THE EFFECTS OF A SYNTHETIC CHILI WASTE ON BIOLOGICAL SEWAGE TREATMENT PLANT OPERATIONS

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ABSTRACT

This research was conducted in order to gain reliable information on the effect of chili waste on a completely mixed activated sludge waste water treatment process.

The system used for the research was a bench scale model of a completely mixed activated sludge system. The system consisted of a primary clarifier, a completely mixed activated sludge unit, and a secondary clarifier. The activated sludge unit tested is rectangular with effluent flow over a single weir. Aeration and mixing were accomplished by compressed air injection.

The system performance was evaluated with sewage and chili waste influents while attempting to hold all other operational parameters constant. The mode of system evaluation was efficiency of COD removal by secondary treatment.

The data obtained from this research led to several conclusions. Chili waste is highly degradable by aerobic microorganisms and is at least as susceptible to treatment by activated sludge as sewage. A completely mixed activated sludge system suffers only a mild upset from shock loading with chili waste and has a quick recovery from the upset.

Based on the results of this research it was recommended that further research be done with process modifications made to give better

control of operational parameters. It was recommended that a biological study be conducted to determine changes in predominance of species in an activated sludge with the change from sewage to chili waste process influent. It was also recommended that treatability of chili waste by anaerobic digestion be studied.

ACKNOWLEDGEMENTS

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NOMENCLATURE

Q - Volumetric loading rate

MLSS - Mixed Liquor Suspended Solids

MLVSS - Mixed Liquor Volatile Suspended Solids

U - Food to microorganism ratio

V/Q - Hydraulic detention time

Q_r - Sludge recirculation rate

θ_c - Mean all residence time or sludge age

BOD_5 - Biochemical Oxygen Demand (Five Day)

COD - Chemical Oxygen Demand

DO - Dissolved Oxygen

C_{ss} - Settled Solids Concentration

Q_I - Process influent flow rate

C_{MLSS} - MLSS Concentration

INTRODUCTION

In New Mexico, a water limited state, more than 90 percent of water usage is for agricultural purposes. The growing and processing of chili is an important agricultural industry in New Mexico and the Rio Grande Valley. There are presently two chili processing plants in Las Cruces. Exact figures are not known but in the past five years Mesilla Valley acreage devoted to chili production has grown from less that 5,000 acres to about 10,000 acres. Continued expansion is expected due to the rapid increase in demand for Mesilla Valley chili.

Processing of chili creates substantial amounts of waste water. The characteristics of this water differ from domestic sewage. Since chili processing is seasonal, an additional problem of shock loading can result from direct addition of chili processing waste to domestic sewage.

The 1972 Federal Water Pollution Control Act requires that all industries whose wastes are treated in a Federally subsidized waste water treatment plant must pay according to their contribution, based on volume and treatability, to the total waste load of that plant. It further requires levels of treatment above those which exist in New Mexico. In order for New Mexico to utilize Federal subsidies in its continuing upgrading of sewage treatment facilities and for planning the most efficient use of water resources it becomes necessary to determine the waste load contribution of all the state's industries.

PURPOSE

The purpose of this research was to determine the effect, if any, of waste water effluent from a chili processing plant on an aerobic biological waste water treatment facility. Most of the research was limited to an activated sludge system with some data obtained from a trickling filter. The effect on an activated sludge system was the primary concern since the city of Las Cruces has already begun remodeling its sewage treatment plant which will include conversion to a completely mixed activated sludge system. The change to an activated sludge system is a natural consequence of upgrading treatment since activated sludge has a higher potential for sewage treatment and is the trend in all cities.

In order to determine the effect of chili waste on an activated sludge system, the system performance was evaluated using both sewage and chili waste influents. The change was made from 100 percent sewage influent to 100 percent chili waste influent. This change represented the most drastic shock condition possible and thus would cause the greatest shock effect to the system.

LITERATURE REVIEW

Aerobic Treatment

The principle on which aerobic biological treatment is based is the utilization of organics by the aerobic microorganisms. Approximately 50 percent of the organic matter utilized is oxidized as an energy source and 50 percent is used as a carbon source for synthesis of new cell material. The decomposition of the organics is a natural process, and a biological treatment process is an acceleration of this natural process by controlling the environment for maximum growth of the microorganisms.

Several factors affect the growth of microorganisms and at least one will always be growth limiting. According to Clark, Viessman, and Hammer (1) the most important growth factors in waste water treatment are temperature, pH, availability of nutrients, oxygen supply, presence of toxins, and type of substrate.

Activated Sludge Process

Although several kinds of activated sludge processes are in use today all operate on the same general principles. An activated sludge process maintains an activated mass of aerobic and facultative microorganisms. The mass of microorganisms is maintained at a satisfactory operating concentration by the recirculation of settled microorganisms from a sedimentation basin. The recirculation can be accomplished by pumping or gravity. The quantity of the activated sludge can be adjusted by the amount of sludge wasted. Mixing and aeration can be provided by mechanical surface aeration, by diffused air, or by a combination of the two.

Bacteria play the most important part of all the microorganisms in an activated sludge process. Bacteria, fungi, protozoa, multicellular rotifers, and nematode worms all colonize in activated sludge systems but according to Warren (2) the environment is inhospitable for larger aquatic organisms, most of which could not withstand the buffeting. Although a multitude of microorganism species enter an activated sludge, the species which can best utilize the organic matter contained in the waste water will predominate. The bacteria can best utilize the substrate for energy and cell synthesis and thus, become dominant. While the organic matter converted to new cell material is not oxidized to low energy compounds, it has been converted from a soluble form to an insoluble form, which, under proper process operation, is readily settleable.

The predominant species in an activated sludge is dependent on the type and quantity of substrate, organic material, present in the waste water. A drastic change in the characteristics of the waste water can, therefore, cause a situation in which the predominant species of the activated sludge cannot readily degrade or utilize the major substrate constituent. This is known as a "shock" and can cause a complete failure of an activated sludge process.

Some of the important criteria and parameters in the design and operation of an activated sludge process are volumetric loading rate (Q), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), food to microorganism ratio (U), hydraulic detention time (V/Q), sludge recirculation rate (Q_r), sludge age or mean cell residence time (θ_c), and oxygen supply and transfer rates. The loading rate is usually measured as pounds of BOD_5 per unit volume of reactor per unit time. The loading rate determines how much organic matter will be available for decomposition. The sludge recirculation rate controls the MLSS and the mean cell residence time. The MLSS is a measure of the amount of sludge present to decompose organic matter. The mean cell residence time is the average time that a microorganism will have to decompose the organic matter in the mixed liquor. Mean cell residence time is also important because the settleability depends on the age of the microbal mass. As the mean age of the cells increases, the surface charge is reduced and the microorganisms produce extra-cellular polymers. The polymers form a slime layer which is sticky and promotes the formation of floc particles that can be readily removed by gravity settling. Some common values of design parameters as given by Metcalf and Eddy (3) are shown in Table 1.

Completely Mixed Activated Sludge

In a completely mixed activated sludge system the influent is rapidly dispersed throughout the reactor. The effluent has the same characteristics as the mixed liquor. Due to the rapid dispersion of the influent there are no concentration gradients and the ability of a completely mixed system to sustain shock loads is greater than other systems. A properly operated, completely mixed, activated sludge process should according to Busch (4) have a BOD removal efficiency of 85 to 95 percent. The efficiency is, of course, dependent on many factors including the organic strength of the influent waste water.

Table 1. Design Parameters for Activated-Sludge Processes

	Parameter					
Process Modification	θ_c, days	U, lb BOD_5/lb MLVSS-day	Volumetric loading, lb BOD_5/1,000 cu ft	MLSS, mg/liter	V/Q, hr	Q_r/Q
Conventional	5-15	0.2 -0.4	20-40	1,500-3,000	4-8	0.25-0.5
Complete-mix	5-15	0.2 -0.6	50-120	3,000-6,000	3-5	0.25-1.0
Step-aeration	5-15	0.2 -0.4	40-60	2,000-3,500	3-5	0.25-0.75
Modified-aeration	0.2-0.5	1.5 -5.0	75-150	200-500	1.5-3	0.05-0.15
Extended-aeration	20-30	0.05-0.15	10-25	3,000-6,000	18-36	0.75-1.50
Kraus process	5-15	0.3 -0.8	40-100	2,000-3,000	4-8	0.5 -1.0
High-rate aeration	5-10	0.4 -1.5	100-1,000	4,000-10,000	0.5-2	1.0 -5.0
Pure-oxygen systems	8-20	0.25-1.0	100-250	6,000-8,000	1-3	0.25-0.5
Contact-stabilization	5-15	0.2 -0.6	60-75			0.25-1.0
contact unit				1,000-3,000	0.5-1.0	
solids stabilization unit				4,000-10,000	3-6	

Chili Literature

There is almost a complete dearth of published information on chili. What few articles exist are limited to a description of optimal growth conditions and composition of chili. Emphasis on composition is directed toward nutrient value of the food. In searching the literature the author used a wide range of scientific indexes. The Scientific Citation Index 1971-1972 did not reference any paper dealing with chili waste. Chemical Titles, an index of chemical research papers from approximately 700 journals and Biological and Agricultural Index, covering 188 journals, both failed to provide any knowledge of research on chili processing waste. Also searched with negative results were Proceedings of the Purdue Industrial Waste Conferences, which is the nation's most prominent industrial waste conference, the 1972 and 1973 Annual Literature Review of the Journal of the Water Pollution Control Federation, and the index of the Water Research Abstracts for 1969-1973. In addition, a literature survey, prepared by the National Technical Information Service on all published government sponsored research was unsuccessful in finding any references to treatment of chili processing waste.

Composition of Chili

Watt and Merrill (5) found the composition of mature red chili including seeds to be 74.3% water, 3.7% protein, 2.3% fat, 18.1% carbohydrate, and 1.6% ash with traces of calcium, phosphorus, iron, sodium, potassium, thiamine, riboflavin, niacin, and ascorbic acid. Chili is also known to contain tocopherols and pungent principles. These with flavonord compounds and ascorbic acid are known to have anti-oxidant properties. Stasch and Johnson (6) demonstrated the anti-oxidant property of chili by showing its ability to reduce the rancidity in meat. It is not known if the demonstrated reduction in rancidity is due to a suppression of biological activity. None of the anti-oxidants mentioned are regarded as toxic or bacterial inhibitors. It might be possible, however, for some combination of these anti-oxidants to have bactericidal properties. This point is of importance in sewage treatment operation as the bacterial oxidative processes are responsible for the decomposition of the organic matter present in the waste water.

Chili Wastewaters

A visit was made to a Las Cruces chili processing plant in order to obtain reliable information concerning chili wastewaters. Wastewater is produced in chili processing through washing operations. Fractured chili produces wastewater solids in addition to wash solids. At the Las Cruces plant the wastewater conduit is an open channel so that floor debris can provide additional solid concentrates. Gross solids are separated by screening. The concentration of the remaining liquid waste is unknown. A diagram of the screening unit is shown in Figure 1.

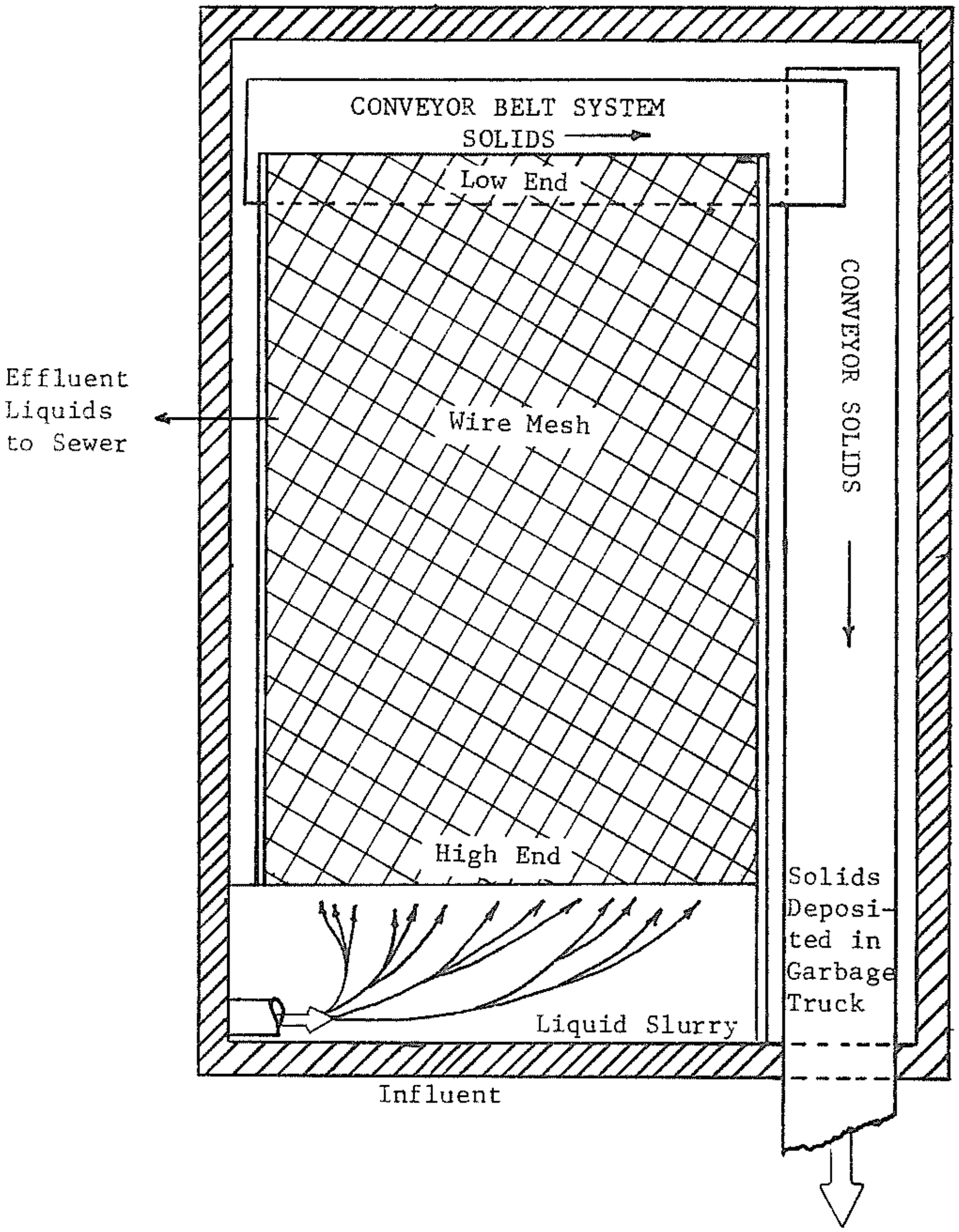

Figure 1. Chili Processing Plant Waste Water Screening Equipment

EXPERIMENTAL PROCEDURE

General Outline

This research was conducted using a bench scale model of an activated sludge process. The research was divided into three basic parts. In the first part the efficiencies of treatment of sewage and chili waste were determined from the bench scale model with no primary clarification. In the second part of the research the treatment efficiencies of the activated sludge unit and secondary clarifier were determined using settled influents of sewage and chili waste. In the third part of the research the removal efficiency, due to physical separation, was determined for both a settled and unsettled influent.

In all instances the efficiency refers to the activated sludge unit influent chemical oxygen demand (COD), less the secondary clarifier effluent COD divided by the activated sludge unit influent COD.

Equipment

A description of the equipment used in this research is given in this section along with operational details of the equipment.

Storage tanks. The storage of the influent to the bench scale model consisted of two twenty-liter polyethylene tanks which were continuously mixed with laboratory stirrers.

Pump. A peristaltic pump with a rate of 68 ml per minute was used to pump the sewage and chili waste into the activated sludge system from storage.

Environmental control room. An environmental control room was used for cold storage of raw sewage, chili waste, and samples. The environmental control room temperature was maintained as near as possible to 2° C. After adjustments were made the temperature did not rise above 4° C.

Primary clarifier. The primary clarifier used is a cylindrical tank 7-1/2 inches in diameter and 13 inches deep. The bottom is spherical and the total volume is 8.4 liters. With the 68 ml per minute flow used, the detention time was approximately 2 hours. Sludge removal was accomplished by pumping through a glass tube inserted from the top of the clarifier. All the sludge was wasted. The primary clarifier is shown in Figure 2 and photo 1.

Activated sludge unit. The activated sludge unit used in this research is a rectangular tank with sloping ends. The effluent is over a single weir across one end behind a stilling wall. The inside width of the tank is 7-1/2 inches and the inside length is 18 inches at operational water level and 8 inches at the bottom. The free board is 3 inches. Total volume of the activated sludge unit is 22 liters which provides a hydraulic detention time of 5 hours 24 minutes. Aeration and mixing were provided by diffused air injection. The dissolved oxygen content was maintained above 6 mg per liter. The activated sludge unit is shown in Figure 3 and photo 2.

Secondary clarifier. The secondary clarifier used in this research is a cylindrical tank 10 inches deep and 11-1/2 inches in diameter. The total volume is 13 liters which provides a detention time of 3 hours 10 minutes. Overflow is provided by a circular weir 8

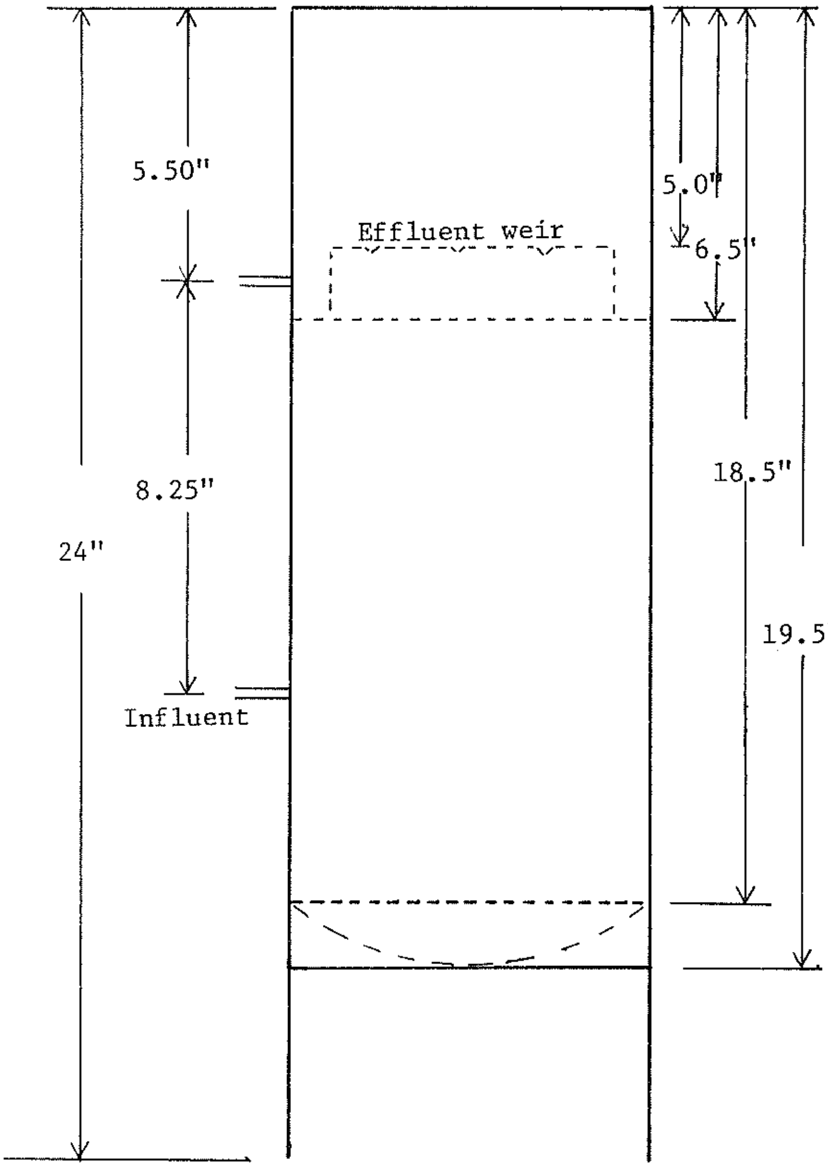

Figure 2. Primary Clarifier

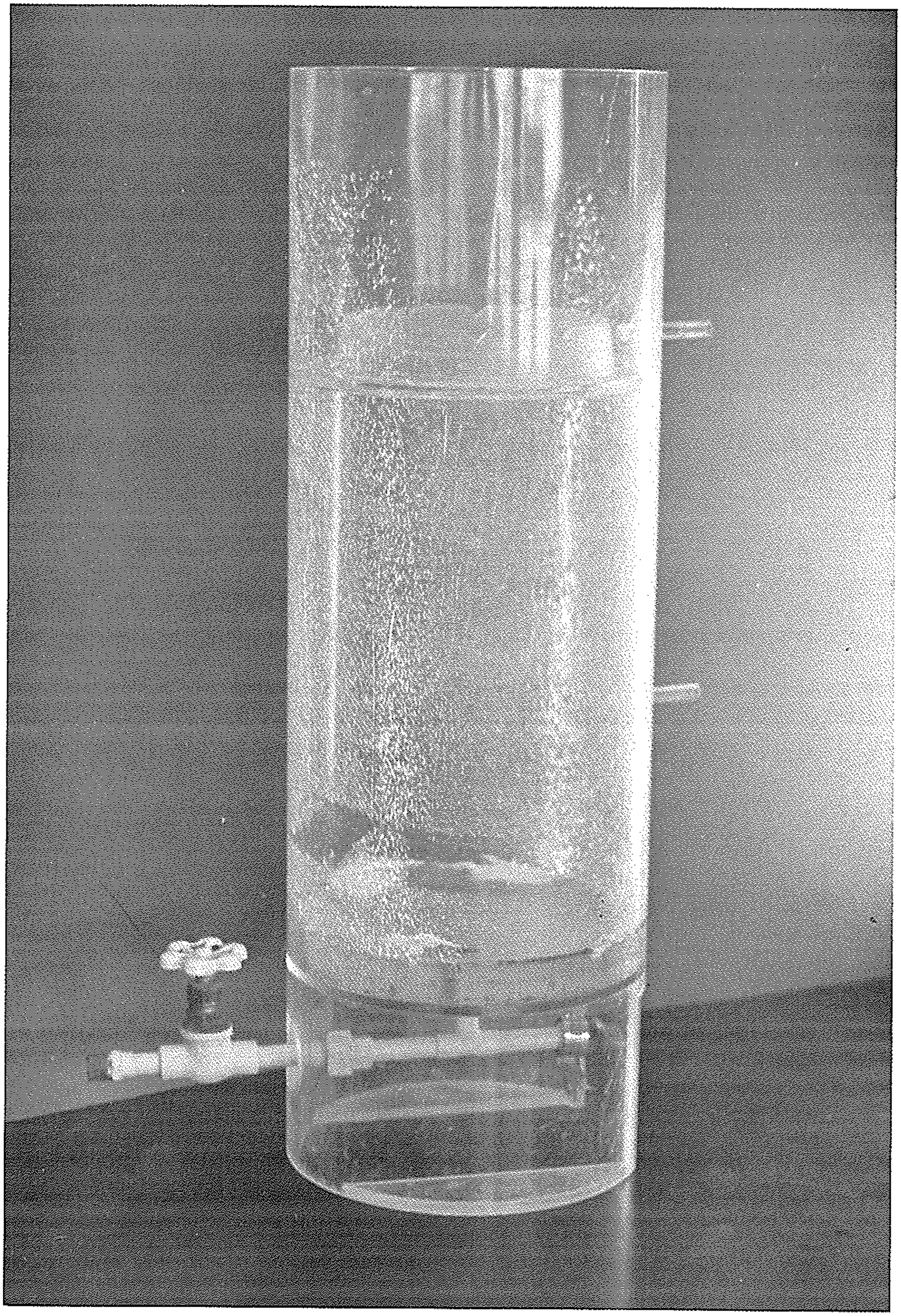

Photo 1. Primary Clarifier

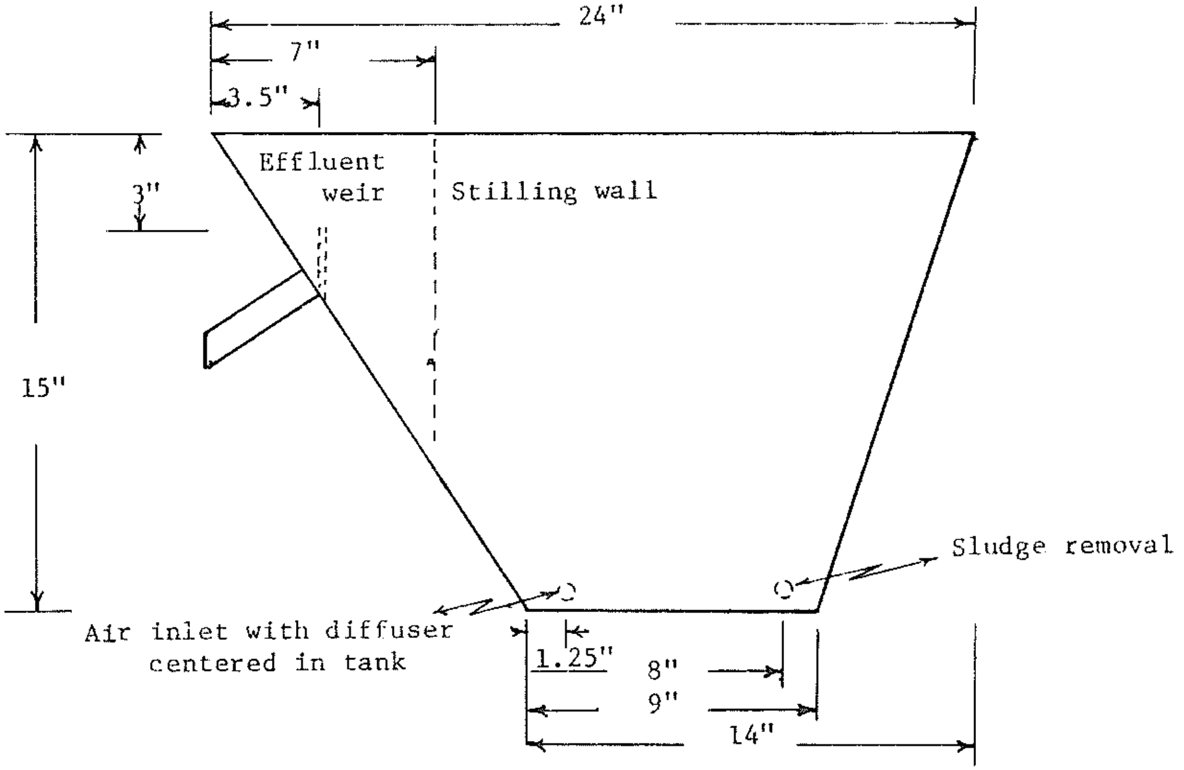

Figure 3. Activated Sludge Unit

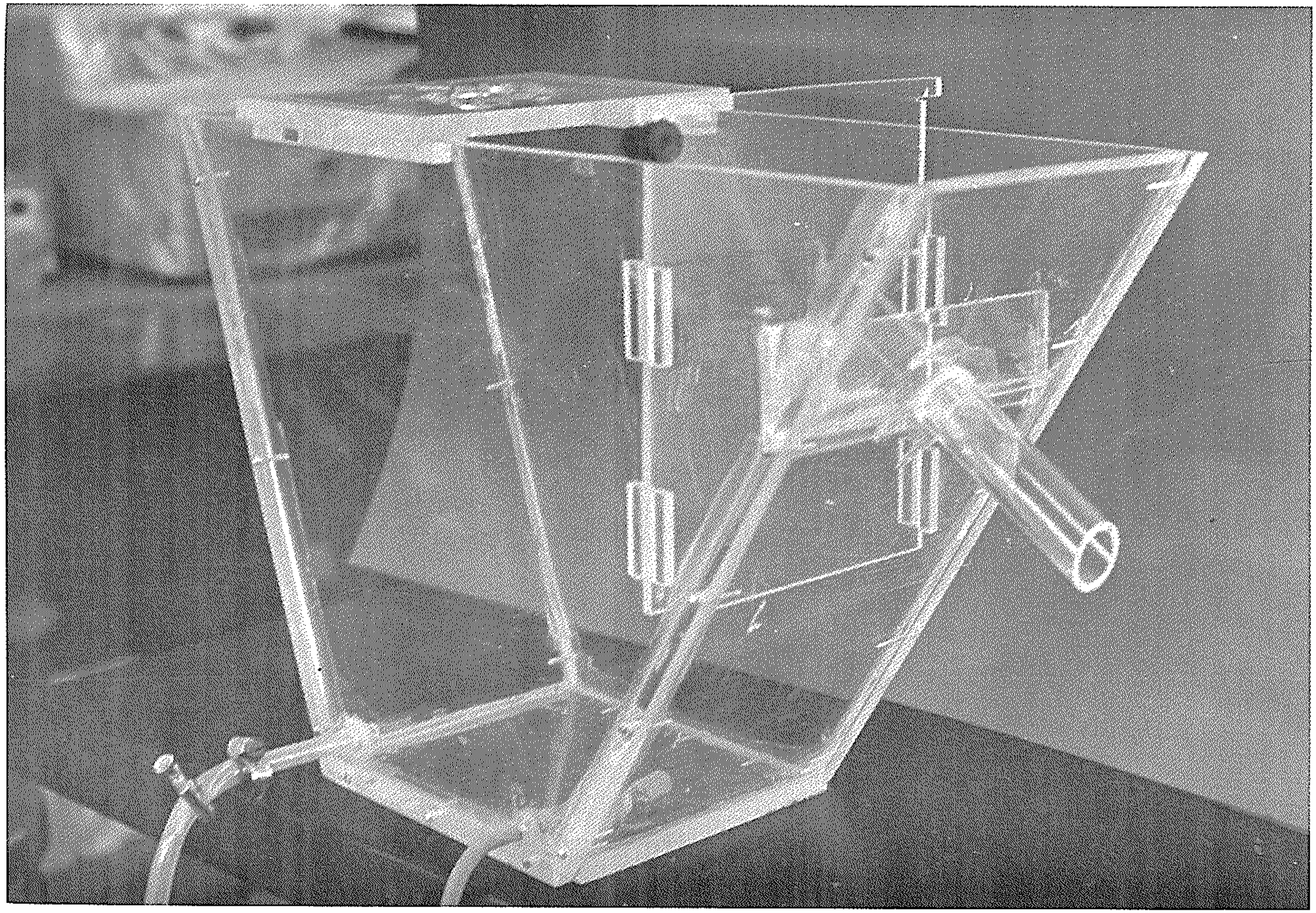

Photo 2. Activated Sludge Unit

inches in diameter. Sludge removal was accomplished by vacuuming the clarifier with a pump. The secondary clarifier is shown in Figure 4 and photo 3.

Treatment of a Non-settled Influent

In the portion of the research without the primary clarifier the process influent was pumped directly to the activated sludge unit. The flow diagram is shown in Figure 5. The system was brought as near as possible to a steady state condition using domestic sewage. The removal efficiencies were monitored for five days. The process influent was then changed to chili waste for one week during which sampling to determine efficiency was continued. At the end of the second week the process influent was changed back to sewage and the test conducted for a third week. Sampling was done at random intervals except during the periods following changes in the influent source. During these periods intensive sampling was done at regular intervals.

The sewage used during this portion of the research was domestic sewage obtained at the manhole just outside Jett Hall. The sewage was obtained 55 gallons at a time and kept in cold storage until used. An attempt was made to maintain a process influent COD of 300 mg per liter by dilution.

The chili waste used for this portion of the experiment was obtained by blending whole, dry, red, Las Cruces-processed chili in water and straining out the solids. An attempt was made to maintain the influent COD at 300 mg per liter. The chili waste was kept in cold storage until it was used.

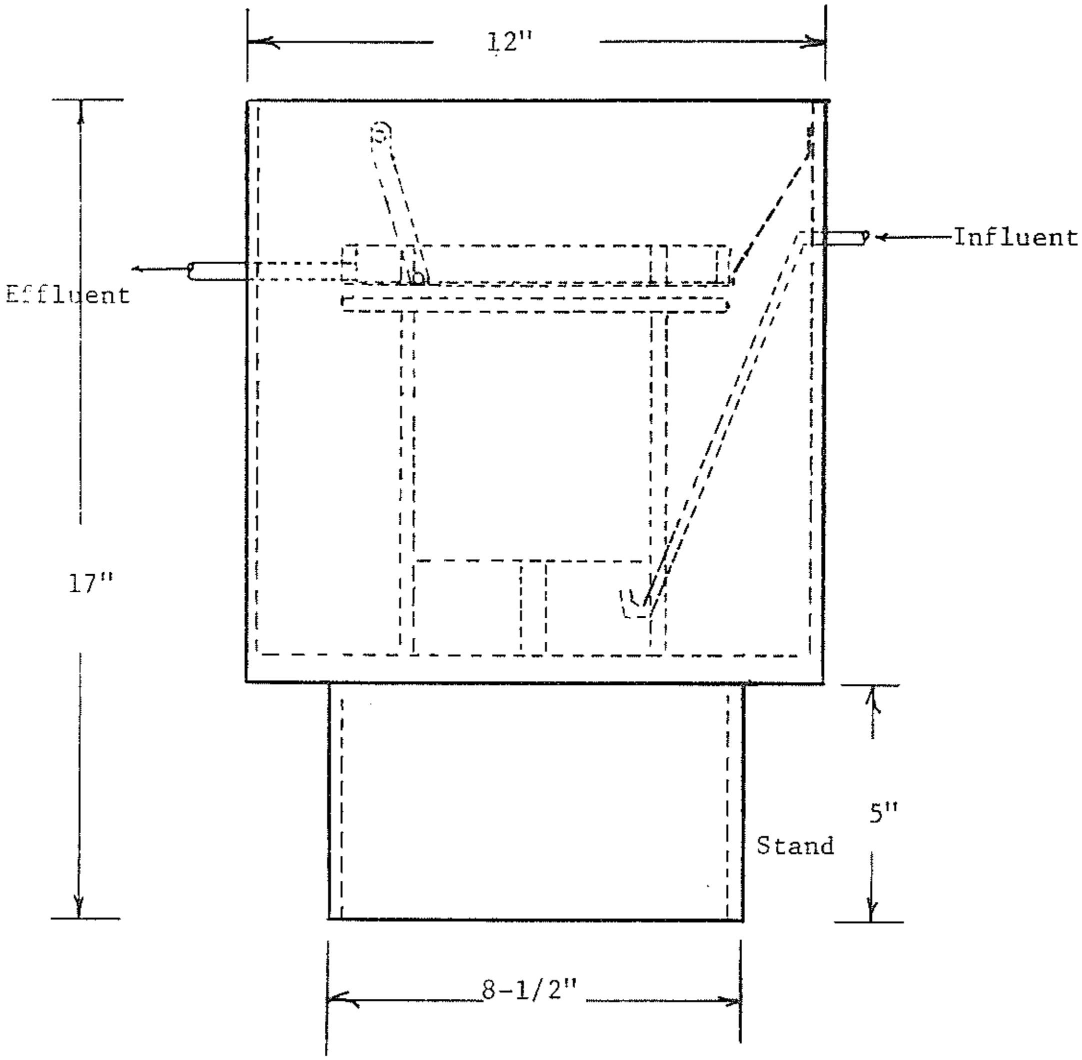

Figure 4. Secondary Clarifier

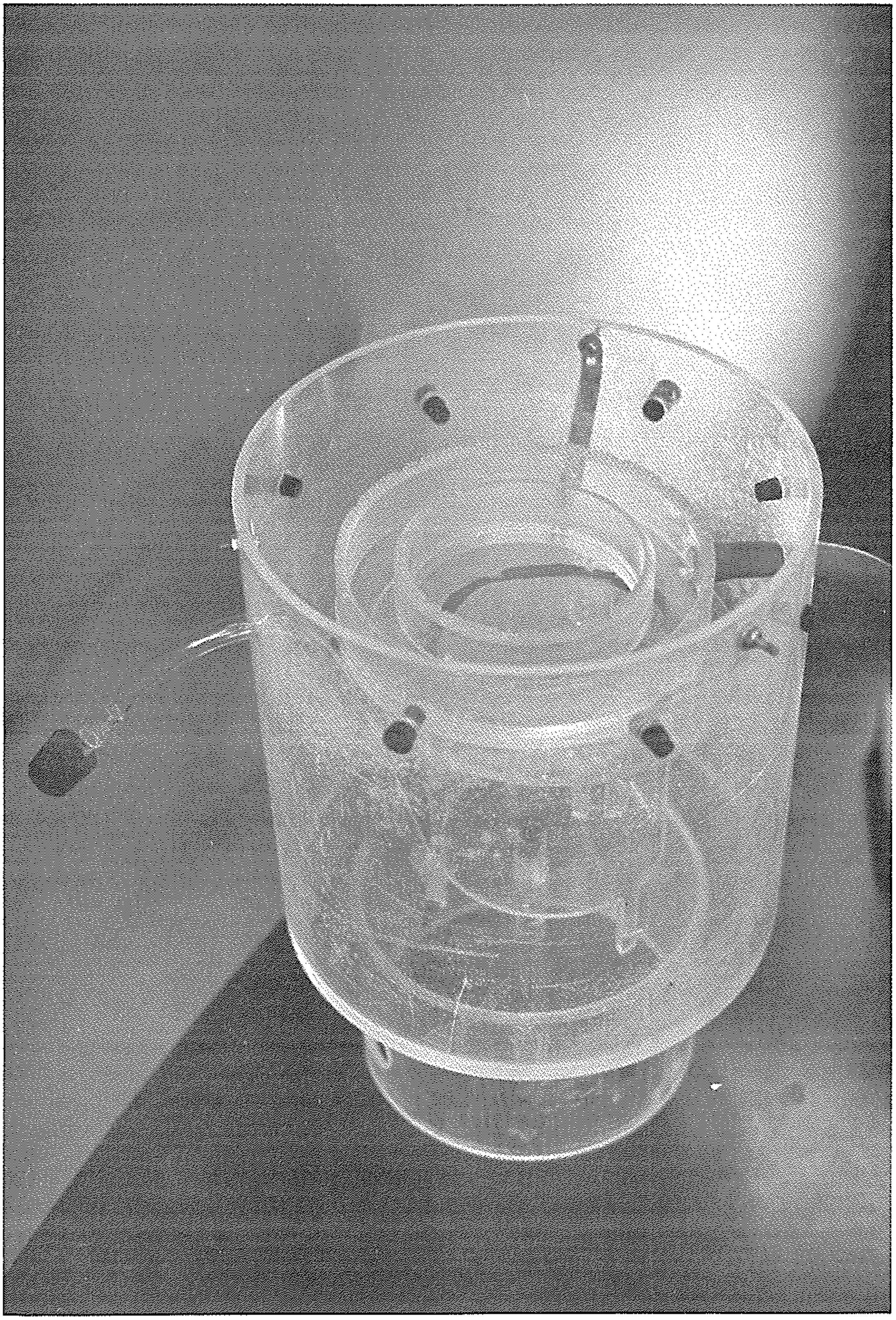

Photo 3. Secondary Clarifier

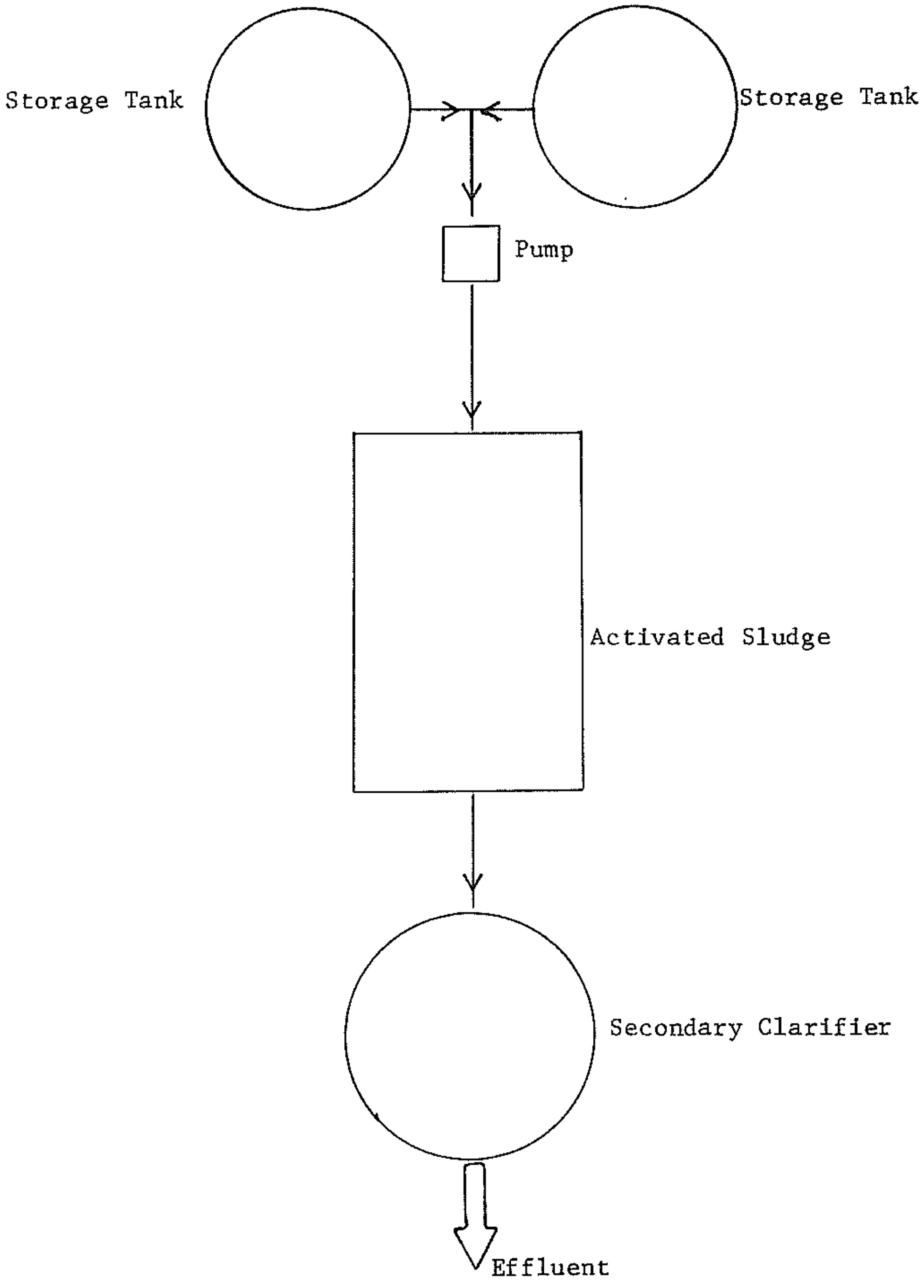

Figure 5. Flow Diagram for Treatment of Non-settled Influent

Treatment of a Settled Influent

In the portion of the research conducted with a primary clarifier as a part of the treatment process, the process influent was pumped to the primary clarifier and flowed by gravity through the rest of the process. Figure 6 is a flow diagram for the process. During this portion of the research the system was monitored for removal efficiency one week with sewage influent followed by one week using chili waste as the process influent.

The sewage used during this portion of the research was obtained from a sewer main which collects the sewage from the married housing portion of campus. No attempt was made to regulate the strength of the sewage other than collecting it from the sewer main only at or near 5:00 p.m. The chili waste was obtained the same as that for the previous portion of the research. An attempt was made to regulate the strength of the chili waste so as to maintain a primary clarifier effluent and an activated sludge unit influent of 300 mg per liter COD. Both the sewage and chili waste were stored in the constant environment room.

A sampling schedule was approximated for the portion of the research conducted with a primary clarifier. The schedule consisted of sampling the activated sludge unit influent and secondary clarifier effluent every six hours with a period of intensive sampling following the change to the chili waste for a process influent. The intensive sampling period consisted of sampling every 2 hours for 24 hours and every 3 hours for another 12 hours. The sampling returned to the normal 6-hour interval after the 36-hour intensive sampling period.

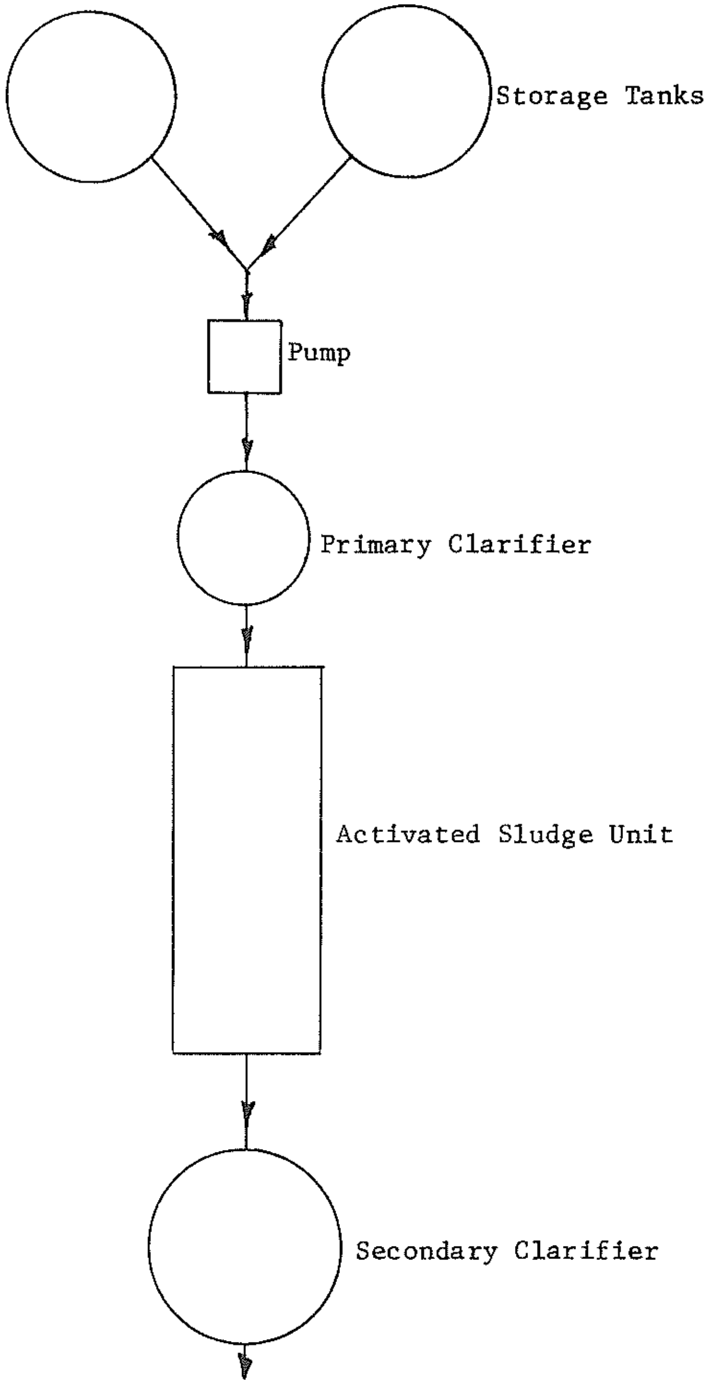

Figure 6. Flow Diagram for Treatment of Settled Influent

The COD's of the samples were determined for evaluating efficiency.

Physical Separation

The part of the research in which the efficiency due to physical settling was determined included four steps. The efficiency of the model with and without the primary clarifier was determined for both sewage and chili waste process influents. The tests were run similar to the previous parts of the experiment with two exceptions. In order to minimize the effect of biological treatment there was no sludge recycle and the process influents were chlorinated with 30 mg per liter chlorine using Purex bleach. Each step in this portion of the research was conducted until steady-state was established. A random sampling procedure was used and COD's of the samples were determined for evaluating the efficiency.

Lag Time Study

In addition to the three basic parts of this research a lag time study was conducted in order to determine the delay in effluent response to a change in influent of the activated sludge system. This was simulated by filling the system with distilled water and using a salt solution for a process influent. The salt solution used was .01 N KCl. After 4 hours of using the KCl solution the process influent was changed to distilled water for 4 hours. The activated sludge unit influent and the secondary clarifier effluent were monitored for KCl concentration throughout the 8-hour study. The flow for the study was the same as the flow for the treatment of a settled influent portion of the research.

DATA AND RESULTS

The data and results of this research are given in this section. Most of the data and results are presented in three sections corresponding to three parts of the research as described in the procedure. Additional data is given from experiments to determine effects of chili waste on a trickling filter and an anaerobic digestor.

Treatment of Non-settled Influent

The efficiency of COD removal of the activated sludge unit and secondary clarifier without primary clarifications was erratic. The removal efficiency as measured varied from a low of 35 percent to a high of 94 percent. During the five days prior to introduction of chili waste the removal efficiency of the process averaged 77.9 percent with a standard deviation of 9.47 percent. During the week that chili was the process influent the average efficiency dropped to 64.6 percent with a standard deviation of 10.8. During the week following the return to a sewage influent the efficiency came back up to 76.8 percent with a standard deviation of 13.8 percent. The removal efficiency for the period of the study conducted without a primary clarifier is given in Table 2 along with the MLSS and other data which was determined for operational purposes. The COD removal efficiency and the MLSS data are shown graphically in Figures 7 and 8, respectively. The DO level was maintained above 6.0 mg/l.

Table 2. Data for Treatment of a Non-settled Influent

Date	Time	Influent COD (mg/1)	Effluent COD (mg/1)	Efficiency (%)	MLSS (mg/1)	MLVSS
4-11	17:00	400	61.0	85	570	
4-12	9:00	390	47.5	88	210	
4-13	16:00				520	
4-14	19:00	415	144	65	670	
4-15	11:00	590	177	70	770	
4-15	11:30	340	200	41	Chili added	
	12:30	344	145	58		
	13:30	336	131	56		
	14:30	352	128	64		
	15:30	352	140	60		
	16:30	310	143	54		
	17:30	302	163	46		
	18:30	760	140	81		
	19:30	302	120	60		
	20:30	314	175	44	1090	
	21:30	299	118	61		
	22:30	284	76	73		
	23:30	275	68	75		
4-16	0:30	300	109	64		
	1:30	324	103	68		
	2:30	215	103	52		
	3:30	258	103	60		
	4:30	212	110	48		
	5:30	274	110	60		
	6:30	328	101	69		
	7:30	378	125	77		
	8:30	345	113	67		
	9:30	420	121	71		
	10:30	370	160	58		
	12:30	320	123	62		
	14:30	285	156	45	1450	
	16:30	248	97	61		
	20:30	322	105	67	1820	
	23:30	333	142	57	1480	
4-17	2:00	236	70	70		
	5:00	232	62	73		
	9:00	222	67	70		
	12:00	216	76	65	2240	
	14:30	336	97	71		
	23:00	264				
4-18	8:30	206	50	76		
	17:30	244	105	57		
4-19	2:00	147	23	84		
	15:00	182	58	68		

Table 2. (Continued).

Date	Time	Influent COD (mg/l)	Effluent COD (mg/l)	Efficiency (%)	MLSS (mg/l)	MLVSS
4-20	2:00	284	56	80	1320	
	10:00	355	60	83	1820	
4-21	13:00	190	74	61		
4-22	8:30	318	85	73		
	17:30	252	101	60	610	590
	22:30	228	91	73		
4-23	11:00	346	95	89	1340	1250
	20:00	1000	112	-		
4-24	14:30	232	82	64		
4-25	11:00	306	31	90	1290	1240
	12:00	276	31	89	Chili	stopped
	13:00	252	34	87		
	14:00	272	29	89	1320	1210
	15:00	270	31	89		
	16:00	160	52	68		
	18:00	720	58	92		
	22:00	300	50	83		
4-26	0:00	284	111	60		
	2:00	184	71	61		
	4:00	288	54	81		
	6:00	284	92	68		
	8:00	159	71	55		
	10:00	340	82	76		
	12:00	365	72	80		
	14:00	334	76	77		
	17:00	-	-	-	920	820
	18:00	384	64	83	550	490
4-27	3:00	128	83	35		
	14:00	143	-	-	860	760
	23:00	333	97	71		
4-28	12:00	466	62	87		
	15:00	457	74	84		
4-29	9:00	570	33	94		
	14:00	364	76	79		
	19:00	281	65	77		
	24:00	332	138	58	1830	1610
4-30	9:00	326	57	83		
	19:00	-	-	-	1430	1240

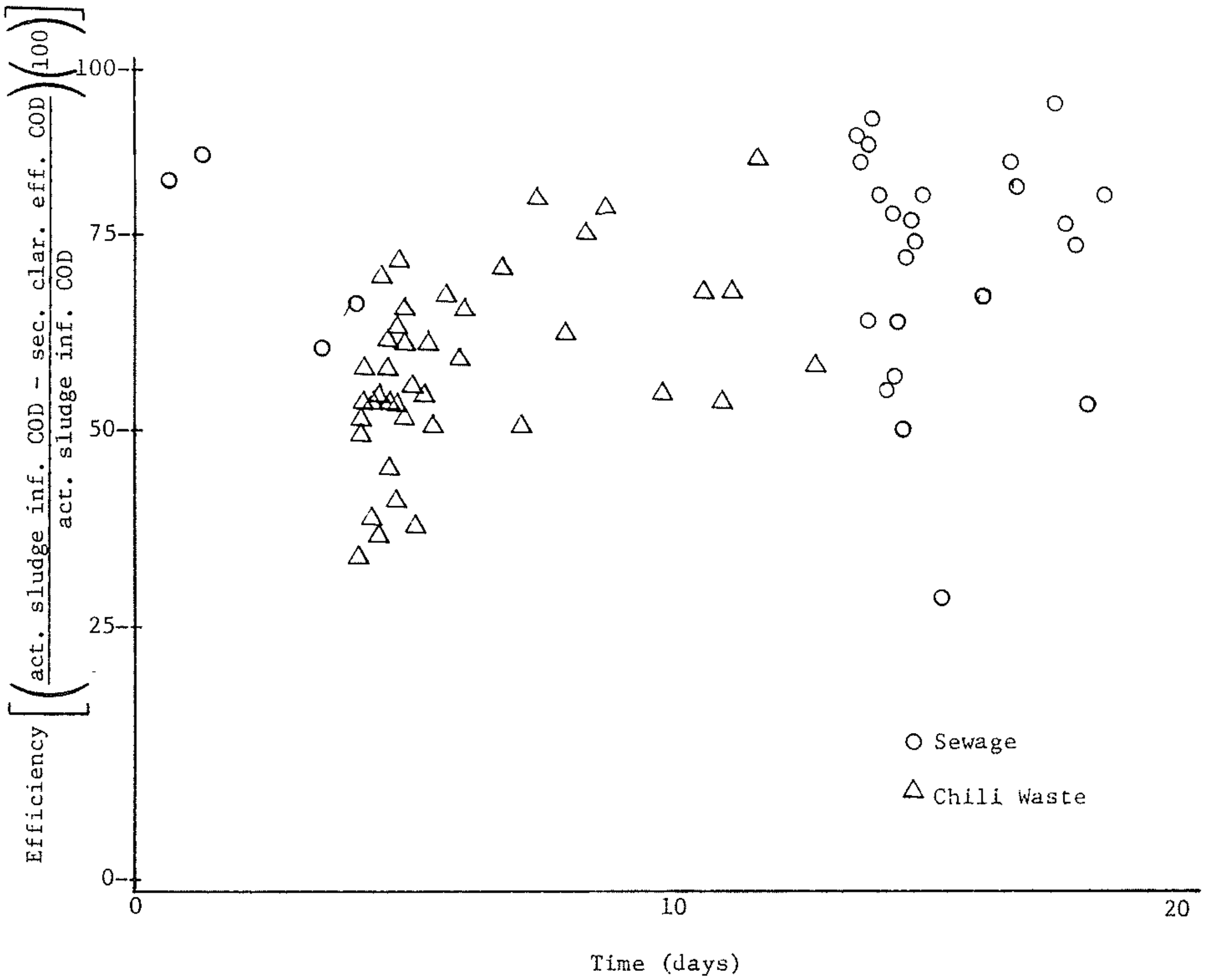

Figure 7. Efficiency for Treatment of Non-settled Influent

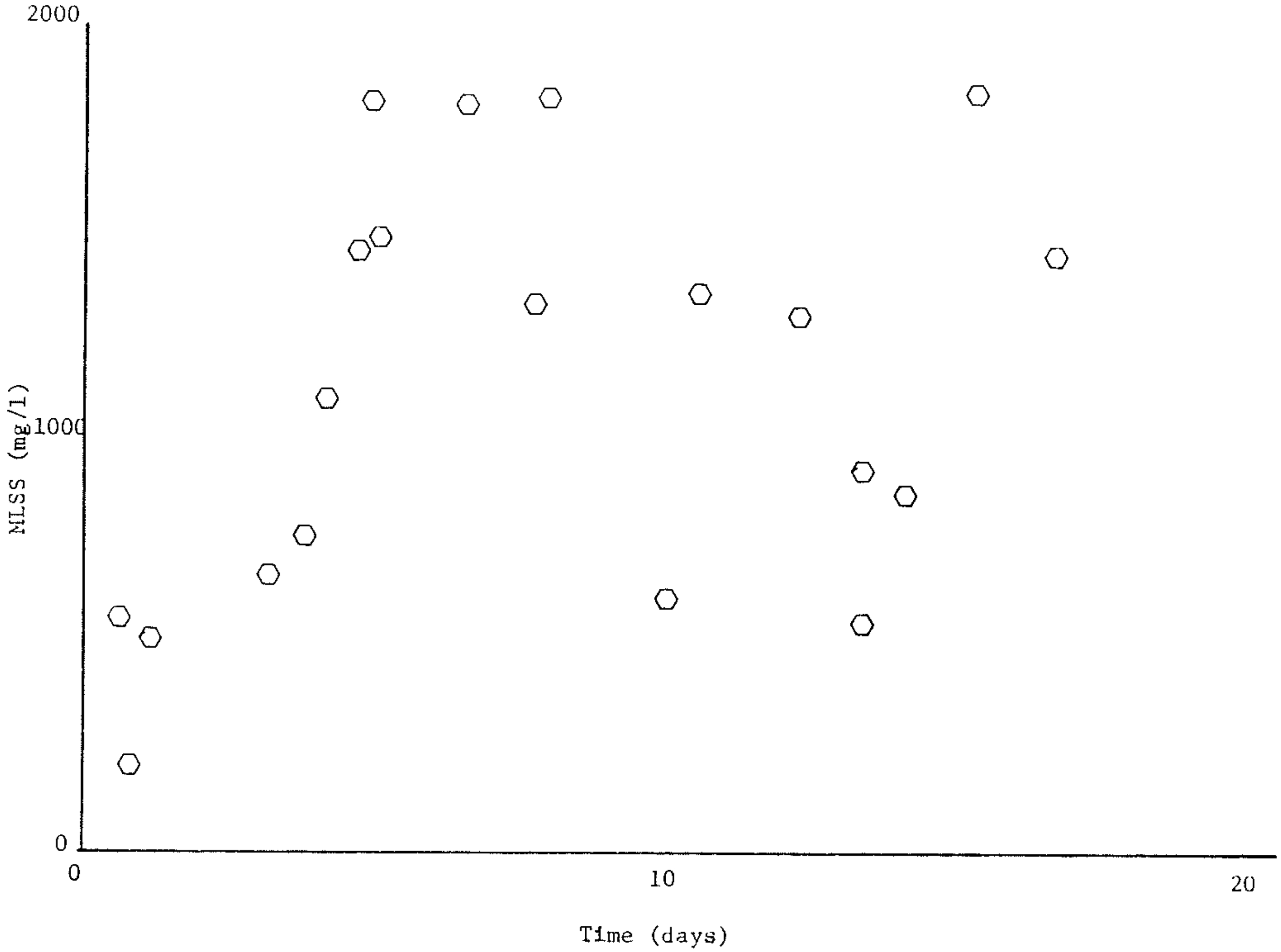

Figure 8. MLSS for Treatment of Non-settled Influent

Treatment of a Settled Influent

The COD removal efficiency for the portion of the research done with a primary clarifier followed definite trends. The efficiency climbed from a low of 48.4 percent on day two of the test to 76 percent on the sixth day of the test. The efficiency then leveled off with a mean of 77.6 percent and a standard deviation of 3 percent for the next two days. At this time the process influent was changed from sewage to chili waste. After the change from sewage to chili waste the efficiency dropped off sharply for about 24 hours to a low of 64.6 percent. The efficiency then steadily increased for 2-1/2 days. For the remaining four days of the test the efficiency had a mean of 80.9 percent and a standard deviation of 2 percent. The influent COD, effluent COD, and efficiency for treatment with a primary clarifier are given in Table 3 along with operational data. The efficiency and MLSS are shown in Figures 9 and 10.

Physical Treatment

The physical treatment portion of the test had results much as expected. With the primary clarifier operating the activated sludge unit and secondary clarifier had a COD removal efficiency of 2.5 percent with a chili waste influent and 21 percent with sewage. With the removal of the primary clarifier the efficiencies rose to 7.7 percent for the chili waste and 26.7 percent for the sewage. The data for this portion of the test is given in Table 4.

Table 3. Data for Treatment of Settled Influent

Date	Time	Influent COD (mg/1)	Effluent COD (mg/1)	Efficiency (%)	MLSS (mg/1)
5-13	15:00	520	105	79.8	470
	21:00	655	170	74.0	
5-14	3:00	250	97	61.2	580
	9:00	440	80	81.8	
	15:00	316	78.5	75.1	410
	21:00	244	126	48.4	
	3:00	282	130	53.9	240
	9:00	272	116	57.4	
	15:00	294	112	61.9	620
	21:00	294	108	63.3	
5-16	9:00	294	108	63.3	
	15:00	240	121	49.6	800
	21:00	286	110	61.5	
5-17	3:00	268	78	70.9	620
	9:00	266	70	73.7	
	15:00	212	75	64.6	
	21:00	344	90	73.8	
5-18	9:00	368	88.5	76.0	360
	15:00	432	78.5	81.8	320
	21:00	322	82.5	74.4	
5-19	3:00	360	90	75.0	700
	9:00				
	12:00	341	81	76.2	
	15:00				
	21:00	415	75.5	81.8	
5-20	3:00	445	93	79.1	750
	11:30	440	105	76.1	Chili added here
	13:30	374	109	70.9	
	15:00	336	117	65.2	580
	17:00	332	93	72.0	
	19:00	346	100	71.1	
	21:00	324	100	69.1	
	23:00	290	100	65.5	

Table 3. (Continued)

Date	Time	Influent COD (mg/1)	Effluent COD (mg/1)	Efficiency (%)	MLSS (mg/1)
5-21	1:00	280	88.5	68.4	
	3:00	268	90.5	66.2	440
	5:00	256	90.5	64.6	
	7:00	268	90.5	66.2	
	9:00	262	86	67.2	
	11:00		88		
	13:00	265	86	67.5	
	15:00	254	47	81.5	
	21:00	278	78	71.9	280
	24:00	282	75	73.4	
5-22	3:00	262	75	71.4	370
	9:00	258	67.5	73.8	
	15:00	266	69.5	73.9	930
	21:00	240	62.5	74.0	
5-23	3:00	240	64.5	73.1	710
	9:00	248	60.5	75.6	
	15:00	252	60.5	76.0	
	23:00	282	58.5	79.2	
5-24	9:00	228	48.5	78.7	
	15:00	260	52.5	79.8	910
	24:00	372	44.5	88.0	
5-25	9:00	234	44.5	81.0	
	15:00	315	52	83.5	860
	24:00	290	54	81.4	
5-26	9:00	234	50	78.6	
	16:00	262	50	80.9	
	21:00	262	50	80.9	
5-27	3:00	243	50	79.4	
	10:00	216	42.5	80.3	
	15:00	255	50	80.4	

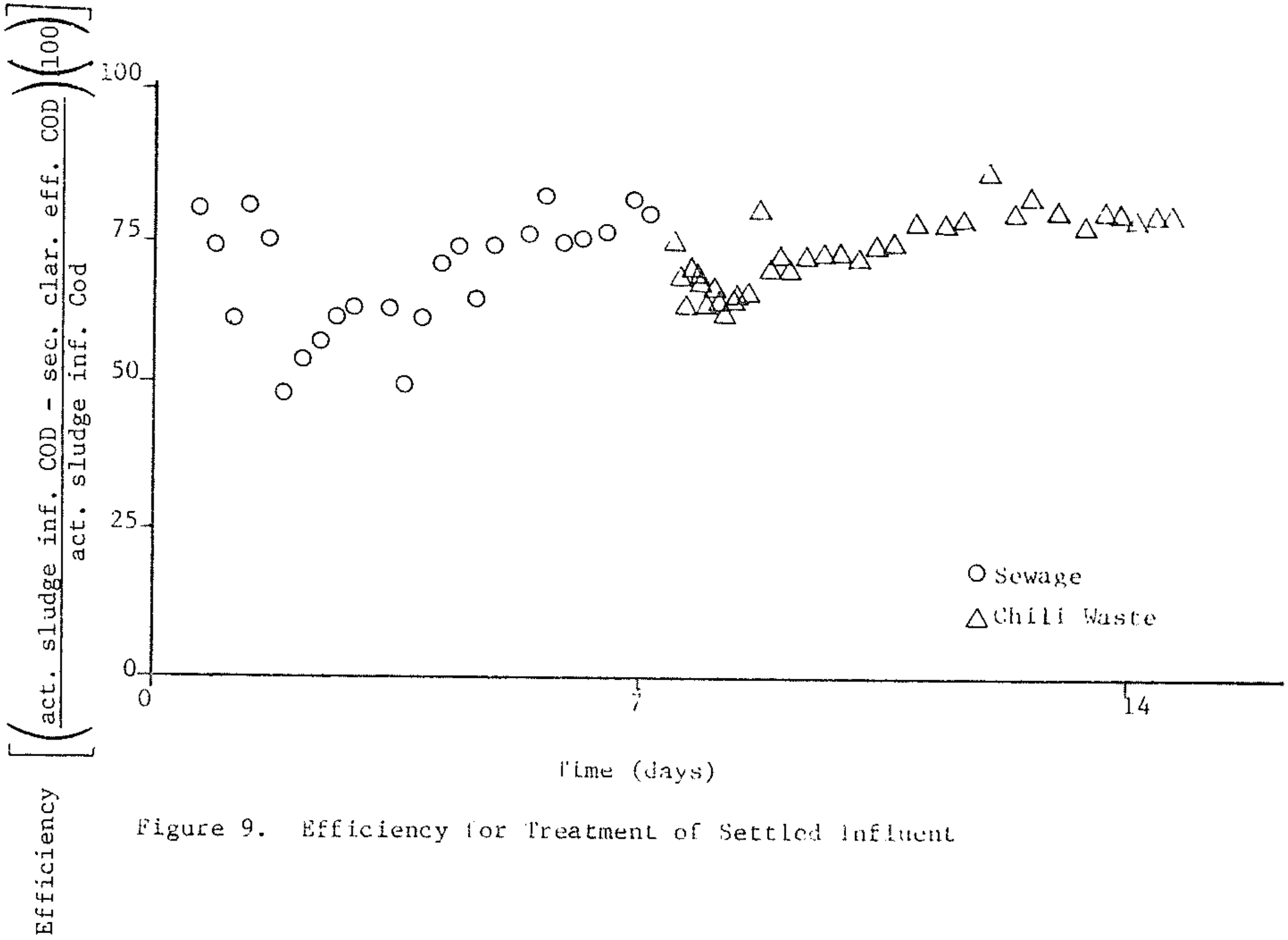

Figure 9. Efficiency for Treatment of Settled Influent

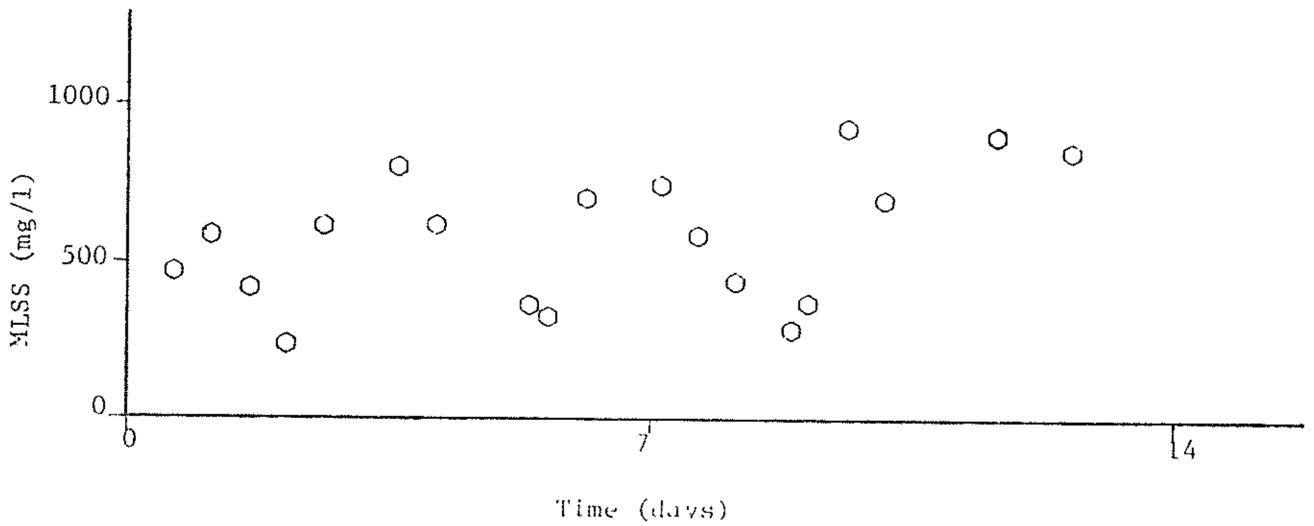

Figure 10. MLSS for Treatment of Settled Influent

Table 4. Data for Physical Treatment

Chili Waste					Sewage				
Date	Time	Influent COD (mg/l)	Effluent COD (mg/l)	Efficiency (%)	Date	Time	Influent COD (mg/l)	Effluent COD (mg/l)	Efficiency (%)
				Settled Influent					
5-28	10:00	212	216	---	6-1	7:00	278	200	28
	13:00	210	208	0.95		12:30	251	200	20
	15:00	197	193	2.0			253	218	14
	17:00	266	254	4.5					
				Non-settled Influent					
6-3	18:00	439	443	---	6-2	9:00	312	245	21.5
		443	418	5.6		16:00	308	228	26.0
		425	404	4.94		21:00	408	262	35.8
		420	367	12.6	6-3	1:30	346	277	19.9
						10:30	463	332	28.3

Lag Time Test

The lag time test conducted showed a time lag of 8 hours 45 minutes between the time of the change from distilled water influent to 0.01 M KCl influent and the time of the maximum effluent concentration of 0.0038 M. The maximum effluent quality effect of changing the influent back to distilled water was not reached in the 13 hours the influent of distilled water was maintained. The data for the lag time experiment is given in Table 5 and the influent and effluent data are plotted in Figure 11.

Trickling Filter and Anaerobic Digestor Research

The CE 559 class (Dept. of Civil Engineering, New Mexico State University) at the instruction of Dr. W. A. Barkley conducted short tests of the effect of chili water on a trickling and an anaerobic digestor.

Trickling filter.

The CE 559 class reported that the aerated trickling filter they used for the research had an efficiency of 76 percent to sewage and sewage was the process influent. When the influent was changed to chili water the efficiency rose almost immediately to 93 percent.

Anaerobic digestor.

The CE 559 class reported that the anaerobic digestor gas production dropped from an average of 6.6 liters per day to 1.0 liters per day when the influent was changed from sewage with 51,000 mg/l COD to chili waste with a COD of 354 mg/l. The pH level remained stable at 7.0.

Table 5. Data for Lag Time Experiment

Time (min)	Influent Conductivity (MHOS)	Influent KCL Molarity	Effluent Conductivity (MHOS)	Effluent KCl Molarity
0	1.4×10^{-2}	.01	5.2×10^{-5}	<.0001
15	1.38×10^{-2}	.01	3.82×10^{-5}	<.0001
30	1.4×10^{-2}	.01	0.58×10^{-4}	<.0001
45	1.4×10^{-2}	.01	1.38×10^{-4}	.0001
60	1.4×10^{-2}	.01	1.74×10^{-4}	.0001
75	1.38×10^{-2}	.01	2.56×10^{-4}	.00016
105	1.4×10^{-2}	.01	0.52×10^{-3}	.00033
135	1.4×10^{-2}	.01	0.74×10^{-3}	.00048
165	1.4×10^{-2}	.01	1.11×10^{-3}	.00074
195	1.4×10^{-2}	.01	1.29×10^{-3}	.00087
225	1.38×10^{-2}	.01	1.9×10^{-3}	.00130
240	1.2×10^{-2}	.01	1.83×10^{-3}	.00125
255	4.8×10^{-5}	<.0001	2.43×10^{-3}	.0017
285	4.46×10^{-5}	<.0001	3.4×10^{-3}	.0024
315	4.86×10^{-5}	<.0001	4.0×10^{-3}	.0028
345	3.0×10^{-5}	<.0001	4.46×10^{-3}	.0032
375	2.92×10^{-5}	<.0001	4.8×10^{-3}	.0034
405	3.6×10^{-5}	<.0001	0.51×10^{-2}	.00365
435	2.72×10^{-5}	<.0001	0.52×10^{-2}	.0037
465	2.54×10^{-5}	<.0001	0.52×10^{-2}	.0037
495	2.7×10^{-5}	<.0001	0.52×10^{-2}	.0037
525	2.5×10^{-5}	<.0001	0.53×10^{-2}	.0038
555	$\left.\begin{matrix}2.1\\3.8\end{matrix}\right\} \times 10^{-5}$	<.0001	0.52×10^{-2}	.0037
585	2.1×10^{-5}	<.0001	0.51×10^{-2}	.00365
615	2.1×10^{-5}	<.0001	4.98×10^{-3}	.00355
630	2.34×10^{-5}	<.0001	4.9×10^{-3}	.0035
660	2.18×10^{-5}	<.0001	4.43×10^{-3}	.00315
720	2.3×10^{-5}	<.0001	3.52×10^{-3}	.00255
780	2.04×10^{-5}	0	2.92×10^{-3}	.00205
840	1.9×10^{-5}	0	2.72×10^{-3}	.0019
930	1.98×10^{-5}	0	2.0×10^{-3}	.00135
1020	2.02×10^{-5}	0	1.31×10^{-3}	.00087

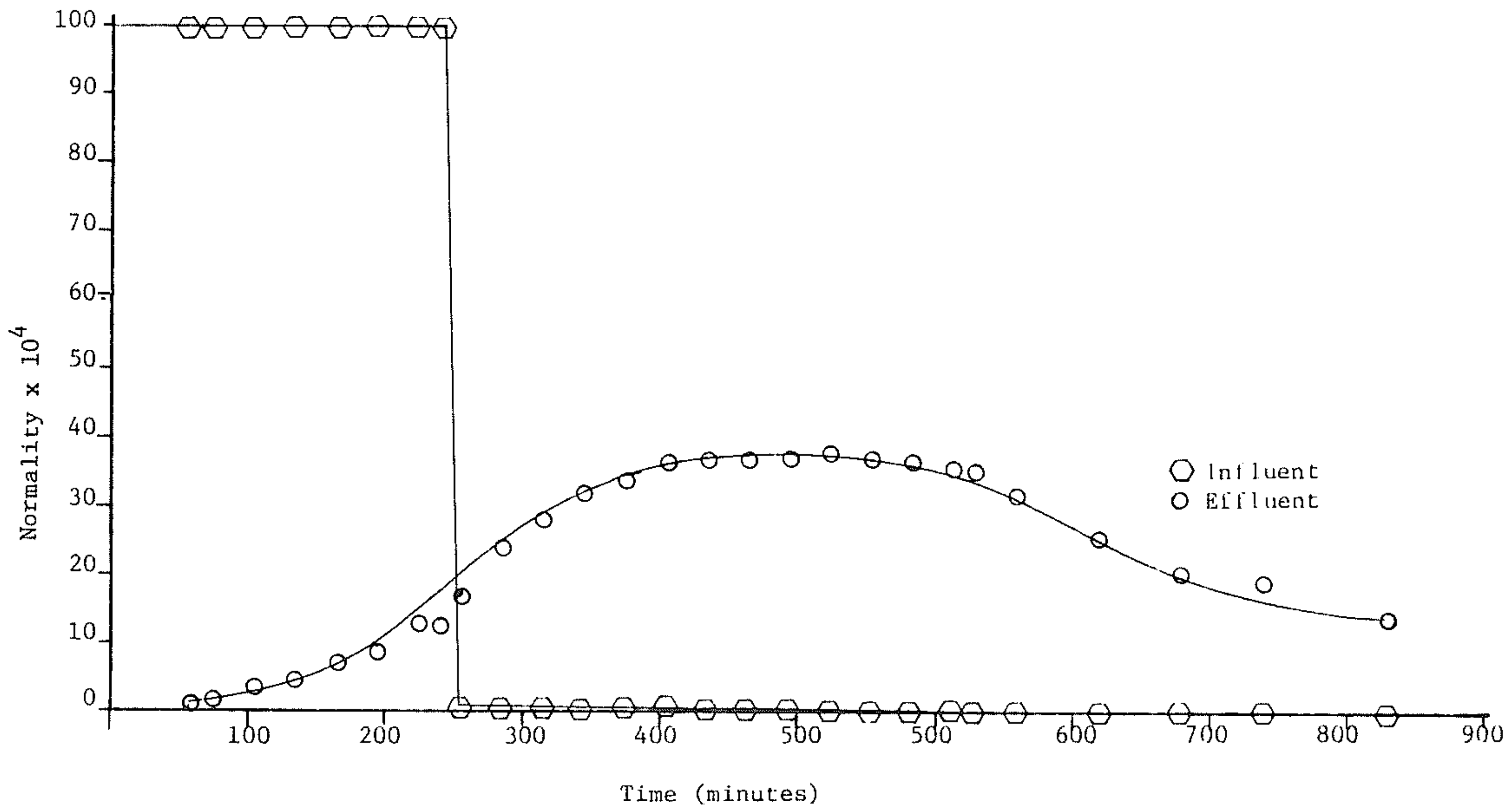

Figure 11. Influent and Effluent Salt Concentrations vs Time During Lag Time Test

Regression Analysis Results

In order to better understand the significance of some of the data obtained a linear regression analysis of the data was performed. A canned APL program, REGHOW, was used to perform the regression. The data for the study of the treatment of a settled influent was analyzed in several groups where tendencies were apparent. This data is presented in Table 3.

An analysis was made of the data taken during the period of increasing efficiency in the second through fourth days of the test. The data used is the sixth through eighteenth sets of data. The regression showed a positive slope of 0.23 percent per hour when efficiency was based on time and influent COD with a T-value of 3.92 for the time. When time was used alone the slope with time was 0.27 percent per hour with a T-value of 4.414. An analysis of the MLSS data available for the period showed a slope of 0.6 mg/l per hour with a T-value of 0.14.

The data from the period of time during which efficiency was fairly constant for 2 days preceding the change to chili waste was analyzed. The data used is the eighteenth through twenty-fifth sets of data. When time and influent COD were used to calculate the efficiency a slope of 0.05 percent per hour was shown with a T-value of 0.89.

An analysis of the data during the decreasing efficiency period following the change to chili water was made using the twenty-sixth through thirty-fourth sets of data. Calculating the efficiency on the basis of time and influent COD the efficiency had a slope of 0.6 percent per hour and a slope with influent COD of 0.13 percent per mg/l. The

T-values of time and influent COD were 1.28 and 1.99, respectively.

An analysis was also conducted of the data from the period of increasing efficiency following the chili waste addition. The data used in the regression is the thirty-fourth through forty-eighth sets of data. The analysis using time and influent COD to calculate efficiency showed an efficiency change with time of 0.15 percent per hour and an efficiency change of 0.03 percent for a 1 mg/1 change in influent COD. The T-values calculated were 3.03 for time and 0.33 for influent COD. The analysis with time only showed an efficiency slope of 0.14 percent per hour and a T-value of 3.14. A regression using MLSS data available for the same period showed a MLSS slope of 17.6 mg/1 per hour of time change and a T-value for time of 1.74

The regression analysis of the time, influent COD, and efficiency data, given in the last 13 sets of data, for the period of near constant efficiency at the end of the testing period showed an efficiency slope with time of 0.02 percent per hour and a T-value of 1.35 for time. The analysis using time only to calculate efficiency showed an efficiency change of 0.009 percent per hour of time change and a T-value for time of 0.36.

An analysis of the MLSS and time data shown in Table 2 from the treatment of non-settled influent was conducted for two periods of time to determine if efficiency was a function of MLSS. The data for the first period analyzed consisted of the sets of data which contain MLSS values for the time period between 11:00 of 4-15 and 10:00 of 4-20. The regression showed an efficiency change of 0.5 percent per mg/1 change in MLSS with a T-value of 0.43 for MLSS. The second period analyzed was from 11:00 of 4-23 to 18:00 of 4-26. The change in efficiency calculated was 0.82 percent per mg/l change in MLSS. The MLSS T-value was 7.05.

BOD-COD Correlation for Chili Waste

Tests were conducted to determine the COD-BOD relationship for the chili waste used in the experiment. It was found that the chili waste COD was approximately twice the BOD.

DISCUSSION

The discussion of results is presented in the following sections.

Treatment of Non-settled Influent

The part of this research which was conducted without a primary clarifier as part of the treatment process had data which is so erratic that it has little value. The data obtained does show that for the testing period the treatment process had a higher efficiency when the process influent was sewage than when the process influent was chili waste. This data is, however, far from conclusive. The difference in the average values of efficiency of 77 and 78 for the sewage and 65 for the chili waste is small considering the high values of the standard deviation 9.5 and 13.8 versus 10.8 respectively. The physical significance of this is shown by the amount of overlapping data points in the graph of efficiency versus time (Figure 7).

The erratic nature of the data is due to the failure of the system to reach steady-state. It is felt that the failure to reach steady-state was due to the highly fluctuating organic strength of the influent. The inability to control the MLSS at a constant level also contributed to changes in efficiency, but to a lesser degree than the influent variation. The main reason for the fluctuation in influent concentration was the change in solids concentration in the influent brought on by slugs of solids. The problem brought on by the slugs of solids is not a problem of system upset but rather a problem of representative sampling. Because of the erratic data in this portion of the research, it was decided to do further research with a primary clarifier in the hopes that the primary's removal of solids would stabilize the influent concentration.

Treatment of Settled Influent

This portion of the research was conducted because of a desire to obtain more reliable data. The effort was successful as the results proved to be much more valuable.

As was previously stated the data obtained yielded efficiency values that followed a definite pattern. From the second to the fourth days the removal efficiency for the sewage steadily climbed from 48.6 percent to 77.5 percent where it leveled off and stayed until the influent was changed to chili waste two days later. These two time periods appear to be first, a period of acclimatization, and secondly, a period of acclimatized treatment at steady-state. A regression analysis of the data obtained for these two periods of time show time to be significant during the first period and insignificant in the second period for predicting treatment of efficiency. Since time was significant in the first period and insignificant in the second period it indicates that acclimatization was taking place in the first period and was complete in the second period.

The efficiency of treatment dropped off sharply to 64.6 percent within a day after the influent was changed to chili waste. This drop in efficiency was probably caused by either of two factors or by their combined effect. The shock to the system caused by a drastic change in influent characteristics would certainly be expected to cause a reduction in treatment efficiency. It is also natural for there to be an apparent reduction in efficiency during periods of decreasing influent concentration such as the one which accompanied the change to chili waste influent.

The reduction in measured efficiency caused by a reduction in influent strength is associated with the lag time, or the time period between the reduction in influent strength and the reduction in effluent strength caused by the influent strength reduction. The efficiency, as determined, is based on an influent and an effluent sample obtained simultaneously, but the effluent sample is actually generated from an influent strength introduced some time before. Therefore an error is introduced if there has been a change in influent strength and if the system has not had time to reach a new steady-state. If a large number of samples are taken with influent strength rising and falling then an average efficiency can be determined that will be representative. However if a limited number of samples are taken and the influent strength changes only one way then a definite error is introduced.

The lag time shown for the salt solution should be directly applicable to a soluble substrate which passes through the system untreated. It was seen that when the activated sludge unit influent salt concentration was raised abruptly and held constant for four hours the maximum salt concentration in the secondary clarifier effluent did not occur for 8 hours and 45 minutes. This peak in effluent salt concentration actually occurred 4 hours 45 minutes after the influent was changed to distilled water. After the activated sludge unit influent was changed back to salt solution the experiment was run for 13 hours during which time the effluent salt concentration continued to rise for 4 hours 45 minutes and then fell steadily. If the salt concentration were thought of as soluble substrate, part of which goes untreated, then it can be easily visualized how a change in influent substrate concentration forces a change in measured efficiency.

The importance of influent COD on efficiency during the sharp one-day decline of efficiency is emphasized by the fact that a regression analysis of the data for the period showed influent COD significant at the 90 percent confidence level in accounting for change in efficiency.

After a sharp decline for one day following the change from sewage to chili waste influent the treatment efficiency rose steadily for about 2-1/2 days to 81 percent. It appears that this 2-1/2 day period was a time of acclimatization. The likelihood of this is supported by the fact that time was significant above the 90 percent confidence level. The reverse of the previously discussed lag period could be responsible for some of the increase. This would come about as the system started reaching steady-state at the new influent concentration.

Following the 2-1/2 days of acclimatization the removal efficiency leveled off and averaged 80.9 percent for the remaining four days of the experiment. The system was stable during the four days and the standard deviation of the efficiency was a low 2.5 percent. This indicated that the system was acclimated. This was also substantiated through regressive analysis when the time parameter proved to be insignificant in calculating COD removal efficiency. Also the slope of the COD efficiency-time error was zero.

Knowledge of several matters of special interest and importance were gained from this portion of the experiment. A period of acclimatization for both the sewage and chili waste was shown. The time for the acclimatization was relatively short for both. The rate of efficiency increased with time during periods of acclimatization was greater for the sewage than for the chili waste. During the time of acclimatization to the sewage the efficiency increased by 0.2695 percent per hour. The increase during the acclimatization to chili waste was 0.1443 percent per hour. The chili waste could have been harder for the microorganisms to adapt to but it is more likely that the microorganisms were already acclimated to the sewage at the start of the test. A problem of controlling MLSS concentration was noted and will be discussed later.

The most important information gained from this portion of the research is that the upset caused by the shock load of chili waste, if it existed at all, was both brief and mild, recovery from the shock was rapid, and the level of removal efficiency after acclimatization to the chili waste was as high as it was for sewage. This conclusion is probably valid for conventional activated sludge systems also, but the slug flow of the conventional system is different from a completely mixed system. Complete mixing reduces concentration gradients making completely mixed systems more resistant to upset caused by shock loads. Overall, this portion of the research indicates that chili waste is highly degradable by an activated sludge process.

Physical Treatment

The portion of the research dealing with physical treatment was conducted in order to determine the treatability of the sewage and chili waste in the absence of biological action. The activated sludge unit and secondary clarifier had an efficiency of 2.5 percent with settled chili waste influent and 7.7 percent with unsettled chili waste. The average efficiency was 21 percent for settled sewage and 26.3 percent for the unsettled sewage. The importance of this data was to determine if the removal efficiencies experienced in the previous portions of the research could have been due to physical treatment. The data for physical treatment further establishes the already obvious fact that biological action was responsible for almost all of the COD removal for the chili waste.

It is interesting that the chili waste is less susceptible to physical treatment than the sewage. This points out that for overall secondary treatment of chili waste to be equally efficient to sewage treatment under the same conditions the chili waste must be more readily biodegradable than the sewage. If physical treatment of the settled chili waste were high enough it could disguise a complete upset of the activated sludge. The possibility of this extreme condition is eliminated by the results of this portion of the research.

Trickling Filter and Anaerobic Digestor Treatment

The research conducted by the CE 559 class on the effects of chili waste on a trickling filter and an anaerobic digestor yielded data which is inconclusive but of value. The results give some support to the propositions made from the activated sludge research and in no way detract from them.

Trickling filter. The trickling filter used for the research by the CE 559 class showed a slight increase in efficiency when treating chili waste. This is not directly applicable to an activated sludge unit because a trickling filter has a different method of accumulating the mass of microorganisms which treat the waste. Both are, however, aerobic treatment units and depend on a population of aerobic bacteria to decompose the organics present in the waste. The fact that the trickling filter showed increased efficiency with a complete change to a chili waste water for influent becomes significant to this study in that it shows the ready treatability of chili waste by an aerobic biological process. This substantiates the earlier proposition that the chili waste was readily decomposed by an activated sludge process.

Anaerobic digestor. The result of the anaerobic digestor experiment was the drastic reduction in gas production by the anaerobic digestor in less than a day following a change to chili waste water. If this reduction in gas production was due to an upset caused by the shock of the change to chili waste from a synthetic waste made from baby food it would not detract from the supposition that chili waste is readily decomposed by an activated sludge for two reasons. One reason is that chili waste could be toxic or shocking to an anaerobic treatment process and still be readily degradable by an aerobic process. Another possible reason for a reduction in gas production lies in the two-step nature of anaerobic digestion. In the first step the anaerobic bacteria reduce the organics to simple organic acids such as acetic and propionic acid. A second group of bacteria then converts the simple organic acids to methane and carbon dioxide. If the chili waste was very easily decomposed by the acid-forming bacteria an acid build-up would result. If an acid build-up occurred the resulting pH drop would kill the methane formers which are extremely pH sensitive. There would then be an even more rapid acid build up and pH drop until the system completely killed itself. In this manner a non-toxic material which is readily degradable could reduce gas production in an anaerobic digestor. This possible explanation for a reduction in gas production is not, however, applicable in this particular instance. The possibility is precluded by the fact that no pH drop was observed with the gas production curtailment. The most logical explanation for the reduction in gas production is the low organic strength of the chili waste compared to the previous baby food waste. It is believed that the anaerobic digestor simply did not have as much material to decompose so gas production fell. Further work is needed to clarify the effect of chili wastes on the anaerobic digestion process.

Operational Problems of Bench Scale Models

There are several problems which are inherent to working with bench scale models. Most of the problems are caused by the inability to scale down the reactants along with the reactor. For instance, bacterial floc and cigarette butts are the same size in a bench scale model as they are in a real sewage treatment plant. The problems which hindered this research the most are discussed in this section.

Control of loading rates.

An attempt was made to maintain constant volumetric and organic load rates. Both presented problems which interfered with the progress of the research.

Volumetric loading rate. Establishing a constant volumetric load rate presented a problem of some duration. The first attempt at controlling the flow was made using a small gear-type pump with an automatic timer for intermittent pumping. It was felt that short enough time periods between pumping will approximate continuous pumping. The gear pump failed to work for two reasons. The flow rate decreased with a decrease in the head of the storage tanks and small particles sometimes locked the pump gears. A constant head source was impractical and would not have solved the gear-locking problem so a change to the peristaltic pump described in the procedure was made. The peristaltic pump solved the problem and allowed a dependable constant rate flow into the system.

Organic loading rate. An influent of constant organic strength with a constant volumetric loading rate would provide a constant organic loading rate. It was found however that the sewage source used was highly variable. The first attempt to solve this problem was to obtain a large quantity of sewage and keep it mixed. This failed due to a large portion of the organic strength of the sewage being in solid form and the inability to equally distribute the solids by mixing. This problem was never completely solved but was subdued by the addition of a primary clarifier to the system and changing to a sewage source with less variability. A primary clarifier with a larger surface area to volume ratio would have been more beneficial.

Control of MLSS Concentration

Throughout both parts of the biological treatment sections of the research an attempt was made to maintain the MLSS concentration at a constant level. There was however a great deal of variation in the MLSS concentration.

In order to maintain a constant MLSS concentration there is a need for a clarifier in which the solids can be concentrated and pumped from the bottom. With such a clarifier the MLSS concentration can be controlled at any desirable level by controlling the amount of solids wasted and recirculated. The amount of sludge needed to be recirculated can be determined from the equation: $\left[Q_r = \frac{(C_{MLSS})(Q_r + Q_I)}{C_{ss}}\right]$

where:

Q_r = recirculation flow rate
C_{ss} = concentration of settled solids
Q_I = process influent flow rate
C_{MLSS} = desired MLSS concentration

However, a bench scale model of a clarifier with constant sludge removal through the bottom is hard to operate. The sludge removal pipe which is scaled down many times is easily plugged by bacterial masses which are not scaled down. The bacterial masses can form a screen over the entrance to the sludge pipe and effectively filter the solids from the liquid. Having gained knowledge of the probable failure of a clarifier with sludge removal from the bottom from the past experience of the thesis advisor, it was decided to remove sludge by essentially vacuum cleaning the bottom of the clarifier.

The vacuum type sludge removal used has distinct disadvantages. The moving of the vacuum pipe disturbs the settled solids causing mixing with the clarified liquid and results in decreased sludge concentration. It also has the disadvantage of being intermittent causing instantaneous increases in MLSS concentration at the times of recirculation with gradual decreases between.

A possible solution would be a clarifier with continuous sludge removal through the bottom and a scraper to move the solids to the sludge pipe and break up any solids built up over the opening to the sludge pipe.

Sampling

Obtaining representative samples from a bench scale model is difficult. Generally, the larger a sample is, the more representative of the whole it will be. With a bench scale model, however, taking numerous large samples can require a significant proportion of the total volume of unit. Sluffing of solids build-ups occurs in full size plants as well as bench scale models but with less effect. The small diameter of the pipes or tubes used in bench scale models cause a higher ratio of circumference to area ratio. The build-up on the walls will occur at about the same rate as in a large pipe thus causing a greater effect in the smaller pipe of the bench scale model.

SUMMARY AND CONCLUSIONS

The treatment of chili waste by an activated sludge process was researched in order to determine possible deleterious effects on the system removal efficiency. Process parameters were monitored and an attempt was made to keep all variables constant except the quality of the process influent which was interchanged between sewage and chili waste. Changes in the process were made as needed in order to better control process parameters and achieve equilibrium. Efficiency of COD removal by the secondary unit was monitored as a means of process evaluation. As a result of this research the following conclusions were reached:

1. Control of operational parameters for bench scale activated sludge system is difficult because biological floc and waste solids remain full size. The addition of a primary clarifier to the system helped to bring about a steady-state condition by making control of the influent COD possible.
2. Instantaneous measurements of efficiency of an activated sludge are not accurate evaluations of the process during periods of time in which the influent organic concentrations are increasing or decreasing.
3. Changing a completely mixed activated sludge process influent from sewage to chili waste produces a mild upset with a slight decline in efficiency.
4. A completely mixed activated sludge system recovers rapidly from an upset brought on by a potential shock load of chili

waste, but acclimatization to chili waste is slower than the acclimatization to sewage.

5. After acclimatization a completely mixed activated sludge process has as high a treatment efficiency for chili waste as for sewage.
6. Chili waste is readily degradable by aerobic biological treatment and has no adverse effects on a completely mixed activated sludge process.
7. Results of experiments on the effect of chili wastes on anaerobic digestion were inconclusive.

RECOMMENDATIONS

Based on the results of the research conducted on the treatability of chili waste several recommendations can be made.

It is recommended that additional studies of chili waste effects on activated sludge systems be conducted using a more homogeneous sewage source and a primary clarifier with a large surface area to volume ratio.

It is recommended that future studies of chili waste effects on activated sludge systems be conducted with a secondary clarifier which has facilities for continuous sludge removal through the bottom and a means of preventing solids screening at the sludge removal port.

It is recommended that research be conducted on the change of biological species which predominate in the activated sludge when a change from sewage to chili waste is made.

It is recommended that research be conducted on the treatability of chili waste by anaerobic digestion.

In order to maintain a consistent quality wastewater this investigation used a synthetic wastewater prepared from dried red chili. It is recommended that the real wastewater from a chili processing plant be tested. An effort should be made to minimize the effects of variation in chili wastewater character.

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