EXAMINATIONS OF THE FEASIBILITY OF USING BIOLOGICAL SOLIDS RECYCLE TO MAINTAIN BIOMASS IN A BIOLOGICAL TOWER UNDER HIGHLY VARIABLE LOADING CONDITIONS

By

DENNIS RAY EMRIE

Bachelor of Science

Colorado State University

Fort Collins, Colorado

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Thesis Approved:

Don F Kincannon
Thesis Adviser

Enos L. Stover

John N. Veenstra

Norman N. Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

In general, design criteria for wastewater treatment processes with municipal and most industrial applications are satisfied using any of a variety of process configurations. A well-run pilot or treatability study should give the design engineer sufficient information to properly select and size a given treatment process. Flow and/or waste concentration (organic load) variability is highly predictable through statistical information accumulated with respect to municipal and industrial wastes, at a specific location, and is typically compensated for in the design criteria, such that, in most systems, anticipated shocking is effectively controlled with operational flexibility.

Problems are encountered when attempting to utilize these same design concepts in unconventional settings. Examples of unconventional applications might include recreational sites, resort areas, and other areas which experience drastic and irregular population variations.

The possibilities for process upsets as considered herein may be common to most if not all treatment systems. However, it is the degree or magnitude of their existence which is of importance when discussing the effects of highly variable loading conditions in a particular design.

The availability of water at a recreational site leads to the generation of wastewater. The type of facilities available at a site will dictate how closely the site waste resembles a domestic waste. For instance, overnight campsites may have limited, if any, bathing facilities. Treatment concerns when processing this waste might include toxic shocks as expected with waste from self-contained vehicles and septage. Whereas, the treatment concerns for a private resort area with complete modern conveniences might include organic, hydraulic, and temperature shocking.

It has been cited that the dominant design for wastewater treatment installations in recreational areas has been extended aeration activated sludge systems. Information gathered by the United States Department of Interior, National Park Service Division will be presented in the following chapter, illustrating typical loadings experienced during the off seasons as well as during periods of heavy visitation at several park facilities, park design situations, and problems and concerns associated with engineering a park wastewater treatment facility.

The objective of this study was to determine the feasibility of operating a biological tower using solids recycle for maintenance of biomass during low flow intervals. The approach taken for establishing a method of evaluating the tower was to simulate anticipated flow conditions, collect data associated with system response to stress (recovery time) and determine whether solids recycle is a probable solution to the stress created on the system.

CHAPTER II

LITERATURE REVIEW

In this chapter fixed-film processes, specifically fixed-bed biological reactors, will be briefly addressed. A summarization, of a previous study on the contribution of recirculation of biological solids to the performance of an experimental fixed-bed reactor, will be presented. The activated biofilter (ABF) will be discussed in brief as a related process. Finally, data from engineering reports regarding waste and flow characteristics at several recreation areas will be presented.

Fixed-Film and Fixed-Bed Reactors

As pointed out in the introduction of this paper, extended aeration activated sludge is the most common process design for treatment facilities in park areas. With activated sludge processes the microbial concentration in the aeration tank is increased to match the incoming organic waste concentration by recirculating the settled microbial mass from the secondary clarifier. Although the procedure is very effective in hastening the biochemical reaction to degrade the organic wastes, the process has unstable characteristics if the influent quality and quantity fluctuate drastically. The activated sludge tends to bulk due to nutrient deficiency, shock loads, changes in pH, and changes in the operating environment. If the dissolved oxygen is insufficient, the sludge will turn septic and rise due to denitrification and trapped gases in the sludge. Very long sludge aeration will result in the formation of very fine sludge particles. Bulking, rising, and fine sludge lower the secondary clarifier efficiency in concentrating the microbial sludge. The activated sludge process thus requires skilled operators for the process to function efficiently (1) (5).

The microbial concentration in the reaction tank may also be increased by providing surface area inside the tank for the microbial organisms to attach and form slime layers (biomass). The microorganisms form a fixed-film waiting for the organic wastes to pass along its surfaces. The fixed-film microbial population is highly diversified and stratified through the depth of the attachment medium. Since the microbial population is already in excess inside the reaction tank and is waiting for the organic wastes, the process is more stable and does not require stringent process control to match the microbial population and the influent waste flow. The organic wastes are adsorbed and later absorbed by the microbial slimes. Dissolved oxygen and essential nutrients are adsorbed and absorbed simultaneously with the organic wastes. Biofilm production is the combined effect of cellular reproduction and extracellular polymer production. The rate of biofilm production depends on the diffusion of nutrients into the biofilm followed by synthesis into the attached biomass. As the slime layer matures, it becomes thicker until cohesive forces between the contact surface and the slime layer become insufficient to support the total weight of the slime layer. At this or any point in the development of the biofilm, portions of the accumulated mass detach and are re-entrained in the fluid. Detachment is the result of either sloughing and/or hydrodynamic conditions (shearing due to force of passing waste stream). A very thin layer of the biofilm is aerobic while the main bulk of the biomass is anoxic. The anaerobic reactions involve degradation of the organic wastes and stabilization of the microbial sludge. The symbiotic reaction between the aerobic and anaerobic organisms recycles the limited nutrients in the wastewater. This improves the stability of the process to treat nutrient deficient wastes (1) (2).

The fixed-bed reactor is filled with a solid media (rocks, wood, plastic) on which microbial slime attaches and grows and over which wastewater flows. The biological reactions are exothermic (releasing heat) which maintains the unit at a temperature higher than ambient conditions. Aside from maintaining the stability of the filter to diurnal variations in temperature, the temperature difference induces air circulation (1).

The presence of fixed-film/fixed-bed reactors existed long before activated sludge processes were developed. Construction savings and the simplicity of common wall construction caused an increase in the popularity of activated sludge in the early 1900's. More recently, the development of plastic media allowed the construction of very tall towers with very low structural cost. Compared to activated sludge, fixed film processes have advantages in lower operating costs and less skilled operations are required, which are kept in balance by the disadvantages of higher capital costs and the lack of operational control or flexibility.

Solids Recycle - In Experimentation and in Practice

A number of studies, pilot and full-scale, have been conducted regarding the effects of recirculation on fixed-film processes. Most of the information available is related to recirculation of either the filter effluent or of a clarified effluent. As pointed out by Lingenfelter, there is much contradictory evidence as to the relevance of recirculation to the performance of the trickling filtration process. Furthermore, when recirculation was found to be complementary, there were divergent opinions as to which factor(s) brought about the additional treatment capacity. The most plausible factors being: 1) the presence of dissolved oxygen in the recirculent, 2) the provision of a greater vehicle for carrying dissolved oxygen while concurrently decreasing the impurity concentration, 3) the continual seeding of the bed with aerobic organisms and beneficial enzymes, and 4) the advantageous effects of greater hydraulic loading, i.e., a) increased mechanical flushing, b) better distribution of waste and microorganisms over media surfaces, and c) extending the biochemical oxidation zone further into the bed (which has been suggested to be of considerable importance) (4) (6).

A variety of flow patterns and recycle combinations have been examined by various workers. With recirculation of activated sludge, secondary (biological filter) settled solids, or combinations of settled solids and filter effluent, it was thought that the higher levels of active microorganisms in the filter influent could improve settleability of solids in the filter underflow. Thus, it was felt that the option of solids recycle offered the hybrid system a greater flexibility, since the filter could be used with or without solids recycle depending on seasonal waste strength and effluent standards (4) (7).

Improvements in plant performance have been documented using the Trickling Filter/Solids Contact (TF/SC) process. This design concept was originally used as a low cost approach for modification and upgrade of a trickling filtration plant for improved performance to meet stricter effluent criteria. By recirculating secondary settled solids to a small aerated contact zone (located intermediate to the trickling filter and the secondary clarifier, being much smaller in size than a conventional activated sludge basin, and having detention times of less than 20 minutes), using tapered aeration and a flocculating center well in the secondary clarifier - it was discovered that the period of gentle agitation prior to sedimentation improved flocculation and removed the finer or smaller poor settling suspended solids, thereby improving the quality of the effluent sufficient to exceed the permit criteria. (10) (11) (12) (13).

Neptune Microfloc's - Activated Biofilter (ABF) is a fixed film process where the settled secondary solids are recirculated and mixed with the influent waste prior to distribution to the attached biomass. System components in the ABF process include primary clarification or screening, wet well/Bio-Cell pump station, ABF Bio-Cell, flow control and splitting, short term aeration, secondary clarification, and return sludge facilities. These, coincidentally, are common components of the vast majority of wastewater treatment facilities with the exception of the Bio-Cell. Process configuration and media design and construction are proprietary with the ABF/Bio-Cell process, where sections of horizontal redwood slats overlapped and overlain (stacked) in a reactor compartment. It was found that recycling sludge through the fixed film biocell significantly improved overall process efficiency and stability. This improved performance was attributable to higher organic removals and bioadsorption within the tower (8) (9) (13) (14) (15) (16). A study was conducted on a combined industrial (food processing)/domestic waste where, plastic media (60 degree crossflow and 45 degree crossflow) and pure oxygen systems were compared to the redwood biocell design. The results indicated a very moderate deviation between the performance of the 60 degree crossflow and the redwood biofilter in performance characteristics (29), both of which were superior to the other tested processes.

Discussion of Variable Flow and Loading Conditions

In the case of larger wastewater treatment plants serving metropolitan areas, the sewage reaches the plant at a fairly constant rate because of the variety of distances and velocities it travels from the source to the plant. In the case of a smaller treatment unit, these distances are usually much smaller, and therefore the variability in rate of flow at the plant is much greater. Heavy surges of flow, which might be damped out in a city sewer system, will result in hydraulic or organic surcharges on the plant in the case of the smaller units.

Other problems such as lack of supervision and maintenance exist at small plants. Also, the release of large volumes of toxics may pass relatively undetected in large plants due to dilution, but would present serious problems in medium to small size plants. Important considerations for small plants are as follows: a) It must operate reliably without continuous skilled supervision. b) It must operate efficiently under a variety of flow conditions, including organic and hydraulic shocks. c) It should not be unsightly. d) It should not generate large volumes of solids for subsequent disposal. e) It should not generate odors (24). These guidelines, as spelled out for treatment facilities in rural areas, are probably the minimum considerations which should be applied to any plant. Design of small treatment plants is an area that has not received the attention from engineers that it requires or deserves. Many times, large firms will pass up the design of small plants or assign them to a young, inexperienced engineer. In other cases, small firms with little or no experience have undertaken the design of these plants. Consequently, many of them have now proved to be inadequate, especially in meeting the more stringent discharge requirements established by various federal and state agencies. Clearly, the design of small plants that work is the responsibility of the engineer and not the operator or contractor (25).

Wastewater studies conducted at several Texas State Parks revealed that the maximum flow rate at a plant usually occurs on summer weekends (Figures 1 and 2) (18) and is generally about five times the average flow to the plant (18). However, some of the national parks report greater than ten times average flow during periods of heavy visitation (19) (20) (21). The characteristics of wastewater from overnight areas are typical of municipal wastewater in terms of the biochemical oxygen demand (BOD = 372 mg/L) and the total suspended solids (SS = 242 mg/L). However, in day use areas, the wastewater is much more dilute (BOD = 86 mg/L and SS = 10 mg/L). On the other hand, the concentration of organic

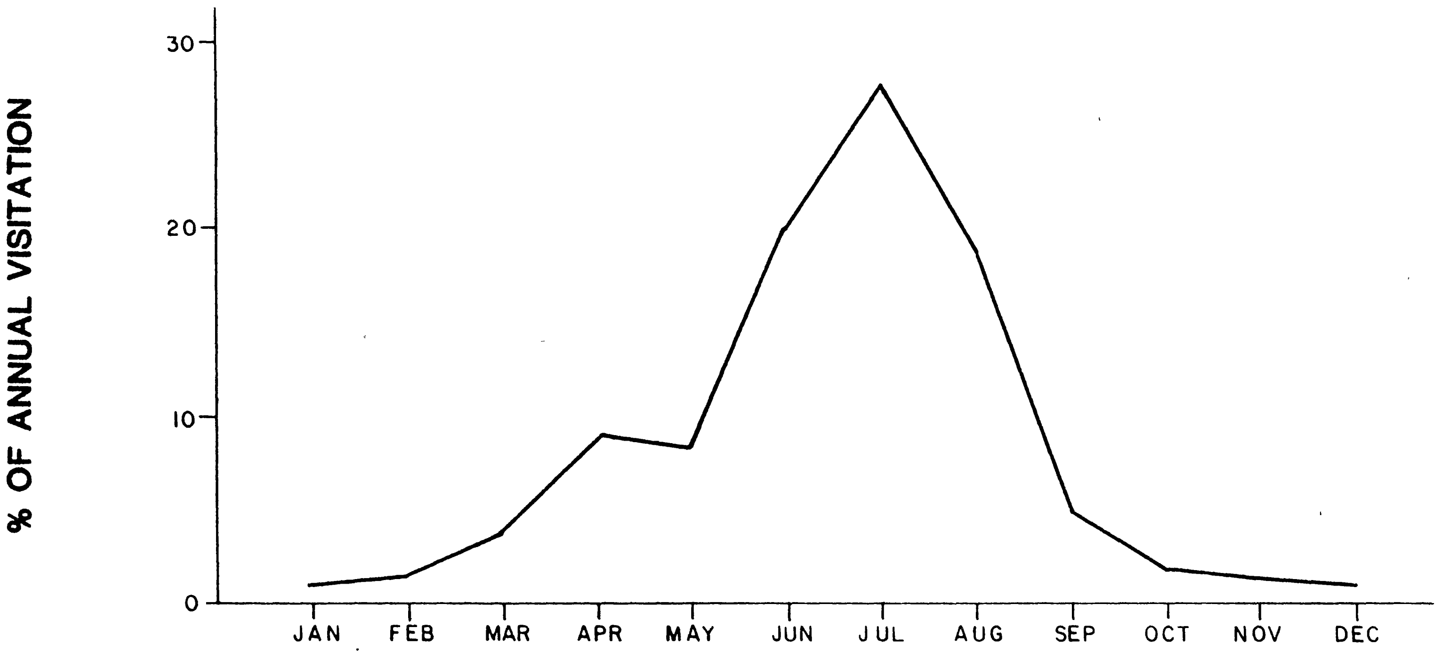

Figure 1. Typical Annual Visitor Distribution (19)

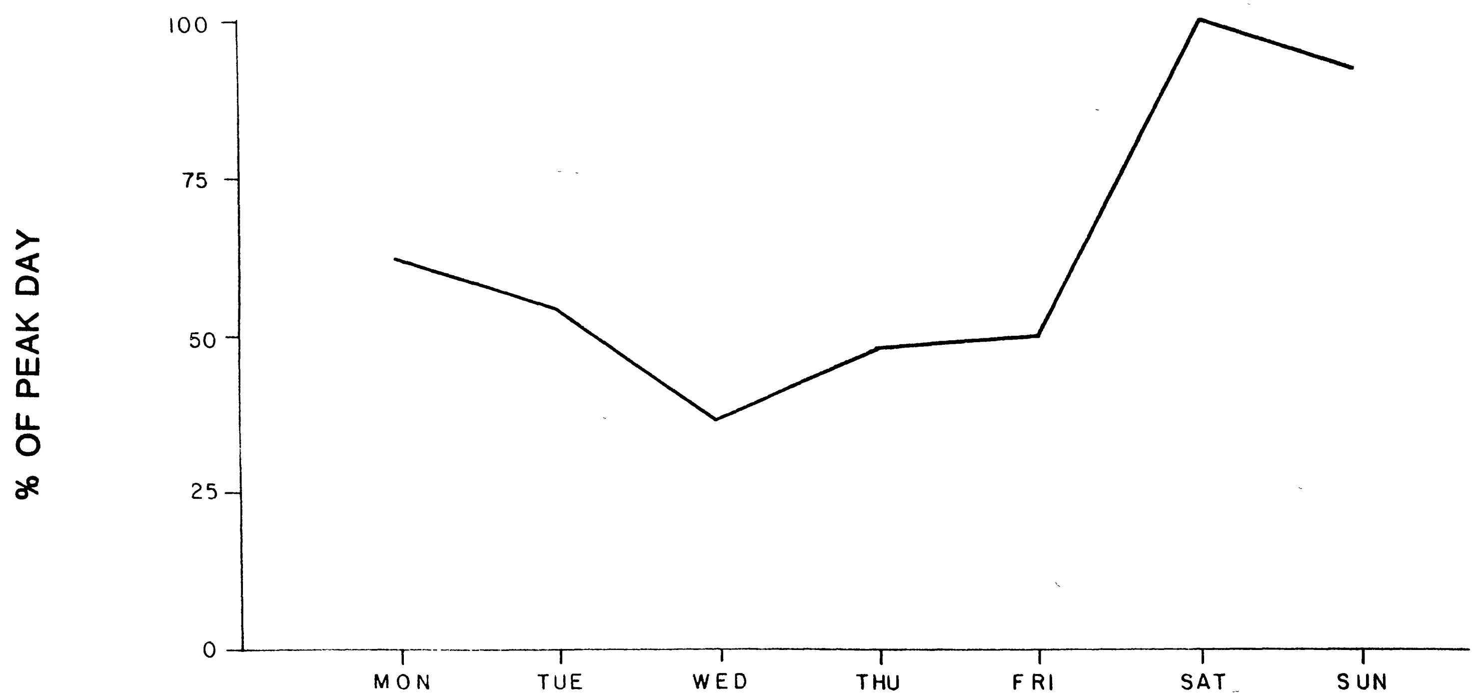

Figure 2. Typical Weekly Visitor Distribution (19)

material (BOD) in trailer dump stations is much higher than that found in municipal waste - as trailer waste contains zinc and formaldehyde, which may be potentially inhibitory or toxic to biological processes (18).

Summary

Since literature pertinent to the topic of this thesis was extremely scarce (the majority of literature being published in foreign journals), the following approach was used to supply support information. General details were presented concerning fixed-film reactors in order to provide a very basic understanding behind the principals of the process. Several process configurations related to the mode of treatment used in this study were discussed to illustrate that solids recycle has been shown to improve plant effluent quality when operating at typical design loading conditions. Finally, a brief discussion of engineering concerns regarding treatment facility design for small rural communities and recreational areas was included to indicate the present need for alteration in design concepts being used for small facility design. Low cost, simple to operate, and reliable forms of treatment are required. The scope of this study was simply to ascertain whether a biological tower could reliably maintain a biomass (microbial population) under variable flow conditions using biological solids recycle as the vehicle of subsistence.

CHAPTER III

MATERIALS AND METHODS

Apparatus and Flow Configuration

A fixed-film reaction vessel of steel construction was as specified and fabricated by Enviroquip, Inc. of Austin, Texas. The reactor dimensions were 4' square by 20' high with 2' of open height above the media for flow distribution and 2' of open height below the media to allow for undisturbed underdraining and collection of tower effluent and to allow passage of air. The volume occupied by the attachment medium was 4' square by 16' high with four (4) sampling ports (one located every 4' of media height beginning 4' from the top of the media. The plastic attachment media (tower packing) used for this study was built in bundles, and consisted of corrugated polyethylene sheets thermal-welded together for strength. The manufacturers information indicated that the media used herein has 38.6 square feet of surface area per cubic foot of volume (approximately 94% open area). Bundles were factory installed such that corrugations or flow channels were 60 degrees from the horizontal, creating a 60^{o} cross flow configuration (Figure 3)

Process flow was diverted from one of the primary clarifiers through a suction manifold with strainers (located in the interstice between the scum baffle and weir plate), into the biological tower using a 3/4 horsepower centrifugal pump. A ball valve on the discharge side of the influent pump was installed to regulate the amount of raw sewage inflow. The flow distribution network consisted of three (3) lateral PVC headers with drilled orifices every 3" of pipe

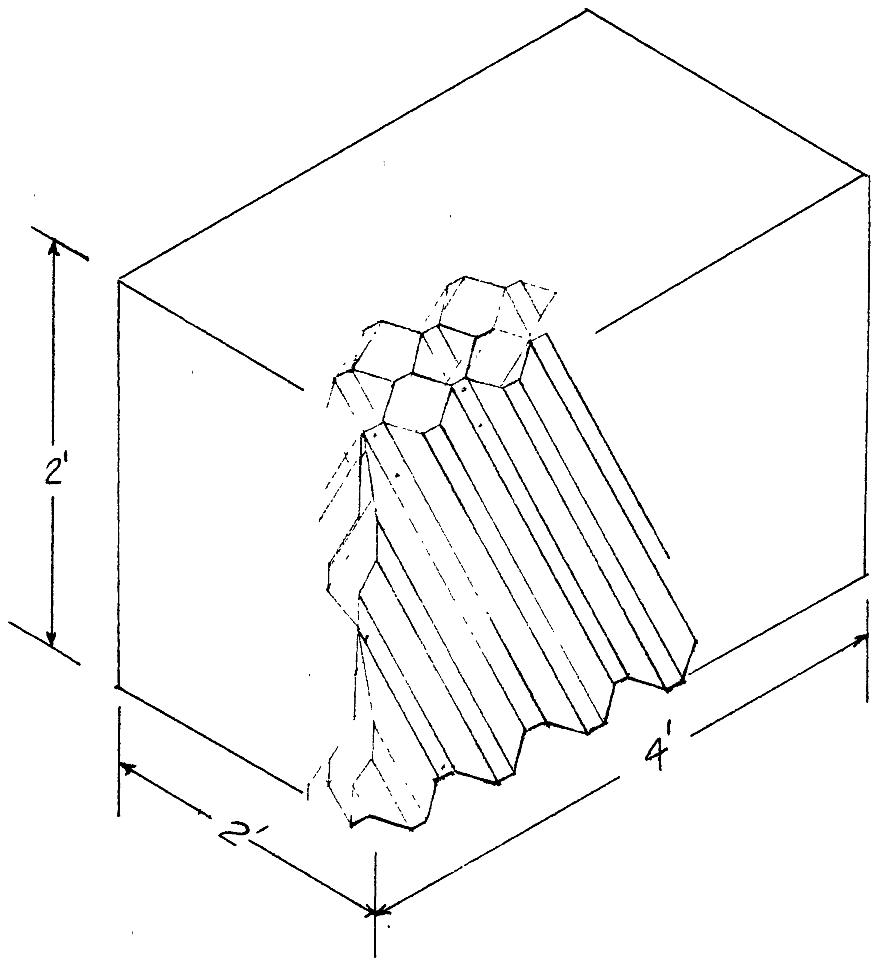

Figure 3. Media Configuration

length on alternating sides of the bottom vertical centerline). The orifices were tapped in the event that insertion of plugs might be required to obtain even flow distribution. Splash boards were also installed to help attain maximum fluid coverage at the top surface area of the media (coverage after adjustment of header and boards was approximately 12 sq ft or 75%). Sample collection tubes (2" diameter steel pipes) were bolted in place horizontally across the center section of the tower at the locations previously described, with the top half of each pipe being dished out to accept a representative aliquot of the passing flow. The steel tower structure had openings below the underbracing to allow for upward passage of air through the media and for biological filtrate to pass for flow measurement and sedimentation. The tower was placed in a 6' square by 2' deep collection trough, and the collection trough was piped to a flow measurement box containing a V-notch weir with two (2) separate upstream gauging devices. Flow would pass the weir into a sump compartment which was piped to a 1/2 horsepower centrifugal pump for transfer of measured filtrate to the sedimentation basin. A series of valves were used to control the rate of transfer to the clarifier or the rate of bypass to the treatment plant sewer piping, depending on the operational scheme at the time. The clarifier was 4' diameter by 8' high (volume = 61.6 6 cu. ft. = 460. 75 gallons, surface area = 12.6 sq. ft.), with outboard effluent troughs, conical bottom and a mechanical sludge scraper. Return sludge was recycled from the bottom of the clarifier into the biological tower using a 3/4 horsepower centrifugal pump. A ball valve was installed on the discharge side of the recycle pump to regulate the amount of sludge returned to the system. The sludge recycle line was tied to the flow distribution header near the connection for raw waste influent, thus return settled biological solids and raw waste would combine and pass through several bends, thereby creating a homogenous blend of nutrients for equal and even distribution to the biological tower.

Table I identifies the flow rates and origin of flow at each of the four flow conditions. Figure 4 is a simplified schematic of the equipment as well as a flow diagram.

TABLE I

VARIABLE FLOW CONDITIONS

Condition #	Date	5 Day Flow %Raw (gpm)	% Recycle (gpm)	2 Day Flow % Raw (gpm)
1	5/10 to 6/14	100 (25)	0 (0)	100 (25)
2	6/15 to 6/28	0 (0)	100 (20)	100 (25)
3	7/1 to 7/12	25 (5)	75 (15)	100 (25)
4	7/13 to 7/26	50 (10)	50 (10)	100 (25)

Approach and Analytical Procedures

Evaluation of an alternative approach to processing wastewater in recreational areas was to be performed by operating a biological tower pilot unit under a variety of flow situations, each situation designed to represent a different variable flow condition. Acclimation of the tower at each flow condition was required prior to measurement of performance characteristics. Substrate removal rate and substrate removal efficiency were used as measurements of performance during normal and stress conditions.

The first case or condition to analyze was the performance of the bio-tower without recirculation of biological solids, in other words, observe the performance

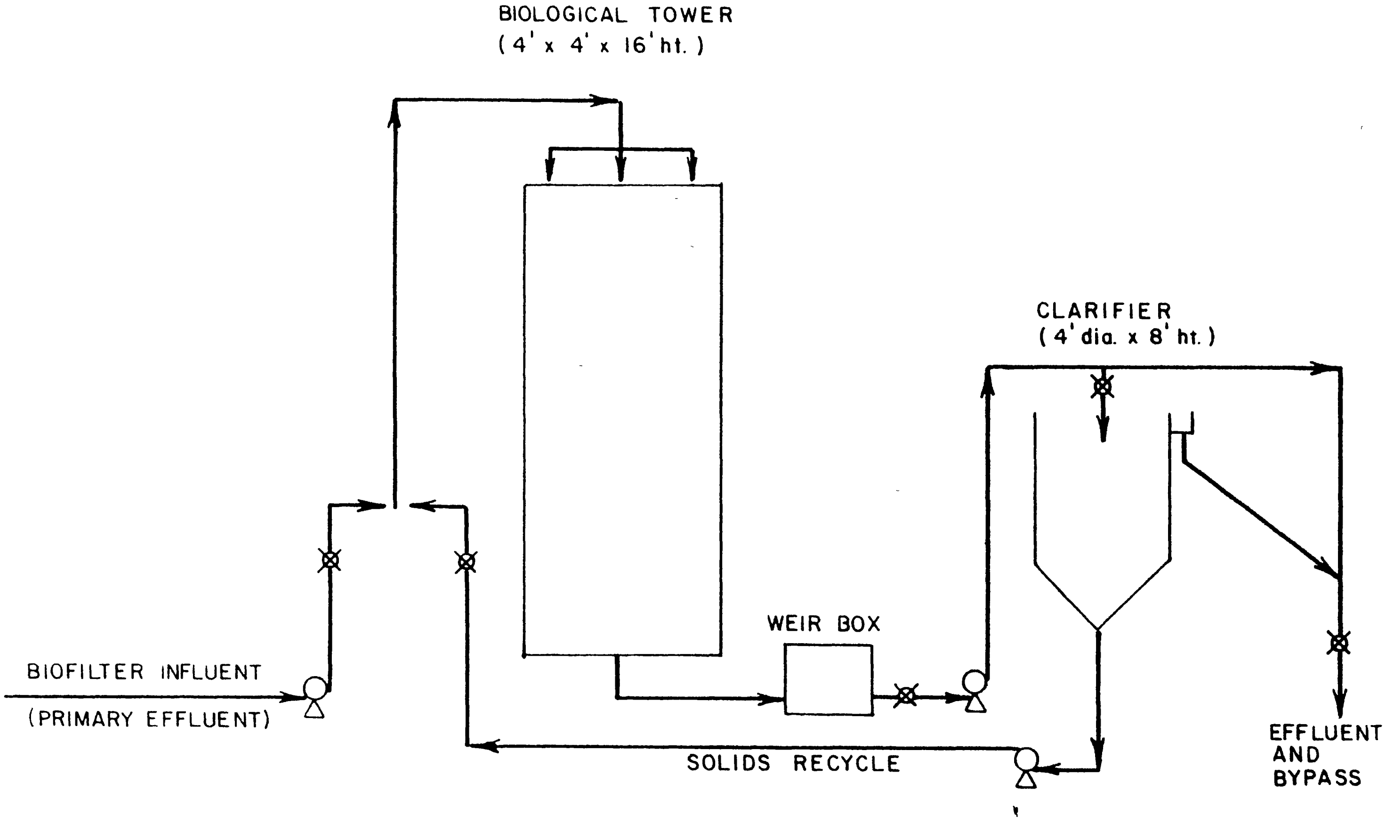

Figure 4. Flow Schematic

under a conventional mode of operation (i.e., low-rate trickling filter process). In the second through fourth conditions, the tower was pumped recycled solids at 100%, 75%, and 50% in combination with raw primary effluent at 0%, 25%, and 50% of the respective flow for five consecutive days followed by two days of feed with 100% raw primary effluent.

The performance of the tower was observed at each condition for a period of at least three weeks. Each week consisted of four consecutive sampling (data collection) days. The first sampling day being at the end of a five-day recycle period, its purpose was to observe if any degradation or improvement in performance had resulted from a transformation in nutrients during recycle. The objective of feeding strictly raw waste for a two-day period (sample days #2 and #3) was to simulate heavy visitation or a weekend situation and create stress to the system. Days #2 and #3 were the most critical sampling times. The final sampling day (day #4) in each week was the first day of recycle following the stress load, the function of this day was to observe recovery in performance (percent) from applied biological stress.

Accurate flow measurement was easily attained when operating with a single flow scheme (either raw or recycle). Flow setting was slightly more difficult, however, when working with a combined flow. First, the greater of the two flows would be set, then the second flow would be added to it and balanced to the desired flow rate.

The flow measurement channel (V-notch weir box) was positioned such that water was backed-up into the tower underdrain or collection trough. This created a situation where heavy solids settled in the tower collection trough instead of the sedimentation basin. Since this was to be a study to determine the effects of recycled solids during variable loading conditions, something had to be done. The problem could have been permanently resolved if the soil and rock under the flow channel could have been broken and the weir box lowered. Since this could not be done, however, the problem was partially alleviated by hand mixing the collection trough contents every hour (with assistance from the treatment plant operators) to re-suspend the prematurely settled solids long enough to transport them to the sedimentation basin for collection and recirculation.

Grab samples from each sampling location were collected four consecutive days each week, the samples were transported to the laboratory for immediate analysis. Parameters measured in the laboratory were pH, Total Suspended Solids (TSS). soluble Biochemical Oxygen Demand (sBOD), and total Biochemical Oxygen Demand (tBOD). All of the laboratory procedures and techniques used were in accordance and as outlined in The Standard Methods (30).

CHAPTER IV

RESULTS AND DISCUSSION

This chapter begins with a discussion of difficulties encountered during the project. After which, data and graphical interpretations of the data will be presented, followed by a brief general discussion of physical observations.

This evaluation was conducted at the City of Stillwater Wastewater Treatment Facility and was a cooperative effort between the University and the City, arranged by the Environmental Division of the Civil Engineering Department at Oklahoma State University.

All of the materials and equipment were received by the middle of March, installation was complete and primary effluent was being pumped to the tower by the end of March.

The first problem encountered was of a mechanical nature and was the result of improper pump performance. Time out of service due to a constantly failing diaphram pump delayed the project approximately eight weeks. Consequently, initiating biological growth and acclimation of the biological tower to an undisturbed and constant flow rate was difficult to maintain in the early phases of the study. Pumping problems were finally remedied by selecting a centrifugal pump to replace the diaphram pump. Originally, it was believed that the diaphram pump was uniquely suited as a low head - low shear pump, as it turned out, vibration caused rapid and complete failure of diaphrams, bearings, and pipe connections, thus causing maintenance headaches. Line surges and high discharge velocities from the diaphram pump caused operational problems with the sedimentation basin, the sludge blanket was disturbed by peaking and surging of the clarifier influent with each stroke of the pump. The centrifugal pump, opposed to initial thinking, did not significantly break up or damage the biological floc, and overall improved settling was observed in the clarifier which was the result of a constant inlet velocity. The trickling filter (biological tower) system includes both a fixed film reactor and a sedimentation basin (secondary clarifier). The clarifier is used for removal of the biological solids that are discharged from the filter. The clarifier used in this study was drastically undersized, i.e., at a design overflow rate of 1000-1200 GPD/sq. ft. the settling unit would be capable of accepting a flow of approximately 12,500-15,000 gallons per day and flow rates used throughout the term of this study varied with the average flow being 36,000 gallons per day. The majority of solids are contributed by the filter instead of the filter influent, and filter efficiencies are generally computed on the basis of effluent quality from the clarifier. However, in this study, clarifier performance was not ciritical in terms of effluent quality, what was most important was to provide adequate storage and eliminate wash-out of solids. Regarding filter efficiency, concentration of soluble organic material was monitored through the depth of filter media.

Of primary interest was the observation that the concentrations of soluble organic material at the Stillwater Wastewater Treatment Plant were much less in the summer than during the remainder of the academic year. The trend in student population exerts a noticeable influence at the treatment plant. As mentioned previously, this study was conducted during the summer session, thus influent soluble BOD's were extremely low (20 mg/L) as shown in Figure 5. Figures 5 and 6 illustrate the differences in soluble organic loadings between the summer semester and the fall semester when student population has increased. The 35 gpm and 17 gpm data was collected during the fall semester, while the 25 gpm

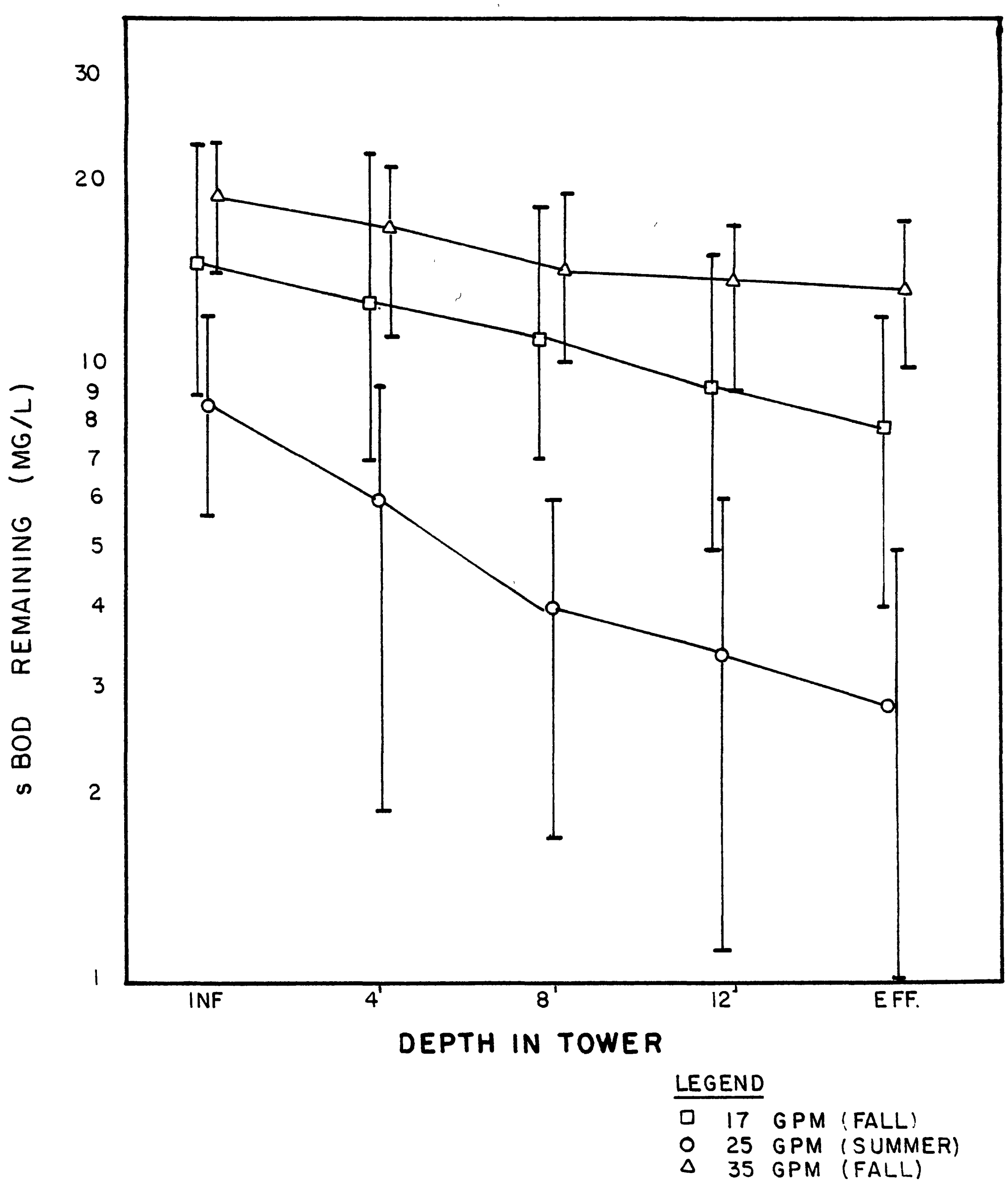

Figure 5. Semilog Relationship of sBOD (mg/L) Remaining vs. Depth in Tower for Condition #1 (no recycle)

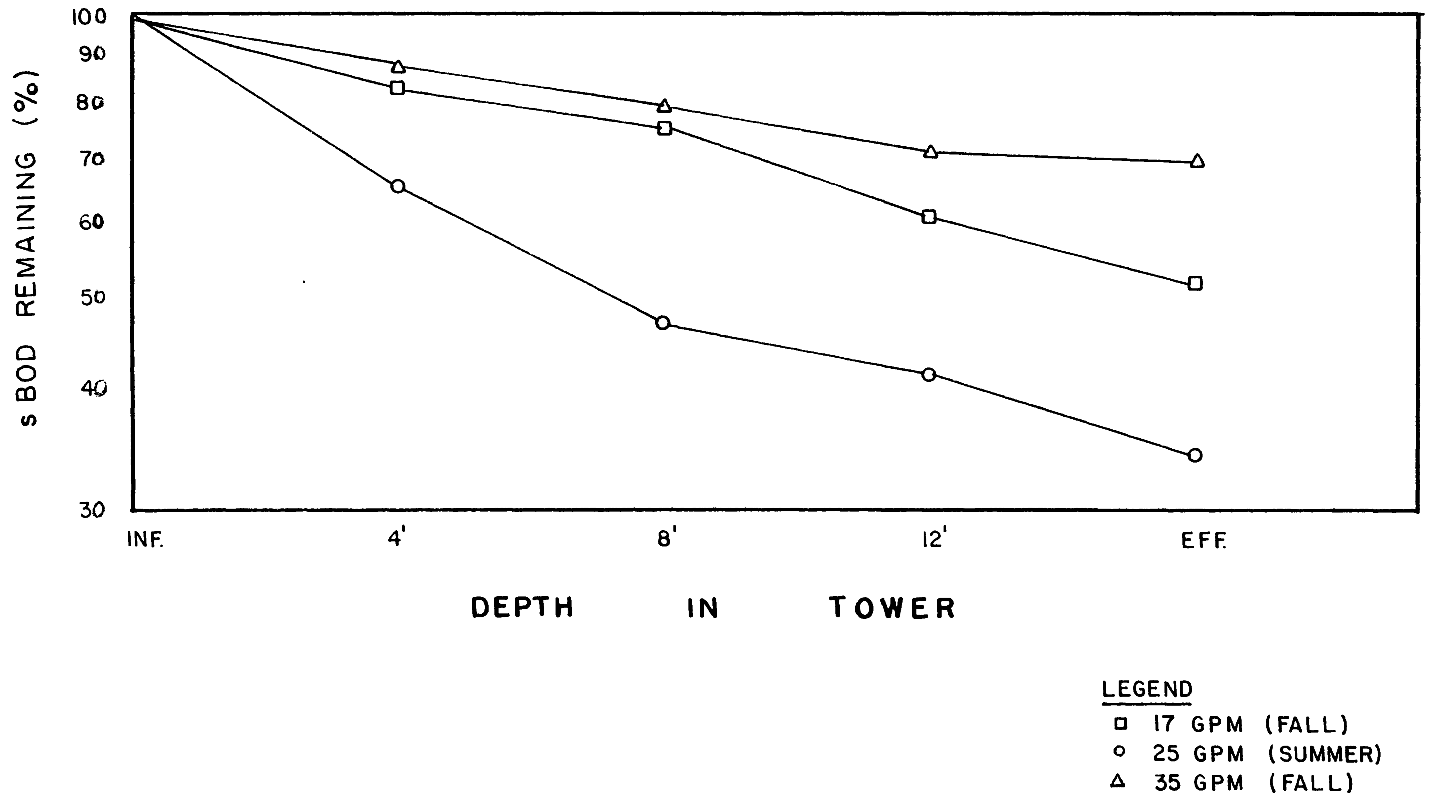

Figure 6. Semilog Relationship of sBOD (%) Remaining vs. Depth in Tower for Condition #1

data was collected in the summer. Note that the 25 gpm line is out of the expected range, it should lie directly between the other two lines, thus indicating a definite difference in waste characteristics at these two times of the year. Probably the main reason contributing to low BOD's in the tower influent was the fact that the equalization basin removed approximately 30-60 percent (according to plant records) of the soluble organics which was the result of being operated as an activated sludge unit ahead of the primary clarifiers. This problem was partially avoided during the summer months by bypassing the equalization basin directly to the primary clarifiers.

Concurrent to this study, a local consulting firm discovered that several industries were frequently in violation of releasing toxic materials into the city sewer system. The nature of the toxics has not been made available for discussion here, in that there may still be charges filed against the violators. Suffice it to say that these unexpected and heavy doses of toxics had detrimental effects on the City treatment process, therefore it is safe to assume that there were some negative effects also experienced by the pilot plant used for this study.

Data was collected over a four-month time period and under four different modes of operation. Within each of the last three modes or conditions, one week of data was represented by four consecutive sampling days. Each of these days is individually representative of a state of change to the system (i.e, either shock loading or recovery to shock) and are reflected as such in Tables II, III, IV and V, and associated figures.

Example:

Day of Week	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.
Mode of Flow	Feed and/or Recycle	Feed and/or Recycle	Feed	Feed	Feed and/or Recycle	Feed and/or Recycle	Feed and/or Recycle
Sampling Day	N.A.	1	2	3	4	N.A.	N.A.

TABLE II

COLLECTED DATA: CONDITION 1

Date	Flow (Gpm		pH		TSS (mg/L)			Soluble BOD (mg/L)						t BOD
	Inf	Recy	In	Eff	Inf	Eff	Recy	Inf	4'	8'	12'	Eff	Recy	Inf
9/18	17	0	6.9	7.5	50	87	--	19	16	18	15	12	--	40
9/19	17	0	7.0	7.5	68	40	--	23	22	17	12	12	--	54
9/20	17	0	6.9	7.5	42	35	--	18	14	13	13	8	--	40
9/23	17	0	7.0	7.2	62	48	--	9	7	7	5	4	--	23
9/24	17	0	6.9	7.3	66	34	--	12	10	8	7	7	--	39
9/25	17	0	6.8	7.2	268	25	--	12	10	8	7	7	--	39
9/26	17	0	6.8	7.3	62	38	--	15	15	10	9	8	--	40
9/27	17	0	6.9	7.2	85	46	--	10	8	9	6	5	--	31
9/30	17	0	7.1	7.3	74	62	--	15	13	12	10	8	--	43
5/24	25	0	7.8	7.8	41	22	--	6	3.2	2.1	2.3	2.1	--	24
5/30	25	0	7.7	7.9	23	16	--	9	6.6	4.0	4.7	2.0	--	18
6/3	25	0	7.5	7.7	24	21	1690	12	9.2	4.3	3.9	4.9	--	23
6/5	25	0	7.4	7.6	39	27	1995	2.6	2.1	1.8	1.4	1.4	--	16
6/7	25	0	7.5	7.7	52	67	4211	8.9	9.0	6.0	6.0	4.4	--	18
6/10	25	0	7.5	7.8	38	11	4101	5.8	1.9	1.7	1.1	1.0	--	21
6/12	25	0	7.5	7.6	31	6	--	12	7.2	5.4	4.2	3.9	--	35
6/14	25	0	7.7	7.8	28	19	1105	7.5	4.6	4.5	1.9	1.5	--	21
8/26	35	0	6.8	7.2	39	42	--	20	20	19	13	11	--	45
8/27	35	0	7.0	7.4	36	34	--	23	21	18	17	17	--	43
8/28	35	0	7.0	7.3	39	31	--	19	16	14	14	13	--	42
8/29	35	0	7.1	7.6	34	22	--	20	20	18	15	15	--	46
8/30	35	0	7.1	7.5	56	37	--	18	16	15	14	13	--	44
9/3	35	0	6.9	7.2	39	13	--	14	11	10	9	19	--	35
9/4	35	0	5.6	7.2	53	34	--	20	18	16	14	15	--	42
9/5	35	0	7.2	7.3	50	29	--	21	17	17	16	16	--	45
9/6	35	0	7.2	7.2	27	17	--	19	16	17	15	14	--	39
9/9	35	0	7.1	7.2	40	26	--	14	13	11	9	11	--	33
9/10	35	0	7.0	7.2	36	33	--	21	17	17	16	14	--	44
9/11	35	0	7.2	7.1	34	41	--	20	17	14	14	13	--	43
9/12	35	0	7.1	7.0	40	29	--	20	18	16	14	13	--	42
9/13	35	0	7.1	7.1	35	33	--	18	15	12	13	12	--	37
9/16	35	0	7.2	7.2	50	37	--	15	12	12	10	10	--	39
9/17	35	0	7.1	7.2	45	40	--	21	18	17	15	15	--	45

TABLE III

COLLECTED DATA: CONDITION 2

Date	Flow (Gpm		pH		TSS (mg/L)			Soluble BOD (mg/L)						t BOD
	Inf	Recy	In	Eff	Inf	Eff	Recy	Inf	4'	8'	12'	Eff	Recy	Inf
6/19	0	20	6.5	6.4	32	59	133	1.1	0.9	0.9	0.8	0.9	1.1	19
6.26	0	20	6.1	6.0	51	355	454	1.0	0.7	0.7	0.8	0.8	1.0	31
6/20	25	0	7.5	7.6	31	10	2205	5.3	3.9	3.9	2.3	1.8	--	20
6/27	25	0	7.5	7.8	31	15	4270	2.3	2.2	2.1	1.9	1.4	--	11
6/21	25	0	6.6	6.7	22	7	965	3.4	2.8	2.1	2.2	1.2	--	6.6
6/28	25	0	7.5	7.7	26	11	7970	5.4	5.0	5.4	5.2	5.1	--	17
6/15	0	20	8.1	8.0	99	180	99	1.7	1.6	1.5	1.3	1.4	1.7	Recy
6/22	0	20	7.6	7.5	3 3	2.0	3.3	1.7	1.6	1.5	1.4	1.5	1.7	Recy

TABLE IV

COLLECTED DATA: CONDITION 3

Date	Flow (Gpm)		pH		TSS (mg/L)			Soluble BOD (mg/L)						t BOD
	Inf	Recy	In	Eff	Inf	Eff	Recy	Inf	4'	8'	12'	Eff	Recy	Inf
7/2	5	15	6.0	8.0	29	132	116	4.6	0.9	0.9	1.1	1.2	1.0	9
7/10	5	15	7.9	0.0	36	25	116	8.9	1.9	2.2	2.2	2.0	2.4	21
7/4	25	0	7.5	7.9	30	33	39075	11	12	11	12	13	--	23
7/11	25	0	7.5	7.8	23	19	3690	6.4	6.6	6.1	6.1	5.3	--	12
7/5	25	0	7.5	7.8	30	29	745	10	8.9	9.8	10	10	--	25
7/12	25	0	7.5	7.8	30	15	178	5.2	4.5	4.9	4.2	4.1	--	12
7/1	5	15	8.1	8.1	50	113	95	8.4	0.6	0.6	0.7	0.8	0.7	18
7/6	5	15	8.1	8.0	24	85	62	7.9	0.6	0.7	0.5	0.5	0.7	17

TABLE V

COLLECTED DATA: CONDITION 4

Date	Flow (Gpm)		pH		TSS (mg/L)			Soluble BOD (mg/L)						t BOD
	Inf	Recy	In	Eff	Inf	Eff	Recy	Inf	4'	8'	12'	Eff	Recy	Inf
7/17	10	10	7.4	7.4	26	579	866	6.9	2.3	2.8	3.9	2.5	1.7	14
7/24	10	10	7.4	7.8	25	238	264	6.6	3.7	4.2	5.6	4.7	2.4	14
7/18	25	0	7.4	7.8	25	29	2235	3.1	3.9	3.6	2.3	1.9	--	7.4
7/25	25	0	7.4	7.9	22	24	--	2.6	4.9	4.9	4.5	4.4	--	8.9
7/19	25	0	7.4	7.8	26	14	945	5.1	4.5	5.3	3.9	3.4	--	12
7/26	25	0	7.0	7.9	20	29	--	3.2	3.6	3.2	3.8	4.8	--	10
7/13	10	10	7.8	7.8	27	14	71	5.6	2.4	4.0	3.6	3.3	1.5	17
7/20	10	10	7.5	7.6	30	348	378	5.2	1.4	1.3	1.1	1.2	1.0	10

The performance of the tower, as mentioned in the previous chapter, was observed at each condition for a period of at least three weeks, with one week serving as an acclimation period.

Before discussing each condition in detail, it should be emphasized that statistical significance cannot be attached to the results presented herein, nor was it the objective to do so. The system was constantly being upset due to changing conditions, making the possibility of overall linear relationships or kinetic descriptions unlikely. The primary concern, however, was to observe general trends in soluble organic removal and to determine if the adverse effects of variable loading to the tower could be dampened or controlled with the use of solids recycle.

It is not certain what degree of association may be drawn between the conditions experienced during this study and conditions experienced in treatment of waste at a recreational site. It was interesting to note, for example, that the concentration of soluble organics going to the biological tower never exceeded 10 mg/L, whereas the lowest concentration from the literature indicated concentrations at camp sites well in excess of five times this amount.

Figures 7 thru 12 illustrate the relationship (for conditions 2 thru 4) between organic material remaining versus relative position in the biological tower, for each of the sampling days. In each of the conditions which implemented a recycle flow scheme (2, 3, and 4) sample days #2 and #3 were of primary interest, since they would indicate the success or failure of the concept under evaluation. As seen in Figures 7, 9, and 11, the biomass did not exhibit the ability to remove organic matter on the critical days, under any of the flow circumstances examined. Recovery response varied in each condition, in condition #2 recovery was gradual with an improvement in effluent quality at the end of each test period and in conditions #3 and #4 recovery was rapid with a break down in effluent

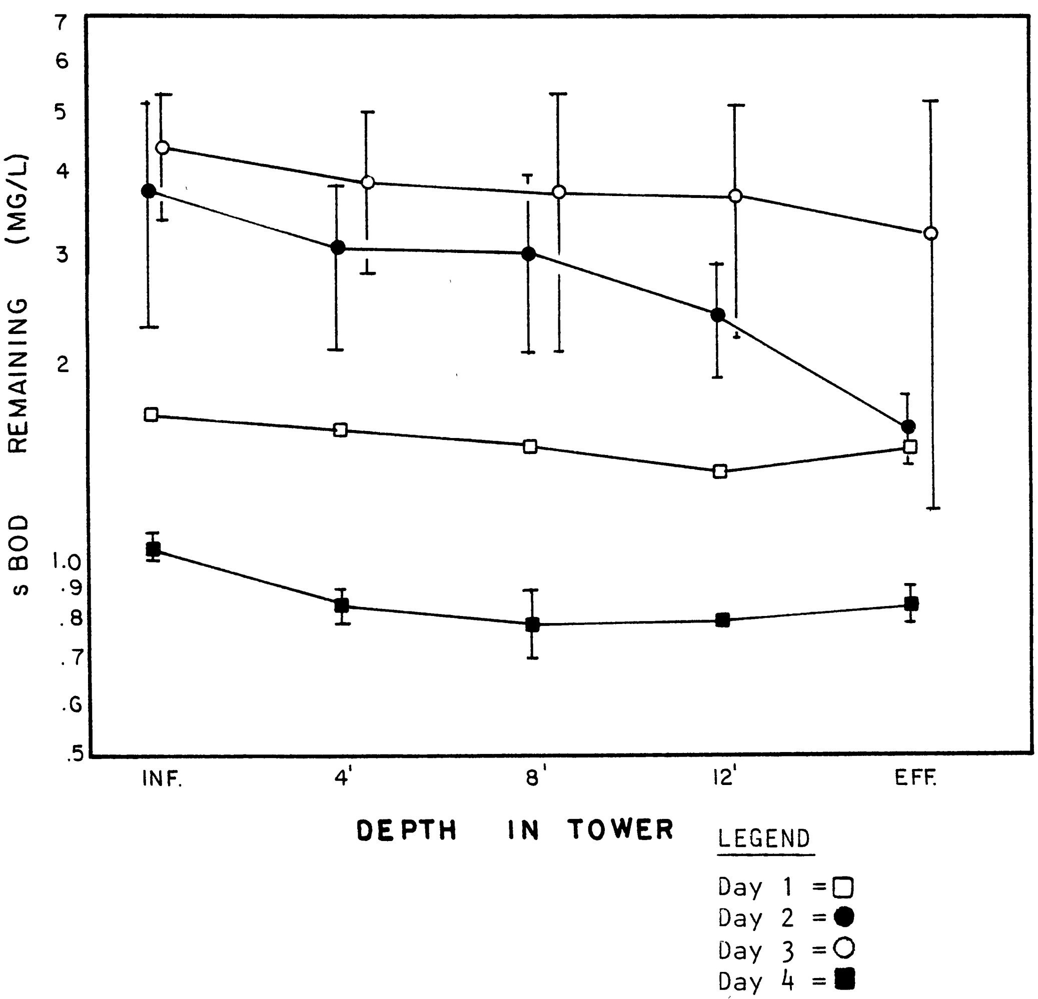

Figure 7. Semilog Relationship of sBOD (mg/L) Remaining vs. Depth in Tower for Condition #2 (100% Recycle)

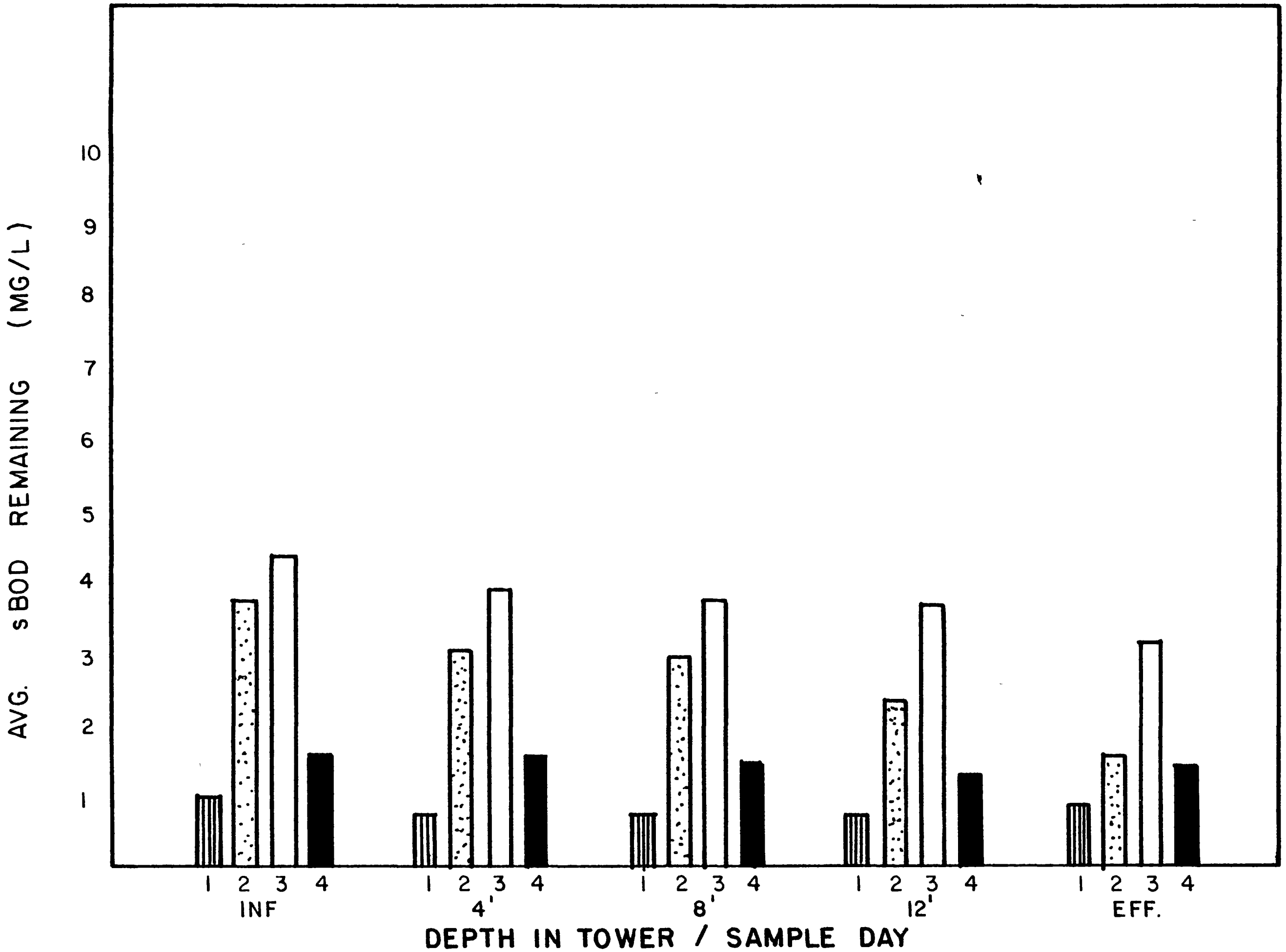

Figure 8. sBOD vs. Depth Trend Chart for Condition #2 - Sample Days 1-4

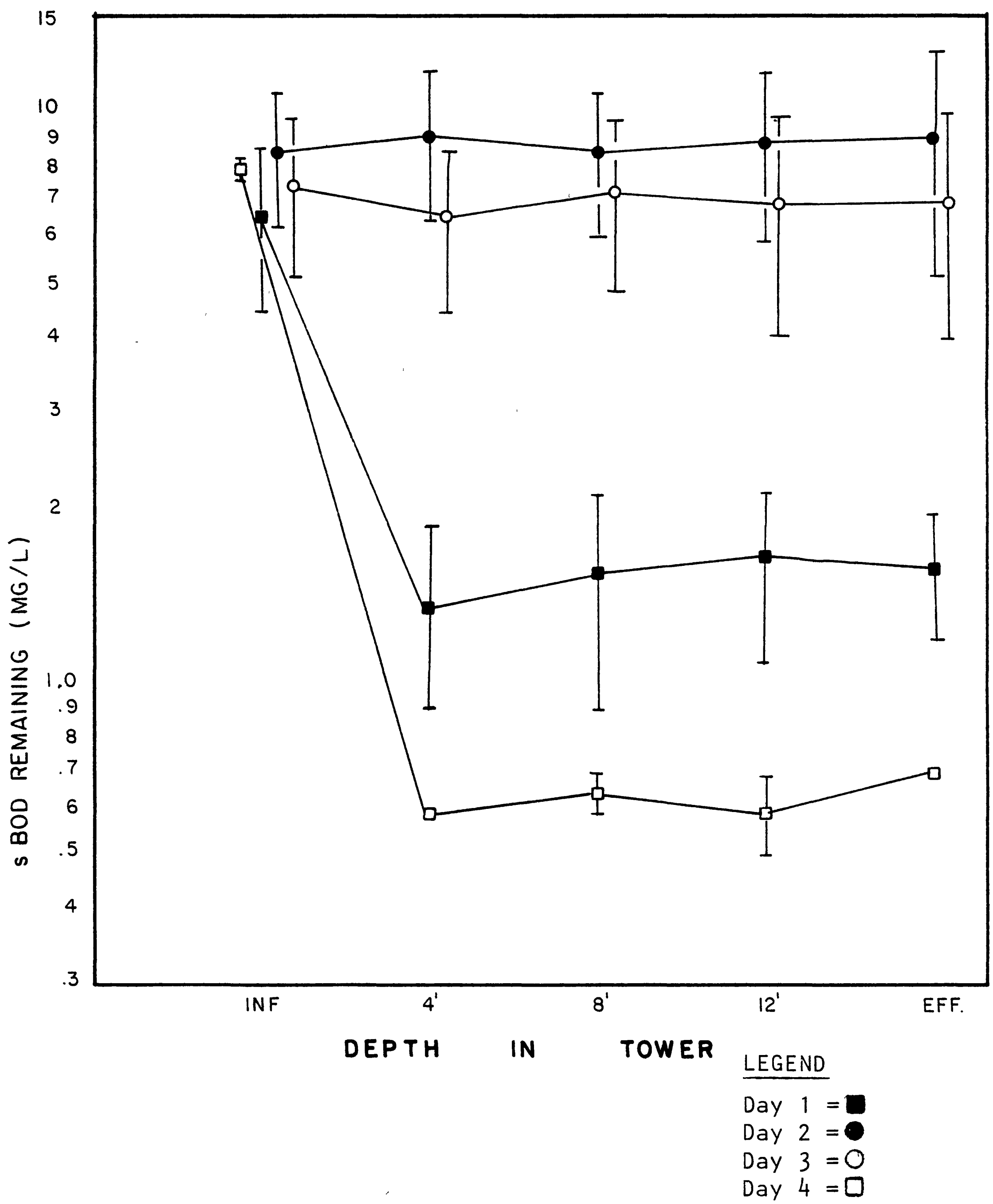

Figure 9. Semilog Relationship of sBOD (mg/L) Remaining vs. Depth in Tower for Condition #3 (75% Recycle)

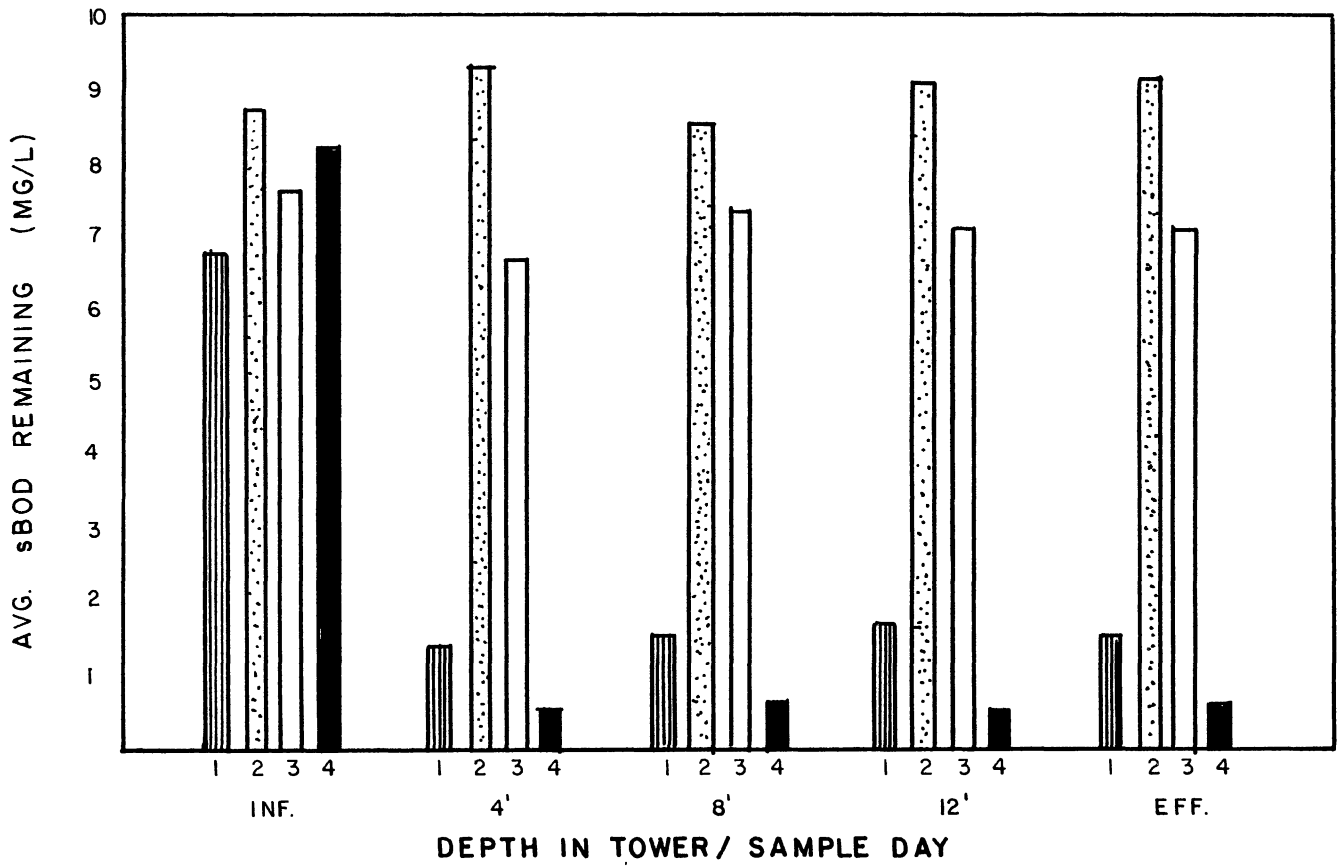

Figure 10. sBOD vs. Depth Trend Chart for Condition #3 - Sample Days 1-4

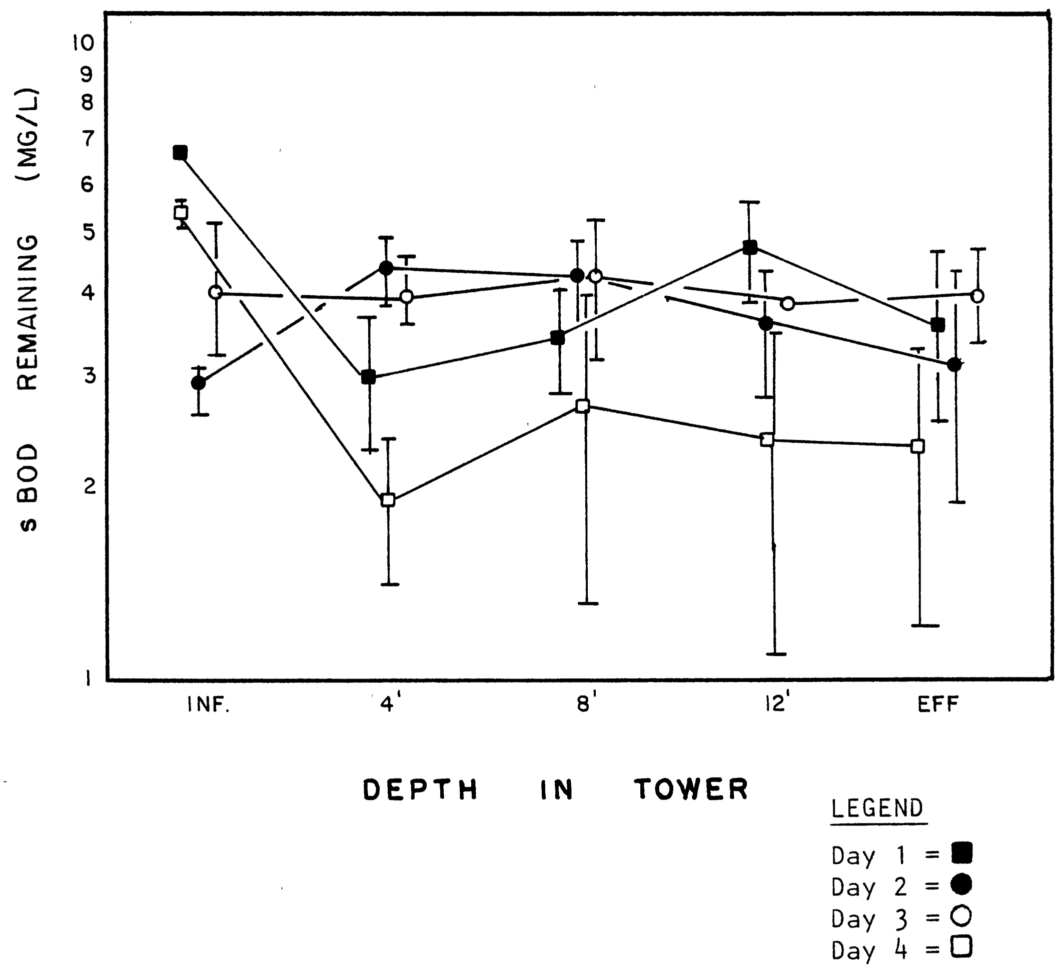

Figure 11. Semilog Relationship of sBOD (mg/L) Remaining vs. Depth in Tower for Condition #4 (50% Recycle)

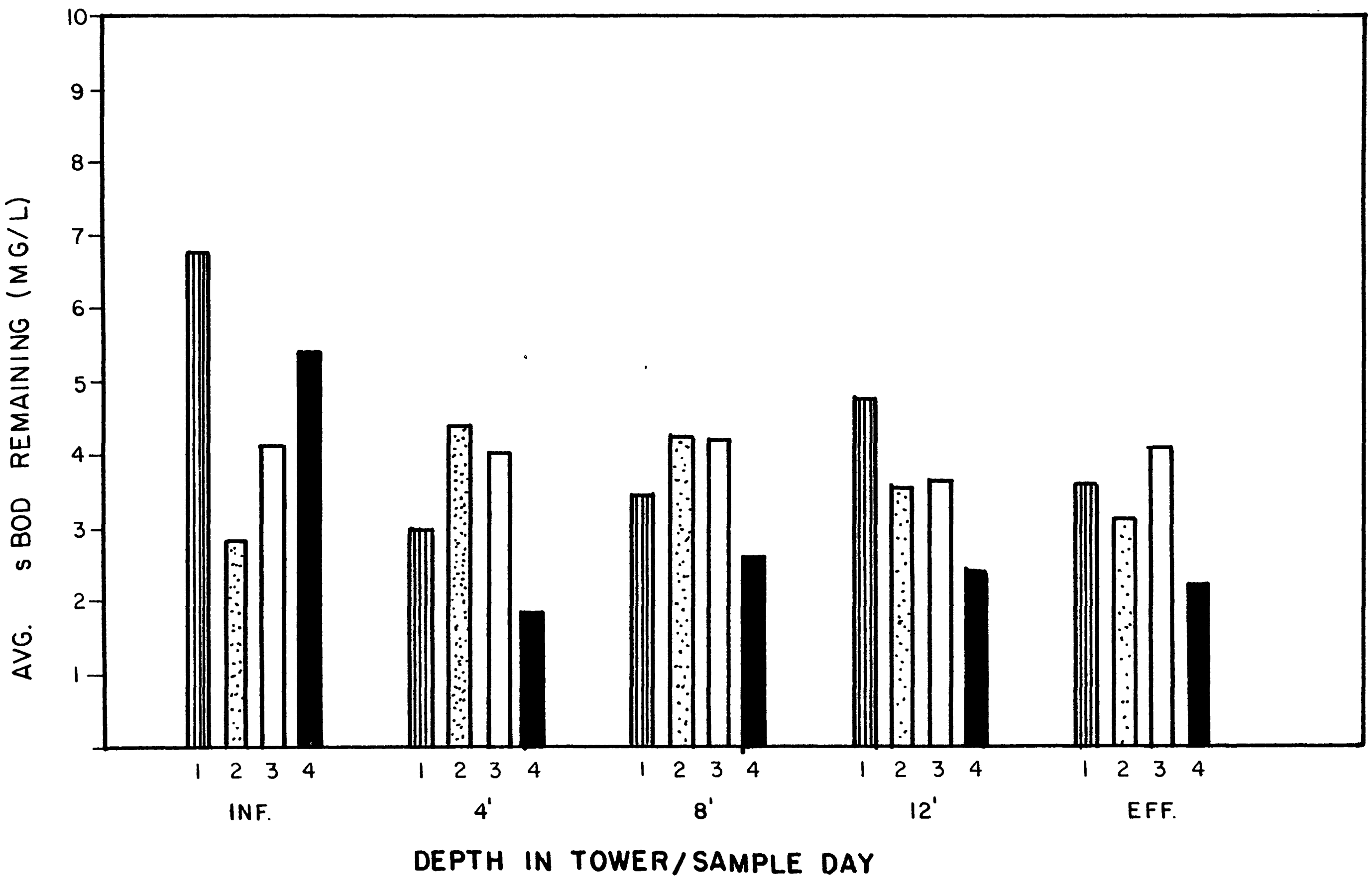

Figure 12. sBOD vs. Depth Trend Chart for Condition #4 - Sampling Days 1-4

quality being exhibited at the end of each recycle period. Again it must be emphasized that the tower influent BOD concentration was less than most treatment plant effluent discharge requirements.

It has been shown that high carbohydrate concentrations in a waste influent may show repression in the protein, utilization rate, i.e., carbohydrates are more easily metabolized, therefore preferred by the microorganisms. The kinetic constants for carbohydrate removal are more or less the same as for BOD removal, as determined in a lab scale evaluation on fixed film biological towers performed at Oklahoma State University. Substrate utilization of a protein waste was found to be much more complex than with a carbohydrate waste, and could not be directly evaluated or generalized in terms of definite removal kinetics or mechanisms (31).

Caution should be exercised when attempting to correlate the treatability results obtained here to situations (possibly more favorable) which exist elsewhere. Due to the difficult nature of the waste being treated (unidentified toxics from industrial wastes) and the low concentration of soluble organics fed to the tower in this study - it is conceivable that recirculation of settled biological solids may have a more positive impact when treating a more balanced waste. On the other hand, hypothetically, if the tower response at elevated organic loadings was similar to those witnessed in this study, the environmental impact would be much more dramatic, and the concept much less feasible.

Some other general observations noted during the study were: (a) biological growth seemed to be healthy and well developed throughout the depth of the tower during all phases of the study (b) raw waste visually appeared to be a typical grey water with moderate turbidity (c) finished or filtered water was clear and relatively void of turbidity with the only visible suspended solids being the larger clusters of biomass stripped from the tower (d) visual appearance of solids characteristics in the waste stream changed during recycle operations, the solids getting lighter in color and settling at a slower rate (e) heavy snail populations occurred during the warm summer months (f) it became obvious that the tower was evaporating a significant amount of water when operating on strictly recycle flow and nothing to supplement the loss of liquid.

The liquid level in the clarifier was the indicator to loss of liquid in the system, with approximately a 2-1/2 ft. drop (250 gallons) in the clarifier water surface in 24 hours. Excessive evaporation was probably the most meaningful observation taken during the study, implying that sufficient storage capacity had to be designed into the clarifier or equalization basin to prevent the system from going dry.

CHAPTER V

CONCLUSIONS

Examination of a biological tower, as described in this study, subjected to variable flow rates of a dilute waste, revealed the following:

1) Attached biological growth did not visably deteriorate when solids recycle was used during periods of low flow.
2) Satisfactory treatment was observed when treating low strength waste with the biological tower, and slightly improved performance was observed when waste was fed to the tower in combination with recycled solids. Thus, recirculation of solids should be implemented into design for improved performance.
3) Performance in terms of soluble organics removal failed when the process was fed strictly raw waste on an intermittent basis regardless of the recycle flow condition.
4) Design of sufficient water storage is required in sizing either the clarifier or equalization basin because of the ability of the tower to evaporate water.
5) Flow equalization should be included in any process where the possibility of highly variable loading conditions exist, to act as a physical buffer for the biological treatment process.

CHAPTER VI

RECOMMENDATIONS FOR FUTURE STUDY

Economical justification for this type of study is lacking because, as mentioned earlier, other processes (extended aeration) are preferred for design and construction at low and variable flow facilities. These other processes have a number of shortcomings but apparently these shortcomings are not significant enough to promote interest in fixed film processes as an alternative.

Provided any interest in solids recycle in biological towers is instituted in the future, the following recommendations are made:

1) Select location based on strength of waste, i.e., study needs to be conducted on waste with higher organic strength.

2) It would be preferable to conduct the study at a recreational area in a side- by-side comparison with an extended aeration plant.

3)All variability (flow, toxic waste inflow, temperature, etc.) should be monitored and, to some degree, controlled in order to effectively analyze the tower's performance.

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VITA

Dennis Ray Emrie

Candidate for the Degree of

Master of Science

Thesis: EXAMINATIONS OF THE FEASIBILITY OF USING BIOLOGICAL SOLIDS RECYCLE TO MAINTAIN BIOMASS IN A BIOLOGICAL TOWER UNDER HIGHLY VARIABLE LOADING CONDITIONS

Major Field: Environmental Engineering

Biographical:

Personal Data: Born October 21, 1953 in Liberal, Kansas, the son of Robert E. and Shirley J. Emrie; married to Patrice M. LeBlanc on May 28, 1983.

Education: Graduated from Broomfield High School, Broomfield, Colorado, in May 1971; received the Degree of Bachelor of Science in Microbiology/Environmental Health from Colorado State University, Fort Collins, Colorado in May 1976; completed the requirements for the Master of Science Degree at Oklahoma State University, Stillwater, Oklahoma, in December 1985.

Professional Experience: State of Colorado, Department of Public Health, Internship November 1975 to May 1976; Enviroquip, Inc., May 1976 to July 1984; Graduate Teaching Assistant, OklahomaS State University, School of Civil Engineering, September 1984 to May of 1985; Enviroquip, Inc., Associate Engineer, September 1985.

Membership in Professional Societies: American Water Works Association, Water Pollution Control Federation, American Society of Civil Engineers, Chi Epsilon, Phi Kappa Phi.