to construct, improve, extend, or otherwise provide and maintain, by contract or otherwise, essential sanitation facilities, including domestic and community water supplies and facilities, drainage facilities, and sewage- and waste-disposal facilities, together with necessary appurtenances and fixtures, for Indian homes, communities, and lands;

"(2) to acquire lands, or rights or interests therein, including sites, rights-of-way, and easements, and to acquire rights to the use of water, by purchase, lease, gift, exchange, or otherwise, when necessary for the purposes of this section, except that no lands or rights or interests therein may be acquired from an Indian tribe, band, group, community, or individual other than by gift or for nominal consideration, if the facility for which such lands or rights or interests therein are acquired is for the exclusive benefit of such tribe, band, group, community, or individual, respectively; Acquisition of lands.

"(3) to make such arrangements and agreements with appropriate public authorities and nonprofit organizations or agencies and with the Indians to be served by such sanitation facilities (and any other person so served) regarding contributions toward the construction, improvement, extension and provision thereof, and responsibilities for maintenance thereof, as in his judgment are equitable and will best assure the future maintenance of facilities in an effective and operating condition; and Construction and maintenance.

"(4) to transfer any facilities provided under this section, together with appurtenant interests in land, with or without a money consideration, and under such terms and conditions as in his judgment are appropriate, having regard to the contributions made and the maintenance responsibilities undertaken, and the special health needs of the Indians concerned, to any State or Territory or subdivision or public authority thereof, or to any Indian tribe, group, band, or community or, in the case of domestic appurtenances and fixtures, to any one or more of the occupants of the Indian home served thereby. Transfer of facilities.

"(b) The Secretary of the Interior is authorized to transfer to the Surgeon General for use in carrying out the purposes of this section such interest and rights in federally owned lands under the jurisdiction of the Department of the Interior, and in Indian-owned lands that either are held by the United States in trust for Indians or are subject to a restriction against alienation imposed by the United States, including appurtenances and improvements thereto, as may be requested by the Surgeon General. Any land or interest therein, including appurtenances and improvements to such land, so transferred shall be subject to disposition by the Surgeon General in accordance with paragraph (4) of subsection (a): *Provided*, That, in any case where a beneficial interest in such land is in any Indian, or Indian tribe, band, or group, the consent of such beneficial owner Transfer of U. S. land.

to any such transfer or disposition shall first be obtained: *Provided further*, That where deemed appropriate by the Secretary of the Interior provisions shall be made for a reversion of title to such land if it ceases to be used for the purpose for which it is transferred or disposed.

"(c) The Surgeon General shall consult with, and encourage the participation of, the Indians concerned, States and political subdivisions thereof, in carrying out the provisions of this section."

42 USC 2001 note.

SEC. 2. Section 6 of such Act is amended by striking out the word "This" and inserting in lieu thereof the words "Sections 1 to 5, inclusive, of this".

Approved July 31, 1959.

Design Guideline #4
Revised 6/75
INDIVIDUAL LAGOONS

GENERAL

Individual lagoons are a preferred means of individual waste disposal where drainfields or seepage beds are not feasible, and where percolation rates are more than one inch in fifty minutes. Sufficient land area for installation and minimum separation shall be required. Gravity discharge is desirable, but sump pumps may be used if nedessary.

The lagoons shall be designed on an individual basis, using the following design parameters:

LOADING

For design of individual sewage lagoons, the following design loading figures shall normally be used:

1. Hydraulic loading - 60 gallons per day per person
2. Organic loading - 0.17 pounds of BOD per day per person
3. Maximum BOD loading rate shall be 20 pounds BOD/acre/day
4. A design population of from 2.0 to 2.5 persons per bedroom shall normally be used.

DESIGN CRITERIA

The following criteria shall normally be used in design of individual lagoons:

1. A minimum 1000 gallon reinforced, precast-concrete septic tank shall be installed to remove settleable and floating solids.

2. A minimum separation of 300 feet shall be maintained between the lagoon and the home. This distance may be increased where state criteria requires same.

3. Lagoons shall not be located above the home or in the direction of the prevailing winds.

4. The primary cell of the lagoon shall be designed to have a retention of one year based upon the estimated total sewage flow and net annual evaporation. An evaporation pan coefficient of 0.8 shall be used. State criteria requires that the lagoon system be total retention. The required surface area shall be obtained by providing for a future second cell.

5. Recommended operating levels shall be three to five feet.

6. Sideslopes shall normally be 2:1, but no less than 3:1 under any circumstance.

7. A 5 foot chain link fence is required on the lagoon system to prevent the entrance of vermin, animals, and children.

   Alternate fence systems, utilizing different types of non-climbable design may be considered if they provide adequate protection.

   A gate shall be provided.

8. A minimum of two warning signs shall be provided. They shall be of metal construction, durable, and strategically located.

TABLE XI

ANALYSIS OF "FRISKIES"* BRAND BEEF FLAVORED DRY PELLET DOG FOOD

Ingredients
Ground yellow corn, meat and bone meal, soy bean meal, animal tallow preserved with BHT, digest of chicken by-products and beef by-products (source of beef flavoring), iodized salt, Vitamin E supplement, iron oxide, Vitamin B_{12} supplement, niacin, managanese sulfate, Vitamin A supplement, potassium Sorbate, zinc oxide, cobalt carbonate, riboflavin supplement, thiamine hydrochloride (Vitamin B_1), copper oxide, potassium iodide, pyridoxine hydrochloride (Vitamin B_2), Vitamin D_3 supplement.

Guaranteed Analysis		
Crude Protein.	(Min.)	21.0%
Crude Fat.	(Min.)	7.0%
Crude Fiber.	(Max.)	5.0%
Moisture	(Max.)	12.0%
Ash.	(Max.)	10.0%

*Manufactured by Carnation Company, Los Angeles, California 90036

TABLE XII

RESULTS OF DIFFERENT METHODS OF PREPARATION OF SYNTHETIC WASTE UTILIZING DRY DOG FOOD

Trial #	Method of Preparing Dog Food	mg/l Dog Food	Total COD mg/l Ave.	High	Low	COD/Dog Food
1	Blender	306	218	261	168	0.71
2	Blender (grit settled out)	497	452	551	394	0.91
3	Blender (grit included)	493	365	420	334	0.74
4	Blender	500	398	384	416	0.80
5	Blender	500	372	392	344	0.74
6	Ground by hand w/hammer	1000	299	343	261	0.30
7	20 mesh screen	1000	720	756	684	0.72
8	20 mesh screen	1000	936	1088	784	0.94
9	40 mesh screen	1000	970	972	968	0.97
10	40 mesh screen	1000	976	992	960	0.98
11	60 mesh screen	1000	972	972	972	0.97
12	60 mesh screen	500	560	572	548	1.12
13	60 mesh screen	500	592	647	536	1.18
14	60 mesh screen	500	566	568	564	1.13

TABLE XIII

COMPOSITION OF SYNTHETIC WASTE DURING EXPERIMENT

Bottle No.	Total COD mg/1 High	Total COD mg/1 Low	Total COD mg/1 Average	Dog Food Conc. mg/1	Glucose Conc. mg/1	Suspended Solids mg/1	Soluble COD mg/1
1	944	712*	821*	366	314	371	340*
2	-	-	-	500	300	-	-
6	1040*	856*	928*	499	212	584	-
12	900*	896*	904*	348	502	-	-
14	848*	752*	784*	365	310	300	424*
15	832*	736*	795*	365	290	246	302*
16	792*	752*	772*	317	300	-	-
16A	600*	248*	704*	241	228	-	-
21	852*	724*	769*	318	338	298	428*
22	905*	712*	764*	331	343	301	316
26	941	635	755	305	289	351	322
27	948	703	828	341	328	273	-
30	968*	904*	939*	461	358	496	-
31	968*	824*	880*	500	209	360	-
32	944*	824*	880*	500	225	444	-
34	904*	832*	865*	467	211	-	-
35	906*	733*	812*	422	234	339	-
40	977*	693*	773*	429	265	508	-
41	938*	724*	822*	504	228	-	-
42	826*	685*	759*	463	248	376	-
45	797	769	783	417	317	372	-
46	803*	732*	774*	426	320	312	-
47	866*	763*	803*	428	321	-	-
50	875*	828*	846*	492	251	520	269
51	772	761	766	448	264	472	207

TABLE XIII (Continued)

Bottle No.	Total COD mg/l High	Low	Average	Dog Food Conc. mg/l	Glucose Conc. mg/l	Suspended Solids mg/l	Soluble COD mg/l
52	800	741	770	460	274	344	261
53	811	698	755	373	316	280	-
54	792	737	765	421	303	288	-
56	865	762	815	443	314	-	-
57	906	792	851	463	308	328	-
58	830	731	776	359	323	556	-
59	708	704	706	340	334	172	-
60	834	771	809	447	305	496	-
61	866	731	782	392	320	296	-
62	889	842	860	459	302	212	-
63	845	668	770	398	327	284	-
64	841	788	813	421	329	360	-
65	868	782	813	394	333	308	-
66	821	739	774	407	318	300	-
67	864	776	808	422	320	348	-
68	897	683	757	432	292	296	-
70	869	770	804	444	319	260	-
71	742	623	688	432	319	312	302
81	957	876	907	559	307	528	314
82	841	736	385	341	272	302	-

Synthetic Waste (Glucose and dry dog food passed through 60-mesh screen)

*10 ml samples

TABLE XIV

TYPICAL WEEKLY SAMPLING SCHEDULE

SATURDAY

Daily feed reactors and take COD samples of feed solution

P. M. - Check DO, pH, temperature, COD, SS sampling

Run titration on COD's
Check COD's new feed solutions - dilute as necessary
Calibrate instruments

SUNDAY

Daily feed reactors and take COD samples of feed solution

P. M. - DO, pH, temperature, COD, SS sampling

Clean COD bottles and set up new for sampling

MONDAY

Daily feed reactors and take COD samples of feed solution

P. M. - DO, pH, temperature, COD, SS sampling

TUESDAY

Daily feed reactors and take COD samples of feed solution

Calibrate instruments

WEDNESDAY

Daily feed reactors and take COD samples of feed solution

P. M. - DO, pH, temperature, COD, SS sampling

Prepare acid for COD titrations
Grind dog food

THURSDAY

Daily feed reactors and take COD samples of feed solution

Prepare new feed solutions (check COD and SS, Sat.)

FRIDAY

Daily feed reactors and take COD samples of feed solution

P. M. - DO, pH, temperature, COD, SS sampling

TABLE XV

EVAPORATIVE LOSSES

Feed Rate ml/day	Average Daily Evaporation ml/day	Average Daily Water Added ml/day
	Lagoon #1 - Direct Fed	
200	450	253
300	410	100
400	530	127
500	500*	0*
200	430	0
	Lagoon #2 - Influent from Septic Tank	
200	490	287
300	415	100
400	540	140
500	620	0
200	435	0

*Overflowed 200 ml on two days.

TABLE XVI

AVERAGE VALUES FOR ALL PARAMETERS FOLLOWING LIGHT CYCLE

	Total COD mg/1			Suspended Solids mg/1		
Feed Rate	Ave.	Max.	Min.	Ave.	Max.	Min.
			Raw Feed Solution			
200 ml/day	779	948	635	319	420	252
300 ml/day	844	927	693	378	496	312
400 ml/day	813	953	698	394	524	280
500 ml/day**	795	889	668	322	496	212
200 ml/day**	758	957	579	326	528	244
			Septic Tank Effluent			
200 ml/day	381	448	310	35	60	20
300 ml/day	434	504	355	13	28	0
400 ml/day	456	528	414	60	64	52
500 ml/day**	527	568	483	77	136	40
200 ml/day**	469	520	434	15	52	12
			Lagoon #1 - Direct Fed			
200 ml/day	65	80	52	13	40	0
300 ml/day	70	92	63	0	0	0
400 ml/day	94	125	16	4	16	0
500 ml/day**	103	115	98	4	12	0
200 ml/day**	101.5	112	87	0	0	0
			Lagoon #2 - Influent from Septic Tank			
200 ml/day	88	108	72	21	48	8
300 ml/day	101	114	92	0	0	0
400 ml/day	158	195	109	47	68	24
500 ml/day**	215	224	209	74	92	40
200 ml/day**	196	248	171	34	76	12

TABLE XVI (Continued)

Feed Rate	Dissolved Oxygen mg/l Ave.	Max.	Min.	pH Ave.	Max.	Min.
		Raw Feed Solution				
200 ml/day	-	-	-	-	-	-
300 ml/day	-	-	-	-	-	-
400 ml/day	-	-	-	-	-	-
500 ml/day**	-	-	-	-	-	-
200 ml/day**	-	-	-	-	-	-
		Septic Tank Effluent				
200 ml/day	1.76	2.0	1.6	5.69	5.85	5.48
300 ml/day	1.74	1.9	1.5	5.26	5.29	5.21
400 ml/day	2.41	2.7	2.3	5.58	5.72	5.45
500 ml/day**	2.39	2.7	1.9	5.66	5.74	5.57
200 ml/day**	2.03	2.3	1.7	5.80	5.85	5.78
		Lagoon #1 - Direct Fed				
200 ml/day	3.5	4.2	2.8	7.51	7.61	7.43
300 ml/day	3.05	3.8	2.3	7.45	7.51	7.39
400 ml/day	3.1	4.8	2.1	7.44	7.62	7.34
500 ml/day**	2.7	3.5	1.9	7.49	7.54	7.37
200 ml/day**	3.63	4.1	3.3	7.81	7.94	7.70
		Lagoon #2 - Influent from Septic Tank				
200 ml/day	4.51	5.4	3.7	7.49	7.62	7.44
300 ml/day	5.4	3.7	3.3	7.19	7.23	7.11
400 ml/day	8.87	10.4	6.9	7.88	8.17	7.56
500 ml/day**	7.24	8.3	6.0	7.44	7.58	7.30
200 ml/day**	9.03	11.3	7.4	7.58	7.82	7.34

TABLE XVI (Continued)

Feed Rate	Temp. °C Ave.	Max.	Min.
Raw Feed Solution			
200 ml/day	-	-	-
300 ml/day	-	-	-
400 ml/day	-	-	-
500 ml/day**	-	-	-
200 ml/day**	-	-	-
Septic Tank Effluent			
200 ml/day	28.1	33	25
300 ml/day	27.15	31	23
400 ml/day	21.71	23.5	21
500 ml/day**	21.5	24	19.5
200 ml/day**	21.4	22	20.5
Lagoon #1 - Direct Fed			
200 ml/day	26.1	30	23
300 ml/day	25.4	29.5	21
400 ml/day	20.5	22	19.5
500 ml/day**	21.0	23.5	19.5
200 ml/day**	20.3	21	20
Lagoon #2 - Influent from Septic Tank			
200 ml/day	26.3	31	23
300 ml/day	25.4	29.5	21
400 ml/day	20.0	21.5	19
500 ml/day**	20.6	23	19
200 ml/day**	20.0	20.5	19.5

**Evaporation not replaced

TABLE XVII

COD AND SUSPENDED SOLIDS REMOVAL FOR EACH TRIAL

	Total COD			Suspended Solids		
	Influent	Effluent	% Reduction	Influent	Effluent	% Reduction
Lagoon #1 - Direct Feed						
200	779	65	91.7	319	13	95.9
300	844	70	91.7	378	0	100
400	813	94	88.4	394	4	99.0
500*	795	103	87.0	322	4	98.8
200*	758	101.5	86.6	326	0	2100
Septic Tank						
200	779	381	51.1	319	35	89.0
300	844	434	48.6	378	13	96.6
400	813	456	43.9	394	60	84.8
500*	795	527	34.0	322	77	76.1
200*	758	469	38.1	326	15	95.4
Lagoon #2 - Receives Septic Tank Effluent						
200	381	88	76.9	35	21	40.0
300	434	101	76.7	13	0	
400	456	158	65.4	60	47	21.7
500*	527	215	59.2	15	34	55.9
200*	469	196	58.2	15	34	55.9

*Evaporation not replaced.

TABLE XVII (Continued)

	Total COD			Suspended Solids		
	Influent	Effluent	% Reduction	Influent	Effluent	% Reduction
Septic Tank and Lagoon #2						
200	779	88	88.7	319	21	93.4
300	844	101	88.0	378	0	
400	813	158	80.6	394	47	88.1
500*	795	215	73.0	322	74	77.0
200*	758	196	74.1	326	34	89.6

*Evaporation not replaced.

TABLE XVIII

PERCENT REMOVAL IN RELATION TO SURFACE LOADING

	% COD Removal			
Loading Rate	Lagoon #1	Septic Tank	Lagoon #2	Lagoon 2 w/ Septic Tank
200 ml/day	91.7	51.1	76.9	88.7
300 ml/day	91.7	48.6	76.7	88.0
400 ml/day	88.4	43.9	65.4	80.6
500 ml/day*	87.0	34.0	59.2	73.6
200 ml/day*	86.6	38.1	58.2	74.1

Loading			
Lagoon #1		Lagoon #2	
lbs. BOD/day/acre	Cap./day/acre	lbs. BOD/day/acre	Cap./day/acre
18.4	108	9.0	53
29.9	176	15.4	91
38.4	226	21.5	126
46.9	276	21.1	183
17.9	105	11.1	65

*Evaporated water not replaced

1 based on BOD = 60% COD

2 based on 0.17 lbs. BOD/person/day

VITA[2]

Dennis Hugh Ackerson

Candidate for the Degree of

Master of Science

Thesis: THE REDUCTION OF EFFLUENT LOADING BY A LABORATORY SEPTIC TANK AND ITS RESULTANT EFFECT ON AN INDIVIDUAL LABORATORY SEWAGE LAGOON

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