EFFECTS OF A SYNTHETIC ALUM SLUDGE ON THE OPERATIONAL PERFORMANCE OF A LABORATORY ACTIVATED SLUDGE UNIT

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CHAPTER I

INTRODUCTION

Man requires clean, safe water for his domestic, commercial, and industrial needs. To fulfill these needs, municipalities throughout the world have operated water utilities for decades. The operation of such a utility requires a water supply of ample size and quality. This raw water supply may be obtained from a reservoir, river, or a groundwater system. The raw water must be adequately treated to remove disease causing contaminants as well as taste, color, and odor producing substances before being distributed to the customer.

Water purification is generally achieved by the addition of chemicals to the raw water followed by flocculation, sedimentation, filtration, and disinfection. Alum (aluminum sulfate) is widely used as a coagulant aide in water treatment. Following its addition to the water, alum chemically reacts with the naturally occuring alkalinity to form aluminum hydroxide. This forms a nucleus for floc formation.

Coagulating with the aluminum hydroxide floc particles are inorganic impurities, microorganisms, soil particles, and other raw water contamimants. Following flocculation, this undesirable material is settled out in sedimentation tanks leaving a clear supernatant ready for filtration, disinfection, and distribution to the customer. This settled material is a waste product, generally termed "alum sludge", which must be disposed.

In years past this sludge has been returned directly to the nearest stream. However, concern for the protection of the environment has led to the passage of Public Law 92-500 and this federal legislation prohibits the discharge of untreated wastes into America's waters.

Disposal of alum sludge has become an increasingly pronounced problem to municipalities especially since enforcement of Public Law 92-500 began. Therefore, research is presently being conducted to determine environmentally safe methods of disposal which are economically practical. A widely used but little researched method of alum sludge disposal is the utilization of existing sewage treatment facilities. Since municipalities generally operate their own sewage treatment system, the potential advantages of such a disposal method are many.

Therefore, it is the purpose of this thesis to investigate the impact of alum sludge on the operational performance of a bench scale activated sludge sewage treatment system. The ultimate goal of this research being to determine whether municipalities presently operating activated sludge sewage treatment plants can seriously consider the possibility of effective disposal of alum sludge by direct discharge into the sanitary sewer system without incurring a loss of treatment efficiency.

The emphasis of this research is on the effects of alum sludge on the operational efficiency of an activated sludge sewage treatment system. Parameters monitored include: chemical oxygen demand (COD), suspended solids (SS), dissolved solids, volatile suspended solids (VSS), and sludge settleability.

CHAPTER II

LITERATURE REVIEW

Only in recent years has much interest been shown in developing effective disposal methods for water treatment plant sludge. In the past, a majority of municipalities disposed of their utility sludge by direct discharge into a receiving water. Only within the past ten to fifteen years have state agencies begun to seriously deter municipalities from this practice. State laws, as well as federal law, prohibit the discharge of water utility sludge into a watercourse.

Due to an awakening of environmental concern and the recent legislative changes, research to determine effective methods of water treatment sludge disposal is presently being conducted. However, little literature is available on this since it was not widely considered a problem in the past.

This chapter contains a brief review of various alum sludge disposal methods. This is preceeded by a section describing the various constituents and characteristics of alum sludge and is followed by a more extensive review of literature concerning sanitary sewage disposal of aluminum hydroxide sludge. For an excellent discussion of water utility sludge disposal, reading of the four part American Waterworks Association Research Foundation Report "Disposal of Wastes from Water Treatment Plants" (1) is urged.

Alum Sludge Properties

Characterization

Gruninger and Westerhoff (2) have identified sand, silt, clay, and microorganisms as the impurities most commonly removed in water treatment. These raw water impurities, 0.5 to 10 mg/l $Al(OH)_3$ as aluminum, and over 99 percent water comprises alum sludge report Hsu and Pipes (3).

Russelmann (4) states that alum sludges may be pale green, yellow-orange, dark brown or even black. The color depending upon the nature of the water supply impurities, the coagulant chemicals, and any decomposition which may be occuring. Studies by Gates and McDermott (5) show that approximately 95 percent of alum sludge total solids are settleable. Aluminum hydroxide sludge display zone settling characteristics and exhibit non-Newtonian flow.

Gruninger (2) reports that alum sludge is nearly insoluble throughout the pH range. Young (6) indicates that temperature and other natural variations can create significant differences in sludge characteristics.

Water treatment plants produce a filter backwash sludge as well as a sedimentation tank underflow sludge. Filter wash sludge is much more dilute than sedimentation sludge. Total solids values of 0.1 to 0.5 percent by weight for sedimentation sludge and 0.01 to 0.02 per cent by weight for filtration sludge are reported by Gruninger and Westerfoff (2). Tables I and II include the characteristics of water utility plant sludges compiled in 1968 by Russelmann (4).

TABLE I

COAGULATION SLUDGE CHARACTERISTICS

treatment	BOD_5 (mg/l)	COD (mg/l)	pH	ts (mg/l)	vs (mg/l)	ss (mg/l)	vss (mg/l)
*alum coag & sedimentation	41	540	7.1	1159	571	1110	620
*alum coag & clarifier	90	2100	7.1	10016	3656	5105	2285
*alum coag & clarifier	108	15500	6.0	16830	10166	19044	10722
*alum coag & clarifier	44		6.0			15790	4130
**alum coag & upflow clarifier	36–77	500–1000	7.0	4300	1030–1500	3600	930–1350

TABLE II

FILTER BACKWASH CHARACTERISTICS

treatment	BOD_5 (mg/l)	COD (mg/l)	pH	ts (mg/l)	vs (mg/l)	ss (mg/l)	vss (mg/l)
*alum coag & sedimentation	4.2	28	7.8	121	44	47	31
*alum coag & clarifier	3.7	75	7.2	378	115	104	53
*alum coag & clarifier	2.8	160	7.8	166	45	75	40

*denotes Russelmann (4) as the data reference, **denotes Neubauer (10)

Volume

Water utilities create a great volume of dilute alum sludge in the water treatment process. Westerhoff and Daly (7) report that a water utility which treats 50 million gallons per day (MGD) of raw water with alum will commonly produce about 2 MGD of waste sludge. The annual alum sludge production in the United States is estimated at about 500,000 tons dry weight by Gruninger and Westerhoff (2). This value, states Krasaukas (8), is about one-tenth of the annual sewage treatment sludge production.

Gruninger and Westerhoff (2) report that 70 percent of the alum sludge volume is contributed by filtration unit backwashing. However, only ten to twenty percent of the solids are contributed by this backwash sludge.

Alum Sludge Disposal Methods

In 1953 Dean (9) surveyed 1,530 American water treatment plants and found that 96 percent of them returned their waste sludge directly to a receiving water. Three percent utilized sludge beds for disposal while the other one percent used sanitary sewers, impounding basins, dry creeks, or irrigation ditches. In this same survey, Dean found that 93 percent of the plants discharged filter backwash directly to a receiving water while two and one-half percent of those plants responding utilized sanitary sewers for disposal and two percent used lagoons.

By 1963, Krausauskas (8) reported that 60 percent of the 100 largest American cities still disposed of their water utility waste by direct discharge to a stream. Krausauskas' findings are listed in Table III.

TABLE III

SURVEY OF WATER UTILITY SLUDGE DISPOSAL METHODS

State	Wash Water Disposal Method*					Sludge Disposal Method*							
	A	B	C	D	E	A	B	C	D	E	F	G	H
Alabama	2					2							
Arizona	1					1							
California	6				2	5							
Colorado			1		1	1		1					
D.C.	1	1				1							
Florida	1					1		1		1		1	
Georgia	2		1			1							
Illinois	2					3							
Indiana	3					2		1					1
Iowa			1			2		1					
Kansas	1									1			
Kentucky	1					1							
Louisiana	2					2							
Maryland	2					2							
Michigan	3	1		1	2	1	4	1			1		1
Minnesota	1					1							
Mississippi				1									
Missouri	2		2		1	2		1					1
Nebraska	1					1							
New York	1					2							
North Carolina	1					1							
Ohio	1		2		1	2							
Oklahoma	1					1							
Pennsylvania	3		1			1	2	1					
Rhode Island			1					1					
Tennessee	2					2							
Texas	3		3		3	2				3	1	3	2
Utah	1		2		2					2		2	
Virginia	2					2							
Wisconsin	1				1	2							
Total	47	2	15	2	13	43	6	8	0	7	2	6	6
Percentage	66	3	21	3	18	60	8	11	0	9	3	8	8

*key;

A: to receiving water
B: to sanitary sewer system
C: to lagoon
D: other (holding tank, swamp area, etc.)
E: return to water treatment system
F: centrifuge dewatering
G: sludge treatment
H: landfill

Many methods of alum sludge disposal have been recommended to replace direct discharge to a watercourse. Most of these alternate methods are discussed on the following pages. These methods of disposal discussed include: lagooning, drying beds, centrifugation, vacuum filtration, filter pressing, freezing, recycling, and sewage disposal. Many methods are not included because of the lack of literature. Some of these are: land disposal, landfilling (generally used as the final disposal method), heat treatment, polyelectrolyte addition, incineration, hydrocyclone, wet-air oxidation, reclaimation for industrial use, and pipeline transportation of sludge.

Moisture Reduction

Due to the dilute characteristics and large volume of alum sludge production, it is generally desirable to thicken the sludge before attempting disposal. Thickening is a process of moisture reduction whereby a clarified effluent is drawn off of a conventional sedimentation tank leaving a concentrated sludge in the bottom.

Neubauer (10) reports that alum sludges of 0.1 to 0.3 percent solids by weight can readily be concentrated to one percent by this technique. Gruninger and Westerhoff's findings (2) show that water treatment filter backwash waste water will settle to about ten percent of the original volume in ten minutes. These men report that gravity thickening of coagulation—sedimentation plant sludge will settle to two to six percent total solids by weight.

Lagooning

Lagooning can be incorporated as a form of thickening, or as an intermediate method of sludge treatment preceeded by conventional thickening techniques, or it can be used as a means of final alum sludge disposal. Krasauskas (8) is one of the many authors to report on the problems of lagooning alum sludge. He witnessed lagoon settled sludges which had not concentrated beyond nine percent solids after years in a lagoon. It is generally accepted that alum sludges must be al least 20 percent solids before they can be hauled to a final disposal site. Krasauskas indicates that odor problems may be present at a lagoon.

Lagooning of hydroxide sludges will form a surface crust with a liquified sludge under the crust. That is, lagooned alum sludge is thixotropic. This problem can be reduced by incremental layering of sludge into a lagoon. Bishop and Fulton (11) successfully concentrated 0.5 percent sludge to six percent solids by such a method.

Neubauer's (10) analysis of lagoon supernatant effluent showed a suspended solids value of 24 mg/l, eight milligrams per liter being volatile suspended solids. Young (6) states that the United Kingdom Planning Authorities object vigorously to the use of lagoons and drying beds near built up areas or in sites of scenic beauty. This is because of the unsightliness and odors of lagooned alum sludge.

Freezing

The aluminum hydroxide in water utility sludge contains water of hydration which can be released by freezing states Fulton (12). Under laboratory conditions, alum sludge samples from a Rochester, New York water treatment plant were frozen to demonstrate the effects of freezing. Fulton reports a solids increase from 3.5 percent feed concentration to 17.5 percent after freezing and subsequent thawing.

Bishop reports in the AWWA Research Foundation Report — Part 1 (1) that he has generated a solids content of 34 percent during a seven month pilot operation. This was conducted in cooperation with the Monroe County, New York Water Authority and incorporated the natural freezing of 0.3 percent sludge in thirty inch depths. The supernatant from this study contained 5 mg/l of solids. The settled sludge was 76 percent volatile material.

Doe, Benn, and Bays (13) reported on a full scale freeze disposal operation at an English water treatment plant. Mechanical freezing was utilized by the Fylde Water Board to produce a sludge of one-eighth the thickened volume. The supernatant solids were monitored and found to comply with a 30 mg/l suspended solids discharge regulation.

Recycling Alum

An American Water Works Association Committee Report (14) reports on the scarcity of alum recycling plants at American water treatment plants. The factors largely responsible for this lack of recycling facilities are believed to be the high initial cost, the problem of generating progressively lower quality sludge, and the likelihood of iron build up in the alum when the raw water contains a high iron concentration.

Roberts and Roddy (15) tests on Tampa, Florida's alum sludge showed that eight to ten recycles of the alum sludge showed no interference from the small amounts of acid insoluble materials. Nor was there any change in the bacterial or chemical quality of the treated water. They suggest that if any problems with insoluble materials (such as iron) should arise then mere wastage of that sludge will solve the problem.

Sulfuric acid treatment of alum sludge can recover a large percent of the aluminum hydroxide and make it reusable as alum. Roberts and Roddy describe the process by the following equation:

$$Al_2O_3 + 11H_2O + 3H_2SO_4 = Al_2(SO_4)_3 + 14H_2O$$

The recycled alum can be dried for coagulant use or maintained in the liquid state and be pH neutralized. Drying the regenerated alum creates a crystalline sludge which can be burned to produce a more refined alum. Combustion drives off the organic impurities.

Pallo, Schwartz, and Wang (16) conducted laboratory experiments on recycling filter backwash sludge and found that filter wash water is an effective coagulant aide. Thus, a reduction of the alum dosage requirement and/or an increase in the clarity of the purified water resulted. It was also noted that the alum sludge generated by recycling settled more rapidly than non-recycled sludge. However, slightly larger volumes of sedimentation tank sludge were created.

Contrary to this finding, several contributing members of the AWWA Research Foundation Report (1) stated that filter backwashing breaks up alum flocs. It was reported that this sludge must be reflocculated before effective coagulation will result. The belief that some alum addition is also required before the filter wash water will act as a coagulant was expressed.

Vacuum Filtration

Neubauer (10) found that a sludge concentration of nearly twenty percent solids could be obtained using vacuum filtration. Although filters employ various medias such as metal mesh, steel coils, and porus cloths for filtration; these media without a precoat of diatomaceous earth would not produce a dense enough sludge cake. The two sludges he worked with (both utilizing Lake Ontario for water supply) did not receive increased filterability with polyelectrolytes. However, about one-quarter to one-third of the sludge consists of the diatomaceous earth filter precoat. A usable alternative to a diatomaceous earth filter precoat is lime addition to the alum sludge.

Studies on the filterability of Auburn, Alabama's water treatment plant alum sludge by Glenn, Judkins, and Morgan (17) showed that the solids concentration is inversely related to the ease of filtration. It was also found that high vacuum pressures will decrease the filterability of alum sludges due to their compressible nature. Recycled alum sludge was found to be more easily filtered than non-recyled sludge, also.

Filter Pressing

Krasauskas (8) reported on two alum sludge filter presses in the United Kingdom. Beginning with a solids concentration of 1.5 to 2.0 percent, a sludge cake of 15-25 percent solids could be obtained in an eight hour press cycle. Pretreatment with lime or polyelectrolytes can produce sludges of 30 to 50 percent solids.

A ten percent lime or a one mg/l polyelectrolyte pretreatment of hydroxide sludge can produce a sludge cake of 35 to 40 percent solids reports Thomas (18). This can be done with a 0.5 to 1.5 percent feed and a cycle time of two to six hours.

Centrifugation

With bench scale centrifuges, Neubauer (10) produced sludge cakes of six to twelve percent solids by utilizing a 0.62 to 1.0 percent alum sludge feed. Krasauskas (8) created a sludge of 17 to 18 percent solids with a pilot centrifuge fed with 1.0 to 1.5 percent alum sludge. Thickening the feed sludge to five percent solids produced a cake of 22 percent upon centrifugation. Pretreatment of alum sludge is reportedly necessary before effective centrifugation can be performed. A 200 gpm centrifuge in operation at Austin, Texas generates an alum sludge of 10 to 15 percent solids reports Krasauskas.

Sanitary Sewage Disposal

Very little available literature reports on the effect of alum sludge on the treatment efficiency of an activated sludge wastewater treatment plant. The existing literature is generally unrelated. Research has been reported on aluminum sulfate—water solution effects on bench scale activated sludge units with or without primary clarification. The effect of aluminum hydroxide flocs on primary wastewater treatment is also reported. Only one article was found which addressed itself to the impact of a coagulated alum sludge on the operational performance of an activated sludge unit.

Table III shows that eight percent of America's one hundred largest cities utilized their sanitary sewer systems for water utility sludge discharge in 1963. Krasauskas (8) reports that Detroit had four water treatment plants discharging alum sludge wastes to a 200 MGD primary wastewater treatment plant. At one time interference with the vacuum filtration of the wastewater sludge was noticed. However, this problem was alleviated when the alum sludge was discharged at a low flow rate. Thus, a more gradual discharge was found to eliminate the problem.

In Philadelphia, Krasauskas reports that one regional wastewater treatment plant noticed improved primary settling when waste alum sludge was added into the sewer system. Hsu and Pipes (3) conducted laboratory experiments with batch fed bench scale units and found aluminum hydroxide flocs to aid in primary clarification. These 90 minute settling tests showed that for every mg/l of $Al(OH)_3$ as aluminum added to the sludge 3.83 mg/l of sludge was produced.

A hydroxide sludge addition which created less than 30 mg/l of Al in the clarifier increased the suspended solids concentration in the supernatant. At concentrations higher than 30 mg/l, however, the suspended solids level in the supernatant decreased significantly. Nearly 100 percent of the aluminum which was added in the form of $Al(OH)_3$ remained insoluble throughout the wastewater treatment process.

In addition to clarifying the primary treatment effluent, Hsu and Pipes found alum sludge to increase phosphate revoval substantially. COD removal increased from 28 to 58 percent efficiency prior to aluminum hydroxide floc additon to 60 to 80 percent efficiency following addition.

Salotto, Farrell, and Dean (19) conducted bench scale tests utilizing an alum-lime sludge fed to an activated sludge unit. A primary clarifier was incorporated in the process and this clarifier removed practically all of the water works sludge. Phosphorus and COD removal, nitrification, and pH were unaffected while turbidity and suspended solids in the effluent were reduced.

In the primary sludge, the total solids percentage dramatically increased while volatile solids decreased from about 80 percent to ten percent. The waste activated sludge showed little difference in character before and after dosing. Salotto, Farrell, and Dean postulated, nevertheless, that some carry-over of the water utility sludge improved settling and process efficiency in the activated sludge unit.

Anderson and Hammer (20) conducted bench scale tests with an eight hour detention time, 3.6 liter activated sludge unit employing a separate settling tank and cintinuous recycle. An aluminum sulfate—water solution was added to the sewage treatment system at various rates.

Experimentation showed that the BOD_5 removal efficiency of the activated sludge unit was not significantly affected by the alum addition. It was found, however, that protoza were nearly completely killed off when an alum concentration above 15 mg/l as Al was maintained in the activated sludge unit. At this concentration, Anderson and Hammer believe that chemical flocculation replaces auto-bioflocculation.

Further findings of Anderson and Hammer showed alum addition to significantly decrease the sludge volume index of a municipal wastewater. However, they found no change in SVI in a unit fed with soluble glucose. It was also noted that ninety percent phosphate removal occured at an Al:P ratio of 1.5:1.

Finger (21) recommends the addition of alum to activated sludge sewage treatment plants in order to control filamentous growth and hydraulic bulking. He found that alum addition, sporatic or continuous, increased the hydraulic load capacity of the Renton, Washington sewage treatment plant. It was believed that alum addition aided wastewater treatment by causing chemical flocculation to occur.

In findings similar to their primary clarification results, Hsu and Pipes (22) found that $Al(OH)_3$ addition adversely affected the sludge settling velocity until a concentration of 150 mg/l as Al was achieved in the aeration tank. At an alum sludge concentration of about 125 mg/l the suspended solids concentration in the supernatant began decreasing from 50 mg/l to about 30 mg/l solids at an aluminum concentration of 300 mg/l.

The sludge volume index was basically unchanged throughout the range of aluminum hydroxide floc addition (zero to 300 mg/l). However, the sludge volume increased considerably at higher alum sludge dosages. COD removal increased by about ten mg/l by the time 300 mg/l of alum sludge was maintained in the aeration unit. Nitrification was found to be unaffected by $Al(OH)_3$ floc addition.

Hsu and Pipes observed that aluminum hydroxide has an inhibitory affect on digestor performance. Aluminum hydroxide concentrations exceeding 100 mg/l as Al retards gas production. The authors hypothesize that a reduction in gas production is due to an inhibitory effect on the acid forming bacteria and not due to any adverse effects on the methane producing bacteria.

It was found that the alum-wastewater sludge dewaters better than wastewater sludge alone. Digested wastewater sludge and alum-wastewater sludge, however, were found to dewater better than their undigested counterparts.

CHAPTER III

MATERIALS AND METHODS

To study the impact of alum sludge on an activated sludge wastewater treatment system a bench scale biological reactor was operated under continuous feed conditions. Descriptions of the laboratory apparatus, feed solution, alum sludge preparation, initial setup, and paramaters monitored in this investigation follow.

Laboratory Apparatus

A schematic diagram of the laboratory setup used in this investigation is shown in Figure 1. The biological activated sludge reactor employed was a rectangular plexiglass unit divided by an adjustable baffle into an aeration chamber and clarifier. A soluble glucose feed was supplied at a rate of 9.6 ml/minute to provide a hydraulic detention time of twelve hours in the 6.9 liter aeration chamber. This was done with a Milton Roy Model MM2-B-96R dual positive displacement pump.

Air was supplied to the aeration chamber through four porus diffuser stones at approximately four liters per minute as measured by a Fischer and Porter 10A4139N-PB air flow meter. This air rate provided good mixing of the microbial population, supplied sufficient oxygen for growth, and provided good recycle of the settled sludge from the clarifier.

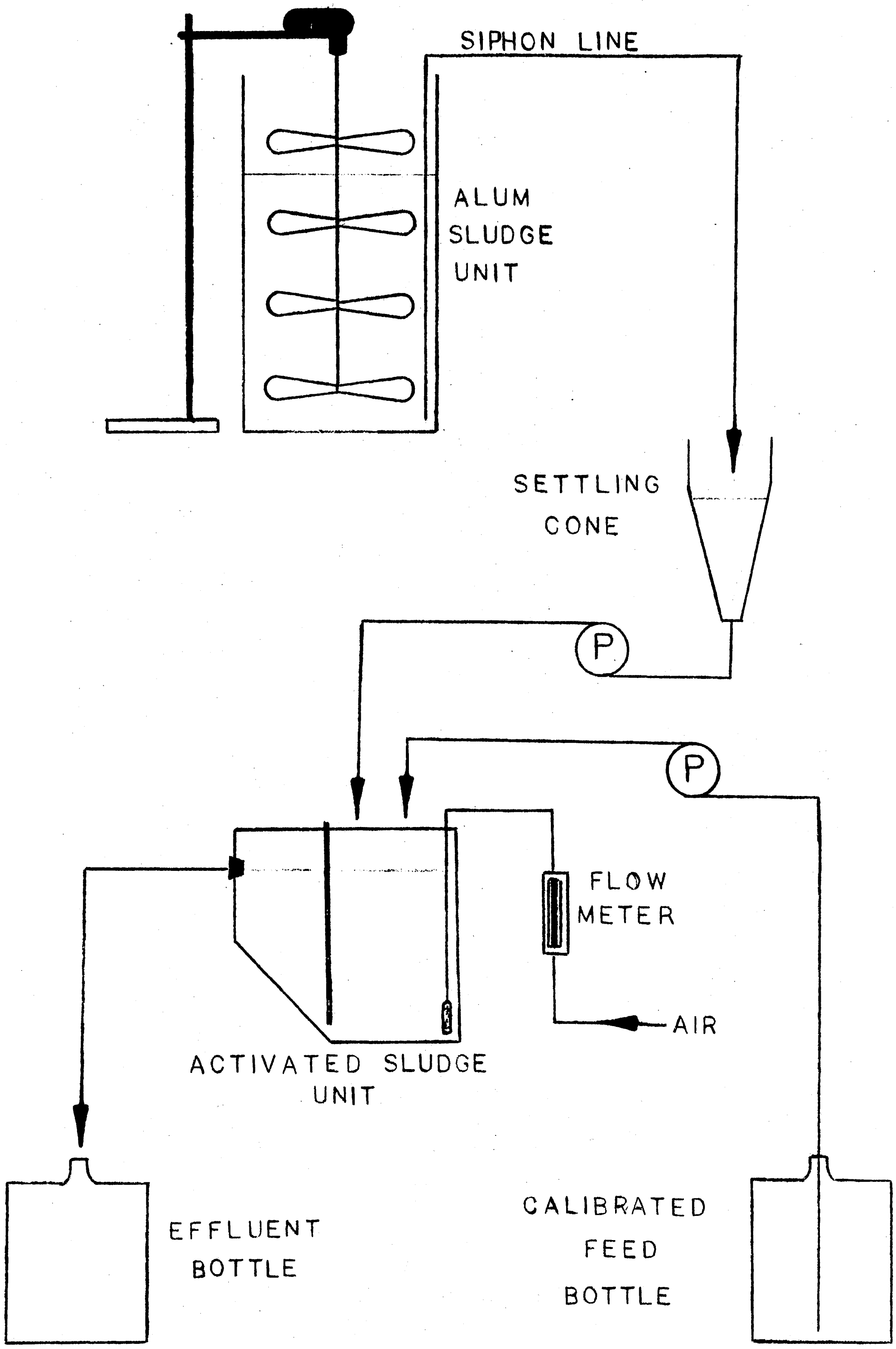

Figure 1. Experimental Apparatus

A cylindrical glass container with a total volume of approximately 38 liters was incorporated for alum sludge production. A three foot vertical shaft with four 3-bladed, eight inch diameter stirring blades was powered by a Lightnin Model v7 Mixer motor to rapid mix and coagulate various amounts of permian red clay and aluminum sulfate stock solution in the container. Following coagulation and settling, the alum sludge was siphoned into a three liter sedimentation cone. From this the concentrated underflow was pumped to the activated sludge unit by a Sigmamotor Model T8 finger pump.

Feed Solution

The activated sludge unit synthetic feed was prepared in four stock solutions: glucose, phosphate pH buffer, ammonia sulfate, and iron salts. Composition and concentrations of these solutions is given in Table IV. The stock solutions were kept refrigerated at about $5^{\circ}C$ and were prepared in two liter batches as need warranted.

Fifteen liters of standard feed was prepared daily in a calibrated twenty liter water bottle. Table V gives the volumes and resulting concentrations of the various stock solutions used in the standard feed. The standard feed remained unchanged throughout the investigation. The feed concentrations were designed to allow a feed COD of 300 mg/l and to insure carbon limitation on microbial growth in the activated sludge reactor by maintaining a COD:N:P ratio in excess of 100:10:1.

Alum Sludge Preparation

Aluminum sulfate forms the precipitant aluminum hydroxide when added to a water containing sufficient alkalinity. The aluminum

TABLE IV

STOCK SOLUTIONS

constituent	grams/ 2 liters
Glucose; $C_6H_{12}O_6$:	400.0
Ammonia sulfate; $(NH_4)_2SO_4$:	200.0
Phosphate buffer (pH 7.5);	
K_2HPO_4:	249.0
KH_2PO_4:	77.5
Iron salts;	
$MgSO_4 \cdot H_2O$:	20.0
$MnSO_4$:	2.0
$CaCl_2$:	1.5
$FeCl_3$:	0.1

TABLE V

STANDARD FEED

constituent	volume/ 15l feed	feed concentration
Glucose:	21 ml	300 mg/l COD
$(NH_4)_2SO_4$:	25 ml	35 mg/l as N
Phosphate buffer:	50 ml	103 mg/l as P
Iron salts:	50 ml	

hydroxide is flocculated in water treatment plants to coagulate and thus precipitate turbidity and other inpurities. The following reaction describes aluminum hydroxide floc formation:

$$Al_2(SO_4)_3 \cdot 18H_2O + 3Ca(HCO_3)_2 = 2Al(OH)_3 + 3CaSO_4 + 6CO_2 + 18H_2O$$

In this study a water utility's method of raw water coagulation was replicated with the glass container and mixer previously described. Three permian red clay concentrations were used during this study: 100 mg/l, 200 mg/l, and 300 mg/l. The permian red clay, a common Oklahoma soil, was obtained from the Oklahoma State University School of Civil Engineering Soils Laboratory.

After sufficient steady state data on the activated sludge unit had been obtained, daily feeding of alum sludge began. Twenty-one liters of manufactured raw water was treated with 150 ml of 10 mg/ml $Al_2(SO_4)_3 \cdot 18H_2O$ stock solution. This was equivalent to an alum dosage of 5.8 mg/l as aluminum and was experimentally derived by jar tests as described by Sawyer and McCarty (23).

Twenty-one liters of raw water was produced by rapid mixing the desired concentration of soil into tap water for approximately ten to fifteen minutes. The soil was weighed immediately prior to use by a Gram-atic Balance manufactured by E. Mettler of Zurich, Switzerland. The permian red clay supply was stored on an open shelf in a wide mouth bottle with a screw top. A 21 liter volume of water treated was chosen by assuming that approximately one-half of the water treated by a water utility is not returned to the sanitary sewer system. That is, one and one-half times the daily feed, 14 liters, is 21 liters.

One hundred and fifty milliliters of alum stock solution was rapid mixed with the synthetic raw water for one minute. Employing a rheostat, the mixing equipment was slowed down to simulate flocculation. A timer was set so that the flocculation continued for one hour. The mixing equipment was then removed from the glass container and the water treatment sludge was allowed to settle for over an hour. The settled sludge was siphoned to a conical clarifier from which it was pumped to the aeration tank of the activated sludge unit. A finger pump was used to pump approximately one-third of a liter of sludge to the biological unit over an hour and fifteen minutes.

Initial Setup

The original microörganism seed for the activated sludge unit came from the effluent of the primary clarifier of the Stillwater, Oklahoma municipal wastewater treatment plant. The unit was run for several days as a batch unit to establish a greater microbial population. Continuous feeding of the synthetic waste was run for about three months prior to initiation of steady-state experimentation in order to allow good settling, acclimation to the feed, and acclimation of the author to the unit's operation. Daily wastage of 1000 milliliters of the aeration volume was conducted during continuous operation of the unit. After about 10 days of steady-state data had been collected, feeding of the biological unit with coagulated alum sludge from a 100 mg/l soil "raw water" began. Approximately three weeks later, 200 mg/l of permian red clay was coagulated with alum and fed to the unit. After three more weeks, the soil concentration was increased to 300 mg/l. During the entire experiment, the alum dosage remained constant at 5.8 mg as aluminum.

Parameters Monitored

Daily monitoring of feed COD, aeration chamber solids level, effluent filtered COD, and effluent solids values were recorded. Settleability tests were periodically recorded and the hydrogen ion concentration was observed and maintained at about pH 7.5 with the phosphate buffer.

COD and solids samples were taken before the daily feeding of the biological unit. Chemical oxidation demand experimentation was performed as outlined in Standard Methods (24). A twenty milliliter unfiltered feed COD and an effluent filtrate COD sample of 20 ml were taken daily. Effluent COD and solids samples were obtained from the effluent container after it had been thoroughly shaken. About 25 ml of effluent was filtered through a 0.45 u Millipore filter to remove the suspended solids before the twenty milliliter COD sample was taken.

Daily recording of total solids, suspended solids, volatile suspended solids, and percentage ash was performed by the following method. Two evaporation dishes were used for each daily aeration tank and each effluent solids sample taken. Thus, four ceramic evaporation dishes were acid washed, rinsed, dried, dessicated, and tared prior to each days sampling. A twenty five milliliter unfiltered sample and a 25 ml filtrate sample was taken from both the activated sludge aeration tank and the effluent bottle. Overnight drying in a 103°C oven followed by at least one hour of cooling in a dessicator preceeded the first weighing. The unfiltered sample's weight minus the filtrate weight was recorded as suspended solids. The unfiltered weight was noted as total solids. These samples were then ignited at 600°C for fifteen to twenty minutes, allowed to cool, and then weighed. The value difference of the filtered and unfiltered samples after ignition was recorded as volatile suspended solids, VSS. Suspended solids minus VSS gave the ash content. Percentage ash was calculated by dividing the ash content by the suspended solids value and multiplying by 100.

Mean cell residence (θ_c) values were also recorded daily. This was calculated using volatile suspended solids values in the equation below:

$$\theta_c = \frac{VX}{V_w X + (V - V_e) X_e}$$

where

V = aeration tank volume (6.9 liters)

X = aeration tank VSS concentration

V_w = volume of sludge wasted (1.0 liters)

X_e = effluent VSS concentration

Periodic settleable solids data was also recorded. This data was obtained by allowing the 1000 ml volume of daily aeration tank wastage to settle in a graduated cylinder. The level of solids settled after 30 minutes divided by ten was recorded as percent settleable solids. Sludge volume index (SVI) was calculated by dividing the percent settleable solids by the percent suspended solids. Since solids values were recorded throughout this investigation as mg/l, the suspended solids percentage was obtained by dividing the recorded value by 1000. Thus, SVI was determined as below:

$$\text{SVI} = \frac{\%\ \text{settleable solids} \times 10{,}000}{\text{mg/l of suspended solids}}$$

CHAPTER IV

RESULTS

Steady state data was recorded for almost ten days of operation of the laboratory activated sludge unit before dosing with alum sludge began. This initial data is listed in Table VI. After sufficient steady state data was recorded, feeding of alum sludge from a raw water containing 100 mg/l permian red clay was begun. This daily sludge feeding was continued for approximately three weeks by which time a new steady state condition had become well established. This data is listed in Table VII.

The concentration of the soil in the raw water was increased to 200 mg/l during the next three weeks. Table VIII lists the data from this soil concentration. After steady state had been assured with the 200 mg/l water supply, the soil concentration was once again increased. This time about three weeks of data for a 300 mg/l permian red concentration in the raw water was recorded. Table IX lists the results of the investigational experimentation during this period.

COD Removal Performance

A feed COD of 260-300 mg/l was maintained throughout this investigation with few deviations. Since the alum sludge COD was found to be nominal (approximately 30 mg/l), the soluble glucose COD was the only feed COD recorded. The filtered effluent COD was generally in the

TABLE VI

RAW DATA — ZERO ALUM SLUDGE DOSAGE

day	Aeration Unit Solids (mg/l)						Effluent Solids (mg/l)						θ_c	COD (mg/l)		
	total	ss	vss	dissolved	ash	%ash	total	ss	vss	dissolved	ash	%ash		feed	eff	%removed
0	1820	1176	928	644	248	21	632	0	0	632	0		6.90	266	25	91
1	1980	1300	1056	680	244	19	704	28	12	676	16	57	6.47	260	20	92
2	2056	1220	952	836	268	22	856	88	0	768	96	100	6.90	256	20	92
3	2092	1360	1108	732	252	19	796	48	20	748	28	58	6.24	264	28	89
4																
5	1940	1212	980	728	232	19	784	41	17	743	24	59	6.26	264	20	92
6	1588	856	660	732	196	23	736	28	8	708	20	71	6.44	264	20	92
7	1512	768	600	744	168	22	760	28	0	732	28	100	6.90	270		
8	1468	684	680	784	4	1	784	44	12	740	32	73	6.25	258	28	89

TABLE VII

RAW DATA —100 MG/L ALUM COAGULATED SOIL DOSAGE

day	Aeration Unit Solids (mg/l)						Effluent Solids (mg/l)						Θ_c	COD (mg/l)		
	total	ss	vss	dissolved	ash	%ash	total	ss	vss	dissolved	ash	%ash		feed	eff	%removed
9	1264	564	404	700	160	28	728	20	20	704	0	0	5.34	254	32	87
10	1276	560	396	716	164	29	888	192	124	696	68	35	2.42	258	16	94
11																
12	1444	656	408	788	248	38	1000	240	104	760	136	57	2.76	254	16	94
13	1488	720	524	768	196	27	720	56	16	664	40	71	5.85	262	16	94
14	1420	616	387	804	228	37	852	312	104	540	208	67	2.67			
15	1560	868	520	692	348	40	724	56	28	668	28	50	5.24	268	28	90
16																
17	1992	1240	600	752	640	52	804	40	4	764	36	90	6.64	268	35	87
18																
19	2300	1536	768	764	768	50	744	20	0	724	24	100	6.90	264	31	88
20	1668	932	500	736	432	46	696	4	0	692	12	100	6.90	268	28	90
21	1804	1140	568	664	572	50	704	16	0	688	16	100	6.90	264	35	87
22	2516	1832	752	684	1080	59	720	8	8	712	0	0	6.49	272	35	87
23	2880	2156	888	724	1268	59	780	32	4	748	28	88	6.72	260	35	87
24																
25																
26	2156	1848	832	308	1016	55	688	0	0	688	0		6.90	232	25	89
27	2976	2376	796	600	1580	66	556	0	0	556	12		6.90	271	21	92
28	3684	3040	1116	644	1924	63	676	24	8	652	16	67	6.62	271	29	89

TABLE VIII

RAW DATA — 200 MG/L ALUM COAGULATED SOIL DOSAGE

day	Aeration Unit Solids (mg/l)						Effluent Solids (mg/l)						θ_c	COD (mg/l)		
	total	ss	vss	dissolved	ash	%ash	total	ss	vss	dissolved	ash	%ash		feed	eff	%removed
29	2956	2304	828	652	1476	64	652	20	0	632	36	100	6.90	279	25	91
30	3272	2612	1044	660	1568	60	676	36	0	640	44	100	6.90	279	29	90
31	3396	2752	1080	644	1672	59	652	28	4	624	24	86	6.75		25	
32	4268	3560	1380	708	2180	61	748	24	12	724	12	50	6.56	271	18	93
33	5704	5032	1746	672	3284	65	680	40	0	640	60	100	6.90	272	16	94
34	4888	4236	1672	652	2564	61	684	56	48	628	8	14	5.90	268	19	93
35	3324	2692	1048	632	1644	61	732	52	8	680	44	85	6.60	268	16	94
36																
37	5492	4844	1740	648	3104	64	700	28	28	672	0	0	6.30	246	23	91
38	5340	4680	1644	660	3036	65	672	40	16	632	24	60	6.53	242	67	72
39	5324	4668	1540	656	3128	67	680	24	12	656	12	50	6.60	254	23	91
40	4104	3452	1344	652	2108	61	688	48	8	640	40	83	6.67	278	20	93
41	3892	3236	1208	656	2028	63	704	40	20	664	20	50	6.30	282	23	92
42	4908	4248	1388	660	2860	67	688	36	0	652	52	100	6.90	286	20	93
43	6184	5460	1404	724	4056	74	756	56	16	700	40	71	6.47	333	23	93
44	6472	5768	1400	704	4368	76								298	20	93
45																
46																
47	5332	4800	1692	532	3108	65	520	4	0	516	16	100	6.90	282	24	91
48	5428	4856	1708	572	3148	65	536	8	0	528	8	100	6.90	306	20	93
49	7200	6516	1716	684	4800	74	680	16	4	644	12	75	6.81	306	24	92

TABLE IX

RAW DATA — 300 MG/L ALUM COAGULATED SOIL DOSAGE

day	Aeration Unit Solids (mg/l)						Effluent Solids (mg/l)						θ_c	COD (mg/l)		
	total	ss	vss	dissolved	ash	%ash	total	ss	vss	dissolved	ash	%ash		feed	eff	%removed
50	6516	5920	1424	596	4496	76	616	12	4	604	8	67	6.97	308	20	94
51	6320	5688	1572	632	4116	72	680	52	16	628	36	69	6.51	304	20	93
52	5300	4720	1636	580	3084	65	636	40	28	596	12	30	6.27	291	16	95
53	4260	2664	1464	596	2200	60	644	44	44	600	0	0	5.86	300	20	93
54	3844	3288	1234	556	2056	63	560	104	20	456	84	81	6.30	394	20	93
55	3352	2784	1056	568	1728	62	608	36	0	572	40	100	6.90	308		
56	4816	4204	1432	612	2772	66	576	0	0	576	0	0	6.90			
57	6880	6292	1404	588	4888	78	624	32	4	592	28	88	6.79			
58	9700	9104	1716	596	7388	81	624	20	16	604	4	25	6.54			
59																
60	4324	3904	1372	420	2532	65	620	32	12	588	20	62	6.56	286	23	92
61	4832	4260	1280	576	2980	70	600	24	0	576	28	100	6.90	286	15	95
62																
63	4080	3520	948	560	2572	73	496	0	0	496	0		6.90	286	64	78
64	7520	7012	884	508	6128	87	540	20	0	520	40	100	6.90	301	53	82
65	4708	4108	1052	600	3056	74	620	16	8	604	8	50	6.60	297	26	91
66	6452	5824	1352	628	4472	77	632	36	12	596	24	67	6.56	301	30	90
67	5324	4688	1280	636	3408	73	724	88	8	636	80	91	6.65	274	23	92
68	9012	8444	1528	568	6916	82	624	36	0	588	44	100	6.90			

range of 20-30 mg/l with no noticeable trend change throughout the investigation. The COD removal efficiency remained near 90 percent throughout the majority of this study. These results are shown in Figure 2. The arrows in this and the following figures indicate the initiation of an increased soil concentration in the daily alum sludge fed to the biological unit.

Solids Data

Total solid, suspended solids, and volatile suspended solids data were recorded for the biological unit effluent as well as the activated sludge aeration chamber. Figure 3 shows the aeration tank solids data while Figure 4 shows the effluent solids plotted daily.

Examination of the aeration solids plotted in Figure 3 shows that throughout this study the volatile suspended solids remained relatively constant between 1000 and 1500 mg/l while the suspended and total solids followed an increase in concentration. A periodic cycling of total and suspended solids became evident shortly after dosing with alum sludge began. Although the total solids munus suspended solids appears constant in Figure 3, examination of Tables VI through IX show a drop of 150 mg/l in dissolved solids.

The effluent solids results displayed in Figure 4 do not indicate any strong trend change for any of the solids data. However, it does appear that a decrease of about 150 mg/l of total solids occured by the end of this study. This is equivalent to the dissolved solids drop in the aeration chamber. Since suspended solids values remained at fifty milligrams per liter and below for the most part, the reduction in total solids was caused by a reduction in dissolved solids during this investigation.

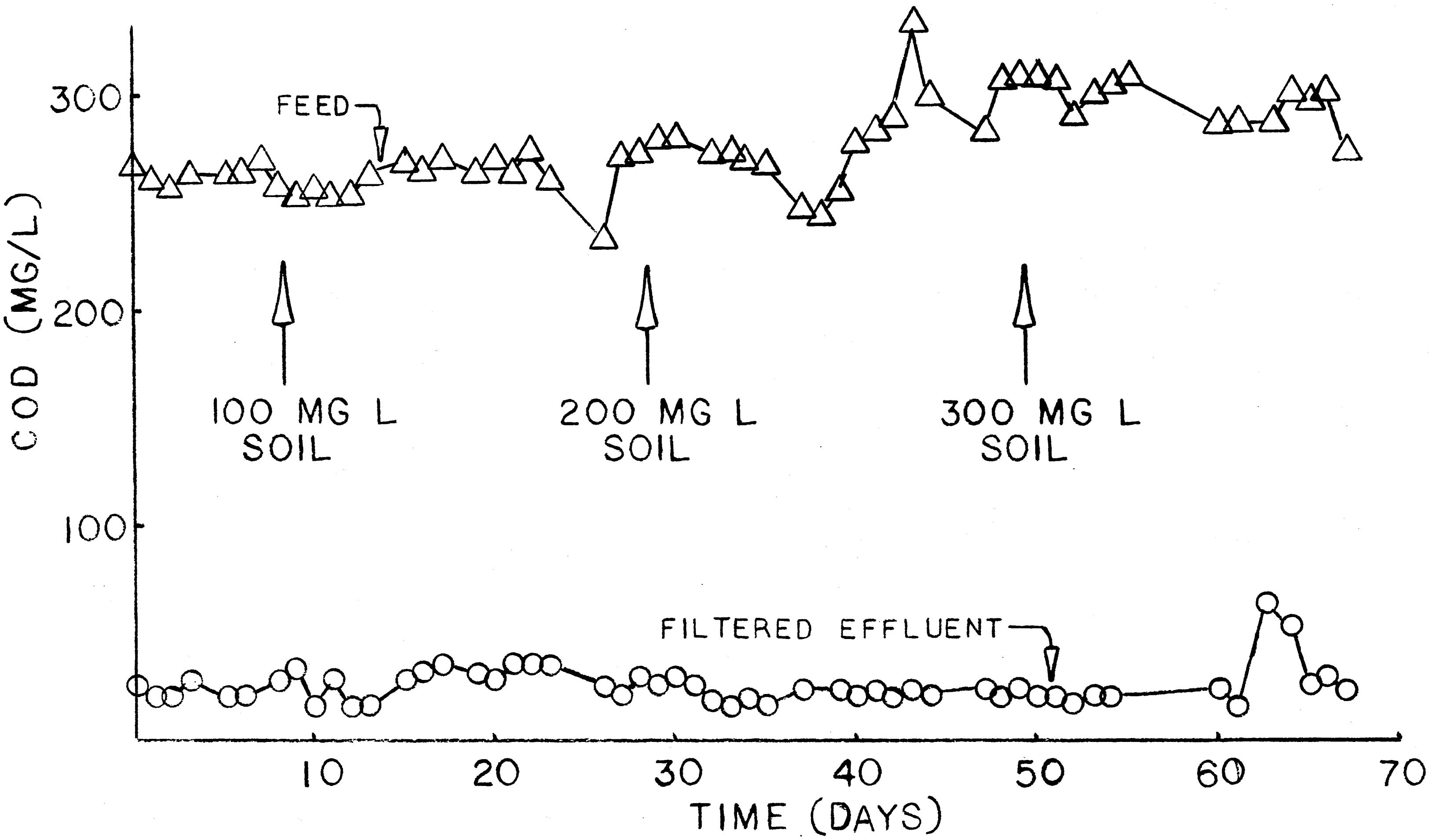

Figure 2. COD Results

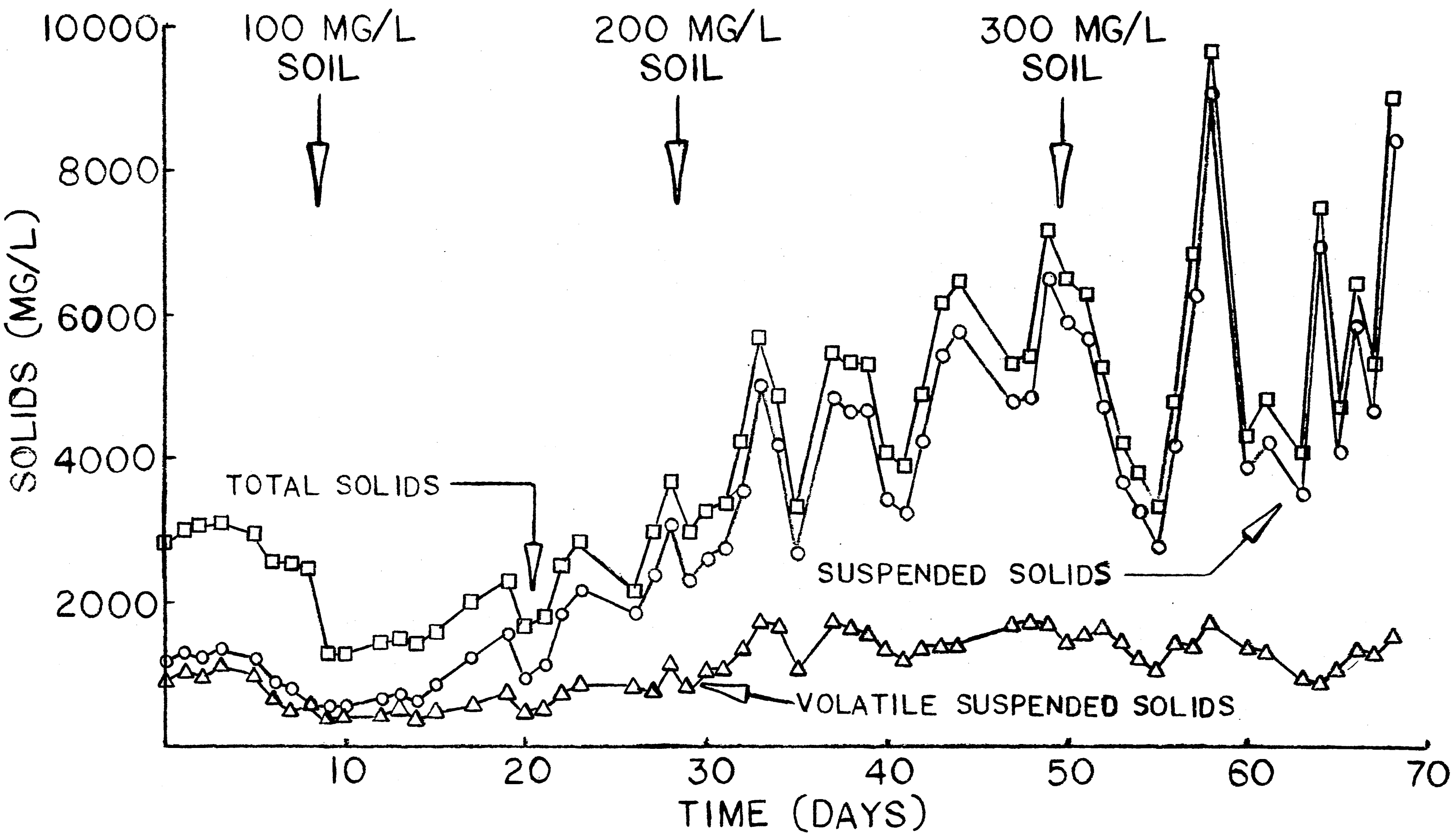

Figure 3. Aeration Solids

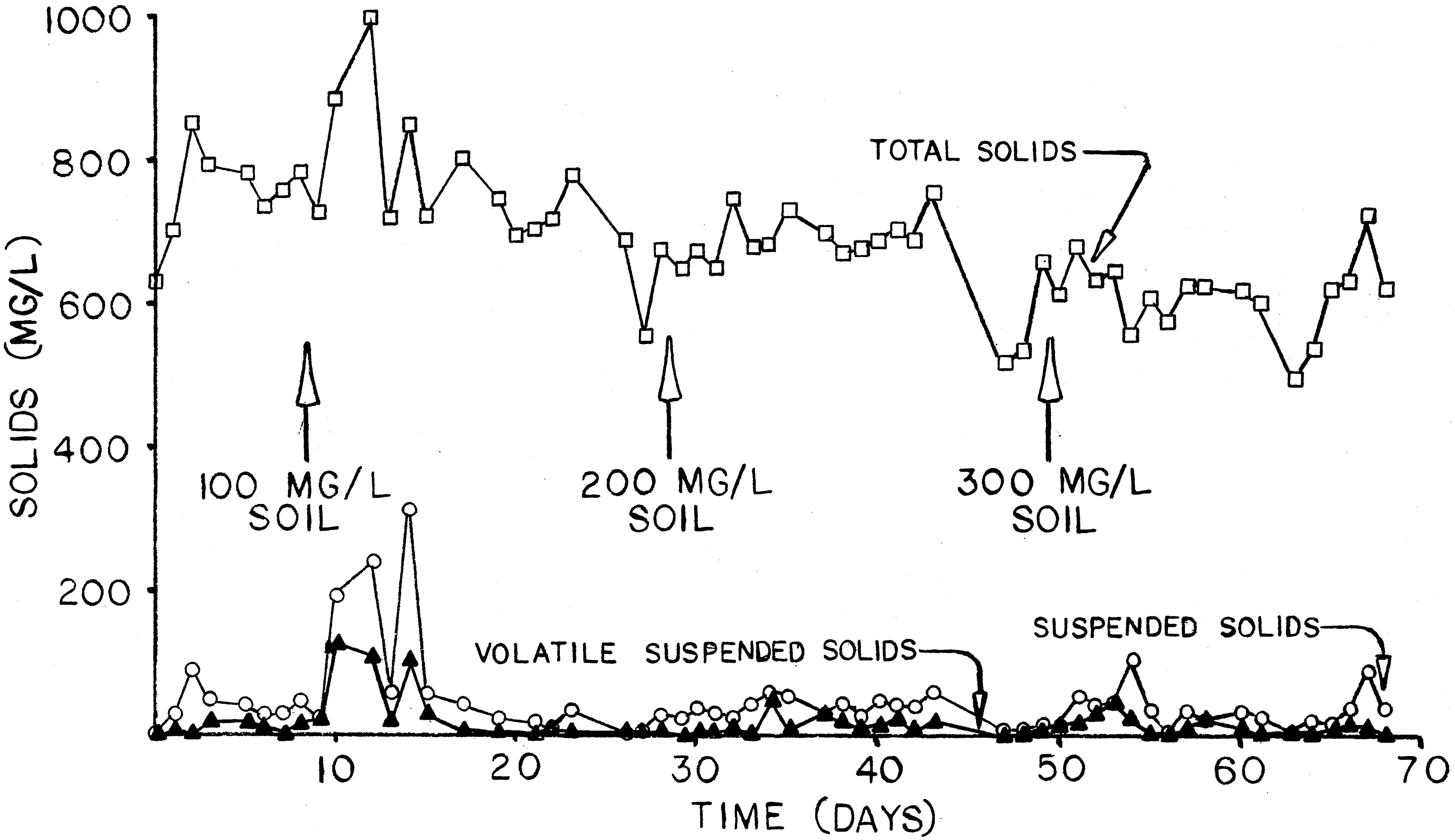

Figure 4. Effluent Solids

Mean Cell Residence Time

Except for a severe dip in the mean cell residence time (θ_c) immediately following the first week of alum sludge addition to the biological unit, Figure 5 displays no major variation of θ_c with time. For the most part, θ_c values of 6.5–6.9 were recorded. A θ_c of 6.9 occurred when no volatile suspended solids were found in the effluent.

Settleable Solids

Settleable solids experiments were conducted periodically throughout this investigation. These results are reported in Table X along with the calculated sludge volume index (SVI) values. Figure 6 is a graphical plot of the percent settleable solids in the activated sludge aeration chamber. This figure displays a sharp initial increase in settleable solids followed by a not too gradual decrease to a level approximately ten percent below the initial value. The author failed to run settleable solids experiments during days 5 to 25 due to the poor settling which existed. Figure 7 shows a similar plot of the SVI values. However, examination of this figure shows a final SVI level below 50. This was well below the values prior to alum sludge addition. Thus, since there is a threefold increase in solids during this study, the return to a comparable settleable solids level and the reduction in SVI indicate that increased compaction of the activated sludge resulted due to the alum sludge addition.

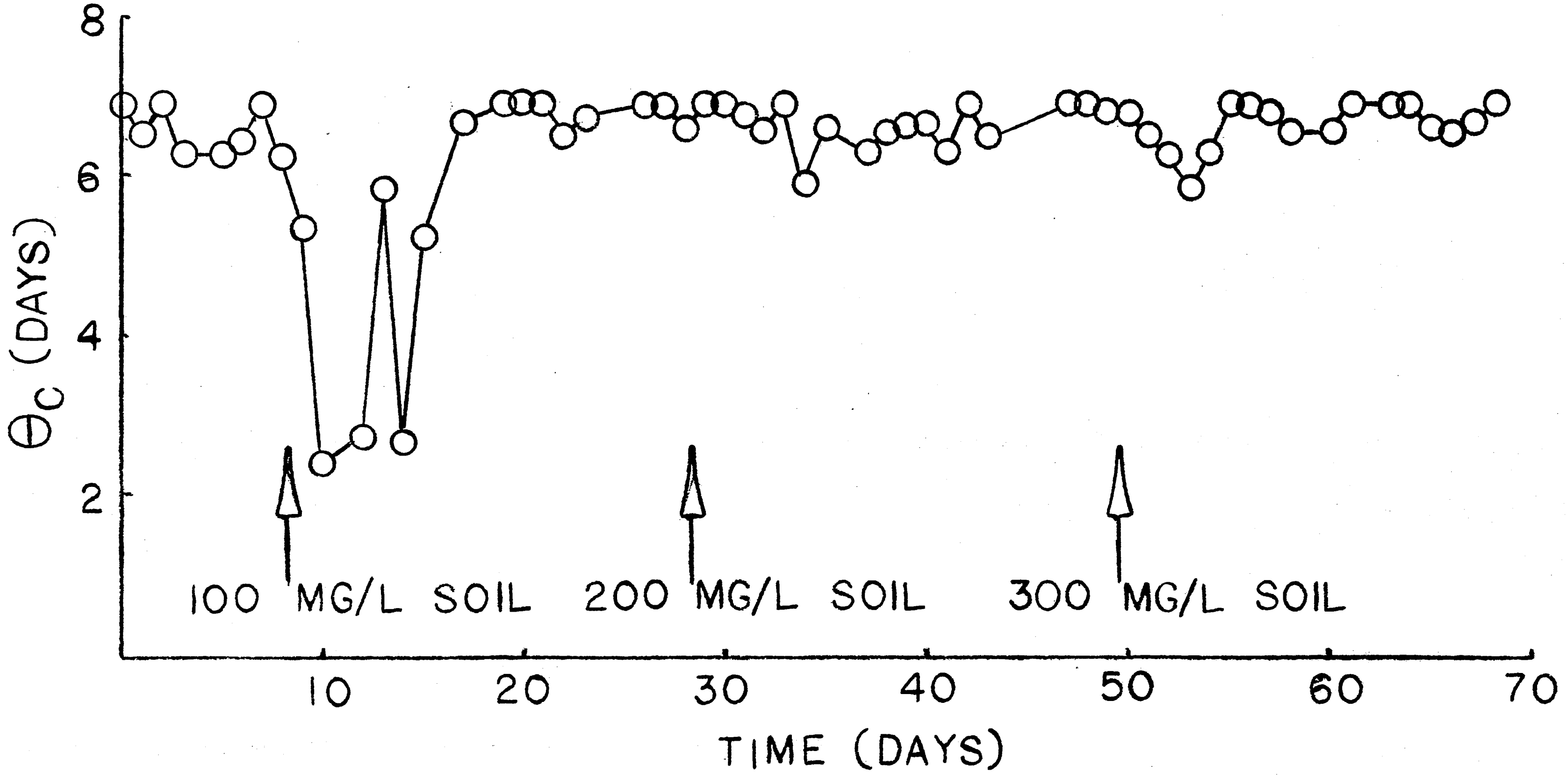

Figure 5. Mean Cell Residence Time

TABLE X

SETTLEABLE SOLIDS

day	% settleable solids	SVI
1	32	246
2	55	451
3	97	713
28	87	286
31	79	287
32	30	84
33	24	48
35	15	56
37	20	45
39	21	45
42	93	219
55	14	50
56	14	33
61	19	45
66	13	22

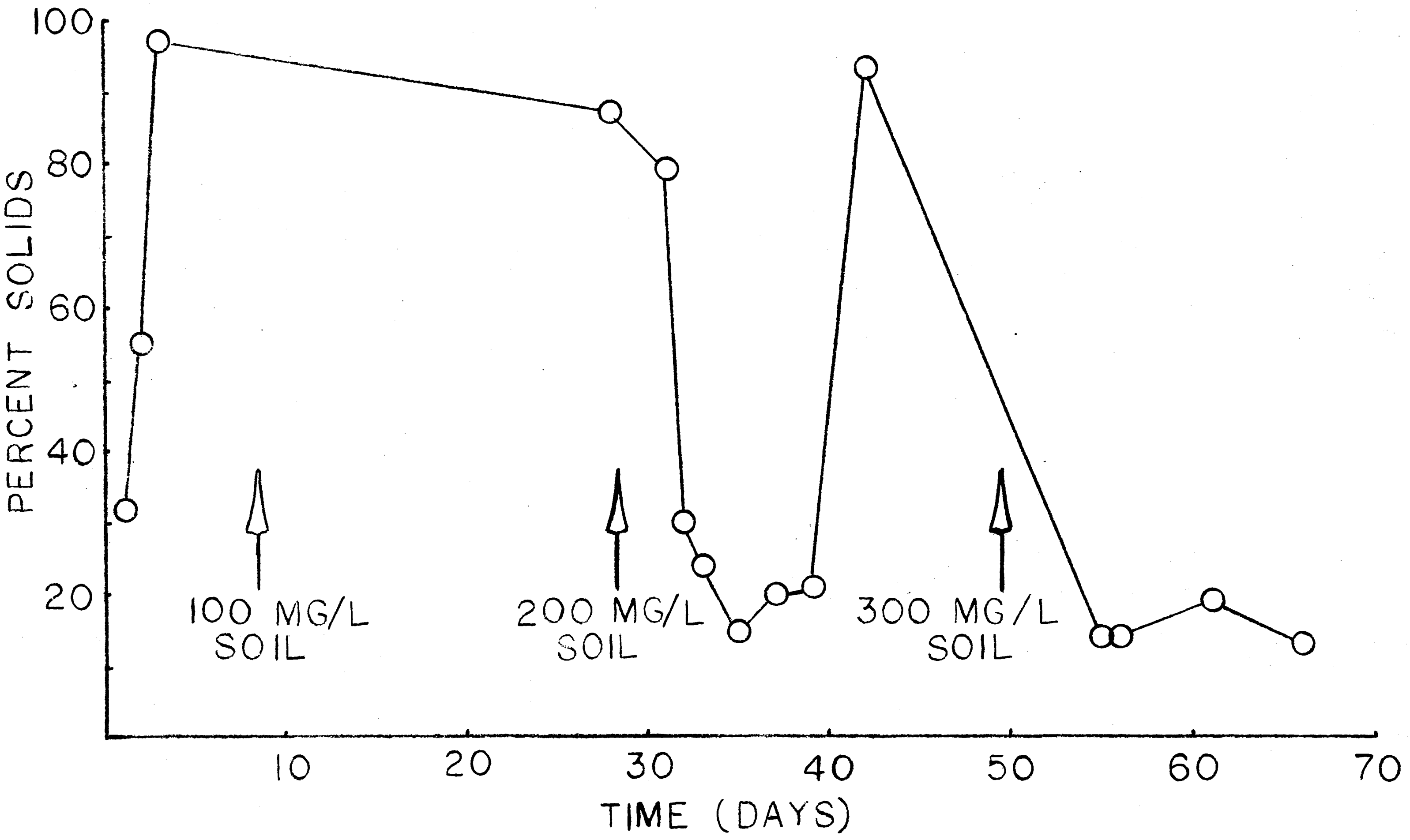

Figure 6. Settleability

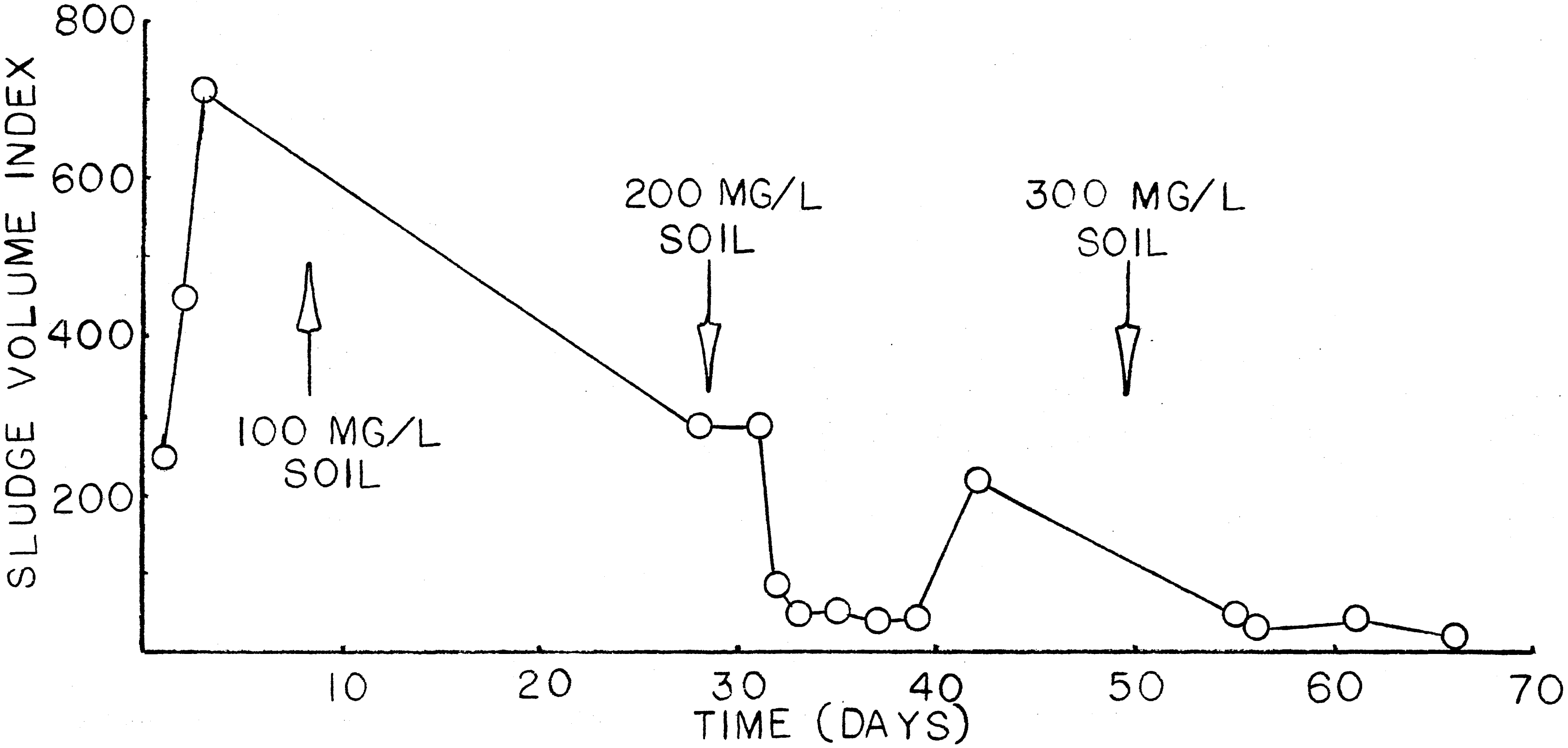

Figure 7. Sludge Volume Index

CHAPTER V

DISCUSSION

In order to determine the impact of alum sludge on the operational performance of a bench scale activated sludge unit, the author chose to produce a synthetic alum sludge of known composition. This was done by the addition of known concentrations of permian red clay to tap water followed by coagulation of the soil with a constant concentration of aluminum sulfate.

Approximately one-third liter of alum sludge was prepared and fed to the activated sludge unit daily. The COD of the alum sludge was experimentally determined to be 30 mg/l. Since the raw water impurities had been removed at the Oklahoma State University water purification plant, this COD value was considerably lower than those given in Table I.

Thus, prior removal of raw water impurities could perhaps account for a difference between the observed results and actual field results. However, a review of the literature indicates that no problems in substrate removal efficiency due to the additional COD were ever encountered in field operations.

COD Results

Since the relationship between the glucose feed COD and the filtered effluent COD as shown in Figure 2 may be difficult to interpret, the COD removal efficiency has been graphically illustrated in Figure 8. This plot is nearly a mirror image of the effluent COD line shown in Figure 2. Since the soluble glucose COD was maintained relatively constant, this was to be expected. Nevertheless, examination of Figure 8 reveals no significant change in the wastewater unit's COD removal efficiency throughout this study.

The shallow dip in removal efficiency immediately following the first few days of alum sludge addition and the two sharp dips at day 38 and days 63 and 64 are considered insignificant. Thus, it can be concluded that disposal of alum sludge into an activated sludge unit does not interfere with the substrate removal efficiency of the wastewater treatment system.

Solids Results

A reduction of dissolved solids in the wastewater unit effluent is apparent in Figure 9. This drop of 150 mg/l could be due to the continued addition of the alum sludge. Perhaps, the coagulating effects of the aluminum hydroxide in alum sludge caused a noticeable amount of the dissolved solids to coalesce and thus become suspended. An equivalent reduction in dissolved solids concentration was recorded in the aeration chamber. This fact helps substantiate the theory of coagulation by the alum sludge since the kinetics of completely mixed units define the dissolved solids level leaving the unit to be equal to the dissolved solids level in the unit.

As noted in Chapter IV, the total solids and the suspended solids in the aeration chamber of the activated sludge unit increased as the investigation progressed. These solids values when plotted in Figure 3

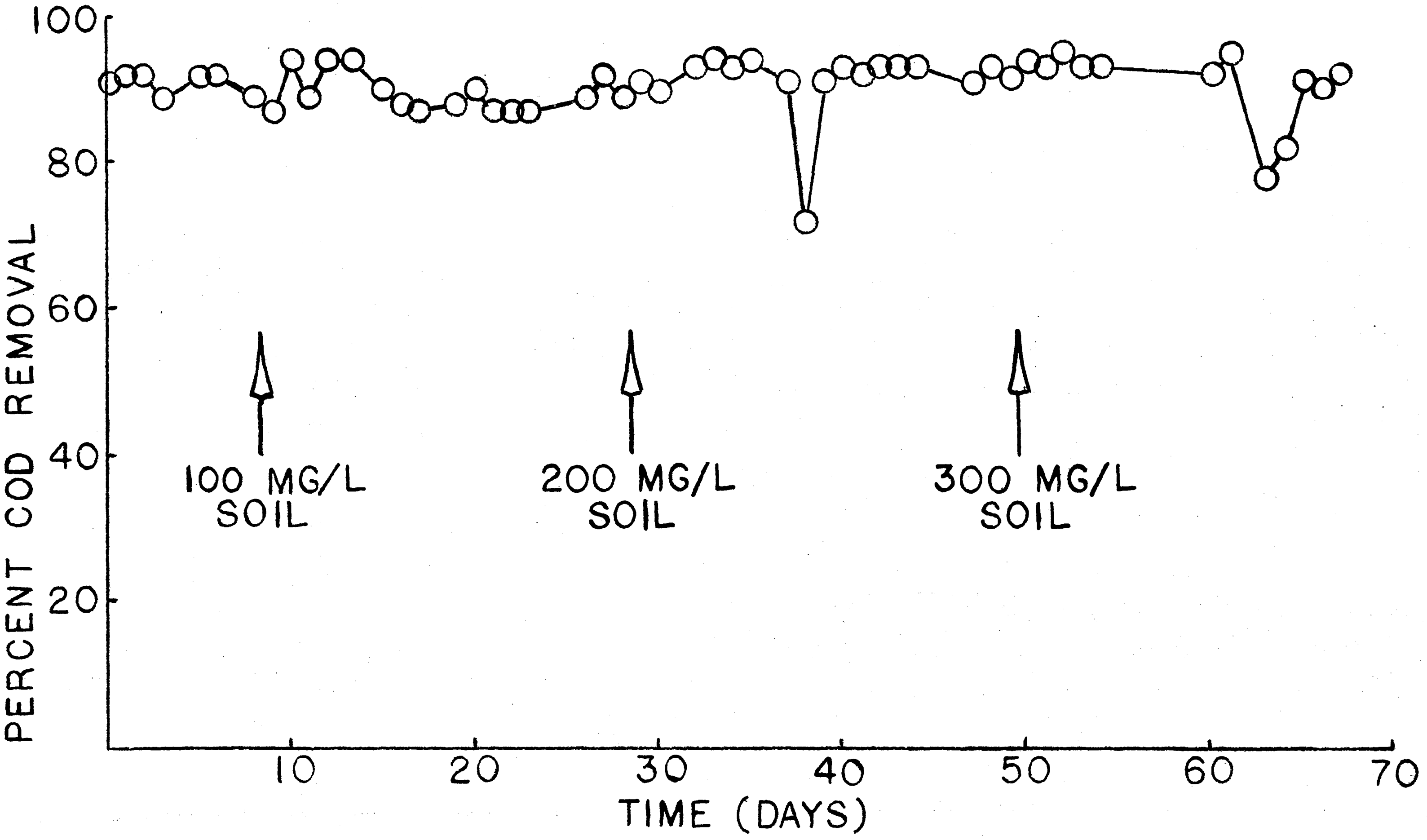

Figure 8. Percent COD Removal

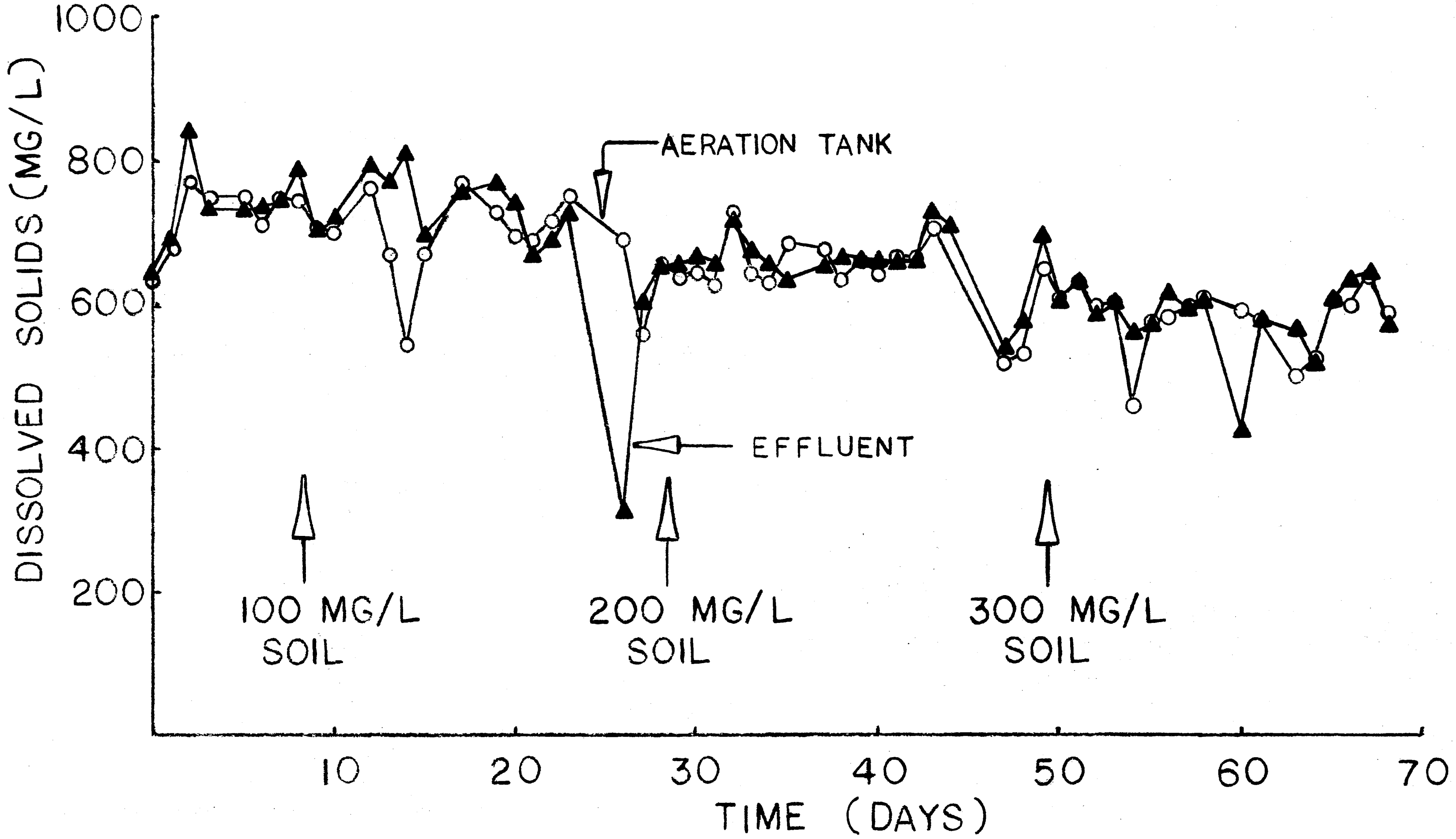

Figure 9. Dissolved Solids

were also noticed to exhibit a cyclic change in concentration. The reason these changes in solids levels and ash content occurred is unclear.

Microbial predominance changes would not explain such a change in ash content since this would not account for the loss of inorganics from the unit and a washout of inorganics was never noticed in the effluent data. Granted, microbial predominance changes may well have occurred during this study but this does not explain what happened to the inorganic solids. Certainly, no change from an insoluble inorganic state to a soluble condition existed since an increase instead of a decrease in the dissolved solids would have resulted.

Because the ash content dropped considerably at times (especially during days 49-55) without producing a resulting rise in the effluent ash content, the inorganic portion must have built up considerably in the clarification chamber. In light of the fact that problems with sludge recycle were commonly plaguing the author during the operation of the bench scale unit, a build up of inorganics in the clarifier is a reasonable explaination of this cycling phenomenon. The fact that a very large drop in ash content and thus suspended and total solids occurred immediately following dosage with 300 mg/l soil is therefore considered coincidental.

In general, the daily addition of the highly inorganic sludge to the biological unit increased the ash content significantly. Initially, the ash content in the aeration unit was about 20 percent. By the termination of this study, the ash content had increased to over 75 percent. The build up of ash in the unit resulted in increased total and suspended solids concentrations. The volatile suspended solids concentration also showed a slight increase during this study. However, this increase was not nearly as substantial as the suspended solids increase and was assumed insignificant. The data from this study seems to indicate that the substrate removal efficiency of an activated sludge unit is unaffected by a high ash content so long as the ash in non-toxic and so long as a sufficient active biological population is maintained. Gaudy, Manickam, Saidi, and Reddy (25) have reported on an activated sludge unit with an ash content of 50-60 percent which has operated for about one and one-half years at a filtrate COD removal efficiency of over 90 percent. Thus, long term operation of activated sludge units with high ash content has been proven possible.

Aluminum Concentration and State

Alkalinity tests were run on the tap water to determine the amount of alum, if any, that remained as aluminum sulfate instead of being converted to aluminum hydroxide during coagulation as below:

$$Al_2(SO_4)_3 \cdot 18H_2O + 3Ca(HCO_3)_2 = 2Al(OH)_3 + 3CaSO_4 + 6CO_2 + 18H_2O$$

Following the procedure outlined in Standard Methods (24), the total and phenolphthalein alkalinity of the tap water were determined. The phenolphthalein alkalinity was found to be zero and the total alkalinity was found equal to 140 mg/l as $CaCO_3$. Tht total alkalinity of the tap water existed wholly as bicarbonate alkalinity. Since the molecular weight of $CaCO_3$ equals 100, the number of moles of alkalinity present was 1.40.

The stoichiometric balance of the above equation shows that 1.40 moles of bicarbonate alkalinity will react with 4.20 moles of aluminum sulfate to produce aluminum hydroxide. However, as given in Chapter III, only 5.8 mg/l as aluminum was added to the water treatment unit. This is equivalent to 0.2 moles of aluminum of 0.4 moles of aluminum sulfate. This is well below the molar concentration of aluminum sulfate which the bicarbonate alkalinity present can convert to aluminum hydroxide. Thus, it was found stoichiometrically that all the alum added to the raw water in the form of aluminum sulfate was converted to aluminum hydroxide and was fed to the biological unit as a hydroxide sludge.

In order to determine the concentration of aluminum hydroxide in the aeration tank, a dilute-in curve was calculated. Since the daily alum sludge dosage had a constant concentration of aluminum sulfate and since it was reported in the Literature Review that nearly 100 percent of the aluminum fed to an activated sludge unit remains insoluble, dilute-in values could be calculated as follows:

5.8 mg/l of aluminum exist in the water treatment unit

21.0 liters is the water treatment unit volume

6.9 liters is the activated sludge aeration tank volume

then,

$$(5.8\ \text{mg/l})\frac{(21.0\ \text{liters})}{(6.9\ \text{liters})} = 17.6\ \text{mg/l of aluminum as fed to the biological unit}$$

however,

1.0 liter of activated sludge was wasted daily

therefore,

$$\frac{(6.9\ \text{liters} - 1.0\ \text{liters})}{6.9\ \text{liters}} = 0.855\ \text{of initial aluminum concentration is left on the second day}$$

so,

$$(0.855)(C_t) + 17.6 = C_{t+1}$$

where C_t = aluminum concentration at day t

C_{t+1} = aluminum concentration at day t+1

Values for an aluminum dilute-in curve were calculated as above and are listed in Table XI and graphically displayed in Figure 10. These values show that the aluminum concentration increased rapidly to about 120 mg/l where it leveled off. Since the activated sludge unit operated at an aluminum hydroxide concentration of approximately 120 mg/l for about forty days without any noticeable effects on the treatment efficiency resulting, it is concluded that such a concentration of aluminum hydroxide is non-toxic to the system.

According to Hsu and Pipes (22), an aluminum hydroxide concentration below 150 mg/l as aluminum should increase the effluent suspended solids level. This theory was not supported by the results of the author's investigation since increased settling was observed below an aluminum concentration of 150 mg/l (see Figures 6 and 9).

Granted, the unit initially appeared to react to the alum sludge by discharging high suspended solids levels in the effluent. However, the author believes this sudden increase in effluent solids was due to a coincidential disruption of the activated sludge system because many such disruptions were observed prior to the initiation of this study. Careful examination of Figure 3 shows that a drop in aeration chamber solids had been occurring for four days prior to the first dosing with alum sludge. It is believed that this disruption continued through about day 20 when the unit returned to a stable condition.

TABLE XI

CALCULATED ALUMINUM DILUTE-IN VALUES

Day	Aluminum in aeration tank (mg/l)	Day	Aluminum in aeration tank (mg/l)
1	0	26	114.2
2	0	27	115.2
3	0	28	116.1
4	0	29	116.9
5	0	30	117.6
6	0	31	118.1
7	0	32	118.6
8	0	33	119.0
9	17.6	34	119.4
10	32.6	35	119.7
11	45.5	36	119.9
12	56.5	37	120.1
13	65.9	38	120.3
14	74.0	39	120.5
15	80.8	40	120.6
16	86.7	41	120.7
17	91.8	42	120.9
18	96.1	43	120.9
19	99.7	44	121.0
20	102.9	45	121.1
21	105.6	46	121.1
22	107.9	47	121.1
23	109.8	48	121.2
24	111.5	49	121.1
25	113.0	50	121.2

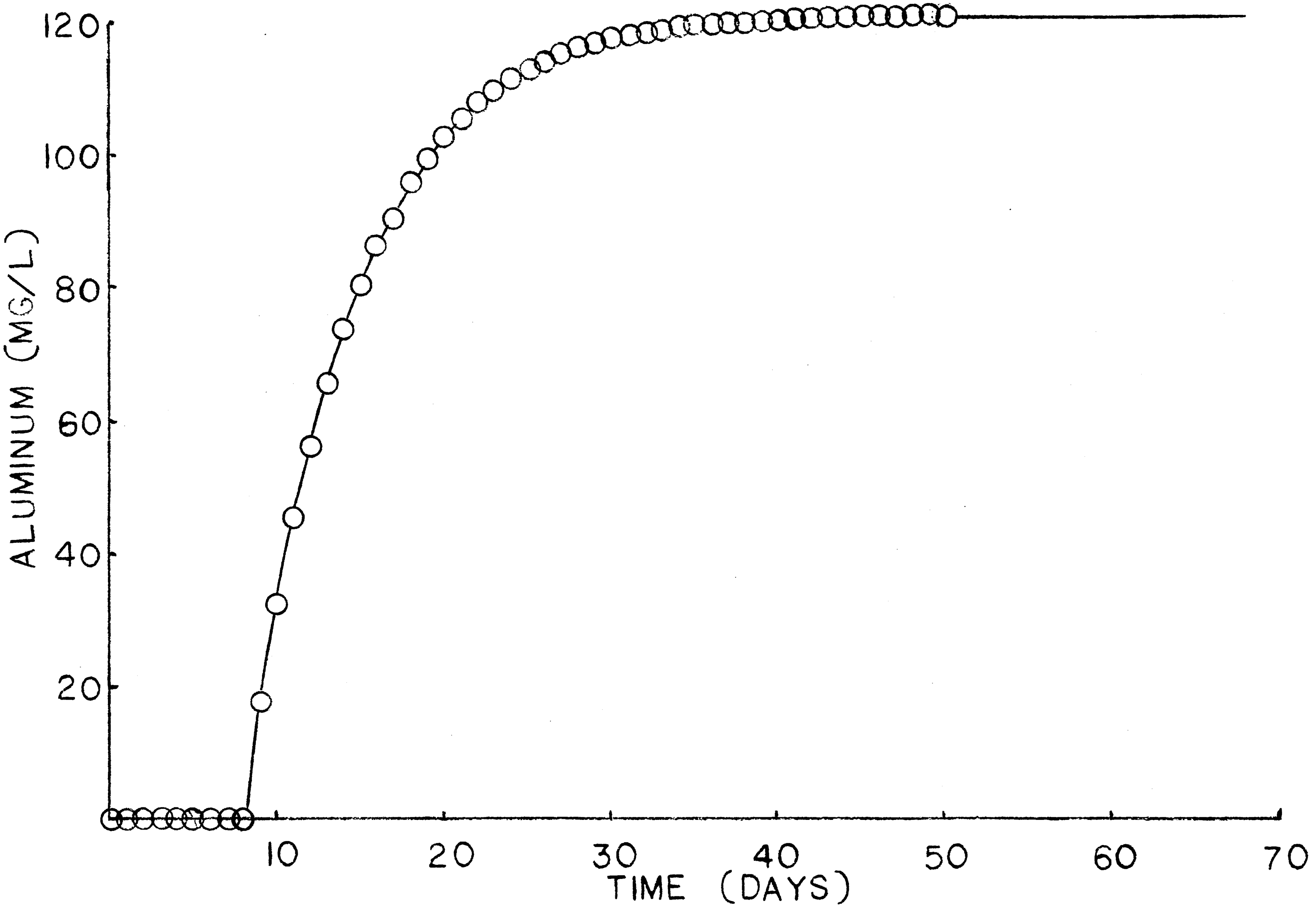

Figure 10, Aluminum Dilute-In

CHAPTER VI

CONCLUSIONS

Based upon the results of this investigation utilizing a completely mixed bench scale activated sludge reactor as a disposal unit for synthetic alum sludge, the following conclusions can be drawn:

1. Daily addition of alum sludge does not interfere with the substrate removal efficiency of an activated sludge unit.

2. Daily addition of alum sludge lowers the sludge volume index of raw waste activated sludge and appears to aid the settleability.

3. Daily addition of alum sludge does not affect the effluent suspended solids concentration.

4. Daily addition of alum sludge decreases the dissolved solids level in an activated sludge wastewater treatment system.

5. Daily addition of alum sludge increases the inorganic fraction of an activated sludge unit.

6. An inorganic fraction (ash content) of over 70 percent as produced by alum sludge addition does not interfere with the operation of an activated sludge unit.

CHAPTER VII

SUGGESTIONS FOR FUTURE STUDY

Because of the lack of research on the effectiveness of alum sludge disposal by sewer discharge, much research on this topic needs to be done. Based on questions raised during this study and a lack of background research, the following suggestions are presented for future study:

1. Study the impact of various alum sludge dosage rates (e.g. daily—over two hours, three hours, etc., twice a day dosing, every other day dosing, weekly dosing, etc.) on the operation of an activated sludge unit.

2. Study the impact of various alum sludges (that is, sludges with varying types and degrees of organic as well as inorganic contaminants) on the operation of activated sludge units.

3. Study the impact of alum sludge on an activated sludge unit at detention times other than 12 hours.

4. Study the impact of alum sludge on an activated sludge unit at θ_c values other than 6.9 days.

5. Conduct studies to determine whether the initial alum sludge dosages create temporary disruption of activated sludge units.

6. Conduct studies to determine the required velocity necessary to prevent the settling of alum sludge in sewer lines. Also, study the effects of alum sludge on a sewer system.

7. Study the effects of alum sludge on the operational performance of trickling filters, biological towers, and rotating biological contactors.

8. Study the filterability of alum—activated sludges.

9. Study the impact of final disposal methods of alum—activated sludges on the environment in order to assure environmentally compatable methods of disposal.

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