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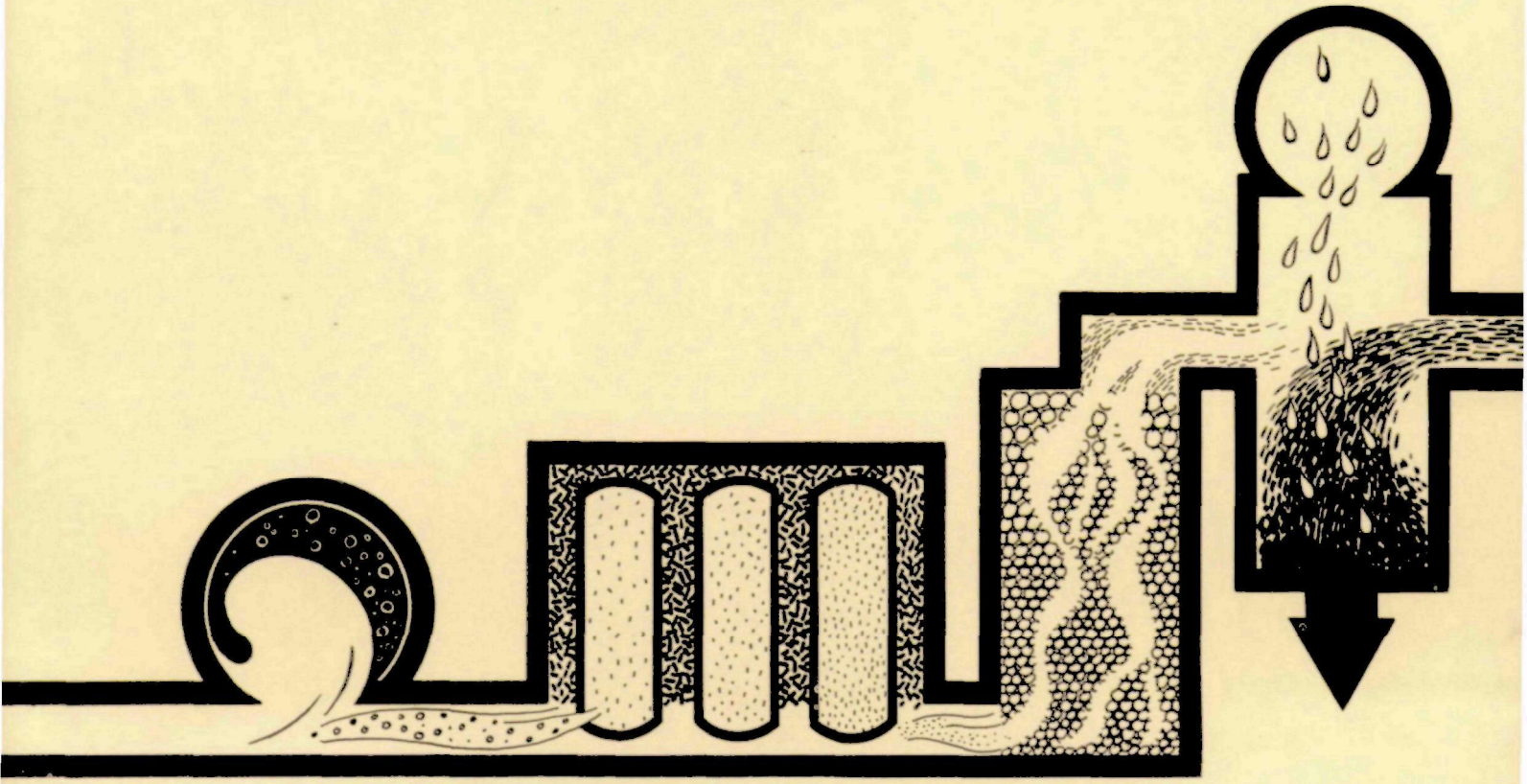
Soluble Phosphorus Removal in the Activated Sludge Process

Part II
Sludge Digestion Study



U.S. ENVIRONMENTAL PROTECTION AGENCY

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SOLUBLE PHOSPHORUS REMOVAL IN THE ACTIVATED SLUDGE PROCESS

PART II

SLUDGE DIGESTION STUDY

by

The Soap and Detergent Association

New York, N. Y. 10016

for the

Office of Research and Monitoring
ENVIRONMENTAL PROTECTION AGENCY

Project #17010 EIP

October 1971

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ABSTRACT

Sludges containing aluminum phosphorus precipitates from an activated sludge wastewater treatment plant were digested in a high-rate digester. Sodium aluminate and liquid alum were used to precipitate the phosphorus from the wastewater. Analyses on both raw and digested sludges showed that once precipitated from the wastewater and incorporated into a sludge the phosphorus did not redissolve while undergoing anaerobic digestion. Most of the soluble phosphorus in both the raw and digested sludges was in the orthophosphate form, and the addition of the inorganic aluminum phosphorus complexes did not adversely effect the anaerobic digester. High concentrations of soluble aluminum ion did not appear in the anaerobic digester, and the use of alum for phosphorus removal caused no additional hydrogen sulfide production during sludge digestion. Analyses also indicated the addition of aluminum compounds enhanced the dewatering properties of the raw sludges.

This report was submitted in fulfillment of Project Number 17010 EIP under the partial sponsorship of the Environmental Protection Agency.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
LIST OF FIGURES	vii
LIST OF TABLES	viii
CONCLUSIONS	1
RECOMMENDATIONS	3
INTRODUCTION	5
ORIGIN AND IMPORTANCE OF THE STUDY	5
STATEMENT OF THE PROBLEM	6
EXPERIMENTAL FACILITIES AND PROCEDURES	7
EXPERIMENTAL FACILITIES	7
Sampling Technique	11
Flow Measurements	12
Sludge Flows	12
Supernatant Return	14
Gas Volume	14
ANALYTICAL TESTS AND PROCEDURES	14
Aluminum	14
Alkalinity	16
Dewatering of Sludges	16
Filtration	16
Gas Analysis	16
pH	16
Phosphorus	16
Solids	17
Sulfate	17
Volatile Acids	17
EXPERIMENTAL RESULTS AND DISCUSSION	19
PHOSPHORUS BALANCE	19
DIGESTER OPERATION	24
pH	30
ALKALINITY AND VOLATILE ACIDS	30
GAS PRODUCTION AND VOLATILE SOLIDS DESTRUCTION	35
SULFATE	38
ALUMINUM	42
SLUDGE DEWATERING	42
GENERAL DISCUSSION	47

TABLE OF CONTENTS (continued)

Page

ACKNOWLEDGEMENTS. 53

BIBLIOGRAPHY. 55

APPENDIX. 57

LIST OF FIGURES

Figure		Page
1	FLOW DIAGRAM OF WASTEWATER THROUGH THE TREATMENT FACILITY .	8
2	FLOW DIAGRAM OF SLUDGE THROUGH THE TREATMENT FACILITY . . .	9
3	CUMULATIVE TOTAL PHOSPHORUS BALANCE OF THE DIGESTER	20
4	CUMULATIVE TOTAL SOLUBLE PHOSPHORUS AND ORTHOPHOSPHATE BALANCES OF THE DIGESTER	22
5	DIGESTER PROFILE OF THE SOLIDS LEVELS IN THE PRIMARY DIGESTER	25
6	DIGESTER PROFILE OF THE SOLIDS LEVELS IN THE SECONDARY DIGESTER	26
7	DIGESTER PROFILE OF THE TOTAL PHOSPHORUS CONCENTRATIONS IN THE SECONDARY DIGESTER.	27
8	DIGESTER PROFILE OF SOLUBLE PHOSPHORUS CONCENTRATIONS IN THE SECONDARY DIGESTER ON JULY 30, 1969.	28
9	CUMULATIVE TOTAL SOLIDS BALANCE OF THE DIGESTER	29
10 a&b	pH VALUES OF VARIOUS SLUDGES THROUGHOUT THE STUDY PERIOD. .	31
11 a&b	ALKALINITY AND VOLATILE ACIDS OF DIGESTED SLUDGE DURING THE STUDY PERIOD	33
12 a&b	DIGESTER GAS PRODUCTION AND VOLATILE SOLIDS LOADING	36
13 a&b	DIGESTER GAS PRODUCTION AND REDUCTION OF VOLATILE SOLIDS. .	39
14	QUANTITATIVE ANALYSIS OF DIGESTER GAS	41
15	SULFATE ION CONCENTRATIONS OF THE SLUDGES	43
16	ALUMINUM ION CONCENTRATIONS OF THE SLUDGES.	44
17	TIME OF VACUUM BREAK AS A FUNCTION OF FERRIC CHLORIDE CONCENTRATIONS ADDED TO WASTE ACTIVATED SLUDGE	48
18	TIME OF VACUUM BREAK AS A FUNCTION OF FERRIC CHLORIDE ADDED TO A 75 PERCENT WASTE ACTIVATED 25 PERCENT RAW SLUDGE MIXTURE	49
19	TIME OF VACUUM BREAK AS A FUNCTION OF FERRIC CHLORIDE ADDED TO A 50 PERCENT WASTE ACTIVATED 50 PERCENT RAW SLUDGE MIXTURE	50
20	A TYPICAL PLOT OF t/V (TIME/VOLUME) AGAINST V (VOLUME) FROM RESULTS OF DEWATERING STUDIES, RUN NO. 1, 9/2/69. . .	59

LIST OF TABLES

Table		Page
1	COMPARISON OF SOLUBLE ALUMINUM ION CONTENT OF DIGESTED SLUDGES BY SPECTROCHEMICAL ANALYSIS VS. THE RAPID MODIFIED ERIOCHROME CYANINE R METHOD	15
2	COMPARISON OF TOTAL PHOSPHORUS CONTENT OF SLUDGES DETERMINED BY A MODIFIED ALKALINE ASH PROCEDURE VS. THE POTASSIUM PERSULFATE METHOD.	18
3	TOTAL SOLUBLE PHOSPHORUS IN THE DIGESTED SLUDGE	23
4	SPECIFIC RESISTANCE AND TOTAL SOLIDS OF SLUDGES	46

CONCLUSIONS

The conclusions which were drawn from this investigation are:

1. Most of the soluble phosphorus in both the raw and digested sludges was in the orthophosphate form.

2. Once precipitated from the wastewater and incorporated into a sludge the phosphorus did not redissolve while undergoing anaerobic digestion, even during a digester upset.

3. The addition of inorganic aluminum phosphorus complexes did not adversely effect the anaerobic digestion process.

4. The use of alum for the removal of phosphorus from wastewater caused no additional hydrogen sulfide production during sludge digestion.

5. High concentrations of soluble aluminum ion did not appear in the anaerobic digester, and aluminum ion toxicity was not apparent.

6. The addition of aluminum compounds for the removal of phosphorus enhanced the dewatering properties of the raw sludges.

RECOMMENDATIONS

During this investigation, it became apparent that further study in the following areas might prove beneficial:

1. A laboratory scale study to determine the maximum aluminum phosphate precipitate concentration which can be tolerated under an anaerobic environment.

2. A study to investigate the effects of the phosphorus enriched sludge on crops and its economic potential as a commercial fertilizer.

3. A study to investigate the economic feasibility of dewatering and wet oxidation of raw sludge containing the chemical precipitates, as a means of sludge disposal.

INTRODUCTION

ORIGIN AND IMPORTANCE OF THE STUDY

The effects of excessive eutrophication in bodies of water has pointed to the need for controlling nutrient additions in water courses. The control of excessive eutrophication as indicated by Leibig's Law of the minimum points to the limitation of some nutritional requirement (14). Phosphorus removal from wastewater treatment plant effluents has been suggested as a means of control by many people (5) (11) (14) (15). Currently, the removal of phosphorus from wastewater discharges is a major area of investigation and research in the field of environmental pollution control. Nesbitt (11) reviewed phosphorus removal methods and showed the method of chemical treatment as most economical because of the ability to incorporate existing treatment facilities in effecting phosphorus removal.

The removal of phosphorus from wastewater by means of chemical precipitation requires the use of a positively charged cation. Five commonly investigated precipitants include lime, aluminum sulfate (alum), sodium aluminate, ferric chloride, and ferric sulfate. All of these coagulants will form a precipitate in which the phosphate ion will bind to the positively charged cation and settle out of solution. Once the phosphorus has been precipitated from solution and incorporated in the sludge, the problems of treatment, handling, and disposal remain. The phosphorus enriched sludge must be treated and/or disposed of in a suitable manner before the problem of nutrient phosphorus removal is effectively solved. This solution requires a knowledge of the effects of this inorganic phosphorus cation precipitate upon methods of sludge treatment, and the effects of sludge treatment on the inorganic phosphorus precipitate.

Controlled anaerobic decomposition of organic raw sludges has been a widely practiced process in wastewater treatment, and the addition of inorganic compounds such as a cation-phosphorus complex into the raw sludges could alter this process. The redissolving of the cation during the digestion process may cause a toxic condition which the bacterial population could not tolerate. Soluble forms of heavy metals, high concentrations of metals, and high concentrations of various salts have been shown to hinder the anaerobic digestion process (9) (12) (13) (20).

Rudolfs et al. (13) reported a retardation in the digestion of some sludges containing iron compounds, while Barth and Ettinger (2) reported acceptable sludge digestion in a pilot plant study using aluminum compounds.

Along with the toxic effect of a metal cation the introduction of excessive amounts of soluble sulfate ion into the digester has caused concern because of the possible production of hydrogen sulfide gas. Although studies utilizing aluminum sulfate for phosphorus removal have been reviewed (1) (2) (5) (23), no results on hydrogen sulfide production were reported.

The dissolving of the cation is not the only area of concern in chemical treatment of wastewaters to achieve phosphorus removal. If the cation-phosphorus precipitate were to redissolve in the digester, the phosphorus could be returned to the wastewater treatment system via the supernatant return and the entire phosphate removal scheme negated. However, various studies to date indicate that the phosphorus precipitate remains insoluble during anaerobic digestion (2) (22) (23).

Finally, to help reduce sludge disposal cost, sludge dewatering may be practiced. The addition of an aluminum compound to activated sludge for removal of phosphorus may also act as a beneficial preconditioning step if vacuum filtration is used for this dewatering.

STATEMENT OF THE PROBLEM

This investigation was conducted on sludges fed to a treatment plant digester, which included precipitates formed by the addition of sodium aluminate [liquid, $Na_2Al_2O_4$] or alum [liquid, $Al_2(SO_4)_3$] to the wastewater being treated in an activated sludge system.

Specific objectives of this research were:

1. To determine the effects of the inorganic precipitate on the anaerobic digestion process.

2. To determine if the aluminum-phosphorus precipitate is harmful to the digestion process.

3. To determine the identity of the different forms of phosphorus, and the effects of anaerobic digestion on them.

4. To determine if the excess sulfate ion, released into solution during phosphate removal utilizing alum, increases the production of hydrogen sulfide.

5. To determine effects of the aluminum-phosphorus precipitate on the dewatering properties of raw sludges.

EXPERIMENTAL FACILITIES AND PROCEDURES

EXPERIMENTAL FACILITIES

The sludge digestion system used in this study was a two-stage system located at the Pennsylvania State University Wastewater Treatment Plant. The plant is designed to accommodate flows of 4 mgd, and receives and treats nearly equal wastewater flows from both the Pennsylvania State University and the Borough of State College. The flows from the University and the Borough are split, and the plant is set up to treat each separately, although flows can be diverted from one flow stream to the other (Fig. 1).

The facility treating Borough wastewater consists of the following:

1. Barminutor
2. Grit chamber
3. Primary aeration and settling tank
4. Secondary aeration and settling tank
5. Common chlorine contact tank

Waste activated sludge removed from the primary and secondary settling tanks flows to a flotation sludge thickener. From there the thickened sludge goes to a sludge well before being pumped to the primary digester. Fig. 2 represents the sludge flow through the plant.

The facility treating University wastewater consists of the following:

1. Barminutor
2. Preaeration and prechlorination tank
3. Primary settling tank
4. High rate trickling filters
5. Final aeration tanks
6. Final settling tanks
7. Common chlorine contact tank

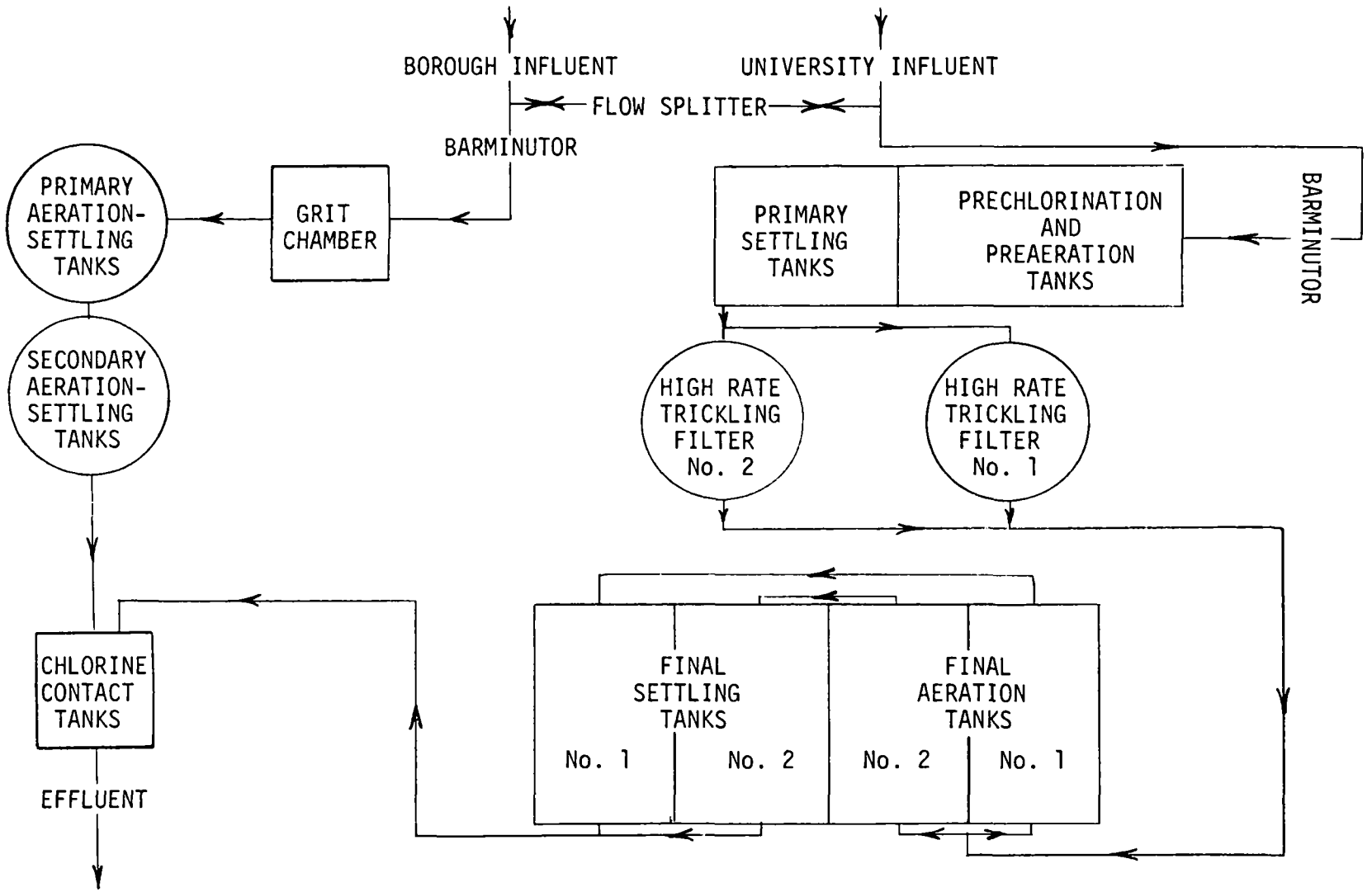

FIGURE 1: FLOW DIAGRAM OF WASTEWATER THROUGH THE TREATMENT FACILITY

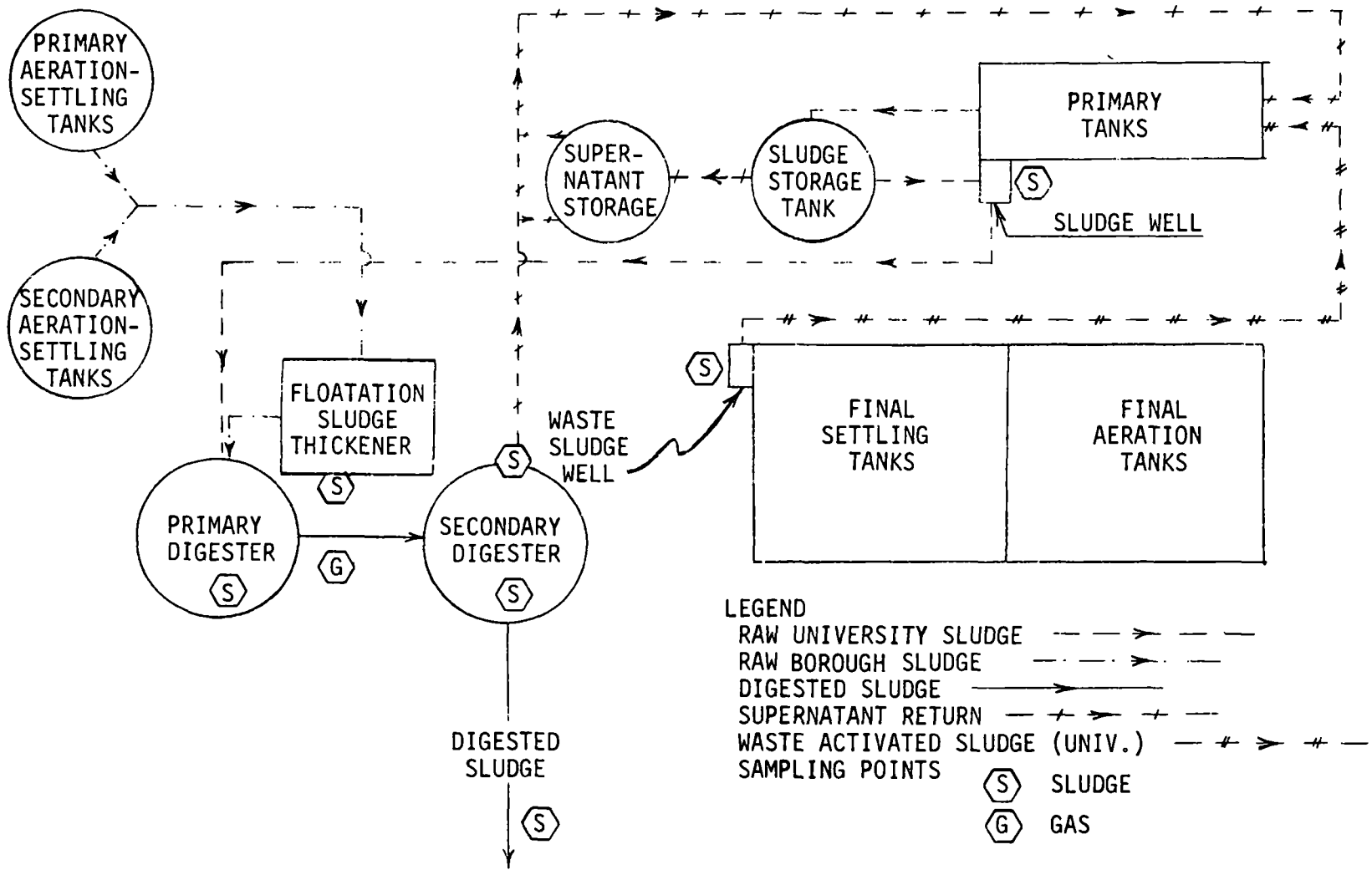

FIGURE 2: FLOW DIAGRAM OF SLUDGE THROUGH THE TREATMENT FACILITY

The sludge from this system is comprised of raw sludge from the primary settling tank and waste activated sludge from the final settling tanks. Waste activated sludge is removed from a waste sludge well and returned to the influent end of the plant prior to the preaeration tank. The waste activated sludge is thus combined with the raw sludge from the primary settling tank and is pumped to the digesters with this sludge. Raw primary sludge can be pumped directly to the primary digester or to a sludge concentration tank prior to entering the primary digester (Fig. 2).

During these studies, chemical was added only to the system treating University wastewater. Chemical additions were based on phosphorus removal requirements and are discussed in detail in a separate report (8). The exact location of the addition was varied, but in all cases was either in the final aeration tanks or in the channel carrying aeration tank effluents to the final settling tanks. Alum was first added to aeration tank #2 on January 27, 1969. This addition was the beginning of Phase I of the study which was designed to determine what precipitant to use, how much to use and where to add it. On February 21, 1969, alum addition was begun in aeration tank #1, and continued in both tanks until May 19, 1969. Sodium aluminate additions began in both tanks on May 28 and continued through August 11, 1969, the end of Phase 1. During the entire test period the coagulants dosage was varied, because of the requirements of this phase of the study. Starting on August 21, 1969, alum was added to only aeration tank #1 and aeration tank #2 was kept as a control. This mode of operation constituted Phase 2 of the study and lasted through August 20, 1970.

The digesters were operated as a two-stage system, with each stage having a capacity of 37,925 cubic feet. There was no recirculation of sludge from the secondary digester to the primary digester during the test period. The primary digester used a Pearth gas recirculation system to keep it operating as a high rate digester. It has a heat exchanger, and the pumping capacity is 150 gpm. The secondary digester was operated as a conventional digester with supernatant being withdrawn when it was formed. During the period from January 1969 through May 1969, the secondary digester was non-stratified, supernatant was withdrawn infrequently, and all of the sludge removed from the digester was hauled by truck to University farm land and disposed of by spraying. A small percentage was returned as supernatant to the supernatant liquor storage tank at times when flow and hauling schedules dictated. During this period both digesters were operated at a capacity of about 36,000 cubic feet, which resulted in a detention time of approximately 19 days.

Starting in the early part of June 1969 and continuing throughout the remainder of the study, raw sludge from the University plant was pumped to a sludge storage tank which concentrated it before it was added to the primary digester (Fig. 2). This procedure reduced sludge volumes and increased the digestion time to approximately 38 days. During this operation sludge supernatant from both

the raw sludge storage tank, and the secondary digester was pumped to the supernatant liquor storage tank, and then to the primary aeration tank. The pumping of sludges varied with operational changes at the plant but raw sludge from the University primary tank was generally pumped to the digester at 2 AM, 10 AM, and 6 PM daily. Excess activated sludge from the Borough flow was thickened in a flotation type thickener and stored in a sludge well located in the thickener building. It was fed to the primary digester along with the University raw sludge.

The secondary digester was stratified and operated as a conventional digester. The supernatant was returned to the supernatant liquor storage tank or was hauled by truck along with the bottom digested sludge from the secondary digester for land disposal. This method of operation was continued throughout the test period.

Sampling Technique

The location of sampling points for sludge samples is shown on Fig. 2. Each of the samples was collected and composited in a different manner.

Samples of Borough raw sludge were taken either from the screw transporting the thickened sludge from the thickener to the storage tank in the thickener building or from the storage tank itself. A one liter sample was taken at the same time the digested sludge was sampled.

Samples of University raw sludge, which included the waste activated sludge, were taken from a sludge well located next to the primary settling tanks. The samples were taken at the pumping times earlier mentioned. Sample volumes of approximately one liter were collected at each pumping and composited into a representative 500 ml sample. The samples were taken on the same days that the Borough raw sludge samples were collected.

Samples of digested sludge being withdrawn for land disposal were collected in 500 ml plastic bottles at three separate times during the withdrawal period. These samples were taken when approximately one-sixth, one-half, and five-sixths of the sludge had been withdrawn. These three samples were then combined into one sample, representing the digested sludge. Digested sludge samples generally were taken on every Monday and Wednesday, but periodically the sampling was done on other days of the week. Analyses were run only on composite samples, and no composits of longer time periods were made.

Supernatant samples were collected at varying intervals as there was not a specific pumping and hauling schedule for the secondary digester supernatant. For hauled supernatant, during Phase I of the study,

samples were collected approximately weekly, while during Phase 2 the sampling frequency was twice weekly. Whenever supernatant was being pumped back through the plant rather than hauled for land disposal, samples were collected at each time of pumping. Similar analyses were run on both supernatant and digested bottom sludge.

Samples used for digester profiles were collected using a weighted Kemmerer type sampler.

Samples used in dewatering tests were collected from two points. Waste activated sludge was obtained from the waste sludge well located next to the final clarifiers in the plant treating university wastewater, and raw sludge from the sludge well located next to the primary clarifiers in the same plant.

Gas samples were collected in two aspirator bottles. A non-gas absorbing sodium sulfate solution was used in the bottles to insure preservation of the sample prior to analysis. The point of collection was a sampling port located on the gas meter in the digester control building.

Flow Measurements

During Phase 1, flow measurements were taken from records maintained at the treatment plant. There were no direct measurements of the sludge flows in and out of the digesters. The daily sludge additions and removals were calculated from a gage which indicated the rise and fall of the digester covers, while the hauled sludge volumes were measured by multiplying truck volume times the number of trips. Supernatant recycle also was measured using a level gage on the supernatant storage tank. The flows were determined in the following manner:

Sludge Flows

Waste sludge from the Borough activated sludge system was measured using a flow meter located ahead of the sludge thickener. Waste activated sludge solids concentrations were measured and an average value determined. Total solids added to the sludge thickener were then computed using the relationship:

$$TS_{(in)} = Q \times P \times 8.35 \quad \ldots\ldots\ldots\ldots \quad [1]$$

where: $TS_{(in)}$ = total pounds of solids into the sludge thickener

Q = flow of waste activated sludge in gallons per day

P = percent solids in the waste activated sludge

The sludge thickener was assumed to recover 100% of the solid material. This value has been observed by plant personnel and is believed to be valid. Using the solids concentration of the thickened sludge the flow out of the thickener can be computed as:

$$Q_{Boro} = \frac{TS_{(in)}}{8.35 \times P_{(out)}} \quad \ldots\ldots\ldots\ldots [2]$$

where: Q_{Boro} = flow of raw Borough sludge to the primary digester in gallons

$TS_{(in)}$ = total pounds of solids into the sludge thickener

$P_{(out)}$ = percent total solids in the thickened sludge

The total sludge addition was measured from the change in elevation of the digester covers, and the quantity of University raw sludge computed as:

$$Q_{Univ} = Q_T - Q_{Boro} \quad \ldots\ldots\ldots\ldots [3]$$

where: Q_{Univ} = Flow of the University raw sludge into the primary digester in gallons

Q_T = Total sludge flow into the primary digester in gallons

Q_{Boro} = Flow of the raw Borough sludge into the primary digester in gallons

During Phase 2, the University raw sludge was measured directly from the drawdown at the raw sludge well during each pumping period. The total sludge flow was measured from the rise in the digester covers. The raw Borough sludge quantities were then calculated as:

$$Q_{Boro} = Q_T - Q_{Univ} \quad \ldots\ldots\ldots\ldots [4]$$

where: Q_{Boro} = Flow of the raw Borough sludge into the primary digester in gallons

Q_T = Total sludge flow into the primary digester in gallons

Q_{Univ} = Flow of the University into the primary digester in gallons

Supernatant Return

Supernatant return volumes were obtained by computing the difference between the volume of total raw sludge added and the volume of digested sludge hauled.

Gas Volume

Gas volume was recorded utilizing a gas meter located in the digester control building.

ANALYTICAL TESTS AND PROCEDURES

The following sections include a summary of the tests performed and the procedure used throughout this investigation.

Aluminum

Soluble aluminum ion was measured utilizing the "Rapid Modified Eriochrome Cyanine R Method for the Determination of Aluminum in Water" as suggested by Shull and Guthan (19). Samples were also sent to the Mineral Constitution Laboratory, at The Pennsylvania State University for spectrochemical analysis. The analyses were carried out using atomic absorption.

Samples tested using the Modified Eriochrome Cyanine R Method, were first centrifuged at 13,300 x g for 15 minutes then filtered using glass fiber filter pads. The samples were then diluted. The diluted samples were turbid and the samples containing Borough wastewater were known to contain fluoride. The fluoride ion interferes with the Eriochrome Cyanine R Method causing the results to be low. In order to determine the error in the tests, samples were analyzed spectrochemically and the results compared with results from the Modified Eriochrome Cyanine R Method. In addition, a sample was ultracentrifuged at 100,000 x g for 60 minutes in order to remove turbidity. While ultracentrifuging removed most of the suspended particles, inspection of the centrifuged sample with a Tyndal beam revealed some turbidity still remained. The results of the tests are shown in Table 1. Samples 1 and 2 were taken June 24, 1969, and the results show the Eriochrome Cyanine R Method to be low compared to the spectrochemical analysis. Samples 3 and 4 were taken August 5, 1969, and sample 3 shows higher soluble aluminum readings by the Eriochrome Cyanine R Method, than by spectrochemical analysis, while the results from sample 4 are opposite. Filtering did not produce a sample which contained only soluble aluminum. Some suspended particles which contained aluminum compounds passed through the filter pad. The low pH in the Eriochrome Cyanine R Method may have caused the suspended precipitated aluminum to redissolve in the test. This phenomenon probably

TABLE 1: COMPARISON OF SOLUBLE ALUMINUM ION CONTENT OF DIGESTED SLUDGES BY SPECTROCHEMICAL ANALYSIS VS. THE RAPID MODIFIED ERIOCHROME CYANINE R METHOD

SAMPLE:	ALUMINUM ION MEASURED ($mg\ AL^{+++}/l$)	
	ERIOCHROME R METHOD	SPECTROCHEMICAL ANALYSIS
1. PRIMARY DIGESTER	0.48	9.27
2. SECONDARY DIGESTER	1.90	7.35
3. SECONDARY DIGESTER	2.0	0.79
4. SECONDARY DIGESTER (ULTRACENTRIFUGED)	0	0.08

occurred in all filtered samples. The sample which most truly represents only soluble aluminum ions is sample 4, which recorded very low values; however, it too is probably high because there was suspended material remaining in sample 4 after ultracentrifuging.

Alkalinity

Alkalinity determinations were carried out utilizing the procedure given in Standard Methods (21).

Dewatering of Sludges

Dewatering tests were carried out in the laboratory using the method of Coackley (3). Buchner funnel tests used Whatman No. 40 filter paper with the vacuum applied through an adjustable vacuum pump. From these tests, the specific resistance of the sludges was computed, using the Coackley formula discussed in the Appendix.

Filtration

Filtration of sludges for sample analysis, excluding dewatering tests, was performed using 5.5 cm dia. Reeve-Angel glass fiber filter pads. In most cases in order to achieve necessary filtrate volumes the sludge samples were centrifuged prior to filtration. Samples were centrifuged for 15 minutes at 13,300 x g.

Gas Analysis

Gas samples were passed through a Hewlett and Packard 5750 F&M Research Chromatograph for analysis. The relative percentages of methane, carbon dioxide, nitrogen, and hydrogen sulfide were recorded by analyzing a 0.5 ml. sample. Analyses were run using a 1/8-inch diameter, 6-foot long, stainless steel column packed with Porapak Q; helium carrier gas; a 60°C column oven temperature; and a thermal conductivity cell with a bridge current of 150 ma. Other temperatures were: detector - 250°C, auxiliary - 250°C, and injection port - 150°C. The chart speed was 0.5 in/min.

pH

pH measurements were made using a pH meter after (21).

Phosphorus

The Stannous Chloride Method for Orthophosphate (21) was used for all of the phosphorus determinations. The test was conducted in an

incubator controlled at 20°C, and ten minutes were allowed for color development before readings were taken. Readings were taken at a wave length of 690 mμ using a Bausch and Lomb Spectronic 20 spectrophotometer and a 2.54 cm light path. The methods of sample preparation varied as indicated below.

Total phosphorus determinations followed a modified alkaline ash procedure used by Eberhardt and Nesbitt (5). In a review of methods for total phosphorus analysis, Harwood et al. (6) found the dry-ashing procedure the most reliable. A comparison between the modified alkaline ash and potassium persulfate method (7) was run and the results are given in Table 2. It would appear that the modified alkaline ash method gave consistantly higher values for digested sludge, while both methods gave similar readings for raw sludge. Though it was the longer test, the modified alkaline ash method was used throughout this study.

Total soluble phosphorus determinations used a modification of the binary acid wet-ash procedures (5). Orthophosphate determinations followed the previously mentioned Standard Methods procedure. Both total soluble phosphate and soluble orthophosphate were determined on samples that were filtered prior to testing. Total phosphorus samples were not filtered. Total phosphorus samples, following initial dilution, were blended for two minutes at high speeds to insure uniform sampling.

Solids

Total, volatile, and fixed solids analyses were conducted following the procedure outlined in Standard Methods (21).

Sulfate

Sulfate analysis followed the Turbidimetric Method (21), using a Beckman D.B. Spectrophotometer, and a 4 cm light path. All samples were filtered and diluted prior to analysis.

Volatile Acids

Volatile acids were determined by the method of direct titration as presented by Di Lallo and Alberson (4). Samples were centrifuged, but not filtered prior to analysis.

TABLE 2: COMPARISON OF TOTAL PHOSPHORUS CONTENT OF SLUDGES DETERMINED BY A MODIFIED ALKALINE ASH PROCEDURE VS. THE POTASSIUM PERSULFATE METHOD

SAMPLE:	PHOSPHORUS CONTENT [a] (mg P/l)	
	ALKALINE ASH METHOD	POTASSIUM PERSULFATE METHOD
1. DIGESTED SLUDGE	605	539
2. DIGESTED SLUDGE	605	539
3. DIGESTED SLUDGE	648	485
4. RAW BOROUGH SLUDGE	578	605
5. RAW UNIVERSITY SLUDGE	600	581

[a] ON A BASIS OF THREE REPLICATE SAMPLES

EXPERIMENTAL RESULTS AND DISCUSSION

PHOSPHORUS BALANCE

To find the identity of the phosphorus during anaerobic digestion, a phosphorus balance was calculated by tracing the types of phosphorus entering and leaving the digester. The balance assumed a steady state flow condition. While daily plant hauling and pumping schedules did vary, the recorded daily sludge flow into the digester was assumed to be the valid, steady state, flow measurement. The amount of sludge removed from the digester during a particular time period was assumed to be equal to the equivalent inflow for that period. The average daily pounds of phosphorus entering or leaving the digester for a one-month period was determined by the following relationship:

$$\text{Pounds of phosphorus} = C_1 \times P \times Q \quad . \; . \; . \; . \; . \; . \; . \; . \quad [5]$$

where: $C_1 = 0.834 \times 10^{-5}$ pounds per gallon

P = average monthly value for phosphorus in the sludge samples collected, expressed as mg P/l

Q = average daily flow of sludge in gallons for a one-month period

The average daily phosphorus values for a one-month period, were calculated using Equation 5 and then used in the phosphorus balance. The total cumulative phosphorus entering and leaving the digester is presented in Fig. 3.

The total phosphorus balance (Fig. 3) showed that less phosphorus was removed from the digester than had been added. Initially, as the phosphorus enriched sludge was first added, the phosphorus in the raw feed sludge was greater than that in the digested sludge. By comparing the slopes of the plotted values of cumulative phosphorus for a given time period the increase or decline of phosphorus in the various sludges was observed. Equal slopes indicate the phosphorus going into the digester was the same as that being removed.

For the month of February, 1969, the slope of the plotted values showed the cumulative phosphorus fed to the digester was greater than that removed from it. Following one detention period, or approximately March 1, 1969 (week 5), both raw and digested sludge plots theoretically should be parallel. Beginning in March and continuing through July 1970 (week 78), the plotted lines were diverted rather than parallel. The plot of the phosphorus in the raw feed sludge had a slope equal to 61°, while the plot of the phosphorus

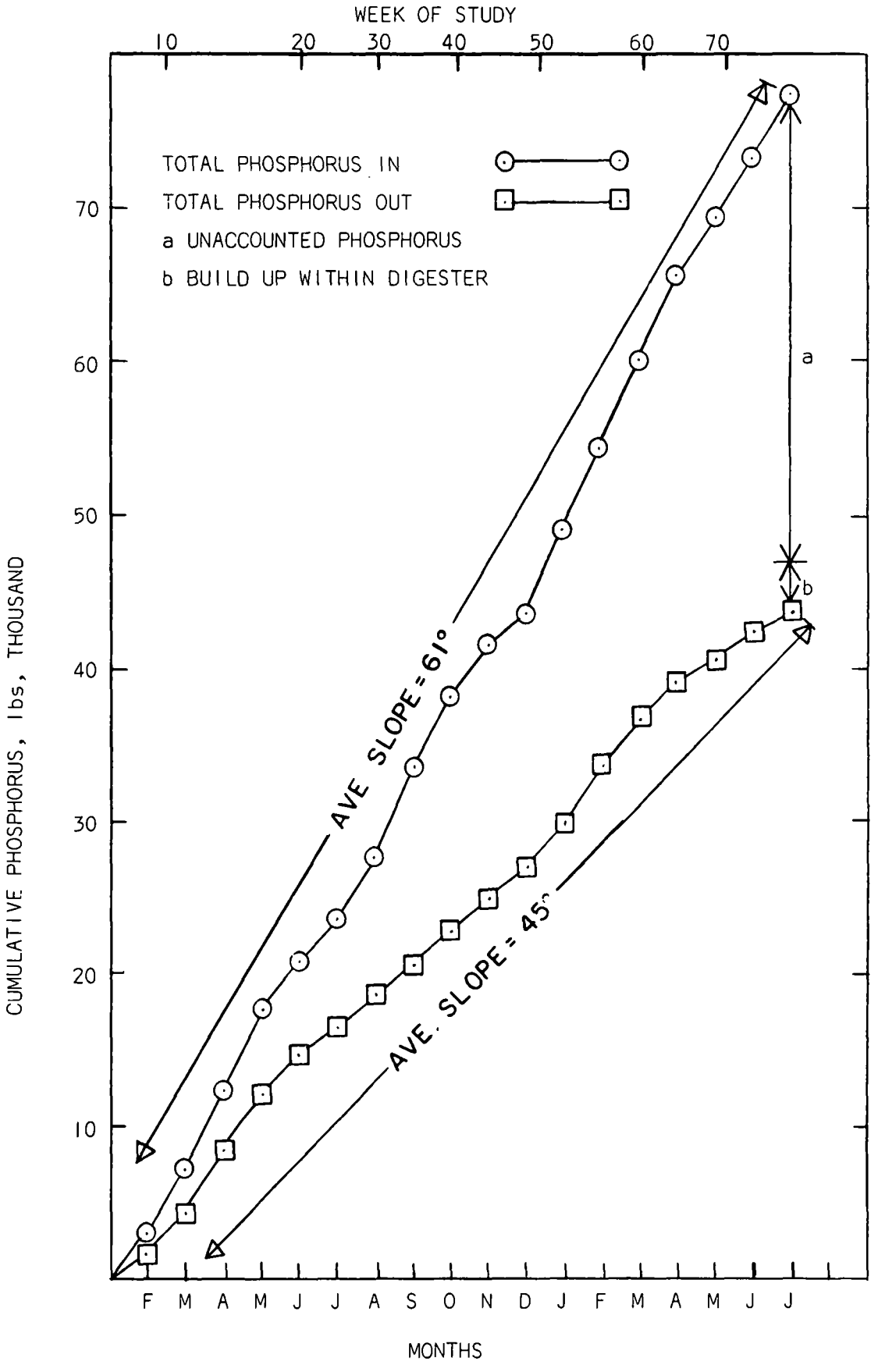

FIGURE 3: CUMULATIVE TOTAL PHOSPHORUS BALANCE OF THE DIGESTER

in the digested sludge had a slope of 45°. At no time during the entire study was the amount of total phosphorus entering the digester equal to the amount in the digested sludge which was removed. At the end of the study period the total discrepancy between phosphorus fed into and removed from the digester was approximately 32,800 lbs. The equilibrium phosphorus within the digester during the detention period was estimated to be 3,200 lbs. and is shown graphically on Fig. 3. Thus a total of 29,600 lbs. of phosphorus as P remained unaccounted for during the study period.

Fig. 4 shows the total soluble phosphorus and orthophosphate balances. The relationship between soluble phosphorus fed into the digester and the amount removed in the digested sludge is closer than the relationship shown in Fig. 3. During the first three months, total soluble phosphorus and orthophosphate removed from the digester equalled or slightly exceeded that being fed. During the rest of phase 1, the phosphorus removal was less than that being fed. This finding indicates that the aluminum phosphorus precipitate, when incorporated into the raw sludge, does not redissolve while undergoing anaerobic digestion. Apparently, soluble phosphorus also precipitated during digestion particularly after the phosphorus rich sludge had accumulated within the digester for one detention period. From Fig. 4, it was evident that most of the soluble phosphorus, in both the raw feed and digested sludges, was in the orthophosphate form.

The variations in the phosphorus levels of the sludges used in calculating the phosphorus balances partly accounts for the variance in the total phosphorus balance. However, errors resulting from these variations should be compensating. It seems more likely that the unaccounted for phosphorus resulted from an inability to collect a representative sample, particularly in the sludge being removed from the digester. Various techniques in sample collection, preparation, and phosphorus analysis were tried during the study, however, the phosphorus discrepancy in the total phosphorus balance remained unchanged. A further discussion of this discrepancy and its relation to sampling will be given later in the section on digester operation.

Table 3 gives the concentration of the total soluble phosphorus of the digested sludge observed during the study period. The soluble phosphorus values were generally lower during phase 1, than in phase 2. During phase 2, phosphorus was removed from only one half the University wastewater flow, as the remaining flow was used as a control. Consequentially, there was less sludge containing hydroxy aluminum phosphate and less total aluminum ion available to precipitate soluble phosphorus in the untreated raw University sludge. Therefore the higher soluble phosphorus values during phase 2 were expected. These phosphorus concentrations varied from 13 mg P/l to 171 mg P/l, however, there was not a significant increase in phosphorus levels during any period of the investigation.

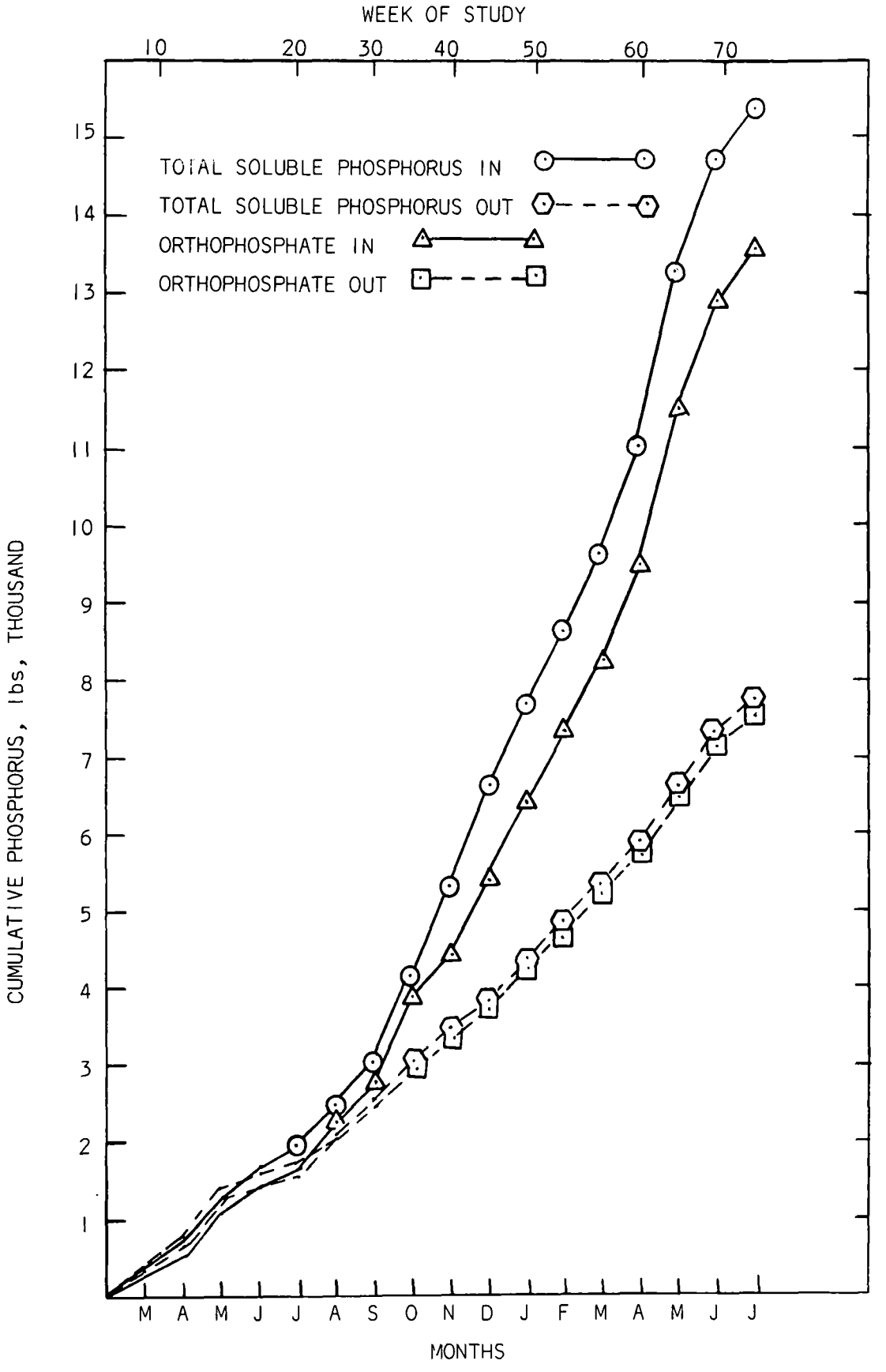

FIGURE 4: CUMULATIVE TOTAL SOLUBLE PHOSPHORUS AND ORTHOPHOSPHATE BALANCES OF THE DIGESTER

TABLE 3: TOTAL SOLUBLE PHOSPHORUS IN THE DIGESTED SLUDGE

WEEK OF STUDY	DATE	PHOSPHORUS mg P/l	WEEK OF STUDY	DATE	PHOSPHORUS mg P/l	WEEK OF STUDY	DATE	PHOSPHORUS mg P/l
	PHASE 1			PHASE 1 (CONTINUED)			PHASE 2 (CONTINUED)	
1	Feb. 5, 1969	108	28	Aug. 13, 1969	97	53	Feb. 4, 1970	95
2	12	92	29	20	88	54	11	90
3	19	79	30	Aug. 27, 1969	112	55	18	82
4	26	114		PHASE 2		56	25	90
5	March 5	36				57	March 4	92
6	12	33	31	Sept. 3, 1969	105	58	11	126
7	19	60	32	10	114	59	18	90
8	26	72	33	17	121	60	25,	77
9	April 2	53	34	24	113	61	April 1,	72
10	9	69	35	Oct. 1	112	62	8	98
11	16	68	36	8	116	63	15	101
12	23	74	37	15	124	64	22	106
13	30	43	38	22	106	65	29	99
14	May 7	66	39	29	109	66	May 6	125
15	14	85	40	Nov. 5	60	67	13	142
16	21	73	41	12	92	68	20	136
17	28	90	42	19	93	69	27	128
18	June 6	52	43	26	87	70	June 3	140
19	11	66	44	Dec. 4	59	71	10	152
20	18	81	45	10	79	72	17	128
21	26	34	46	17	86	73	24	147
22	July 2	20	47	23	85	74	July 1	160
23	9	13	48	31, 1969	93	75	8	92
24	16	29	49	Jan. 7, 1970	92	76	16	171
25	23	59	50	14	111	77	22	142
26	30	72	51	21	101	78	29	-
27	Aug. 6	105	52	28	110	79	Aug. 5	-
						80	12	-
						81	19, 1970	151

This fact is considered important, as a digester upset occurred at the end of May. During this upset period evidence of precipitated phosphorus redissolving in soluble phosphorus forms was not found. The relative insolubility of the precipitated phosphorus is shown by both the values in Table 3, and the phosphorus balances shown in Fig. 4. The digester upset will be discussed in greater detail in following sections.

DIGESTER OPERATION

As stated previously, the digester was operated as a two stage unit, with the primary digester utilizing gas recirculation for mixing. Fig. 5 shows the results of five digester profiles run on the primary digester. These profile results show that for the most part, the primary digester was operating as a high rate digester with fairly little change in solids level from top to bottom. Note, however, that top scum layers and heavier bottom sludges did accumulate at times. The secondary digester, which was designed to behave as a conventional digester without mixing, maintained a rather constant solids level in the sludge at distances of from 4 to 12 feet above the digester floor. The profiles for the secondary digester, shown in Fig. 6, indicate that this digester was stratified. This stratification, which consisted of a thicker bottom sludge and a thicker scum layer existed throughout the entire study period.

Figs. 7 and 8 show the profiles of total phosphorus and total soluble phosphorus concentrations in the secondary digester. A trend toward higher total phosphorus in the heavier bottom sludge is indicated. The soluble phosphorus concentrations remained relatively constant throughout the digester even though the digester was stratified. The relationships between total and soluble phosphorus and solids level may help to explain the discrepancy in the total phosphorus balance. While the soluble phosphorus level is relatively independent of solids content, a relationship between total phosphorus and total solids does exist as expected. Therefore, because of the uneven distribution of solids, a sample could be collected which was not a true composite of the sludge removed, thus causing an error in the total phosphorus balance. Also, in this same sample, there would be less of an effect on the total soluble and orthophosphate balances.

In an effort to determine the cause of error in the total phosphorus balance, a total solids balance was calculated, Fig. 9. This balance plotted the cumulative solids in, cumulative solids out, and cumulative solids destroyed. The value for volatile solids reduction was obtained from Sawyer and Grumbling (16), based on the percent volatile solids in the raw sludge feed, and the digester detention time.

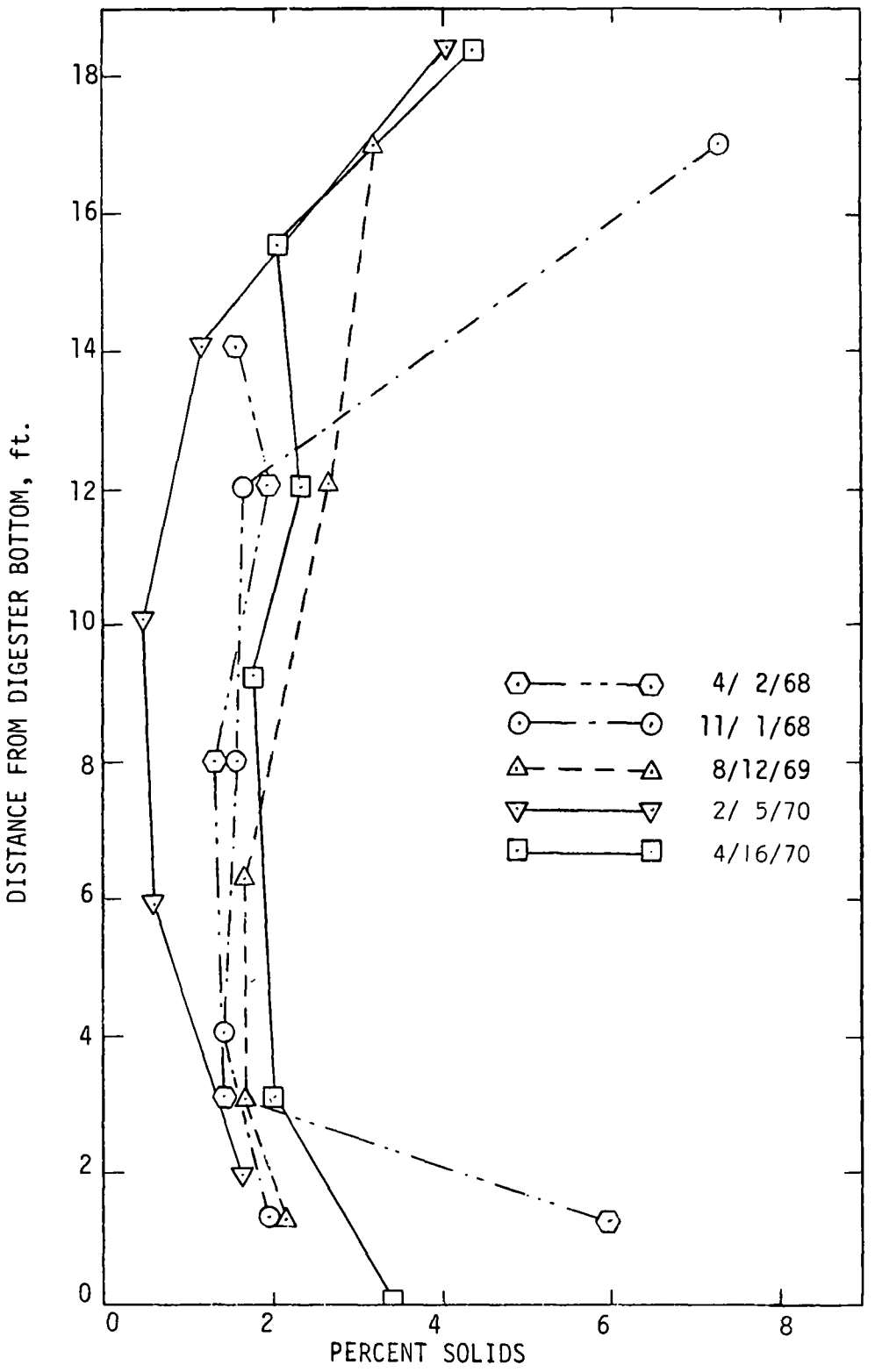

FIGURE 5: DIGESTER PROFILE OF THE SOLIDS LEVELS IN THE PRIMARY DIGESTER

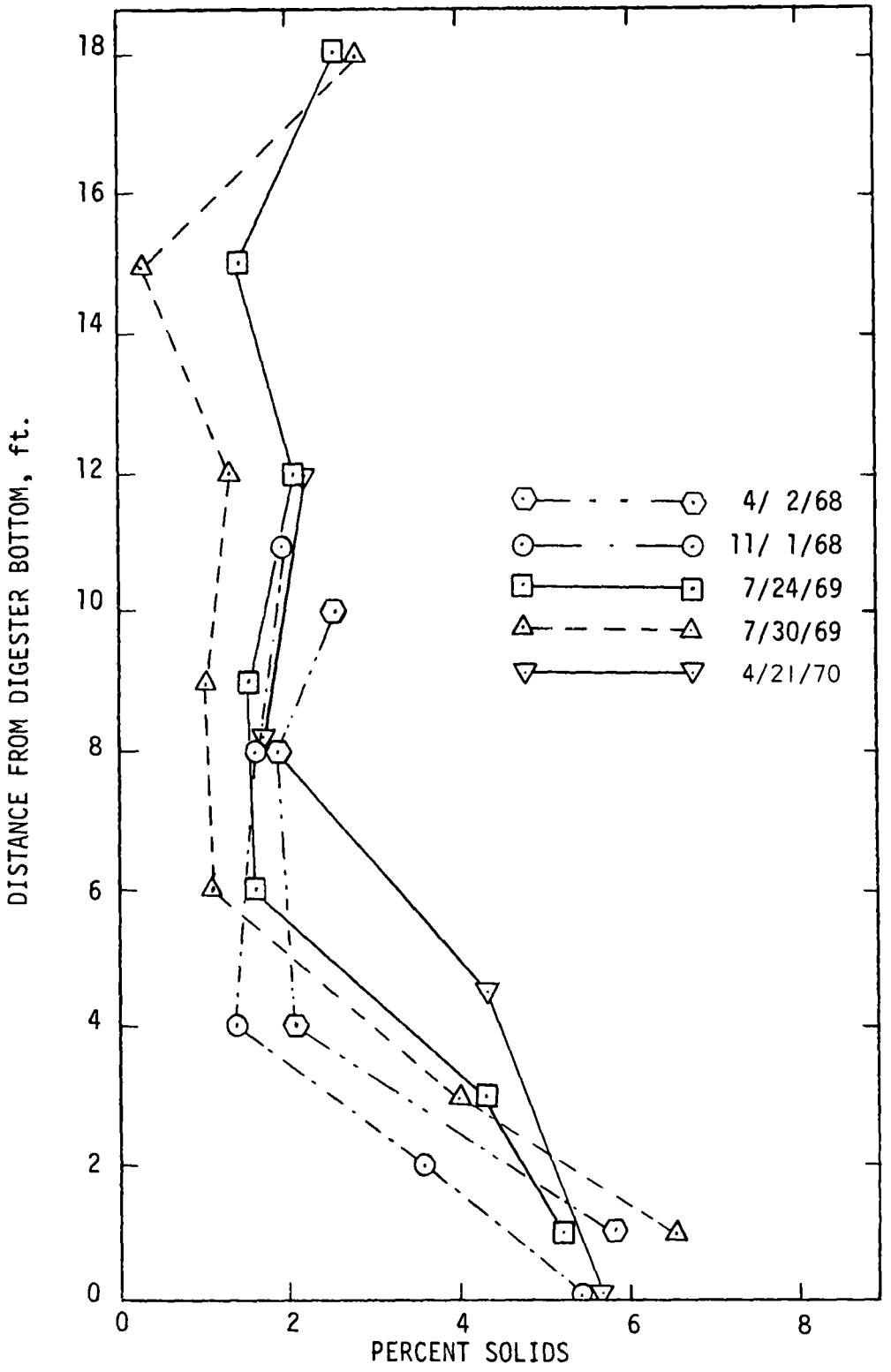

FIGURE 6: DIGESTER PROFILE OF THE SOLIDS LEVELS IN THE SECONDARY DIGESTER

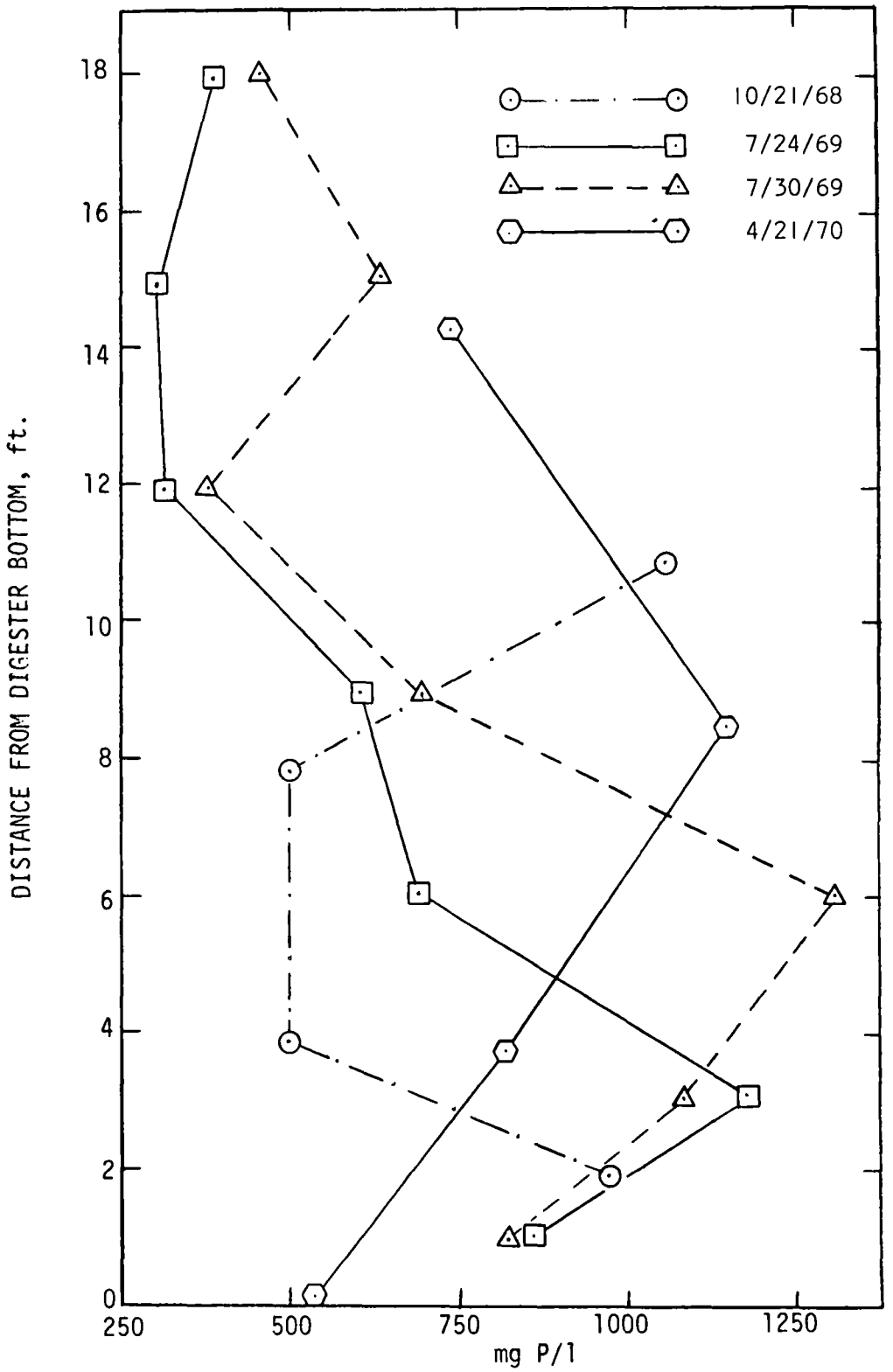

FIGURE 7: DIGESTER PROFILE OF THE TOTAL PHOSPHORUS CONCENTRATIONS IN THE SECONDARY DIGESTER

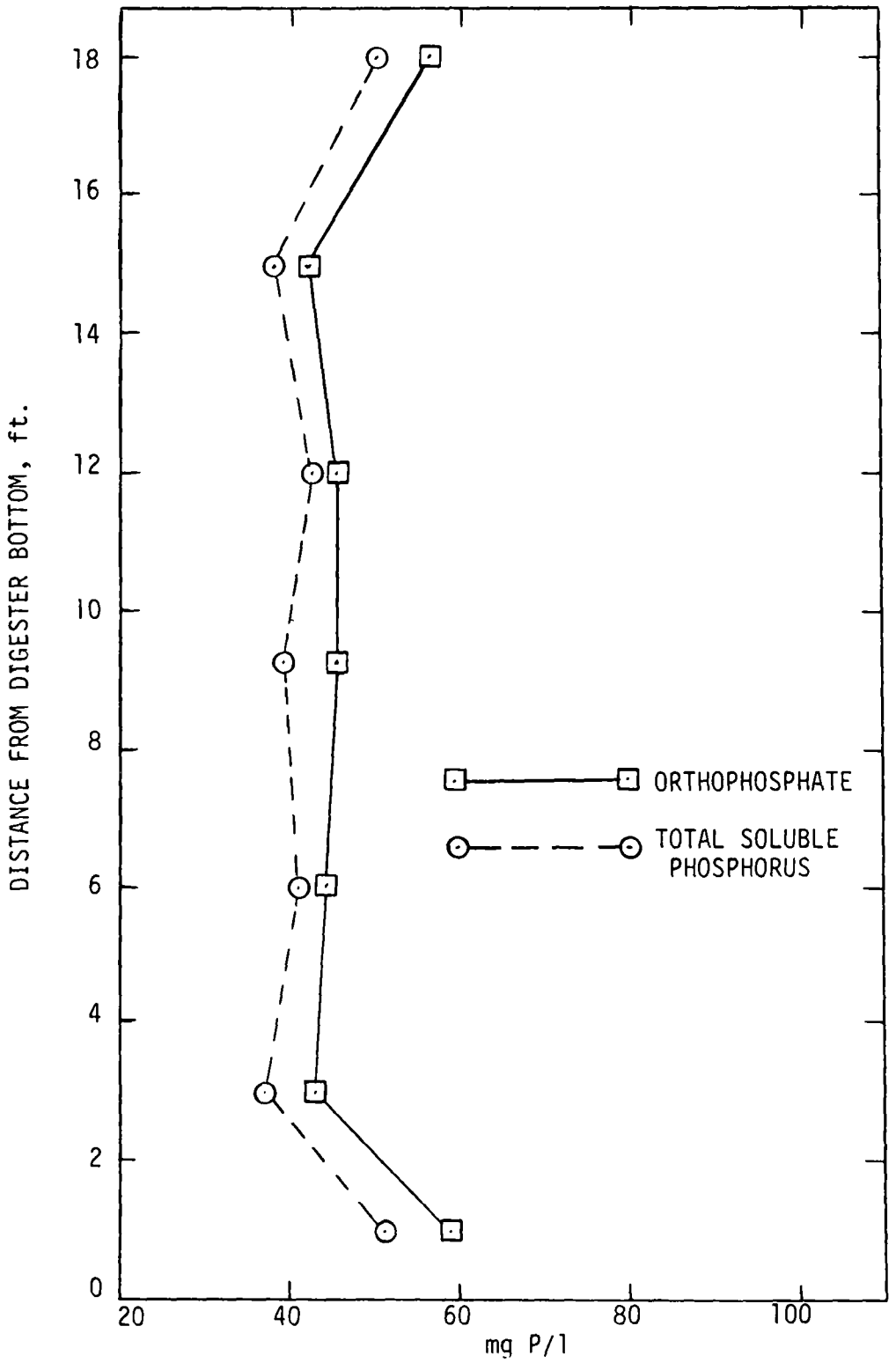

FIGURE 8: DIGESTER PROFILE OF SOLUBLE PHOSPHORUS CONCENTRATIONS IN THE SECONDARY DIGESTER ON JULY 30, 1969

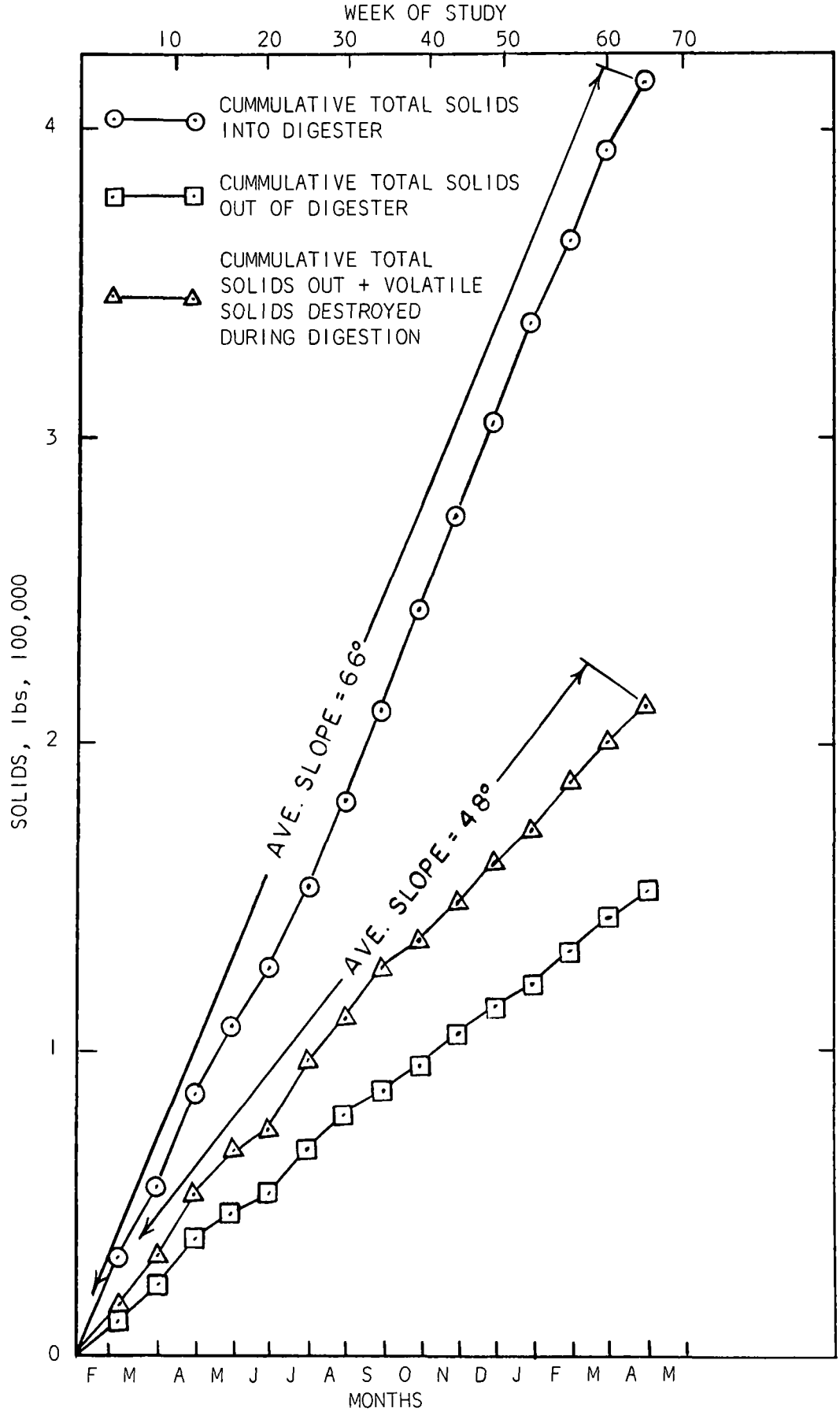

FIGURE 9: CUMMULATIVE SOLIDS BALANCE OF THE DIGESTER

As with the total phosphorus balance (Fig. 3), the total solids balance (Fig. 9) showed that more solids entered the digester than were both reduced in and removed from the digester. Theoretically, these two values should be equal, but they are not. The average slopes of the lines in Fig. 9 (solids balance) are close to those of the lines in Fig. 3 (total phosphorus balance). This similarity indicates that the samples of digested sludge obtained were not representative of the sludge removed from the digester. Sludge samples were taken only twice a week. This frequency was adequate for the raw sludge which was fairly uniform in quality. However, for the digested sludge it appears that insufficient samples were taken of the thicker bottom sludge.

pH

Figs. 10a and 10b show the pH values of the University raw sludge, Borough raw sludge, and the digested sludge recorded during the study period. The digested sludge maintained a pH between 7.0 to 7.4 until the end of May 1969 (week 15), when the pH began to drop. The decrease of pH values continued until a value of 6.3 was reached on June 5, 1969 (week 18). Correspondingly, the pH of both raw sludges varied between 6.0 and 7.1 from February 1969 (week 1), until mid-May 1969 (week 14). Each of the raw sludges showed a decline in pH which preceded the pH decrease of the digested sludge by approximately two weeks.

After June 5, 1969 (week 18), the pH values of the digested sludge increased until a value of 7.0 was reached at the end of June 1969 (week 22). The pH then generally remained above 7.0 for the rest of the study period. However, the pH values of the raw sludges did not return to their pre-upset levels until the fall of 1969 (week 33). These continued lower pH values can be attributed to a change in operation at the plant. Starting in June (week 19), the raw University sludge was fed into a sludge concentrator prior to pumping to the digester and this procedure was continued throughout the rest of the study. Feedings were also reduced from three times daily to only once daily during the summer months of 1969 and twice daily during the summer of 1970. These changes in operation could have caused higher volatile acids and thus lower pH values to be present in the raw sludge fed to the digester.

While the change of operation can account for the continued lower pH values of the raw sludges, the initial mid-May decrease is unexplained and may have been related to the cause of the digester upset.

ALKALINITY AND VOLATILE ACIDS

Figs. 11a and 11b show the alkalinity and volatile acid values of the sludges for the study period. The results indicate the digester

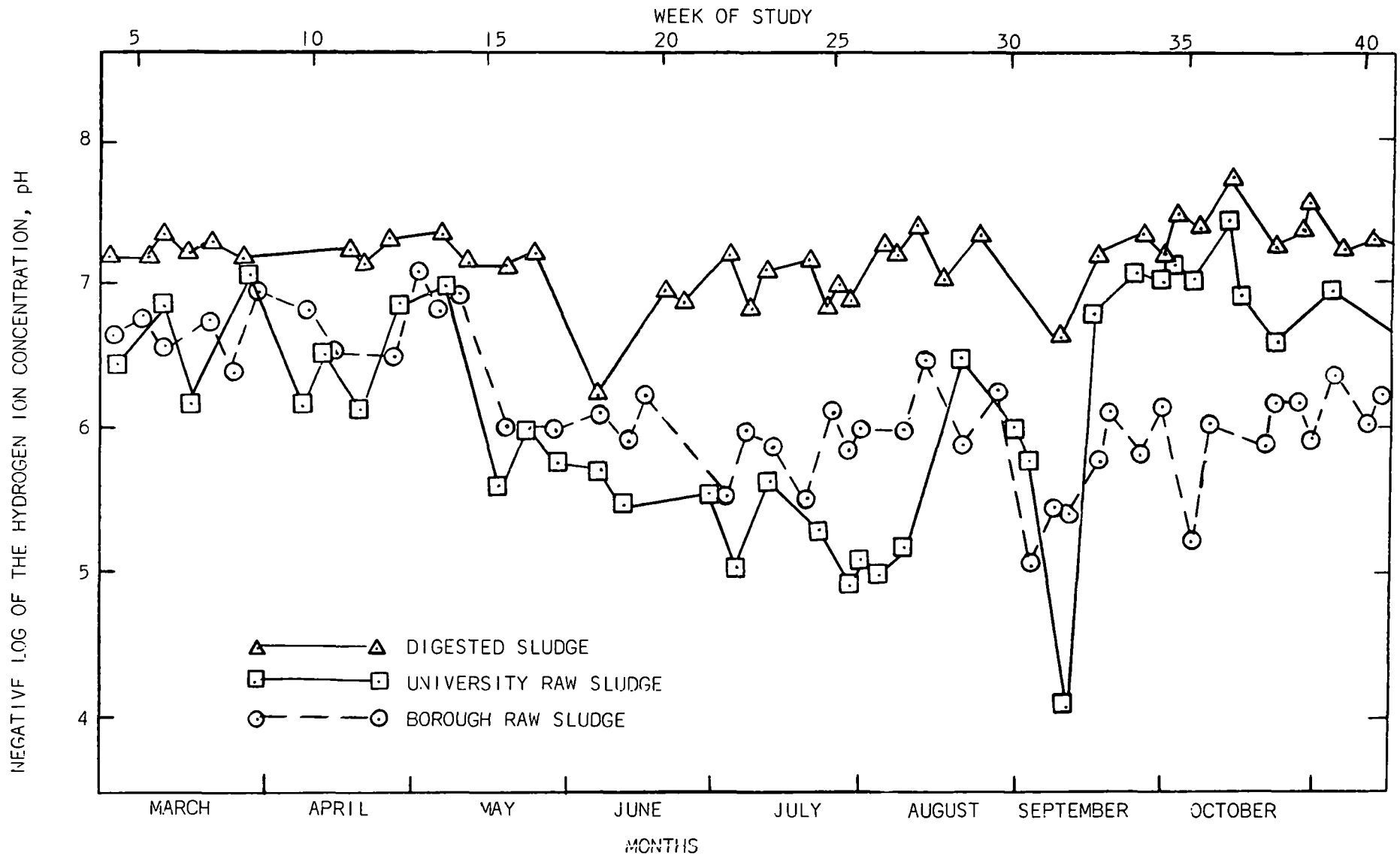

FIGURE 10a: pH VALUES OF VARIOUS SLUDGES THROUGHOUT THE STUDY PERIOD

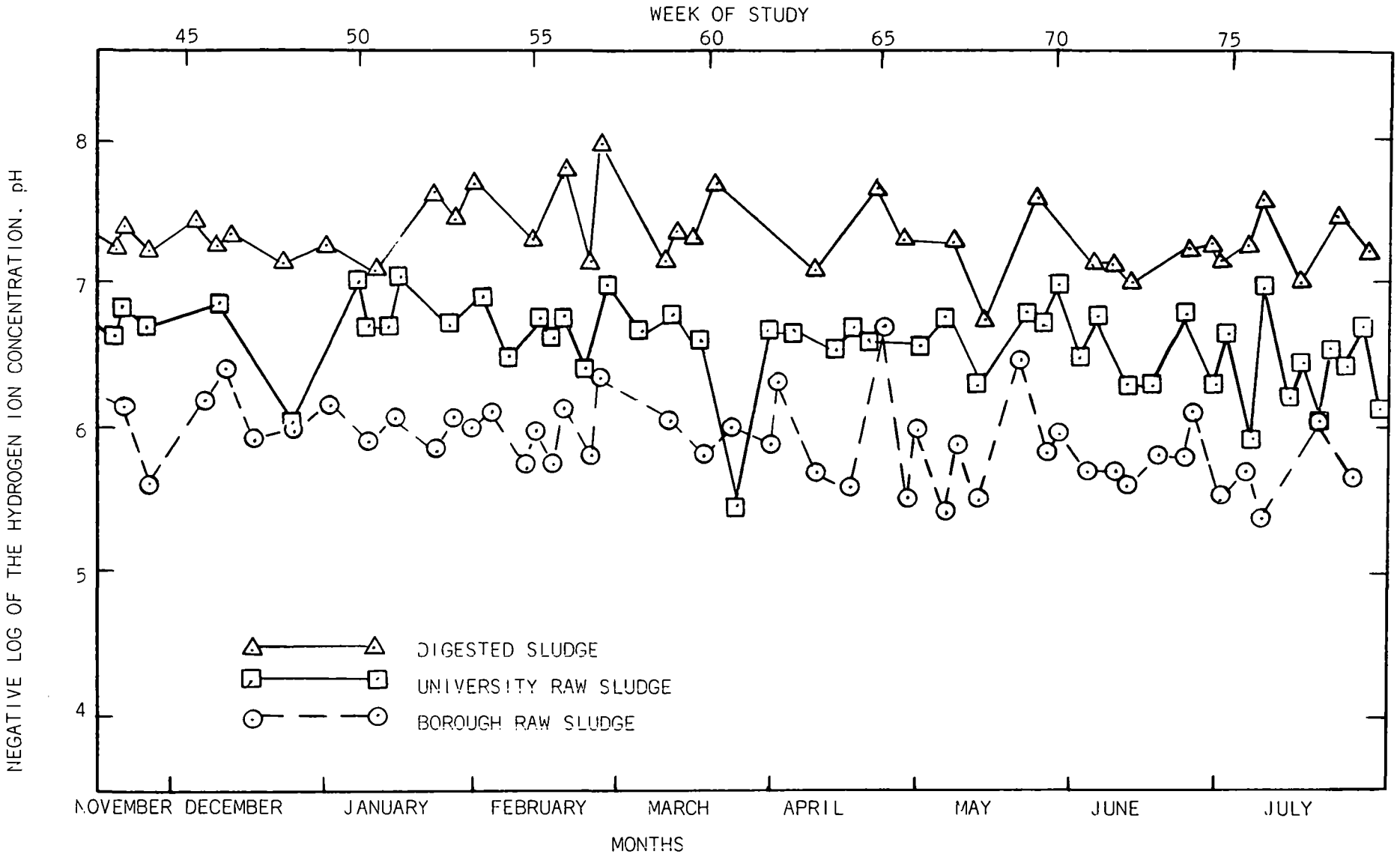

FIGURE 10b: pH VALUES OF VARIOUS SLUDGES THROUGHOUT THE STUDY PERIOD

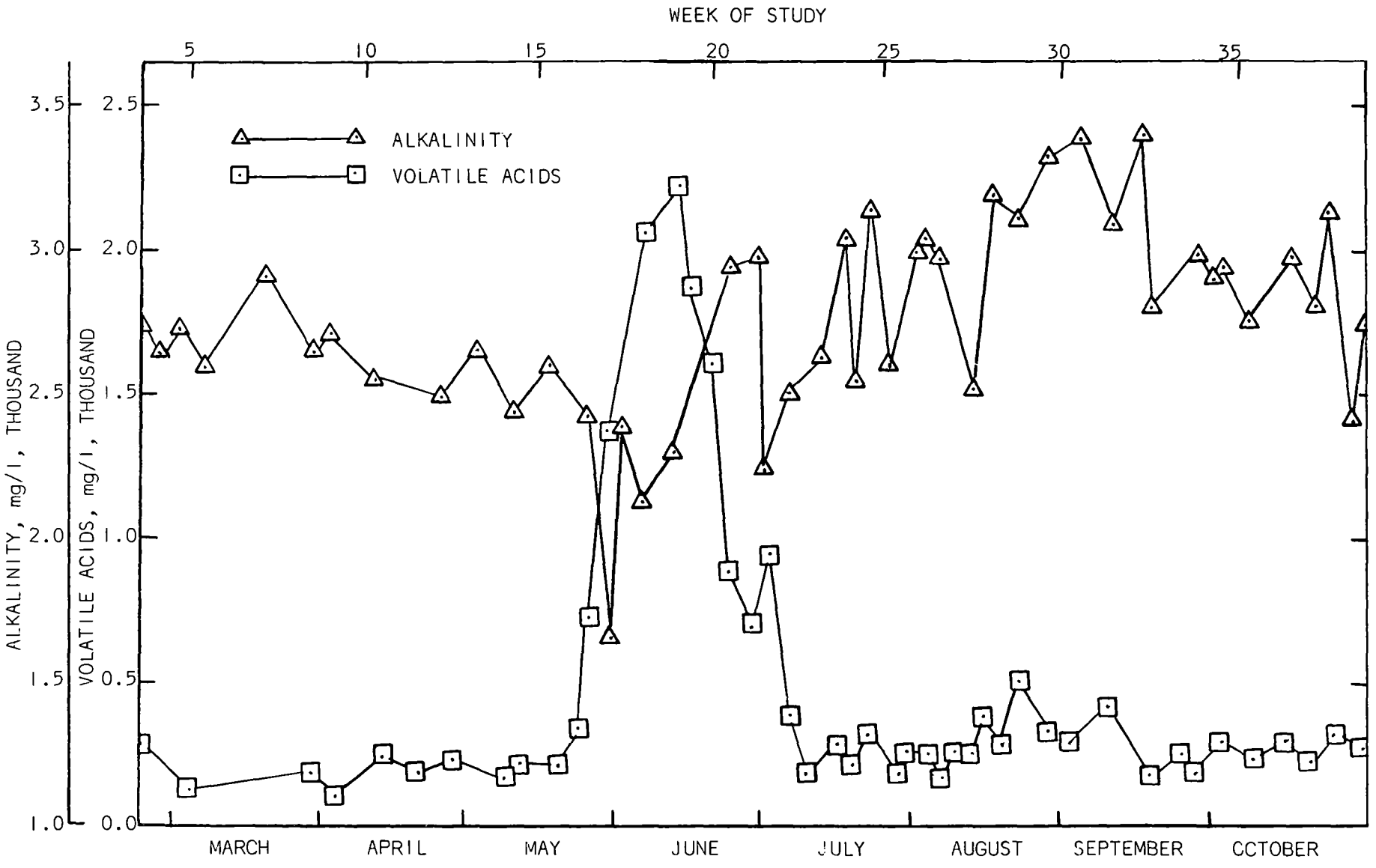

FIGURE 11a : ALKALINITY AND VOLATILE ACIDS OF DIGESTED SLUDGE DURING THE STUDY PERIOD

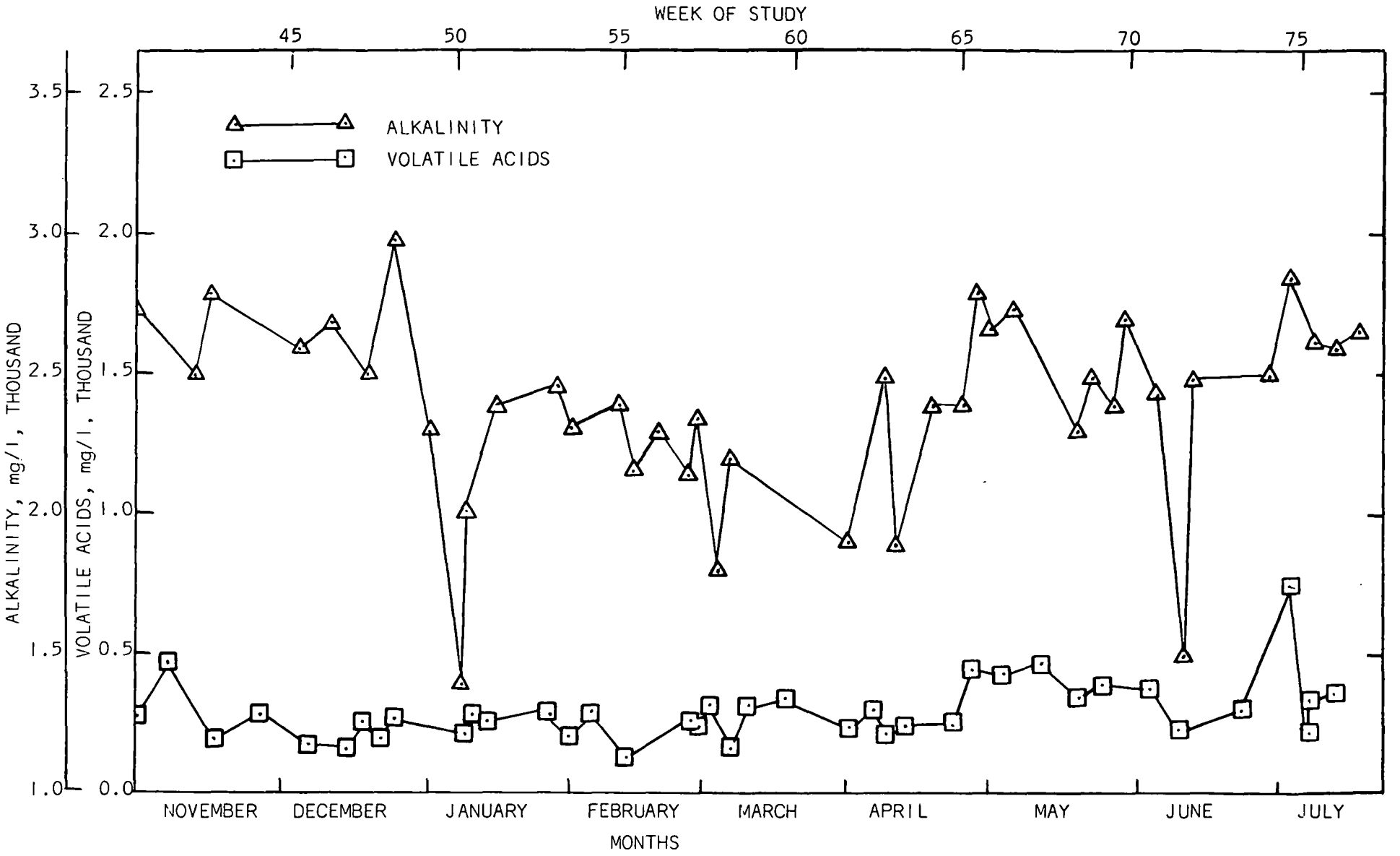

FIGURE 11b: ALKALINITY AND VOLATILE ACIDS OF DIGESTED SLUDGE DURING THE STUDY PERIOD

upset occurred at the same time the pH of the digested sludge decreased. Alkalinity decreased slowly through March 1969 (week 7) and April 1969 (week 16) and then dropped suddenly at the end of May 1969 (week 18). The alkalinity returned to 3,000 mg/l on June 25, 1969 (week 20), when lime was added to the digester to help correct the digester upset and then remained about 2,500 mg/l through November 1969 (week 45) with an exception during week 40. Lime addition ceased during the latter part of June 1969 (week 22) and the fluctuation in alkalinity may be attributed to the stratification in the secondary digester.

The level of volatile acids remained fairly constant until the May 1969 digester upset (week 17). During the upset, volatile acids increased from 250 mg/l to 3,220 mg/l. As the upset was corrected the volatile acids level returned to the pre-upset level of 250 mg/l.

While the upset period from mid-May 1969 (week 17) through the end of June 1969 (week 24) produced conditions of high volatile acids, lower pHs, and reduced alkalinity, the concentration of soluble phosphorus in the sludge removed from the digester was lower than the mean value for the remainder of the study period. The mean value for the upset period was 66 mg P/l, while the value for phase 1 was 71 mg P/l, and Phase 2 was 108 mg P/l. Thus it appears that even during a digester upset, with its corresponding increased acid levels, the precipitated phosphorus does not become soluble. This result would be expected as the optimum pH for precipitation of phosphate with aluminum was shown to be between 5.5 and 6.0 (5).

GAS PRODUCTION AND VOLATILE SOLIDS DESTRUCTION

Gas production and volatile solids loading for the study period are shown in Figs. 12a and 12b. A normal relationship existed between volatile solids loading and the corresponding gas production. Beginning in February 1969 (week 1) and extending through the end of May 1969 (week 18), the plots of gas production and volatile solids loading are generally parallel showing a relatively stable level of digestion was achieved in the digester. The sharp reduction in both volatile solids loading and gas production at the end of March 1969 (week 10) can be related to the reduced student population between the winter and spring terms.

As was shown in the sludge pH, alkalinity, and volatile acids analyses, a digester upset is also noted in the gas production values. Beginning in the latter part of May 1969 (week 18) and continuing until mid-June 1969 (week 22), gas production values were significantly reduced. Once the upset was noted, an effort to reduce the loading on the digester was begun. This effort involved the hauling of raw sludges to a sludge lagoon. The decreased student population in mid-June, also aided in the reduction of volatile solids loadings. Since the reduced gas production preceded the reduction in volatile solids loading, the initial reduction of gas production was caused by the digester upset, and not the reduced volatile solids loading.

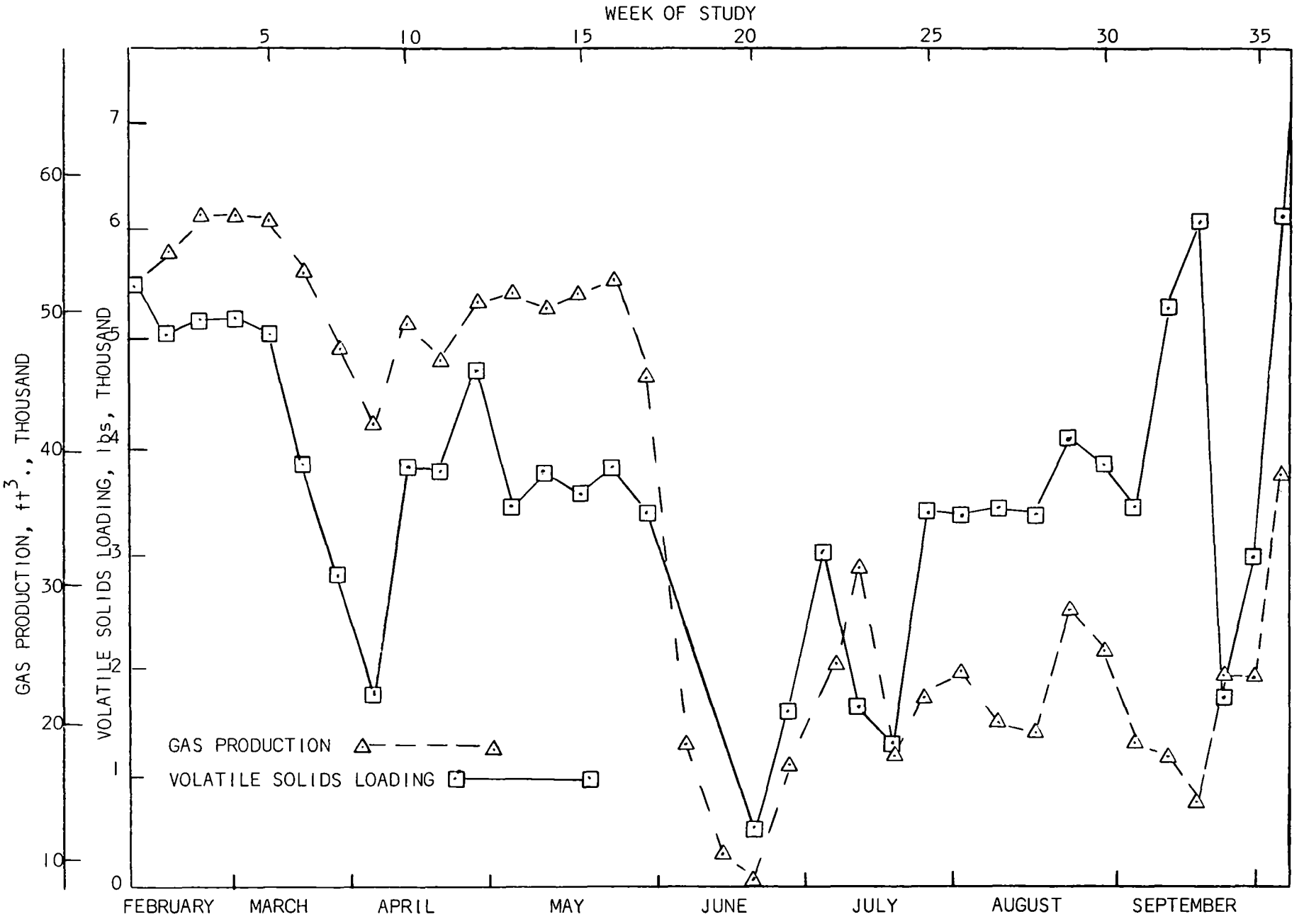

FIGURE 12a: DIGESTER GAS PRODUCTION AND VOLATILE SOLIDS LOADING

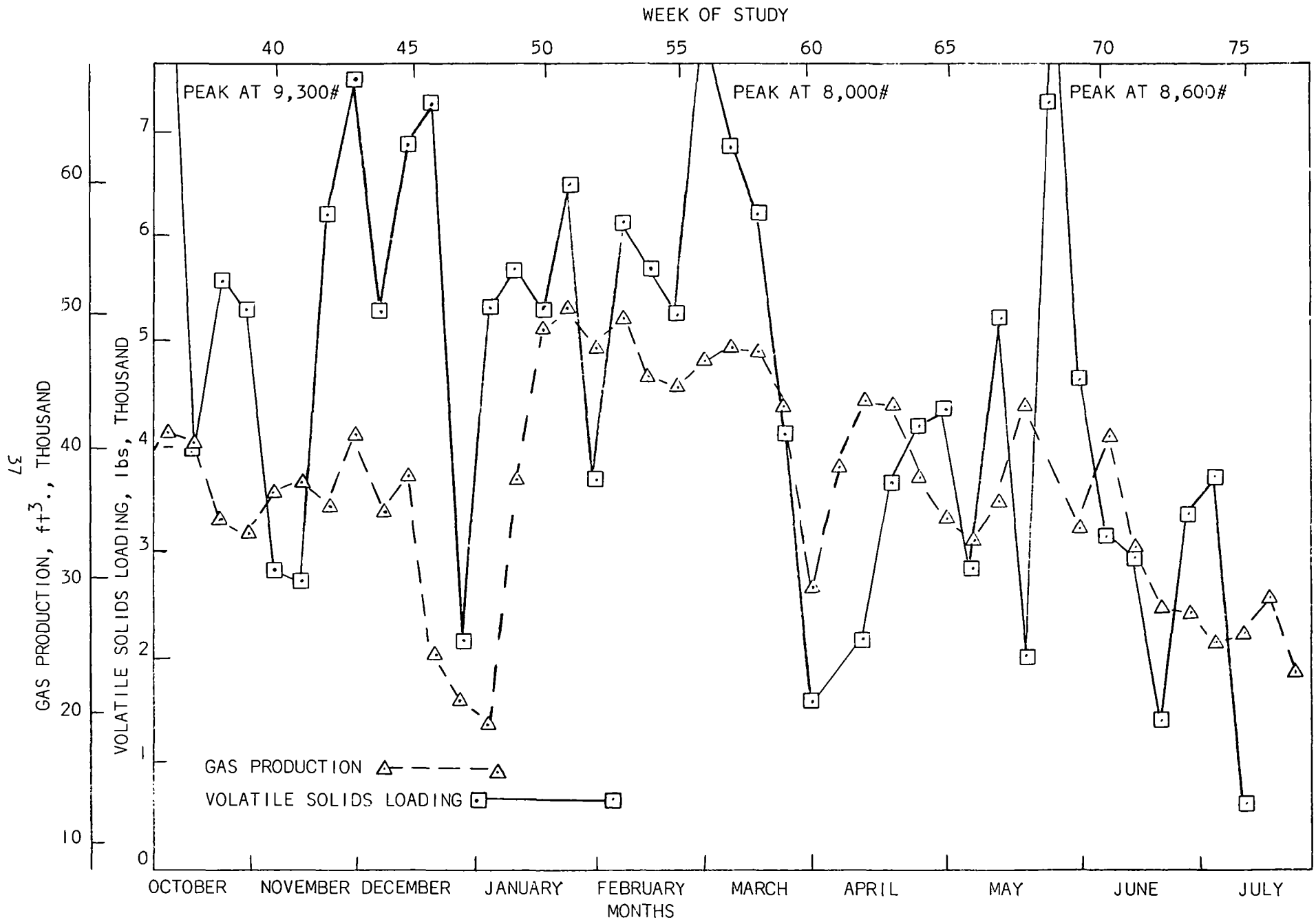

FIGURE 12b: DIGESTER GAS PRODUCTION AND VOLATILE SOLIDS LOADING

Gas production and volatile solids reduction are shown in Figs. 13a and 13b. Gas production, volatile solids loading (V.S.L.) and volatile solids reduced (V.S.R.) appear to be lower than those found in the literature (18), but agree well with those calculated for digester operation from January 1968 through December 1968 before the study was begun. During this period, no phosphorus enriched sludge was added to the digester, and it can be considered a semi-control period. During 1968 gas production values averaged 5.3 ft^3/lb V.S.L. and 8.2 ft^3/lb V.S.R. In phase 1 of the study, gas production averaged 6.1 ft^3/lb V.S.L. and 8.7 ft^3/lb V.S.R., while phase 2 had 5.8 ft^3/lb V.S.L. and 7.9 ft^3/lb V.S.R. Thus, the addition of the chemical biological sludge to the digester had no effect on these digestion parameters. Figs. 12a, 12b, and 13a and 13b, showed that the gas production response followed both the volatile solids loading and the volatile solids reduction.

Analyses to determine the methane, carbon dioxide, and hydrogen sulfide content of the digester gas were made and are plotted in Fig. 14. These analyses were only run during phase 1 of the study. Methane comprised slightly more than 60 percent and carbon dioxide slightly less than 40 percent of the gas sample volume. These results agree with the range expressed by Sawyer and McCarty (17) who state that the methane content of digester gas ranges from 55 to 65 percent, while carbon dioxide content varies from 33 to 38 percent. Exceptions to these ranges occurred during the "upset period" when the methane content was reduced. This reduction is expected as the high concentrations of volatile acids and corresponding drop in pH decreases the growth rate of the methane forming organisms.

SULFATE

Another purpose of this study was to determine whether the sulfate ion introduced into the system when the phosphate was precipitated with alum would find its way into the digester and be reduced to hydrogen sulfide gas. This excess hydrogen sulfide could cause corrosion and odor problems in the treatment plant. Sulfate analyses of sludges were conducted during phase 1, as this period had the highest concentrations of sulfate ions. At no time during the study were any measurable quantities of hydrogen sulfide found. Even during the digester upset, measurable quantities of hydrogen sulfide were not shown in the analyses, although trace hydrogen sulfide odors were observed in the digester buildings.

Samples collected on 5, 10, and 12 June 1969 showed higher hydrogen sulfide values, however, these values were still too small to be significant.

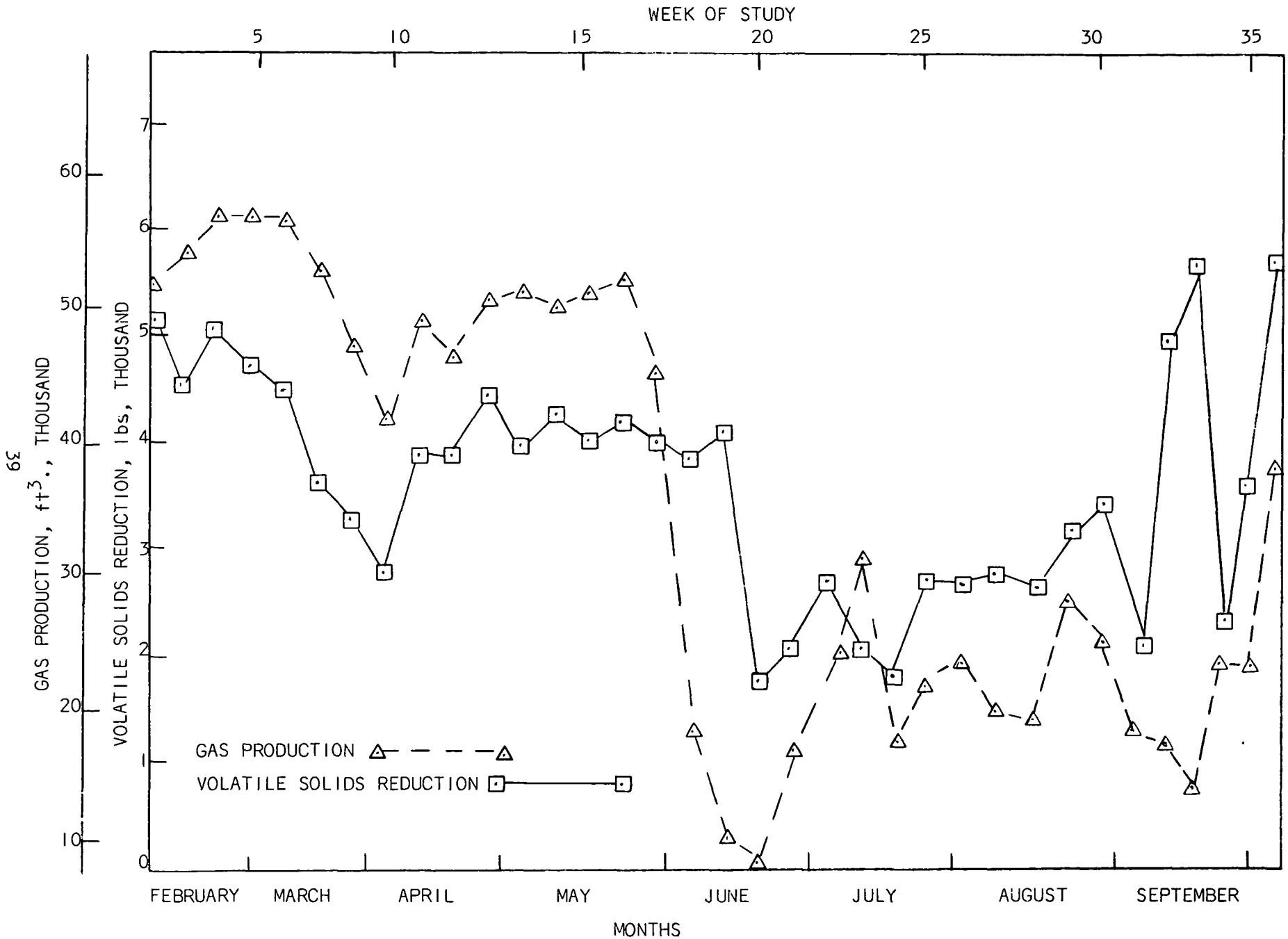

FIGURE 13a: DIGESTER GAS PRODUCTION AND REDUCTION OF VOLATILE SOLIDS

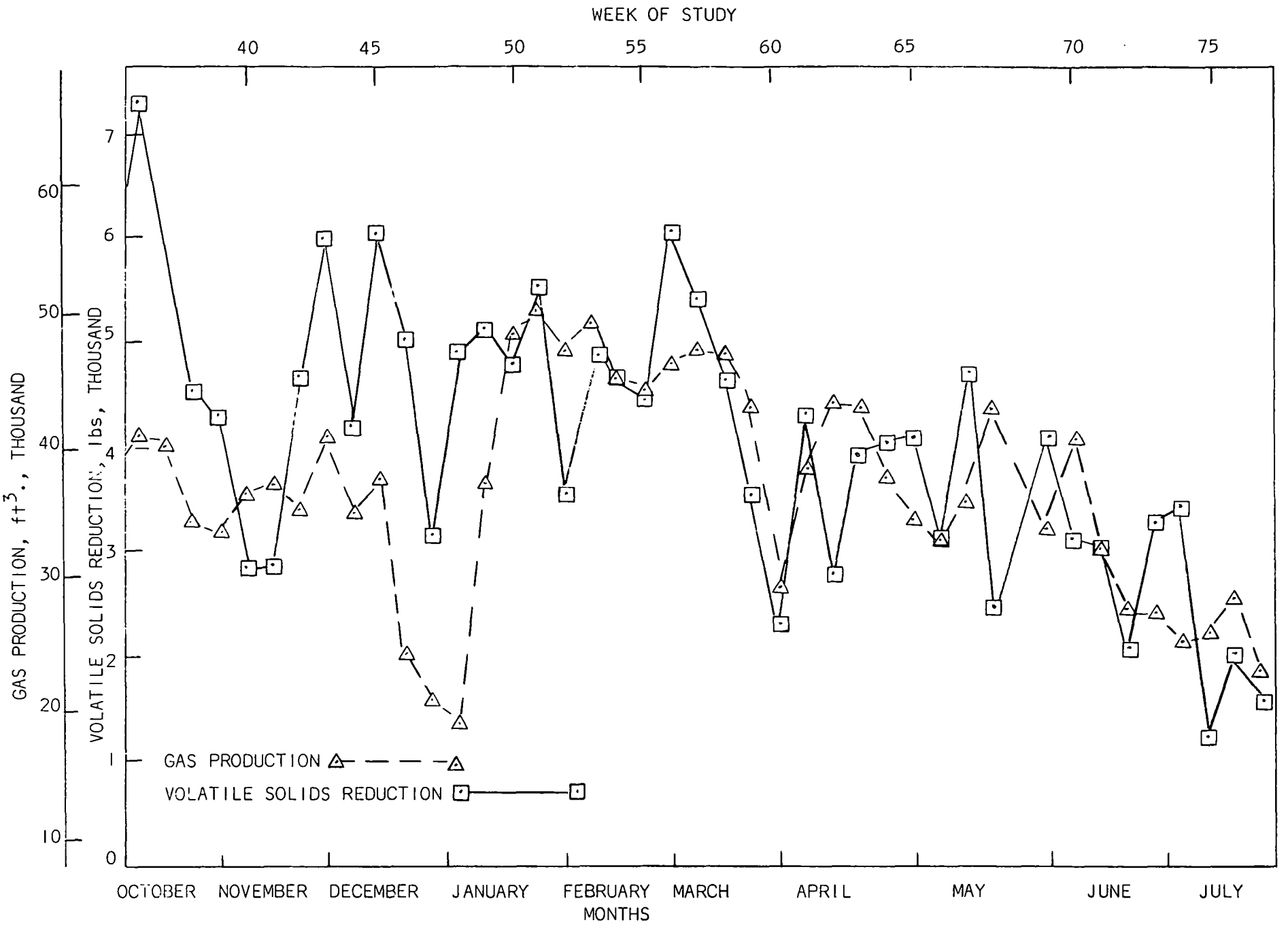

FIGURE 13b: DIGESTER GAS PRODUCTION AND REDUCTION OF VOLATILE SOLIDS

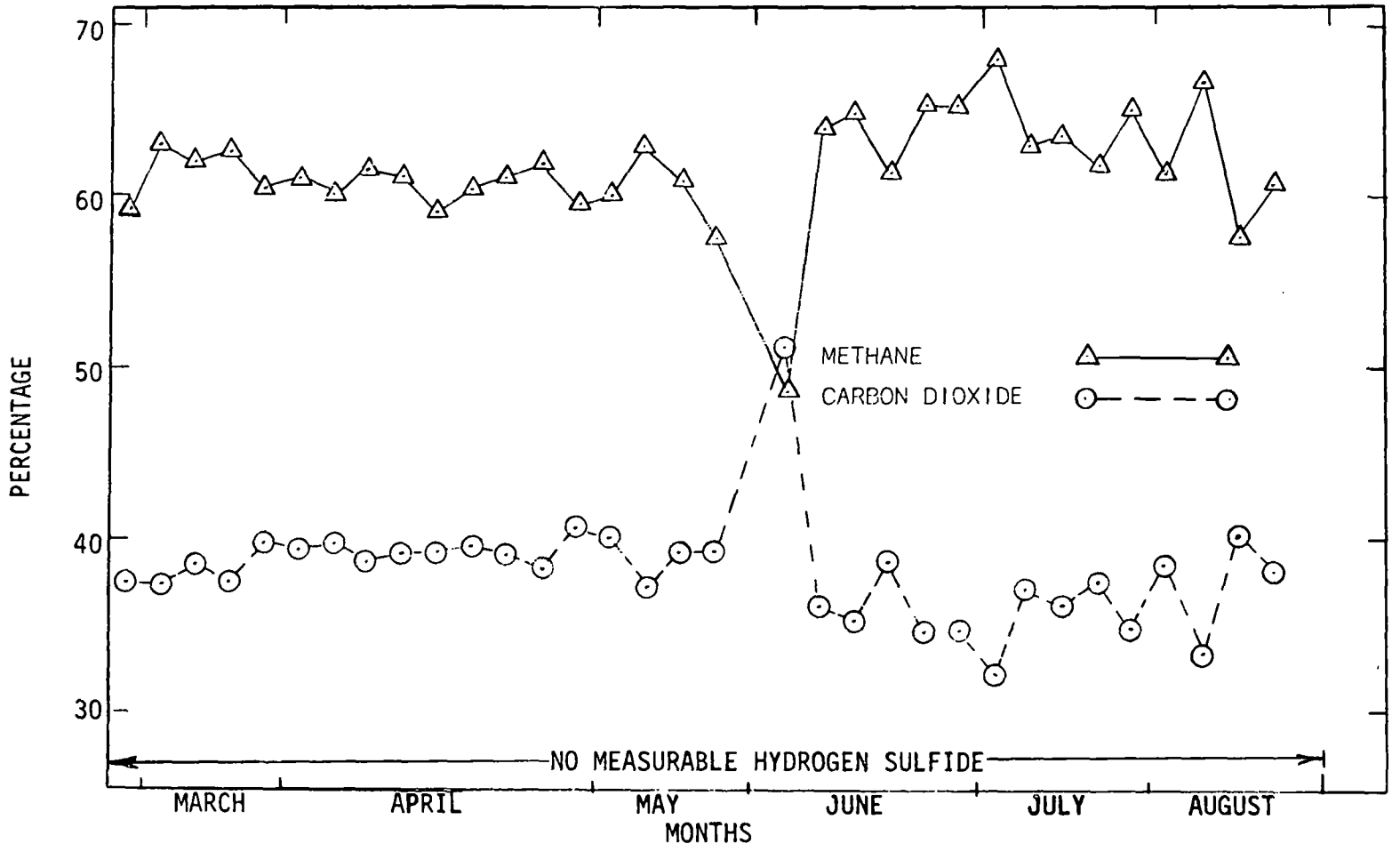

FIGURE 14: QUANTITATIVE ANALYSIS OF DIGESTER GAS

Fig. 15 shows the sulfate ion concentration of the sludges recorded during phase 1 of the study period. The sulfate concentrations in the digested sludge through May 28, 1969 were higher than the levels recorded in June. This was expected as alum was added to the system until May 28, 1969, then sodium aluminate additions began. Note, that even with alum additions, a large increase of sulfate ion was not observed in the sludges. The levels of sulfate ion in both the raw sludges are approximately equal, although raw Borough sludge had no alum additions. It appears that chemical precipitation of phosphorus from wastewater, utilizing alum, will not stimulate production of hydrogen sulfide gas during anaerobic digestion, because the sulfate ion is not incorporated in the sludge to any extent and thus does not enter the digester.

ALUMINUM

Fig. 16 shows the values obtained for soluble aluminum ion utilizing the Rapid Modified Eriochrome Cyanine R Method after Schull and Guthan (19) and run during Phase 1 of the study. The values are quite low for the raw sludges and reach a maximum of only 2.5 mg/l in the digested sludge. Even during the digester upset a marked increase in the soluble aluminum ion concentration did not occur. For the reasons pointed out in the discussion of this method on pages 14-16 the values obtained are probably higher than the actual ion concentrations. It is the authors' contention that there was very little soluble aluminum, and that values measured represented mostly redissolved aluminum compounds.

It is very unlikely that the digester upset was caused by "aluminum ion toxicity" because of the low aluminum ion concentrations, the fact that the upset occurred four months after the introduction of the aluminum compound into the digester, and the fact that the digester recovered without a cessation in the aluminum addition.

SLUDGE DEWATERING

During this investigation, dewatering tests were conducted to determine the effect of the aluminum phosphate complex on sludge dewatering. Analyses were run only on raw University sludge as a digested sludge which did not contain the aluminum phosphate was unavailable to use for a control. Therefore, comparison of raw sludges gave a better indication of the sludge conditioning properties of the phosphate precipitate. Data and calculations of test results from the dewatering studies are included in the Appendix.

Two sets of analyses were carried out on sludges containing precipitates formed when sodium aluminate was being added, the first on June 26, 1969, and the second on July 23, 1969. On September 2, 1969, sludge which contained no chemical additions, and sludge containing

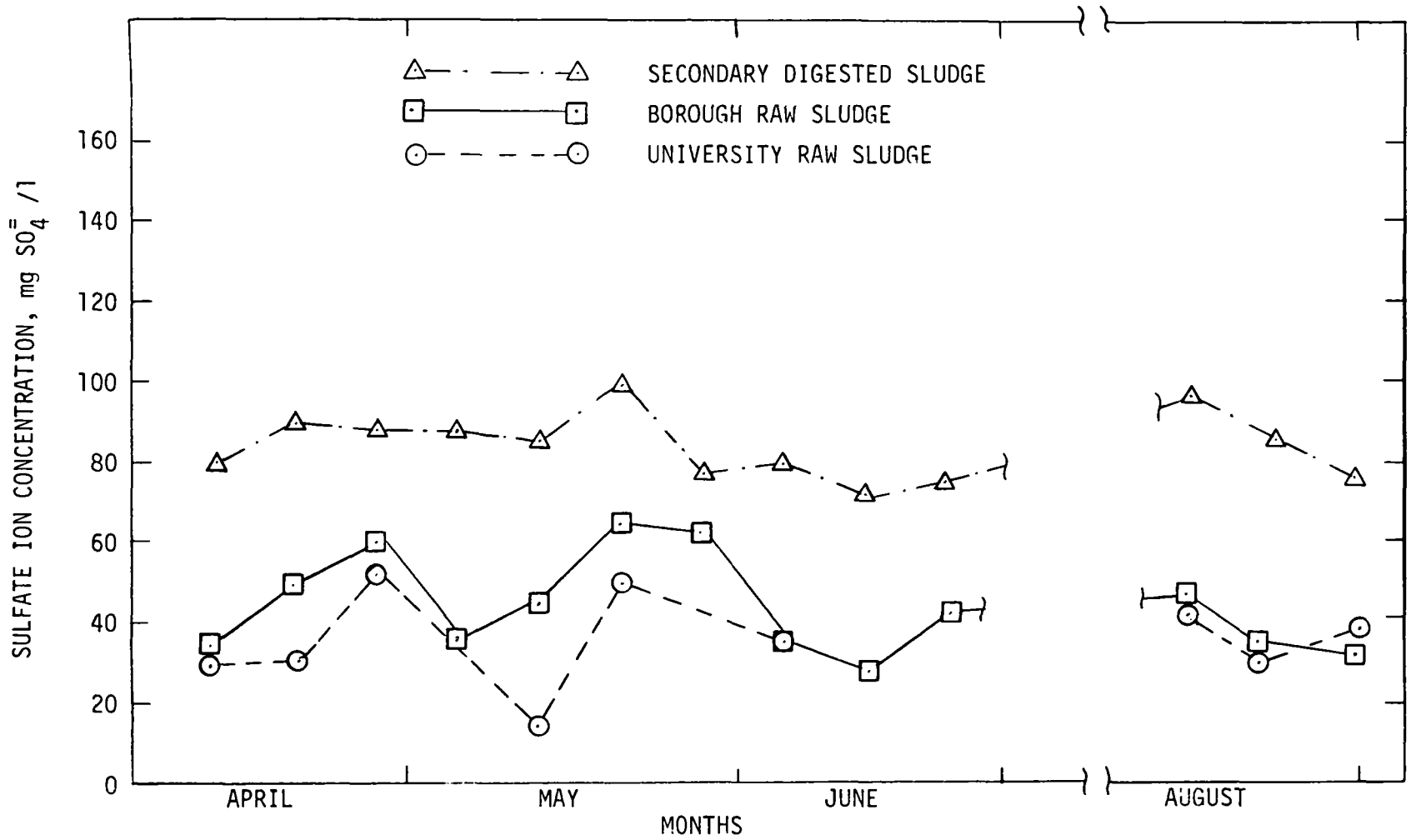

FIGURE 15: SULFATE ION CONCENTRATIONS OF THE SLUDGES

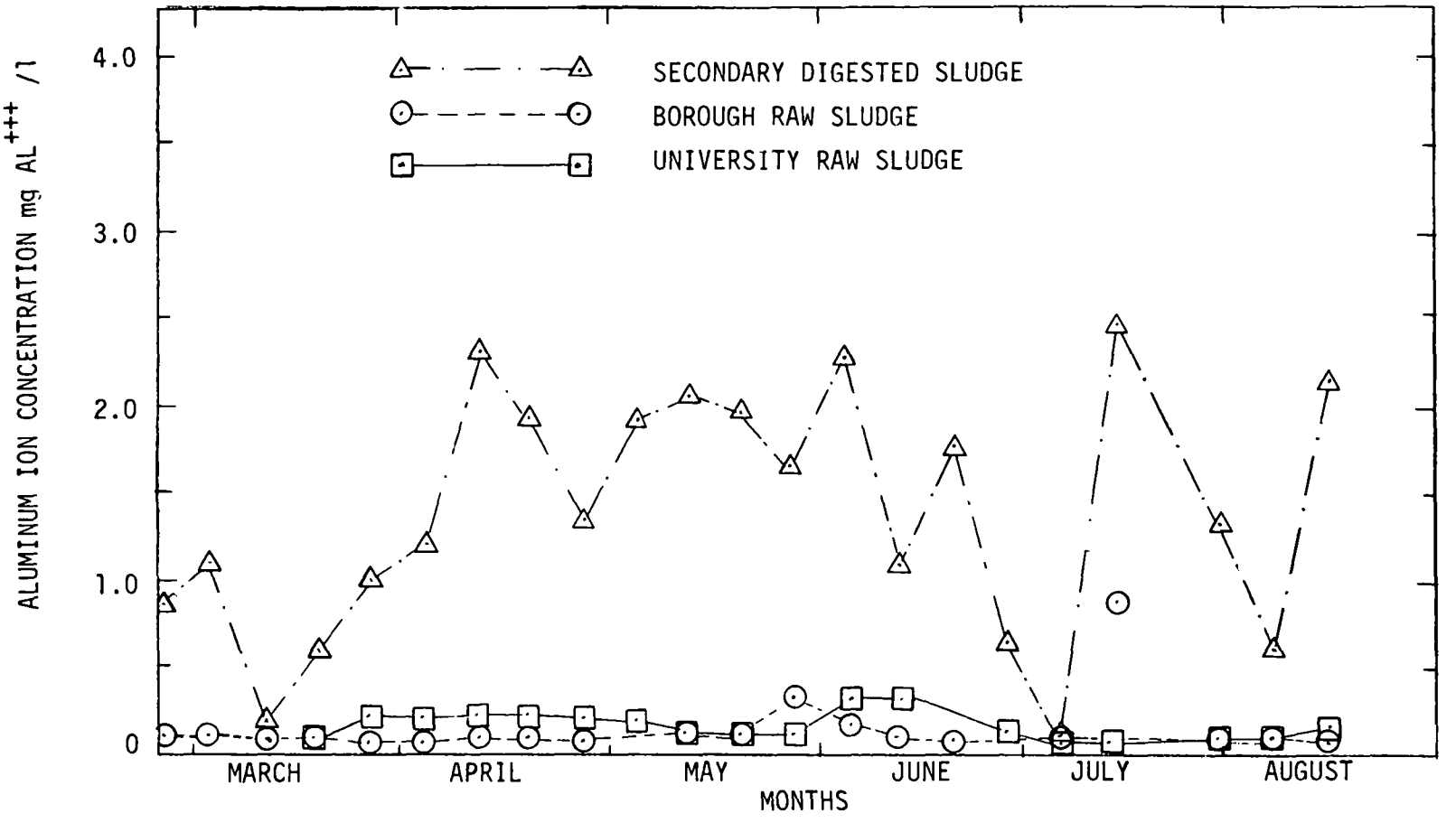

FIGURE 16: ALUMINUM ION CONCENTRATIONS OF THE SLUDGES

precipitates from the addition of alum were tested. The sludge which contained no chemical addition was used as a control sample. The raw University sludge did contain small amounts of precipitate as the waste activated sludge was recycled to the influent end of the plant, but the amount recycled was small and should have little effect on the sludge characteristics. These sludges were analyzed as 100 percent waste activated sludge, a mixture of 25 percent raw University sludge and 75 percent waste activated sludge, and a mixture of 50 percent raw University sludge and 50 percent waste activated sludge. All mixtures were composited by volume and all composite samples totaled 200 ml. Table 4 shows the specific resistance and total solids of the various sludges. The specific resistance is an indication of the dewaterability of a sludge; with a low specific resistance indicating easier dewatering (3).

Samples tested on June 26, showed increasing values of specific resistance as the percentage of raw sludge was increased, but these changes were quite small.

Samples tested on July 23 contained aluminum phosphate compounds formed from the addition of sodium aluminate to the activated sludge. These samples showed almost no change in specific resistance values for the three composite sludges. In fact, a slight decrease in specific resistance and an increase in total solids was noted as the percentage of raw sludges in the sample was increased. This difference may be explained by the fact that the average total phosphorus indicates that less precipitate was available to precondition the waste activated sludge. The specific resistance values for the waste activated sludges of June 26, 1969 and July 23, 1969, also supports this statement.

During this stage of the study, sodium aluminate was added to both of the aeration tanks, so that a control sample was not available. On September 2, 1969, the sample collected from aeration tank No. 1 contained precipitate formed from the addition of alum while the activated sludge sample from aeration tank No. 2 contained no chemical precipitate. In these samples the specific resistance increased as the percentage of raw sludge increased. Comparison of the control sample and the sample containing precipitate formed from the addition of alum showed at least one order of magnitude difference for the 100 percent activated sludge and the 75 percent activated sludge and 25 percent raw sludge samples. A smaller difference was found between the 50 percent activated sludge and 50 percent raw sludge sample and the control sample. It is concluded that under these conditions alum addition to wastewater for the removal of phosphorus also produces a waste activated sludge which is easier to dewater. Also, when this sludge is combined with raw primary sludge, the resulting mixture again shows an increased ability to be dewatered.

While sludges containing precipitate formed from the addition of sodium aluminate could not be compared against a control taken at

TABLE 4: SPECIFIC RESISTANCE AND TOTAL SOLIDS OF SLUDGES

SAMPLE:		SPECIFIC RESISTANCE sec^2/gm	TOTAL SOLIDS %
6/26/69	100% AS[a]	0.84×10^9	3.08
SODIUM	100% AS	0.70×10^9	3.14
ALUMINATE	75%AS-25%RS[b]	1.28×10^9	2.72
	50%AS-50%RS	2.01×10^9	2.60
7/23/69	100% AS	2.88×10^9	2.20
SODIUM	75%AS-25%RS	2.78×10^9	2.80
ALUMINATE	50%AS-50%RS	2.31×10^9	3.50
9/2/69	100% AS	0.38×10^9	1.09
ALUM	75%AS-25%RS	0.63×10^9	1.20
	50%AS-50%RS	2.78×10^9	1.41
9/2/69	100% AS	5.06×10^9	1.84
NO CHEMICALS	75%AS-25%RS	9.15×10^9	1.78
ADDED	50%AS-50%RS	10.04×10^9	1.79

[a]AS-WASTE ACTIVATED SLUDGE

[b]RS-RAW UNIVERSITY PRIMARY SLUDGE

the same time as the samples, the relative values of specific resistance for these samples (Table 4) suggests that a similar ease of dewatering was obtained with sodium aluminate treatment.

Along with the specific resistance analyses, additional tests were run in which ferric chloride was added as a preconditioner prior to filtration. The amount of ferric chloride varied from 50 to 500 mg/l in a 200 ml sludge sample. The time of vacuum break was plotted against ferric chloride added, and the results shown in Figs. 17, 18 and 19. Samples containing precipitate formed from the addition of alum may be compared directly against the control samples having no chemical addition. Samples in which sodium aluminate was added did not have a direct control, but again may be compared with the other control without serious error.

In all cases, sludges treated with alum required less ferric chloride to condition than did the other sludges. The minimum time to vacuum break for this sludge occurred with concentrations of 125 mg/l of ferric chloride, while the control contained 250 mg/l. Sludges containing precipitate formed by the addition of sodium aluminate dewatered more readily than did the control for the alum sludge. The sludges treated with sodium aluminate also had a shorter time to vacuum break after a sufficient quantity of ferric chloride was added. Whether this was caused by the precipitate or was due to intrinsic sludge properties could not be determined in these studies.

In view of specific resistance values and results from the increasing dosages of ferric chloride, it appears that sludges which have been treated with alum to remove phosphorus are dewatered more easily than those which are not treated. These results also indicate that this statement may be true for sludges treated with sodium aluminate.

GENERAL DISCUSSION

The foregoing data indicate that a biological sludge containing a complex aluminum phosphate precipitate can be processed in an anaerobic digester without harm to the digestion process and without the process causing any phosphorus to be returned to the liquid waste stream. Although the total phosphorus balance indicated that all the phosphorus leaving the digester was not accounted for, the analyses appeared to be in error because of the uneven distribution of the solids in the digester which resulted in a non-representative sample being collected of the sludge leaving the digester.

The balance of soluble forms of phosphorus showed a better agreement although less phosphorus left the digester than entered it. This better agreement can be related to a more even distribution throughout the digester (Fig. 8). The unaccounted for soluble phosphorus was probably removed from the untreated sludge through precipitation or adsorption reactions with the insoluble hydrous aluminum phosphate. The soluble phosphorus balance also showed that most of the soluble

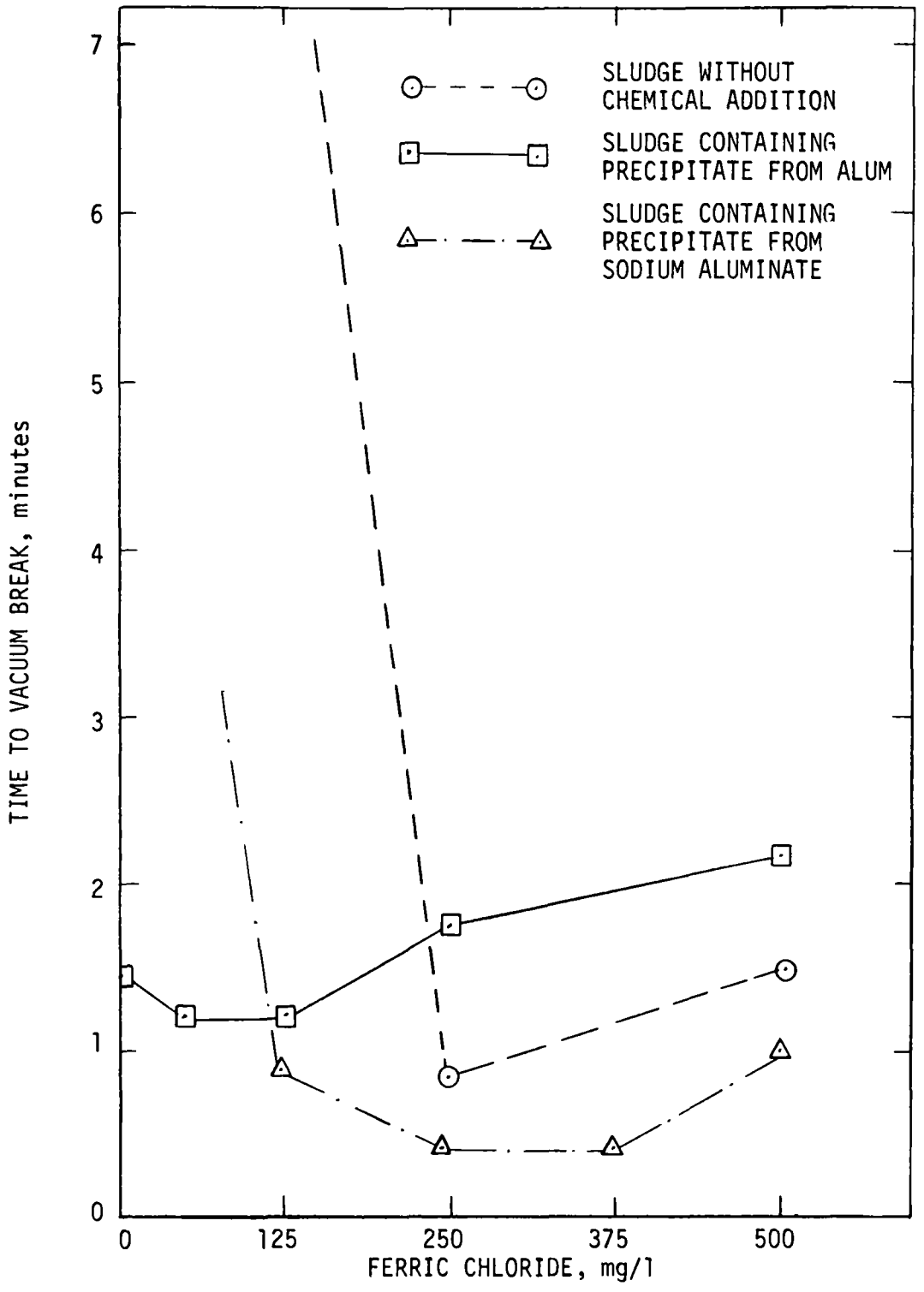

FIGURE 17: TIME OF VACUUM BREAK AS A FUNCTION OF FERRIC CHLORIDE CONCENTRATIONS ADDED TO WASTE ACTIVATED SLUDGE

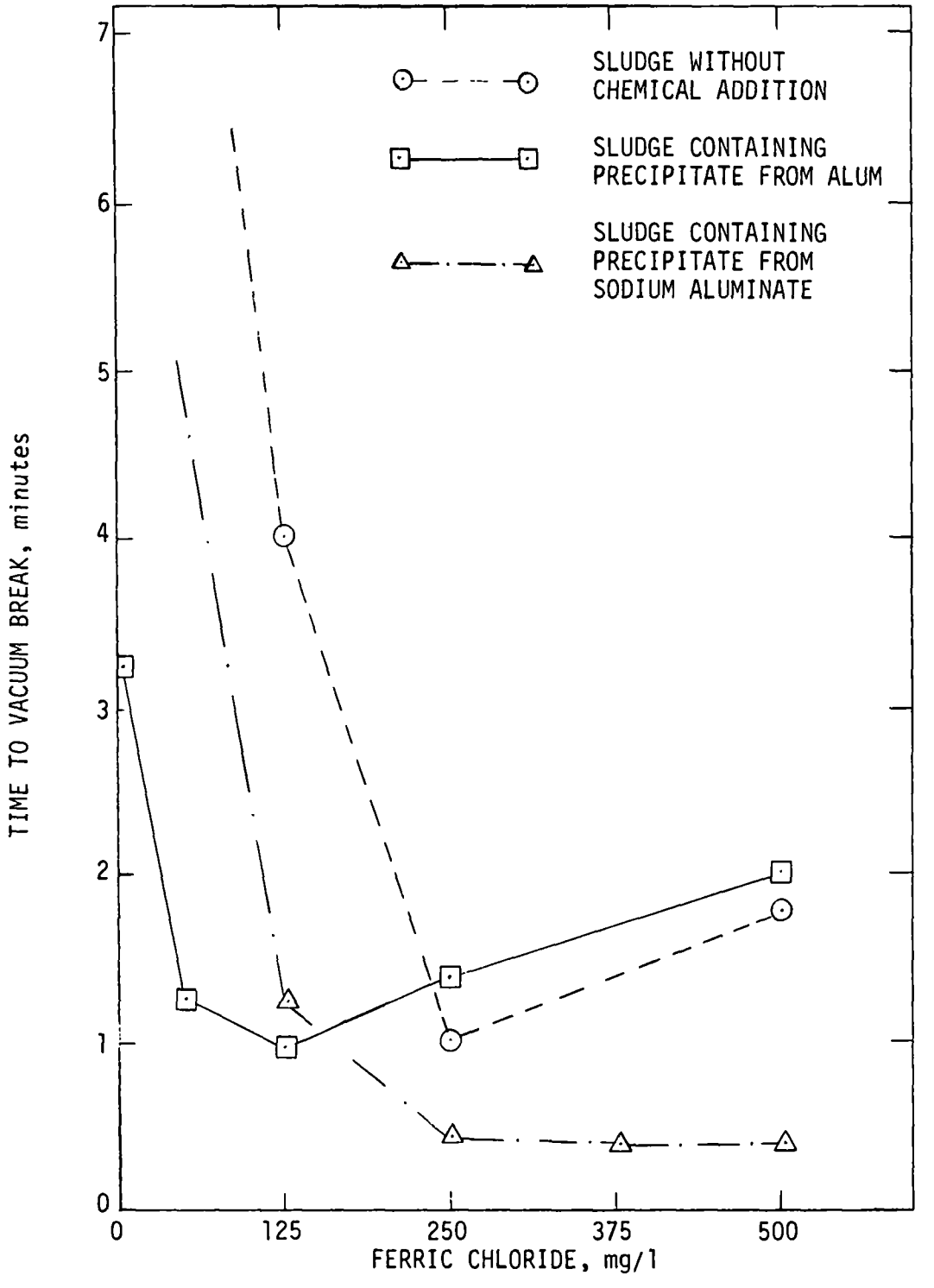

FIGURE 18: TIME OF VACUUM BREAK AS A FUNCTION OF FERRIC CHLORIDE CONCENTRATIONS ADDED TO A 75 PERCENT WASTE ACTIVATED 25 PERCENT RAW SLUDGE MIXTURE

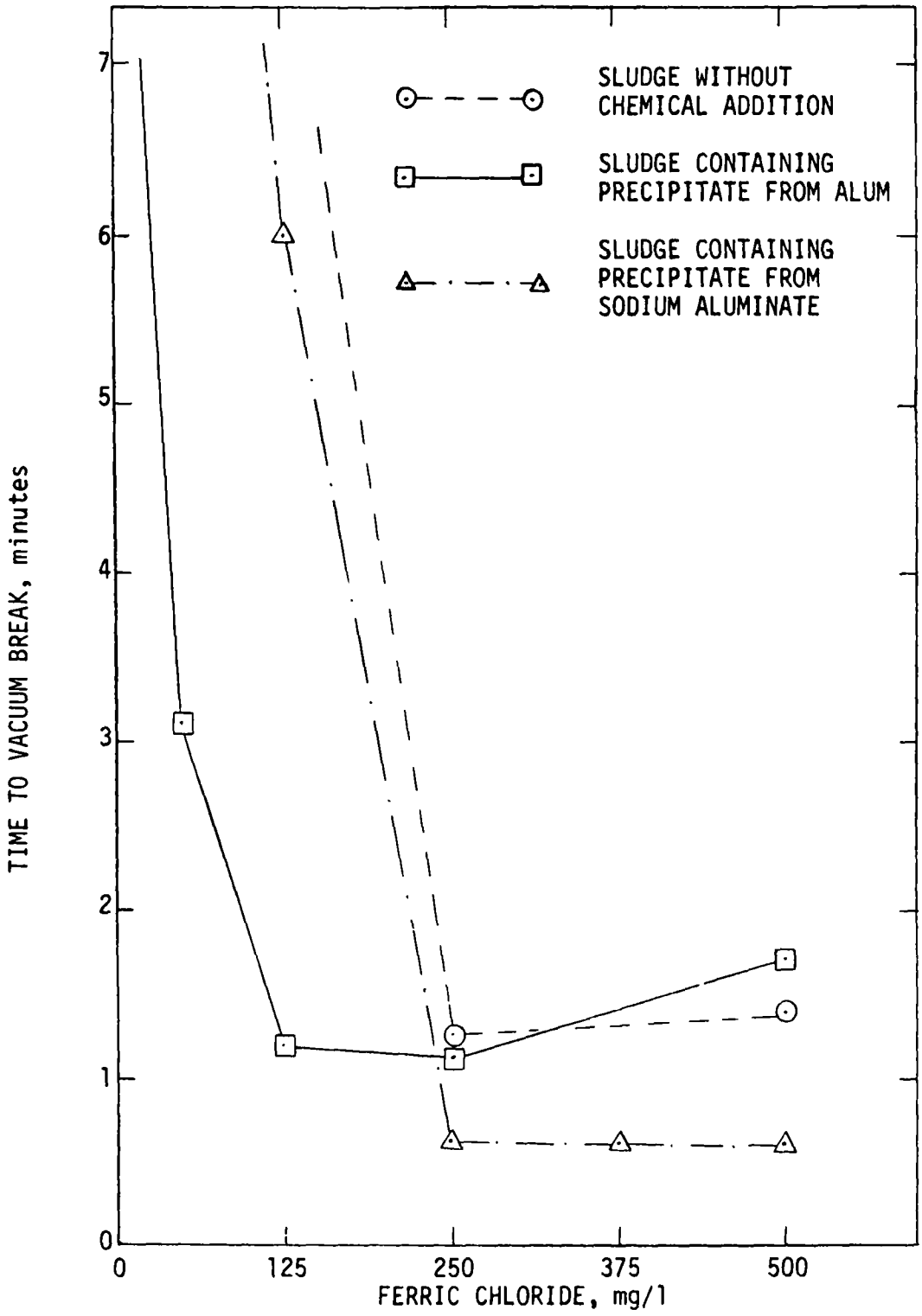

FIGURE 19: TIME OF VACUUM BREAK AS A FUNCTION OF FERRIC CHLORIDE CONCENTRATIONS ADDED TO A 50 PERCENT WASTE ACTIVATED 50 PERCENT RAW SLUDGE MIXTURE

phosphorus was in the orthophosphate form. No evidence was found that the precipitated phosphorus redissolved while undergoing anaerobic digestion. This is in agreement with findings of Barth and Ettinger (2) and Zenz and Pivnicka (23). Further, during a digester upset with the lowering of the digester pH, the precipitated phosphorus remained insoluble.

The measurement of several digestion parameters (alkalinity, volatile acids, pH, gas production, volatile solids destruction) showed that a relatively stable digestion period existed from the beginning of February 1969 until the end of May 1969. Beginning in the latter part of May 1969, a digester upset developed. This digester upset was probably related to a drop in the pH of the raw sludges beginning about mid-May. The reason for this pH reduction on both raw sludges could not be established, but was corrected by mid-July 1969, by reducing the volatile solids loadings and adding lime to the raw feed sludges.

Quantitative analyses of digester gas and sulfate ion in the various sludges showed that sulfate ion added during the removal of phosphorus from wastewaters using alum, did not cause a detectable amount of hydrogen sulfide to be produced during anaerobic digestion. A high soluble aluminum ion concentration did not occur in the sludges even during the digester upset period.

In comparing these various parameters, it appears that removal of phosphorus from wastewater by means of chemical precipitation using either alum or sodium aluminate and the addition of these phosphorus rich sludges to an anaerobic digester, will not cause adverse effects upon the anaerobic digestion process.

Finally, a series of dewatering tests run on waste activated sludge, and combinations of waste activated and raw University primary sludge showed that a sludge which incorporates the precipitates of the chemical additives dewaters more readily than a sludge which does not include these precipitates.

During phase 1, phosphorus was removed from only half of the total plant flow. The amount of precipitated phosphorus which entered the digester during this period was only approximately half that which can be expected in a plant treating all of its wastewater for phosphorus removal. During phase 2, phosphorus was removed from only one-fourth of the wastewater flow and the resulting sludge was only one-fourth of that which could be expected in a plant removing phosphorus from all of its flow. Zenz and Pivnicka (23) showed that in a plant treating all of the wastewater flow for phosphorus removal, the average difference in total phosphorus levels between the sludge containing phosphorus and the control sludge was 593 mg P/l. In this study the difference between the phosphorus level in the digested sludge prior to chemical additions and those after phosphorus removal

began was calculated to be 353 mg P/l. However, although a higher phosphorus level would be expected in a waste treatment removing phosphorus from its total flow, the distribution and effects of the phosphate precipitate should be no different from those recorded in this study.

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APPENDIX - SLUDGE DEWATERING DATA

This Appendix contains the data and calculations for the dewatering tests run during the investigation.

The method used for measuring the dewatering potential of a sludge was the specific resistance as presented by Coackley (3).

$$r = \frac{2bPA^2}{\mu c} \quad \ldots\ldots\ldots\ldots\ldots \quad [6]$$

where: r = specific resistance (sec^2 per gm)

b = slope of the plot of time divided by the volume of filtrate vs volume of filtrate

P = pressure vacuum across the filter membrane (gm per cm^2)

A = filter area (cm^2)

μ = the filtrate viscosity (poises)

c = solids content (gm per ml)

The specific resistance of a sludge can be determined and compared numerically with values obtained from other sludges to give a relative indication of the sludge dewaterability.

The following example shows a typical calculation for specific resistance.

Example: Date - 9/2/69

Run - No. 1

Sample - 100% waste activated sludge, alum precipitates incorporated

Temp. of filtrate (T) - 26°C

Viscosity of filtrate (μ) - 0.00875 poises

Total solids content of sludge (X) - 1.09%

Solids content of the filter cake (Y) - 6.0%

Area of the filter - 95.0 cm^2 (a constant value)

Pressure of the vacuum (P) - 790.6 gm/cm^2 (a constant value)

Filter Run Data:

time (sec) t	filtrate volume (ml) V	t/V
0	0	0
15	70	0.214
30	105	0.386
45	125	0.360
60	145	0.414
75	163	0.460
90	172	0.523

t_b = time of vacuum break recorded at 85 sec.

The value of b_1 which is the slope of the plot of t/V against V was obtained from Fig. 20.

$b = 0.0291$

$C_i = 100 - X = 100 - 1.09 = 98.91$

$C_f = 100 - X = 100 - 6.0 = 94.0$

$$C = \frac{1}{\frac{C_i}{X} - \frac{C_f}{Y}} = \frac{1}{\frac{98.91}{1.09} - \frac{94.0}{6.0}} = 0.0133$$

$$r = \frac{2bPA^2}{\mu c} = \frac{2(.00291)(790.6)(95.0)^2}{(.00875)(.0133)} = 0.384 \times 10^9$$

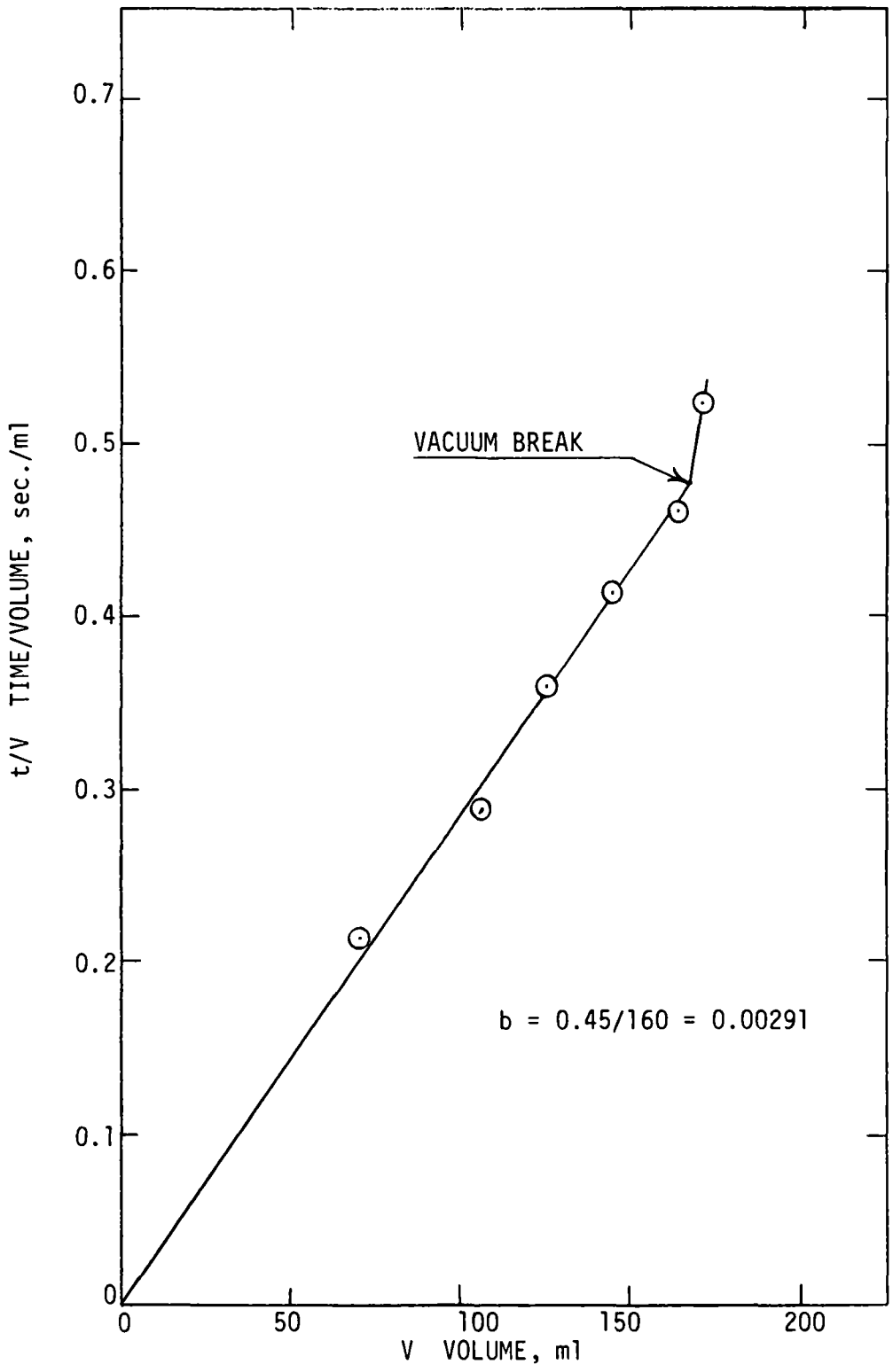

FIGURE 20: A TYPICAL PLOT OF t/V (TIME/VOLUME) AGAINST V (VOLUME) FROM RESULTS OF DEWATERING STUDIES, RUN No. 1, 9/2/69

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16. Abstract

Sludges containing aluminum phosphorus precipitates from an activated sludge wastewater treatment plant were digested in a high rate digester. Sodium aluminate and liquid alum were used to precipitate the phosphorus from the wastewater. Analyses on both raw and digested sludges showed that once precipitated from the wastewater and incorporated into a sludge the phosphorus did not redissolve while undergoing anaerobic digestion. Most of the soluble phosphorus in both the raw and digested sludges was in the orthophosphate form, and the addition of the inorganic aluminum phosphorus complexes did not adversely effect the anaerobic digester. High concentrations of soluble aluminum ion did not appear in the anaerobic digester, and the use of alum for phosphorus removal caused no additional hydrogen sulfide production during sludge digestion. Analyses also indicated the addition of aluminum compounds enhanced the dewatering properties of the raw sludges.

17a. Descriptors

*Activated Sludge, *Chemical Waste Treatment, *Phosphate, *Phosphorus, *Sludge, *Sludge Digestion,

Eutrophication, Nitrification, Nutrients

17b. Identifiers

*Aluminum, Sludge Gases, Sludge Dewatering Alkalinity, Volatile Acids

17c. COWRR Field & Group 05D

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