CHEMICAL CHARACTERISTICS OF AEROBICALLY DIGESTED ORGANIC SLUDGE

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

A. General

For many years, the sanitary engineer has been plagued with the problems of sludge disposal. The problem probably began in England in 1857, with a proposal to remove part of the "filth" in sewage prior to its discharge into a receiving stream. Methods for disposal of this filth, now referred to as sludge, accounts for 20 to 40 per cent of the total treatment cost.

Many new ideas for sludge treatment and disposal have been proposed and/or put into use in recent years. Tighter effluent criteria, increasing land scarcity, and population pressures have combined to make sludge disposal more difficult and expensive. The increasingly large quantities of sludge resulting from growth of industry also poses disposal problems. With these developments, the bioengineer continues to work toward more acceptable methods of sludge disposal.

The method most commonly used today is that of anaerobic digestion followed by dewatering of sludge. Some normal dewatering practices are: use of drying beds, vacuum filtration, and heat drying. Heat drying usually precedes sludge incineration. A newer method for sludge disposal that is being practiced more today is that of aerobic biological oxidation of organic solids. Actually, air has been used in the treatment of sewage waste since the 1930's. It first found its use in the activated sludge processes where it was used as a means of secondary treatment. In this process, primary and/or secondary sludges are sent to separate sludge digesters for further decomposition. It has been only in the last five or ten years that we have utilized aerobic digesters for the treatment of waste secondary activated sludge, and only recently have we utilized separate aerobic digestion for the treatment of combinations of primary and secondary sludges. This has been used only in conjunction with activated sludge processes. Bioengineers are now studying the feasibility of using separate aerobic digestion of primary and secondary sludge in conjunction with plants other than activated sludge. In other words, the trickling filter type plants. This research project deals with this concept.

B. Purpose of Sludge Digestion

Any discussion of sludge digestion is based on the assumption that sewage has been treated and the pollution of streams has been prevented by the removal of all of the objectionable material from sewage. The chemist classifies these materials as organic matter composed of carbon and hydrogen which, in the presence of sulfates, produce foul-smelling hydrogen sulfides, and we have purified sewage whenever we have removed the carbon and hydrogen compounds from the polluted liquor. When this is done aerobically, the chief endproducts are CO_2 and H_2O.

One can readily see that by definition, aerobic digestion seems to imply total oxidation. It is also easy to imagine that a treatment process that can dispose of all organic solids and not produce any residue is perhaps the engineer's dream. This process, however, has not yet been developed. Many researchers have argued the feasibility of such a design. In this paper, aerobic digestion is used to describe the separate aeration of waste primary sludge for a specified period of time. Its ultimate goal is not total oxidation, but the production of an inoffensive sludge that dewaters and dries readily.

C. Comparison of Anaerobic and Aerobic Digestion

It is appropriate at this time to make some comparison with anaerobic and aerobic digestion. It must be pointed out, however, that most aerobic digesters have been used in conjunction with activated sludge processes, and that the same comparison might not be true in conjunction with other treatment processes, such as the trickling filter.

1. Aerobic digestion has been found to be completely odorless, whereas anaerobic digestion is malodorous, especially when waste gas containing H_2S is burned incompletely.
2. Aerobic processes may be safely placed close to dwellings.
3. Construction cost for an aerobic digester is less.
4. Aerddigesters are not as sensitive to environmental changes such as grease, pH, and temperature.
5. Aerobic processes have less explosive hazards.
6. An aerobic process appears to require less time than anaerobic processes for degradation of organic material.

Certain disadvantages of aerobic digestion are:

1. The lack of a usable byproduct.
2. The cost of supplying air.
3. Larger sludge volume will be produced in aerobic digestion of primary and activated sludge due to synthesis of additional microbial cells. This is not necessarily true in conjunction with primary waste sludge alone.

D. Purpose of This Study

The purpose of this particular study was to examine the chemical characteristic of aerobically digested sludge on a pilot scale using both semi-continuous completely mixed and batch fed reactors. The physical characteristics including dewatering, drainability, and setteability were studied, and the results presented in a separate paper. Although this particular study was conducted using primary sludge alone, plans are being made to do similar type research using a mixture of primary and secondary sludge as well as secondary sludge alone. This information will be available at a later date. In all investigations, a comparison was made with sludge that had been anaerobically digested.

CHAPTER II

LITERATURE REVIEW

Most of the available literature concerning aerobic digestion of organic solids deals with the activated sludge process and its modifications. The information available is based mostly on studies conducted on small laboratory bench scales. The primary emphasis in these investigations was on environmental control and volatile solids reduction at various detention times. One researcher (13) dealt with similar chemical parameters as were included in this study. However, waste activated sludge was used instead of primary sludge from a conventional pollution control plant. There was no literature which reported on any pilot type studies. The data presented in this study will be the first report based on aerobic digestion of organic waste on a pilot scale.

In 1950, Coackley (1), using inverted quart bottles as aeration vessels, conducted a series of experiments to determine the extent of aerobic digestion of sludge previously subjected to anaerobic digestion. In one series, the anaerobic sludge was aerated without the addition of aerobic organisms. The other series of experiments was carried out after inoculating the sludge, usually after two days of aeration, with a culture of organisms obtained from a compost heap. He found that at a temperature of 18°C, the reduction in volatile solids after 48 days of digestion was not appreciable, even in the inoculated series. In the

37°C non-inoculated series, the volatile solids were reduced from 2.98 to 1.08 per cent after 48 days. This amounts to a 64 per cent reduction in volatile solids. He also reports values of 2.98 to 1.76 per cent in six days, or 41 per cent reduction, and 2.98 to 2.00 per cent in 28 days, or 33 per cent reduction. In the inoculated series, volatile solids were reduced from 2.66 to 1.52 per cent in 47 days. This amounts to a 43 per cent reduction. They also reported a reduction from 2.66 to 1.96 per cent in 28 days. This is a reduction of 26 per cent.

Jaworski, Lawton, and Rohlich (2) studied the effects of temperature, time, and loading rates on aerobic digestion of mixtures of primary and waste activated sludges. Both batch type and continuous feeding studies were conducted. The digesters used in this study were 6-liter Erlenmeyer flasks. They concluded that the reduction of volatile solids was a function of detention time and greater reductions in volatile solids were obtained at higher digestion temperatures. They reported 21, 32, 41, and 46 per cent reductions in volatile solids content of sludge at 5, 10, 30, and 60-day detention times, respectively, at a digestion temperature of 15°C. They also reported 24, 41, 44, and 46 per cent reductions at 5, 10, 30, and 60-day detention times at a temperature of 20°C.

Lawton and Norman (3) conducted a three-year aerobic digestion study at the University of Wisconsin investigating the effects of detention time, temperature, pH, aeration rate, and loading rate on the reduction of volatile solids and the characteristics of the digested sludge. The activated sludge used was produced from a domestic waste comprised of 1/2 pretreated meat packing waste and 2/3 domestic sewage. They concluded that aerobic digestion of sludge can produce sufficient volatile solids reduction to render a humus-like biologically stable endproduct. They also reported that environments in which the pH was as low as 5.0 did not appear to affect significantly the digestion efficiency. Their research also showed that increased temperatures within limits resulted in increased volatile solids reduction. They reported reduction in volatile solids of 14-20 per cent, 34-41 per cent, and 39-53 per cent at 5, 15, and 30-day detention times, respectively, at a temperature of 20°C.

Moriarity (4) compared aerobic and anaerobic digestion under the same temperature, loading rate, and detention time. Based on CO_2 production, he found aerobic digestion to be more complete.

Reyes and Kruse (5) aerobically digested night soil and found the reduction in volatile matter increased as temperature of digestion increased. They reported a reduction of 25-35 per cent at 8°C, and up to 67 per cent at 60°C when night soil was aerated for 20 days.

Drier (6)(7) reported on results obtained from a number of municipalities incorporating aerobic digestion of waste activated sludge. He reports appreciable reduction in volatile solids at all plants, although detention times were not given.

Eckenfelder (8) states that sludge accumulated in a bio-oxidation system will undergo oxidation at varying rates depending upon the factors of temperature, waste characteristics, microbial content, and sludge age, and that the microbial content of sludge will vary widely, depending upon the nature of the waste being treated. Eckenfelder reported on oxidation of sludges originating from a variety of wastes. His results for a domestic waste, using thickened sludge obtained from the recycle system of a bio-oxidation plant, showed the volatile content of sludge was reduced from 76.5 to 63.5 per cent. This was a reduction of 17 per cent at 25°C and detention time of seven days. He also reported a BOD reduction of 48 per cent and a suspended solids reduction of 38.2 per cent for the same time period.

Reynolds (9) reported on experiments with waste sludge from a bisorption plant in Austin, Texas. He concluded that stabilization of waste activated sludge is feasible. Batch studies showed the maximum stabilization time for 95 per cent destruction of biodegradable solids at the Austin plant to be 5.7 days.

Ritter (10) reports observation from three plants in Pennsylvania that are using aerobic digestion of waste activated sludge. The digesters of each plant produce a stable sludge which dries readily. The liquid sludge and sludge cake are useful for soil conditioning. Based on his study, anaerobic digestion accomplishes greater reduction in volatile solids than does aerobic digestion.

Barrett (11), using two 8-gallon tanks and four 2-liter tanks, studied aerobic sludge digestion without temperature control. Temperatures varied from 29°C in July to 20°C in September. Detention times of 2, 4, 8, and 16 days were studied. Tests showed a reduction in volatile solids of 34 per cent for the 4-day detention time, 45 per cent for the 8-day detention time, and 55 per cent for the 16-day period.

Dr. Roar L. Irgens and Dr. H. Orin Halvorson (13) of the Department of Microbiology, University of Illinois, reported results of aerobic digesters, using a mixture of primary and secondary activated sluge. Detention times of 7, 10, 13, 20, and 40 days were studied at temperatures of 23°C and 20°C. Organic loadings to the reactors were kept constant by collecting one large sample and diluting it to a standard concentration having a COD of 50,000 ppm. The sample was stored in a dark room and utilized as needed according to the detention time used. They found that it took about seven days to obtain flocculent sludge which, upon standing, left a clear supernatant. It took 27 days to obtain equilibrium. At detention times of 7, 10, 20, and 40 days, the mixed liquor showed COD reduction of 45, 48, 57, and 60 per cent. BOD reduction varied from 83 to 89 per cent. Kjeldahl nitrogen reduction ran from 13 to 17 per cent, and volatile solids reduction varied from 32 to 38 per cent. Phosphate content of treated sludge was the same as that of the raw sludge.

Ballard (12) studied the digestion of sewage sludge by aerobic processes. Detention times of 4 and 8 days were investigated. He reported volatile solids removal of 20 to 52 per cent for the 4-day detention period, and 27 to 48 per cent removal for the 8-day detention time. He also reported that the 8-day detention time produced sludge with greater drainability than did the 4-day detention period.

CHAPTER III

MATERIALS AND METHODS

A. Experimental Feed and Setup

The feed used in these experiments was primary sludge obtained from the primary clarifier at the Stillwater, Oklahoma, pollution control plant. Figure 1 shows a schematic of the treatment plant and the point at which sludge was withdrawn. Sludge from the primary clarifier was pumped to separate reactors with various detention times. Figure 2 shows a schematic of the experimental layout. At the Stillwater plant, as a matter of operational procedure, secondary sludge from the final clarifier is pumped to the primary clarifier for thickening and subsequent pumping to the separate sludge digester. In order to keep from getting a mixture of primary and secondary sludge, the piping at the Stillwater plant had to be rerouted in order to allow one clarifier to contain primary sludge only. The sludge was then pumped from this clarifier to the pilot plant where it was harvested in a 15-gallon container and pumped to each reactor as needed according to detention time. Flow to the reservoir from the primary clarifier was regulated by an automatic valve which, in turn, was controlled by the sludge level in the reservoir. Time control metering pumps transferred sludge from reservoir to reactors. The system was operated as a completely mixed semi-continuous flow operation. Each pump pumped a fraction of each thirty minutes, depending upon reactor detention time. The same amount of

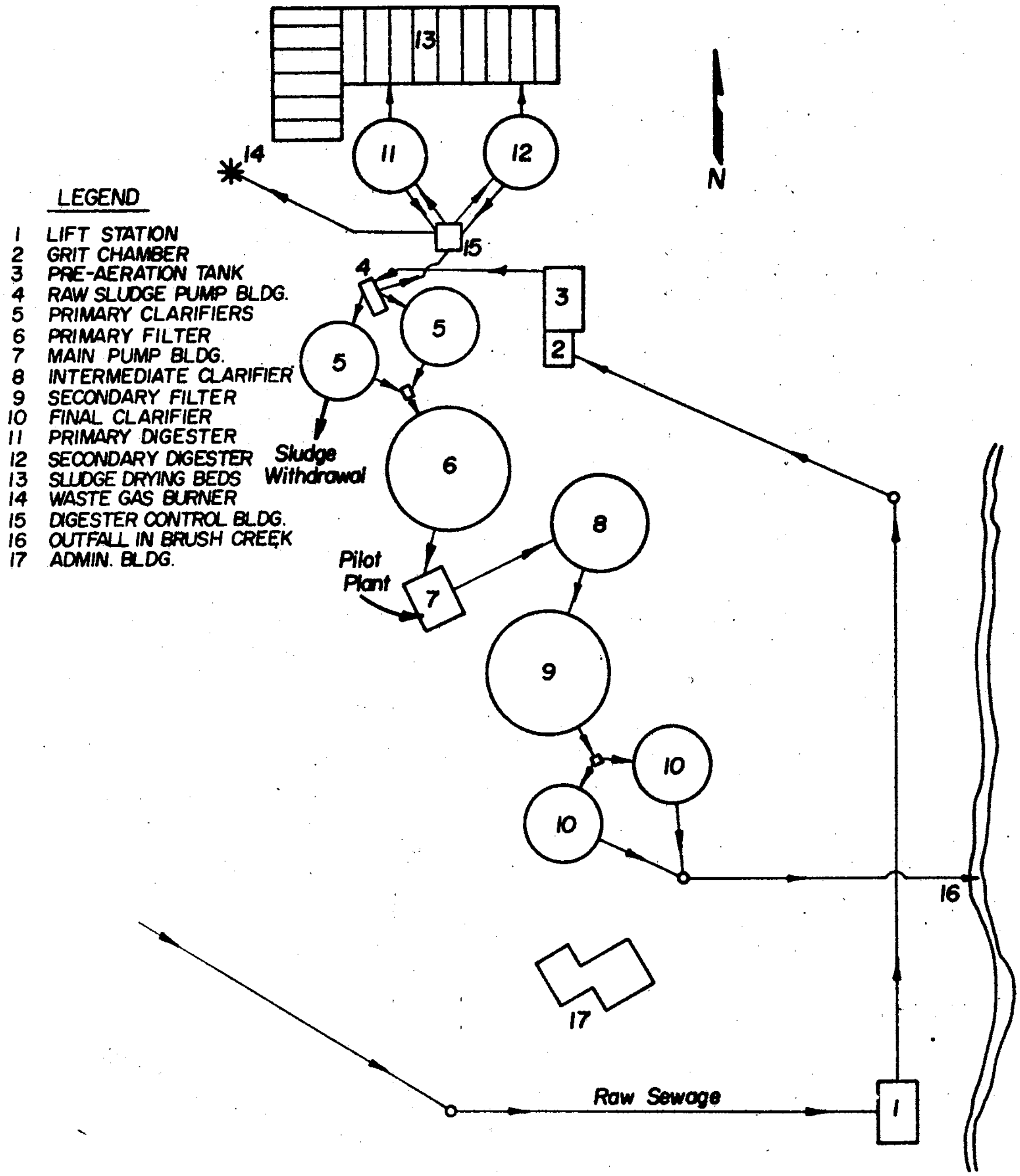

Figure 1 - Schematic Flow Diagram of the Stillwater Center for Pollution Control.

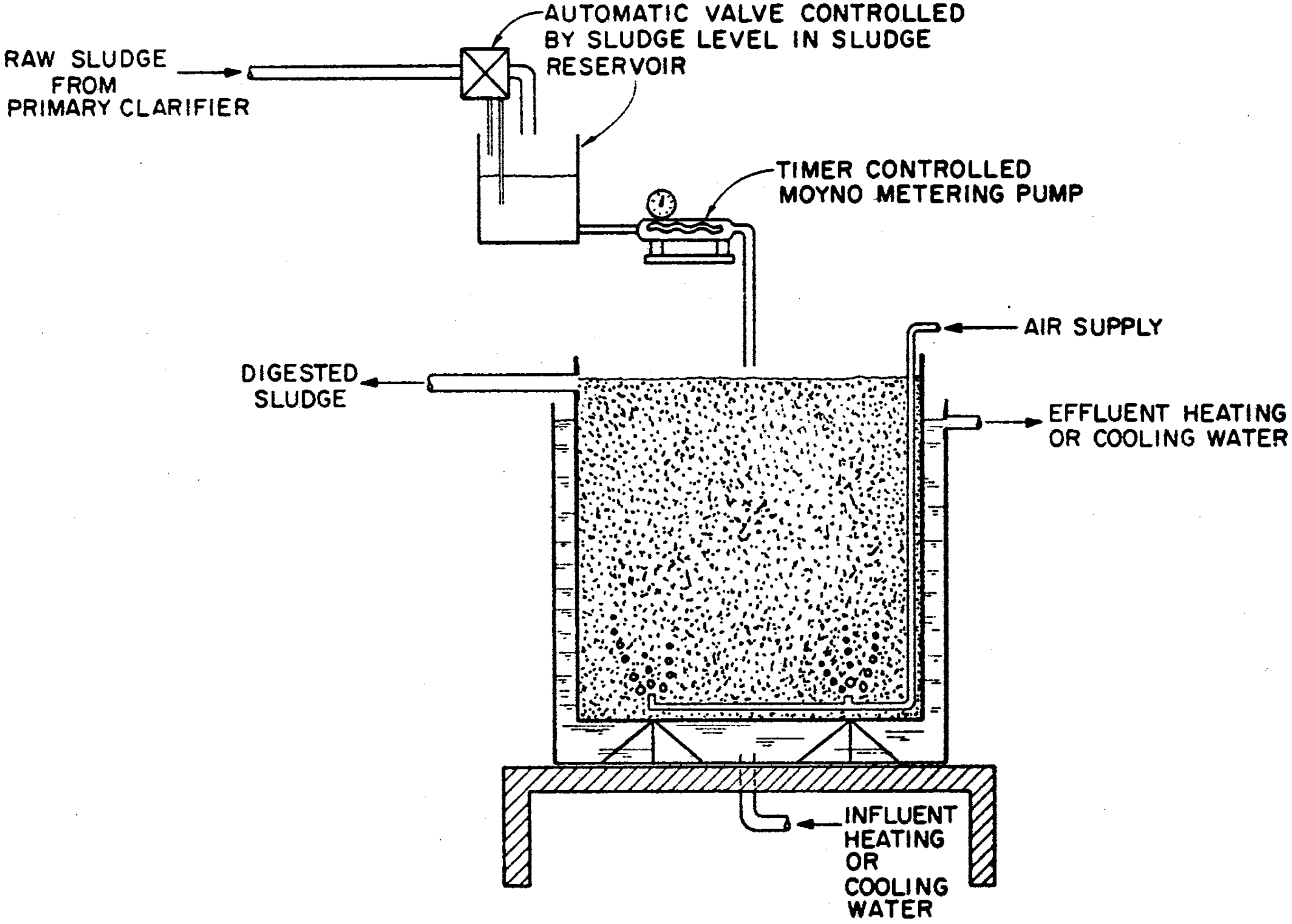

Figure 2 - Schematic Diagram of Completely Mixed Semi-continuous Flow Reactors.

waste was discharged as was fed to the reactor; i.e., inflow was equal to outflow. Detention times of 2, 4, 8, 12, 18, 24, and 30 days were investigated at a temperature of 25°C. Air was supplied to the reactors through diffusers located several inches from the bottom of each reactor. Air flow rate was set at 88 cfm/1000 cu ft of digester space. Air flow rate was measured by calibrated flowmeters. Each reactor capacity was 180 gallons. Each reactor was placed inside a 250-gallon tank. The larger tanks were used for temperature control. Heated or cooled water was pumped through the bottom of the outside tank, between the walls of the outside tank and the reactor to maintain a temperature of 25°C within the reactors.

B. Experimental Protocol

Digested sludge was collected from the reactors periodically for chemical and physical analyses. Samples were split into three fractions for analyses. One fraction, the mixed liquor, was tested for the following parameters: COD, BOD, ammonia nitrogen, nitrate nitrogen, total phosphates, total solids, volatile solids, and pH. A second fraction was the filtrate from the mixed liquor. "Filtrate" here means that liquid which passes through No. 40 Whatman filter paper. COD, BOD, PO_4, Kjeldahl-nitrogen, and nitrate nitrogen were run on this fraction.

The third fraction was the mixed liquor after settling for four hours. The supernatant was drawn off and the concentrated mixed liquor was applied to the sand beds for determination of dewatering characteristics. That liquid portion passing through the sand beds was then analyzed for COD, PO_4, and Kjeldahl-nitrogen.

Although it is well known that the character of raw sludge varies from day to day, no measures were taken to control the feed concentration. The reactors were fed, using a fixed volume of sludge, but the organic load was not kept constant. Halvorson (13), et al. did some studies utilizing activated sludge where organic loadings were kept constant. The result of these findings will be compared with their findings.

C. Test Period and Method of Reporting Data

The data presented in this investigation were gathered over a period of six months. The experimental reactors were placed into operation by first filling them with 1/3 primary sludge and 2/3 tap water. The units were then aerated for a period of approximately six weeks. During this period, additional primary sludge was added to each unit to maintain adequate food supply and to replace evaporation losses. After the acclimation period was completed, solids profiles on the reactors were run to determine if the system was completely mixed. Figure 3 shows results of these profile analyses. When the systems approached the completely mixed state, the reactors were fed on the basis of the following detention times: 2, 4, 8, 12, 18, 24, and 30 days. Samples were then collected as previously stated, and analyzed. Experiments were conducted in three phases. Phase I included samples taken from October through December. This phase included six separate analytical runs which were averaged and reported as experimental run No. 1. The second phase included a series of three different analytical runs conducted in January, 1971. The results from these experiments were averaged and reported as experimental run No. 2. The third phase included two experiments run in February, 1971. These were averaged and reported as experimental run No. 3. Averages from all three phases were then

Sample Elev.	Solids (mg/l)	Volatile Solids (mg/l)	Tank #
6"	46,000	20,000	1
↓	38,000	20,000	2
↓	14,000	4,000	3
↓	14,000	8,000	4
24"	52,000	24,000	1
↓	30,000	20,000	2
↓	12,000	10,000	3
↓	8,000	2,000	4
TOP	50,000	20,000	1
↓	28,000	14,000	2
↓	14,000	10,000	3
↓	14,000	8,000	4

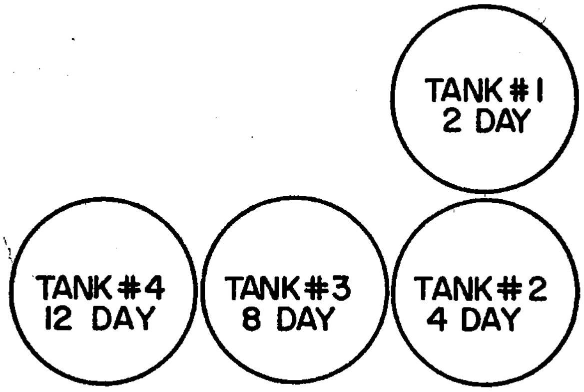

Figure 3 - Solids Profile for Four Detention Times Studied With Semi-continuous Completely Mixed Reactors.

compiled and reported as overall averages for all runs. This information was then plotted and will be discussed in the discussion section of this report.

The analytical data for the batch study was taken once, using a trpilicate sample for each detention time. The average results for the triplicate samples were then determined and plotted.

The batch unit was a unit of identical makeup as the completely mixed semi-continuous flow unit (Figure 2)., It was placed into operation by filling the 180-gallon reactor with primary sludge seeded with 10 per cent aerobic sludge. An aeration unit was placed near the bottom of the reactor, and air flow measured by use of a calibrated flowmeter. The sludge was then aerated for one hour to develop a completely mixed environment. A sample was drawn after one hour of operation and labeled time zero. Samples were taken at 2, 4, 8, 12, 18, 24, and 30-day intervals. One-gallon samples were taken for chemical analyses. COD, BOD, total solids, ammonia nitrogen, nitrates, volatile solids, and pH were run on all samples. Temperature and DO determinations were made directly on the reactor contents. During this study no water was added to compensate for the sample taken or for evaporation losses. No other additional feed was added to the unit. Samples were also drawn three times during this study to test for the dewatering characteristics of the aerated sludge. In most cases this amounted to about ten gallons of sample material. Again, water was not added to take care of sample losses.

D. Analytical Procedures

Analytical methods and analytical techniques were the same for both the batch and the semi-continuous completely mixed reactors. All tests described herein and all calculations made therefrom were in accordance with procedures as listed in Standard Methods for Examination of Water and Waste Water (15). Any variance in the above mentioned procedure will be described in detail.

(a) Total Solids

This test measured the amount of suspended and dissolved material present in the waste. Tared evaporating dishes were used, dried at 103°C and ignited at a temperature of 600°C in a muffle furnace. This procedure was taken to allow for determination of volatile solids. Initially, 100 ml samples were used. The samples were later increased to 250 ml for better accuracy. The results were reported as mg/l total residue.

(b) Ammonia Nitrogen

Determinations were made in accordance with recommended methods of the Federal Water Pollution Control Agency's Ada laboratory (16). Eight hundred millimeter Kjeldahl flasks were used with 400 ml of sample. The pH of the samples was adjusted to 9.5 with one normal sodium hydroxide. Twenty-five ml of borate buffer were added. Three hundred ml of the sample were distilled at a rate of 6-10 ml/min into 50 ml of 2 per cent boric acid. The sample was then titrated with 0.02N H_2SO_4 in the presence of a mixed indicator.

Calculations:

$$\text{mg/l } NH_3\text{-N} = \frac{A X 0{\cdot}28 \times 1000}{S}$$

in which A = ml of 0.02N H_2SO_4 used

S = ml of sample

(c) Nitrates

Nitrates were determined by the Brucine method as outlined in Standard Methods and recommended by the Federal Water Pollution Control Agency's Ada laboratory (16). The method is based upon the reaction of nitrate ion with brucine sulfate in 13N H_2SO_4 sulfuric acid solution at a temperature of 100°C. The color of the resulting complex was measured at 410 mμ. The temperature control of the color reaction was extremely critical.

(d) Total Phosphates

Phosphates were determined according to methods outlined by the Federal Water Pollution Control Agency. Total phosphates referred to in this report include total orthophosphates--both inorganic and hydrolyzable phosphates. Ammonium molybdate and potassium antimonyl tartrate react in an acid medium with dilute solutions of phosphorus to form an intensely blue-colored complex by ascorbic acid. The color is proportional to the phosphorus concentration. A spectrometer suitable for measurements at 880 mμ and providing a light path of 1-inch (2.54 cm) or longer was used in the phosphate determination. All glassware used in the determination was washed in hot 1:1 HCl, and rinsed with distilled water.

(e) Volatile Solids

Residues from total solids determinations were ignited at 600°C, and the loss in weight recorded as volatile solids. Volatile solids measured that percent of total solids which was organic.

(f) Fixed Solids

The difference in total solids and volatile solids, calculated arithmetically, were reported as fixed solids.

(g) pH

The pH was determined by using a Beckman Expandomatic SS-2 pH meter. The instrument was always standardized to pH 7 before use.

(h) Dissolved Oxygen (DO)

DO was measured by use of a galvanic cell oxygen analyzer. The instrument was calibrated by the Winkler method before use.

CHAPTER IV

RESULTS

A. Batch Studies

Figure 4 shows a plot of temperature, pH, and dissolved oxygen at various aeration times. It will be noted that the temperature remained constant at 25°C. The pH of the mixed liquor varied from a low of 6.3 at 4 and 8 days, to 8.0 at the end of 30 days. The pH at time zero was 6.8. The dissolved oxygen varied from 0.5 ppm at time zero, and 2 days to a maximum of 1.7 at 24 days. The DO showed a slight decrease from the 24 to 30-day aeration times.

Figure 5 is a plot of the total solids, fixed solids, and volatile solids in the mixed liquor. It might be pointed out that fixed solids were determined arithmetically by difference. Total solids minus volatile solids equals fixed solids. The total solids gradually decreased through 8 days. It showed a significant increase at 12 days, and then began a gradual decrease through 30 days. The volatile solids decreased through 4 days of aeration, leveled off through 8 days, increased slightly at 12 days, then leveled off again through 30 days. The highest volatile solids reduction occurred at 4 and 8 days.

Figure 6 shows a plot of the COD of the mixed liquor, filtrate, and sludge residue. Sludge residue is determined arithmetically by difference. The COD of the mixed liquor showed a slight increase at

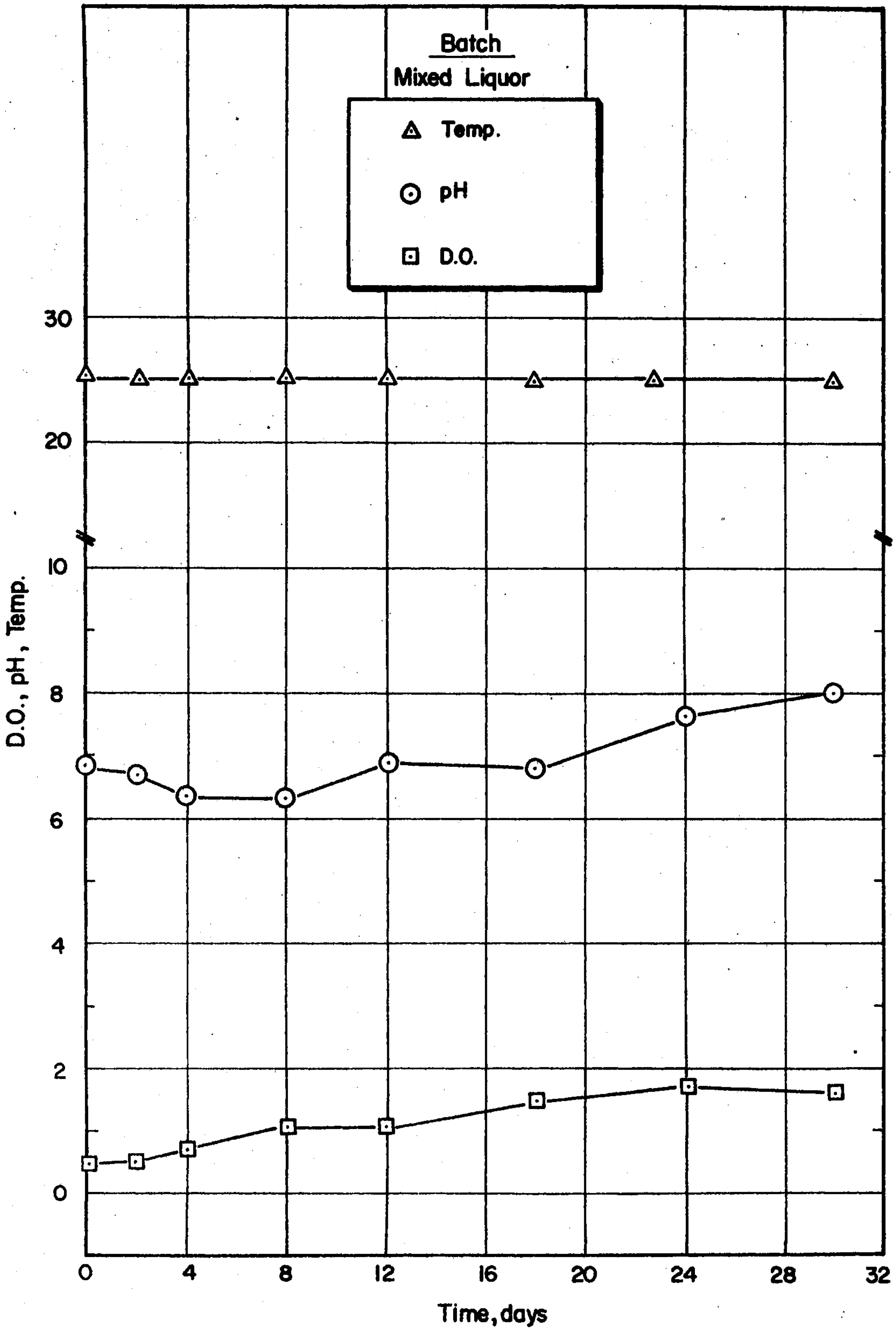

Figure 4 - Batch System Response to pH, Temperature, and Dissolved Oxygen for Various Detention Times.

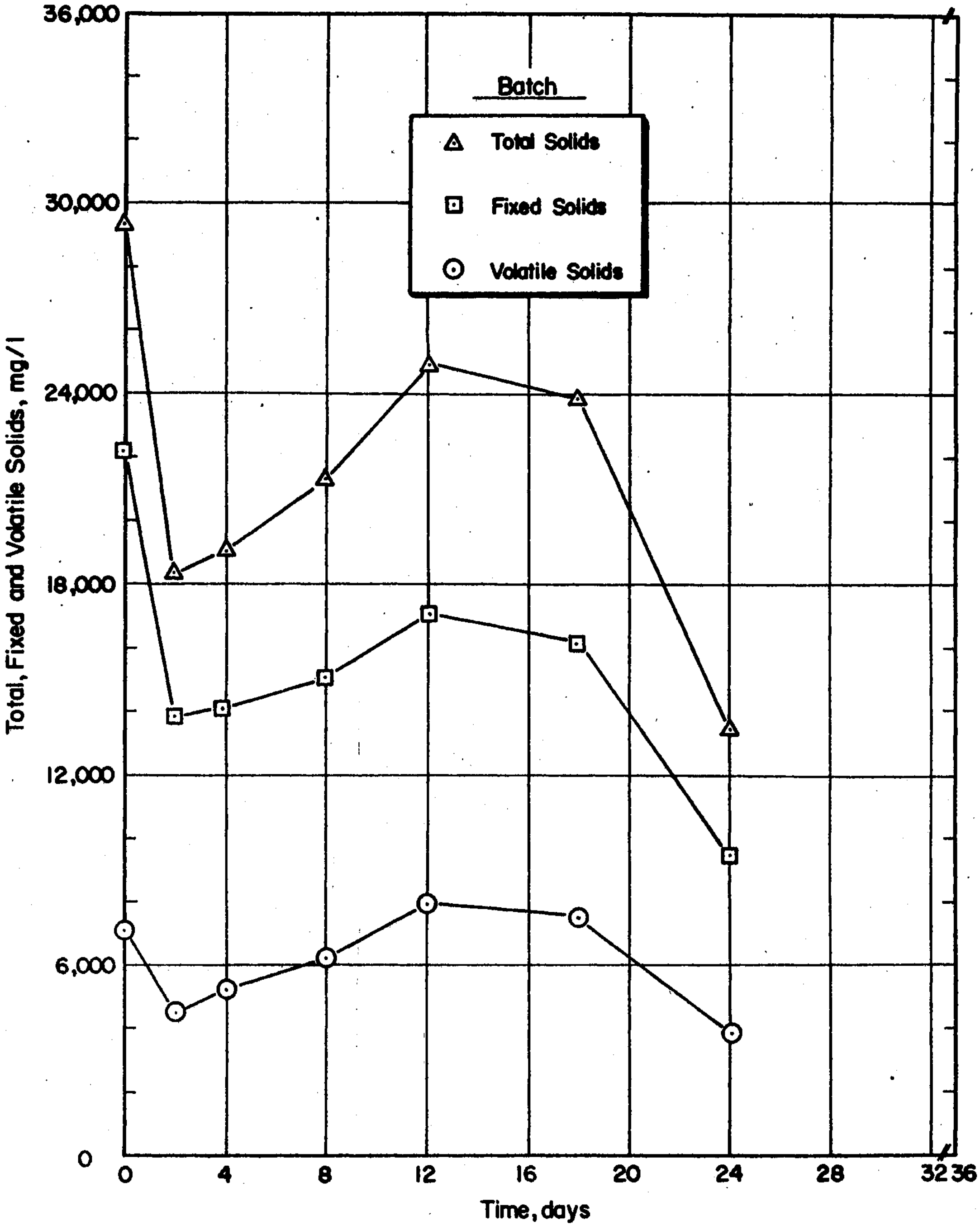

Figure 5 - Batch System Comparison of Total Solids, Volatile Solids, and Fixed Solids for Various Detention Times.

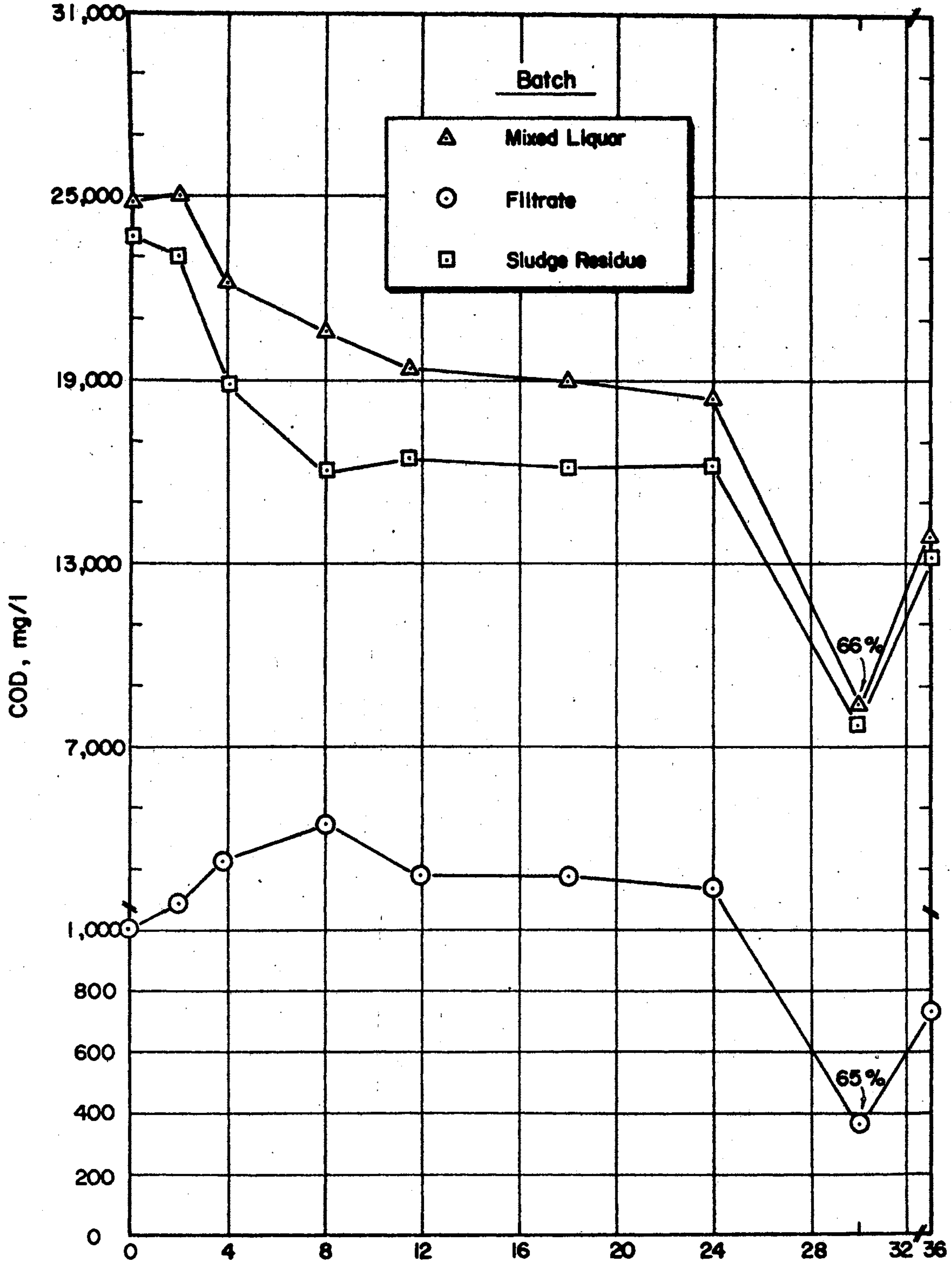

Figure 6 - Batch System Comparison of COD Values for Various Detention Times.

2 days, followed by gradual decreases through 24 days, followed by a rather significant decrease between 24 and 30 days. A sample was taken after 36 days and analyzed for COD content. A significant increase in COD was shown. The filtrate COD increased initially, reaching its highest value in 8 days. There was a decrease shown at 12 days, followed by a leveling off period from 12 to 24 days. There was a very significant decrease between 24 and 30 days. The overall reduction in filtrate COD after 30 days' aeration was 65 per cent.

Figure 7 shows what happened to the BOD relative to aeration time. The BOD increased through the first 4 days of aeration, dropped slightly at 8 days and 12 days, and increased slightly at 18 days. BOD decreased significantly between 24 and 30 days. The results show a 21 per cent reduction in BOD after 30 days, and a 38 per cent reduction after 36 days.

Figure 8 shows the relationship between COD and BOD in terms of aeration time. It may be noted that they follow somewhat similar patterns.

Figure 9 shows the results of ammonia nitrogen content in the mixed liquor, and filtrate and sludge residue at various detention times. The ammonia nitrogen contained in the sludge residue was determined arithmetically by difference. Most of the ammonia nitrogen in the mixed liquor was stripped at the end of 8 days. After 8 days there was a gradual increase in ammonia up through 24 days. This was followed by a significant decrease between 24 and 30 days. There was very little change in filtrate ammonia N. It varied from a minimum of 63 mg/1 at time zero to a maximum of 82 mg/1 at 30 days. It appears from the plot that all free ammonia had been removed from the mixed liquor at the

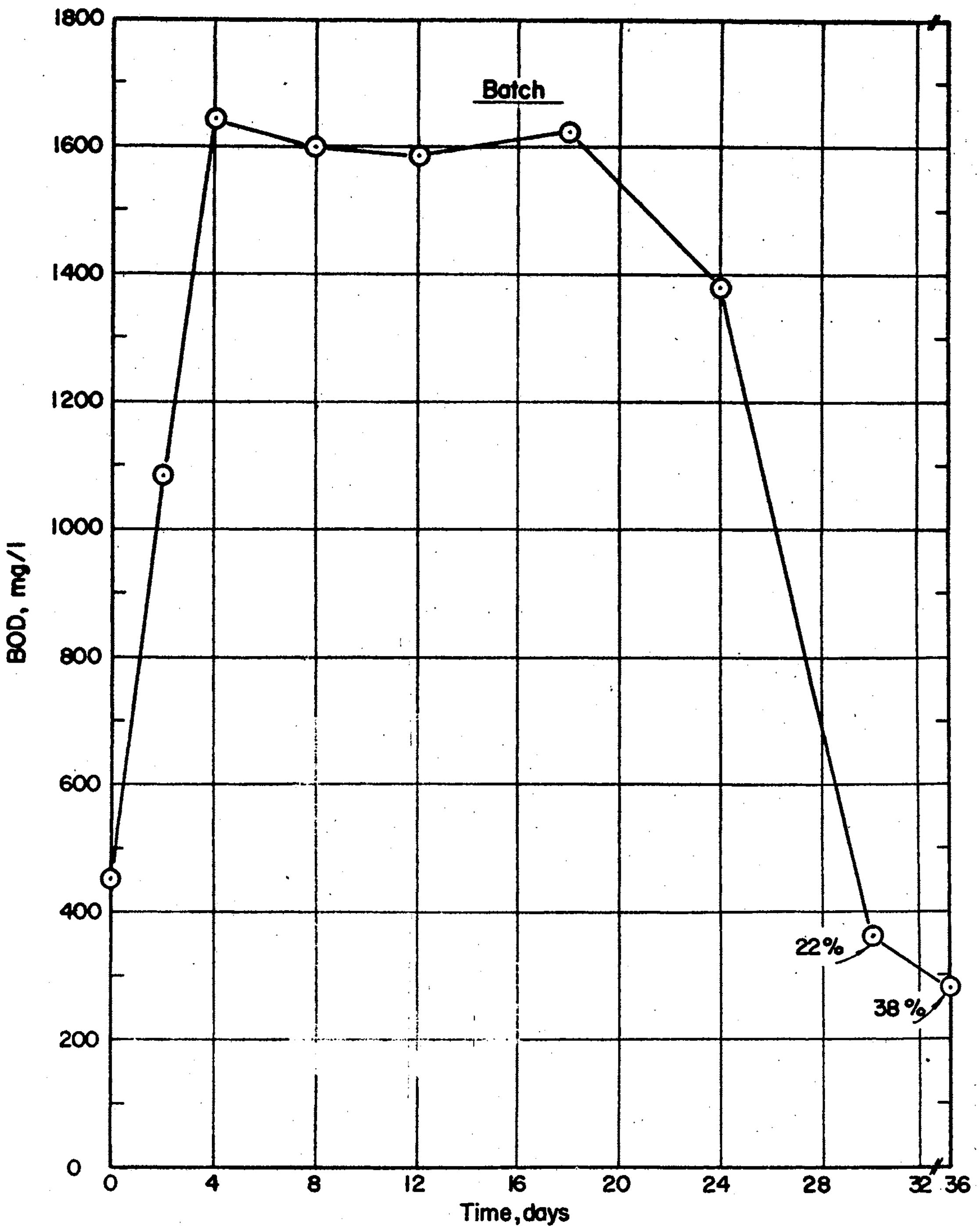

Figure 7 - Batch System Comparison of BOD Values for Various Detention Times.

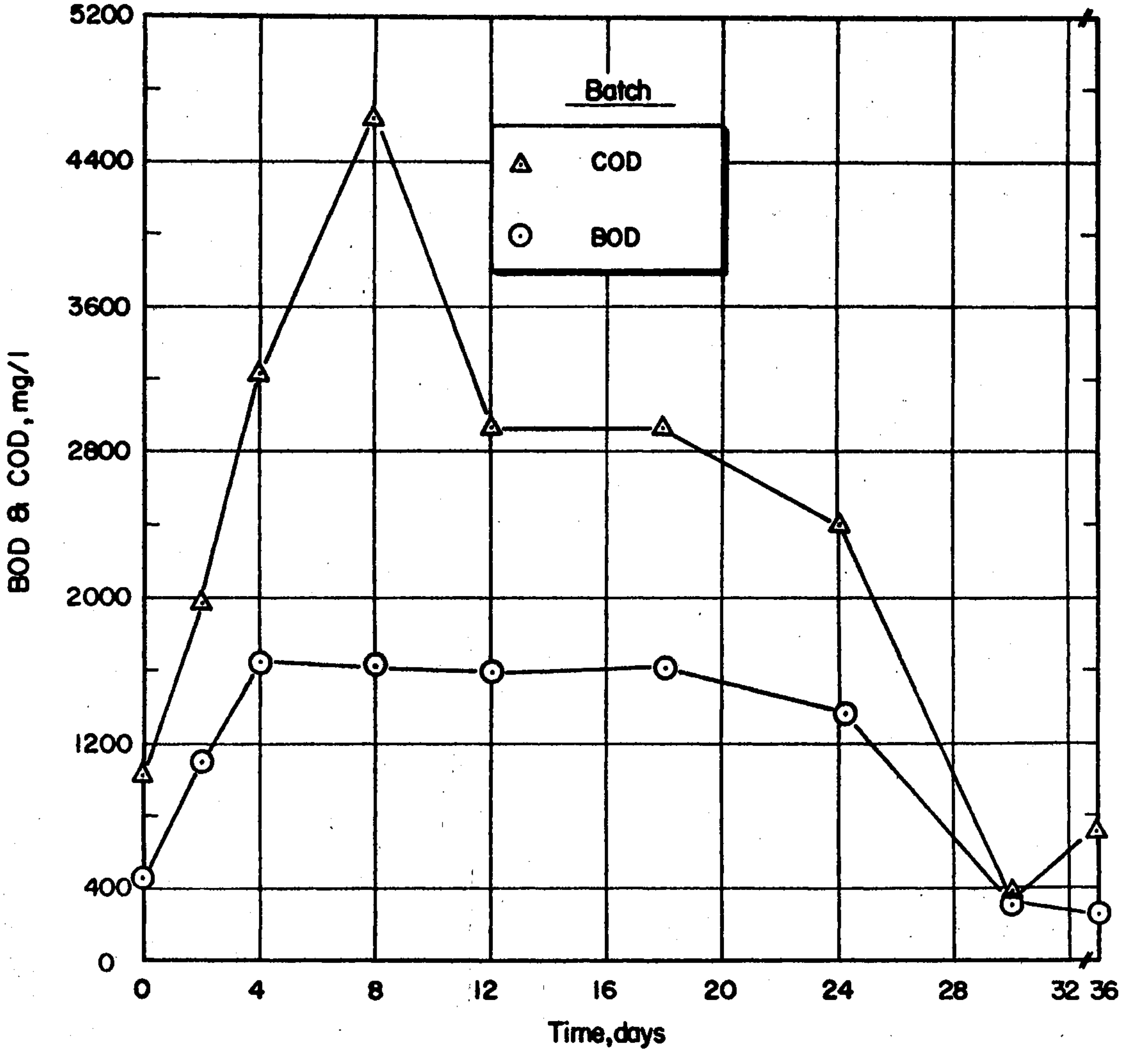

Figure 8 - A Comparison of COD and BOD Values in Batch System for Various Detention Times.

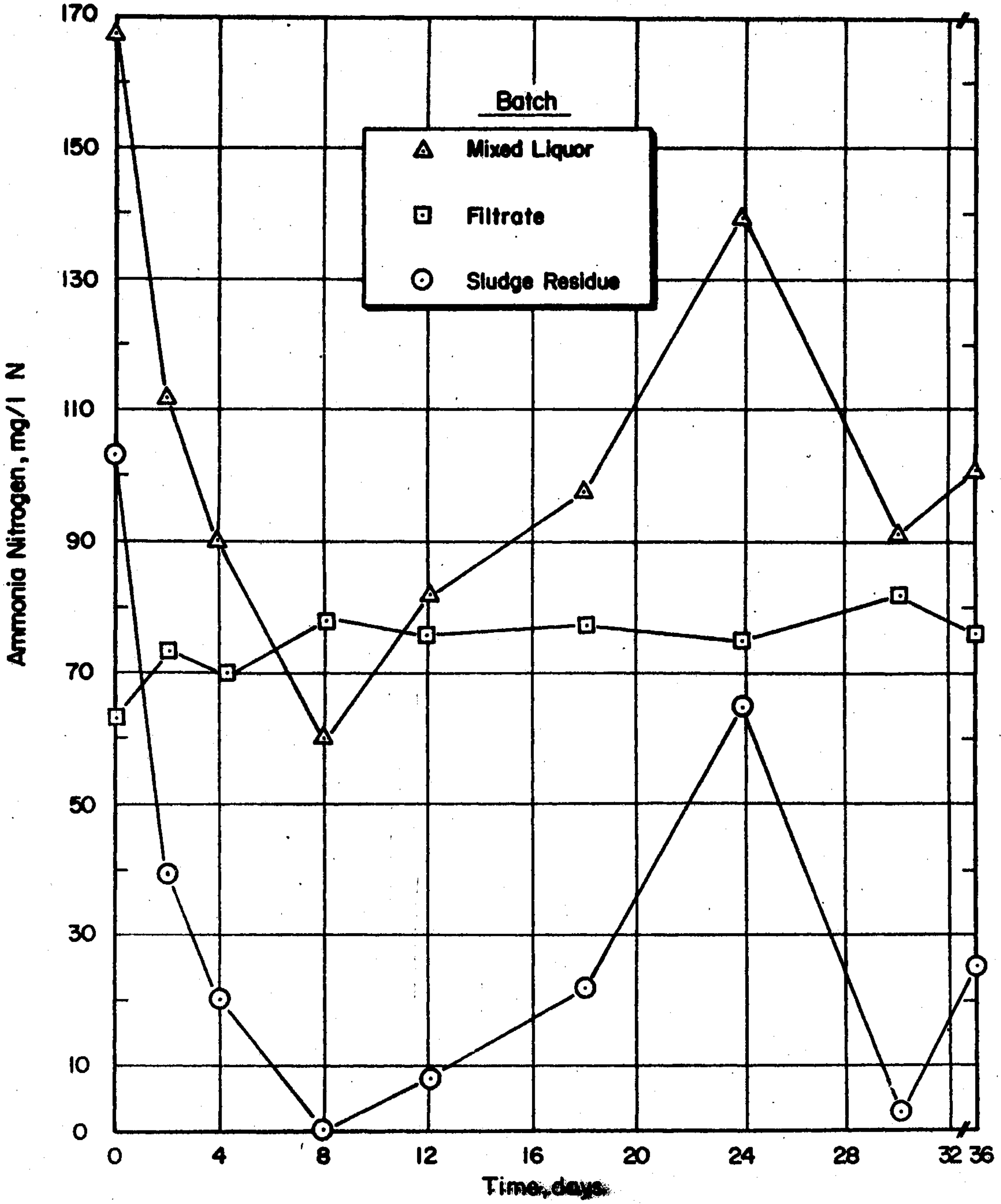

Figure 9 - Batch System Comparison of Ammonia Nitrogen Values for Various Detention Times.

end of 8 days.

Figure 10 shows a plot of the nitrates contained in the mixed liquor, filtrate, and sludge residue. The sludge residue values were obtained by differences. The nitrates in the mixed liquor and sludge residue decreased from time zero through 12 days. A significant increase in nitrate was noted after 12 days of aeration followed by decreases after 18, 24, and 30 days of aeration. The nitrate levels in the filtrate were low and rather insignificant through the 30-day aeration period.

Figure 11 shows the phosphate values for various aeration times. The phosphate in the mixed liquor decreased slightly at 2 days, and leveled off between 2 and 4 days. It increased at 8 days, leveled again between 8 and 12 days. It increased at 18 days, leveled at 24 days, and then showed a significant decrease from 24 to 30 days and a continued decreasing through 36 days. The phosphate in the filtrate decreased at 2 days, increased gradually through 8 days, decreased at 12 days and leveled between 12 and 14 days. A significant decrease in filtrate PO_4 was noted between the 24 and 30 days of aeration. A further decrease was noted after 36 days of aeration.

Figure 12 shows a plot of percent volatile solids in the mixed liquors. The percent volatile solids decreased rapidly the second day. It showed a slight decrease the fourth day. Volatile solids began to increase through the 4, 8, and 12 days of aeration, and then decreased somewhat at 18 days. Volatile solids increased through 24 as well as the 30-day aeration period.

Figure 13 is a plot of filtrate values for COD, BOD, PO_4, ammonia nitrogen, and nitrate nitrogen.

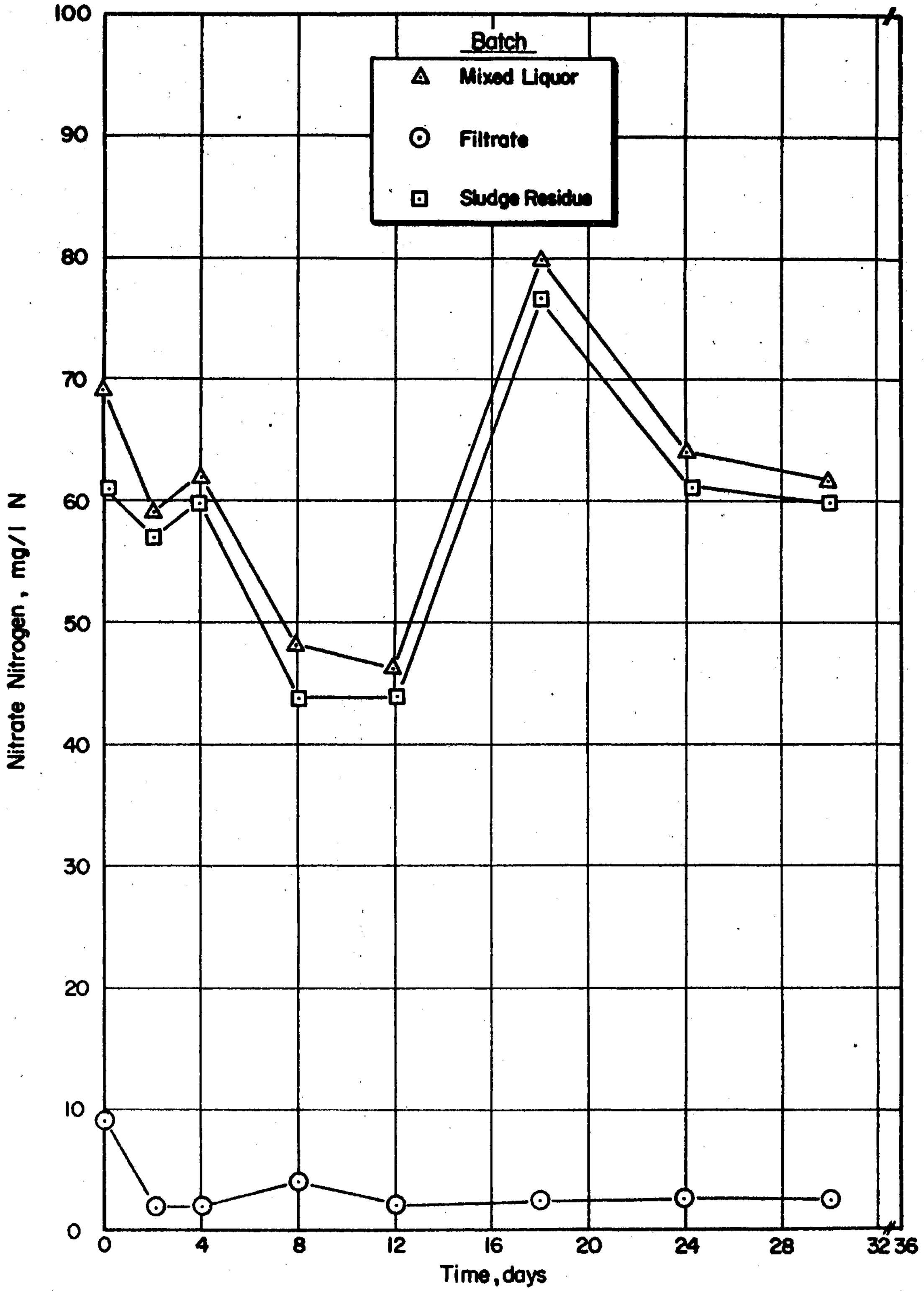

Figure 10 - Batch System Comparison of Nitrate Nitrogen for Various Detention Times.

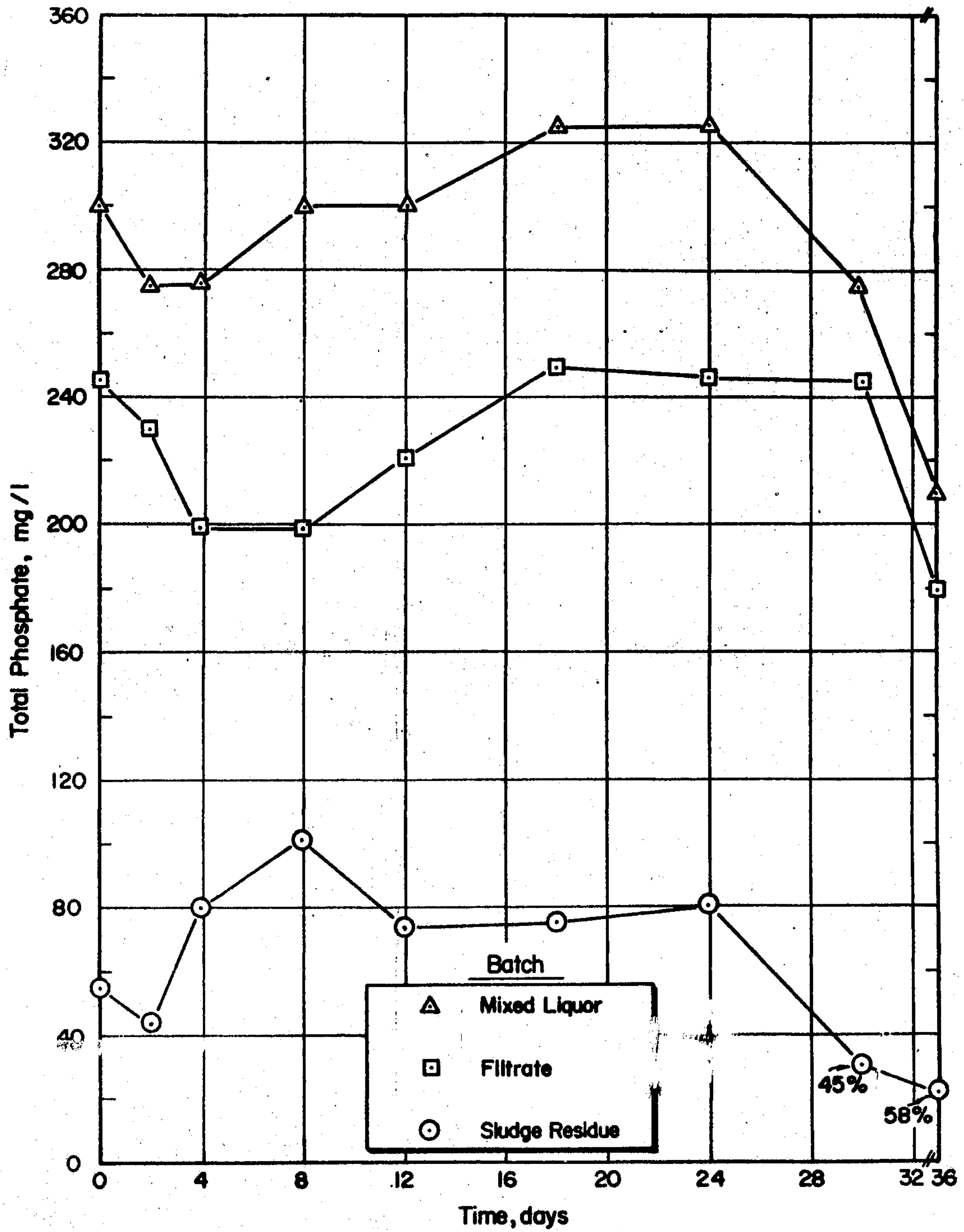

Figure 11 - Batch System Comparison of Total Orthophosphate at Various Detention Times.

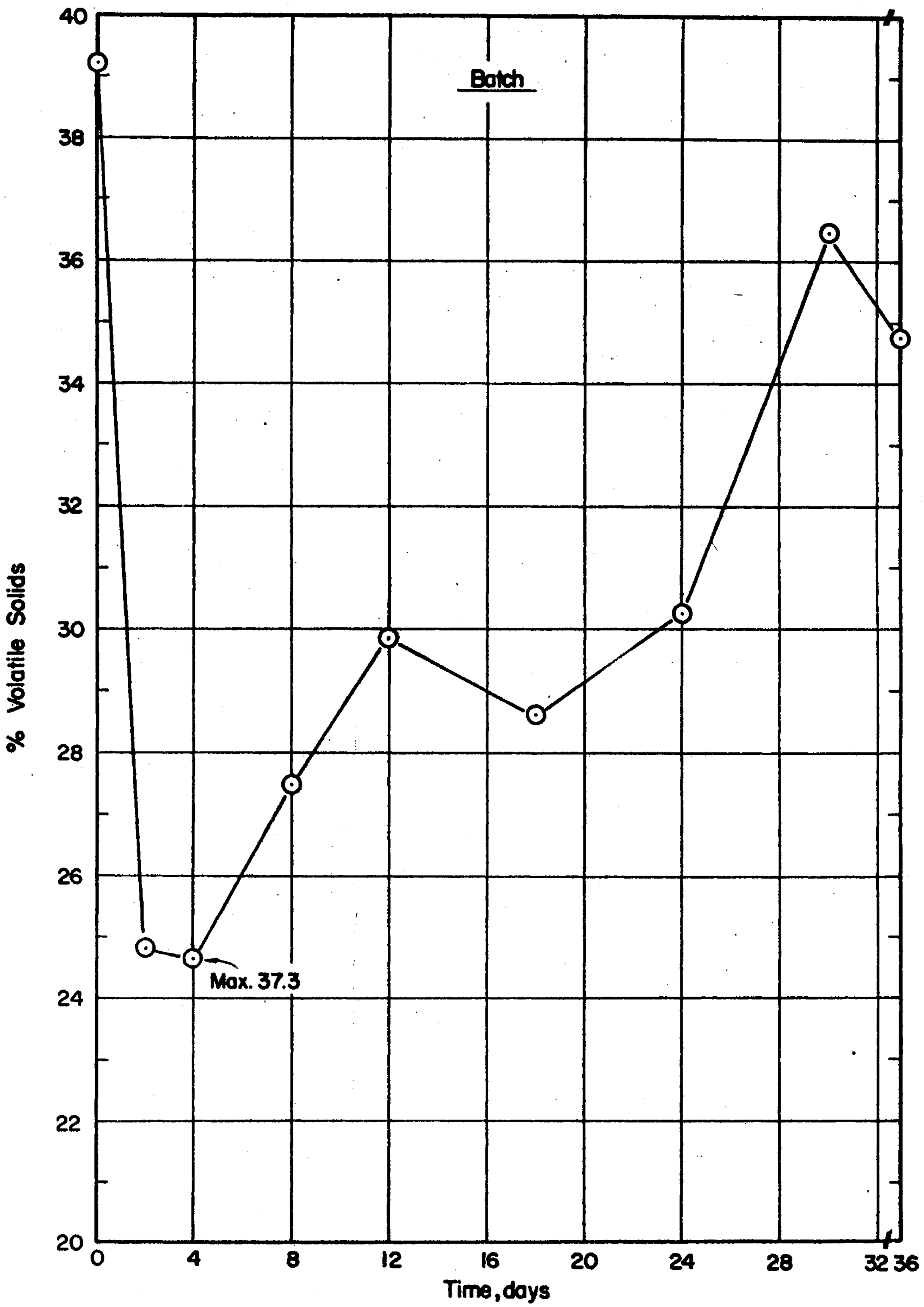

Figure 12 - Batch System Comparison of Percent Volatile Solids for Various Detention Times.

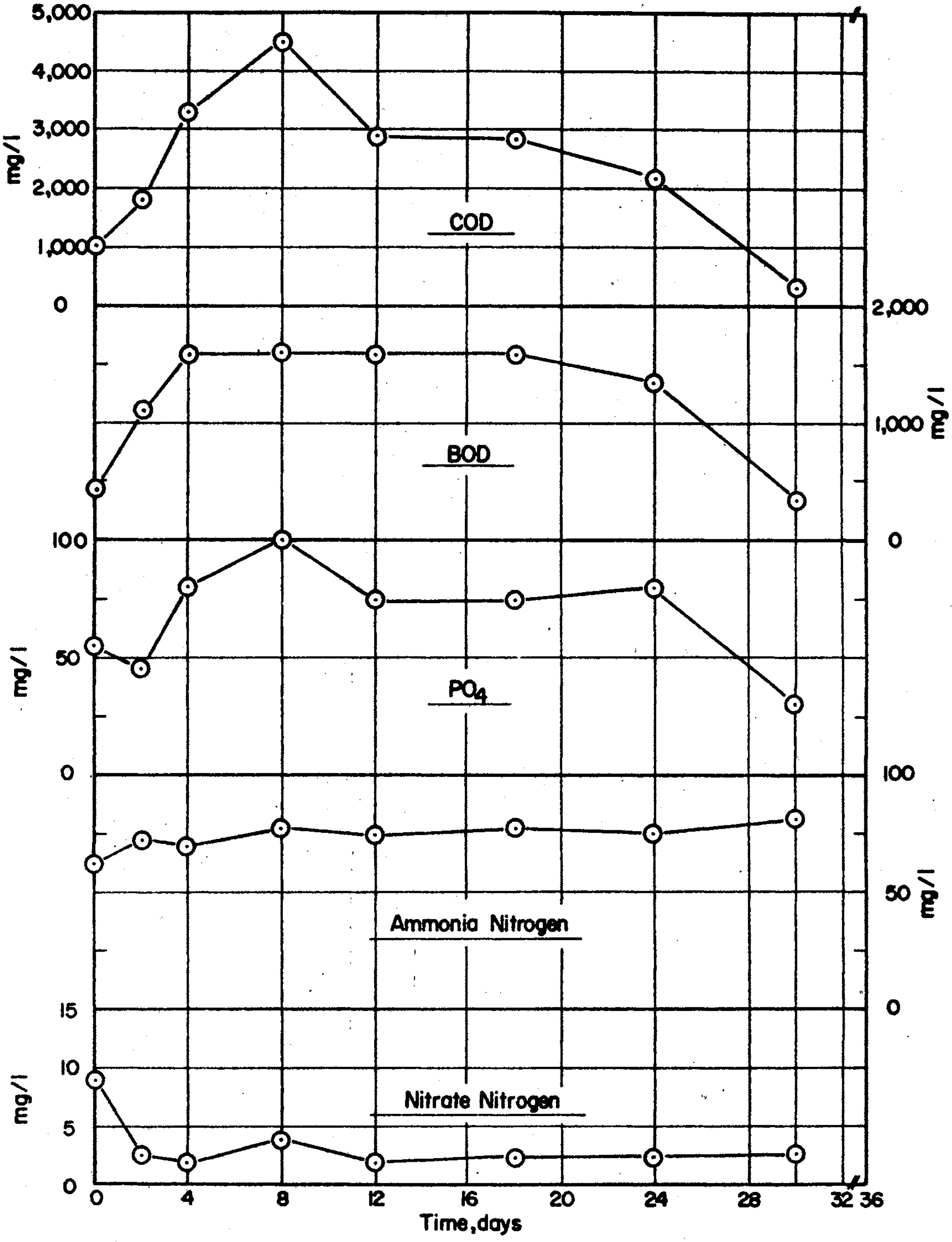

Figure 13 - Batch System Comparison of Filtrate Values for COD, BOD, PO_4, Ammonia Nitrogen, and Nitrate Nitrogen for Various Detention Times.

Figure 14 is a plot of total and volatile solids after 4 hours' settling time. It points out characteristics of the sludge taken and applied to drying beds for the dewatering study. Table I shows chemical composition of the sludge applied to the drying bed and the quality of effluent discharged.

B. Semi-continuous Flow Study

Figure 15 shows a plot of the DO, temperature, and pH determinations. The temperature varied from an average of 24°C for the 2 and 4-day detention times to an average of 25°C throughout the remainder of the detention times investigated. The pH of the mixed liquor varied from 5.8 in the raw to 7.3 in the 30-day detention time reactor. The DO values varied from a maximum of 0.6 ppm to a minimum of 0.4 ppm.

Figure 16 is a plot of the overall averages of total solids, fixed solids, and volatile solids in the mixed liquor at various detention times. The fixed solids were determined by difference. In comparison with the raw sludge, the total solids decreased significantly in the reactor with the 2-day detention period. They increased somewhat in the 4-day reactor, then decreased at the 8-day and 12-day detention times. The plot shows another increase at 18 days, followed by decreases at the 24-day and a small increase at the 30-day detention times. The volatile solids in comparison with the raw sludge showed a decrease at the 2-day detention time. An increase at the 4-day detention time was followed by significant decreases at 8, 12, 18, 24, and 30-day detention times.

Figures 17, 18, and 19 show the average values for each of the three experimental runs. These plots show how the system varied during each experimental phase under different loading conditions.

Figure 20 shows the average results for all experiments of the

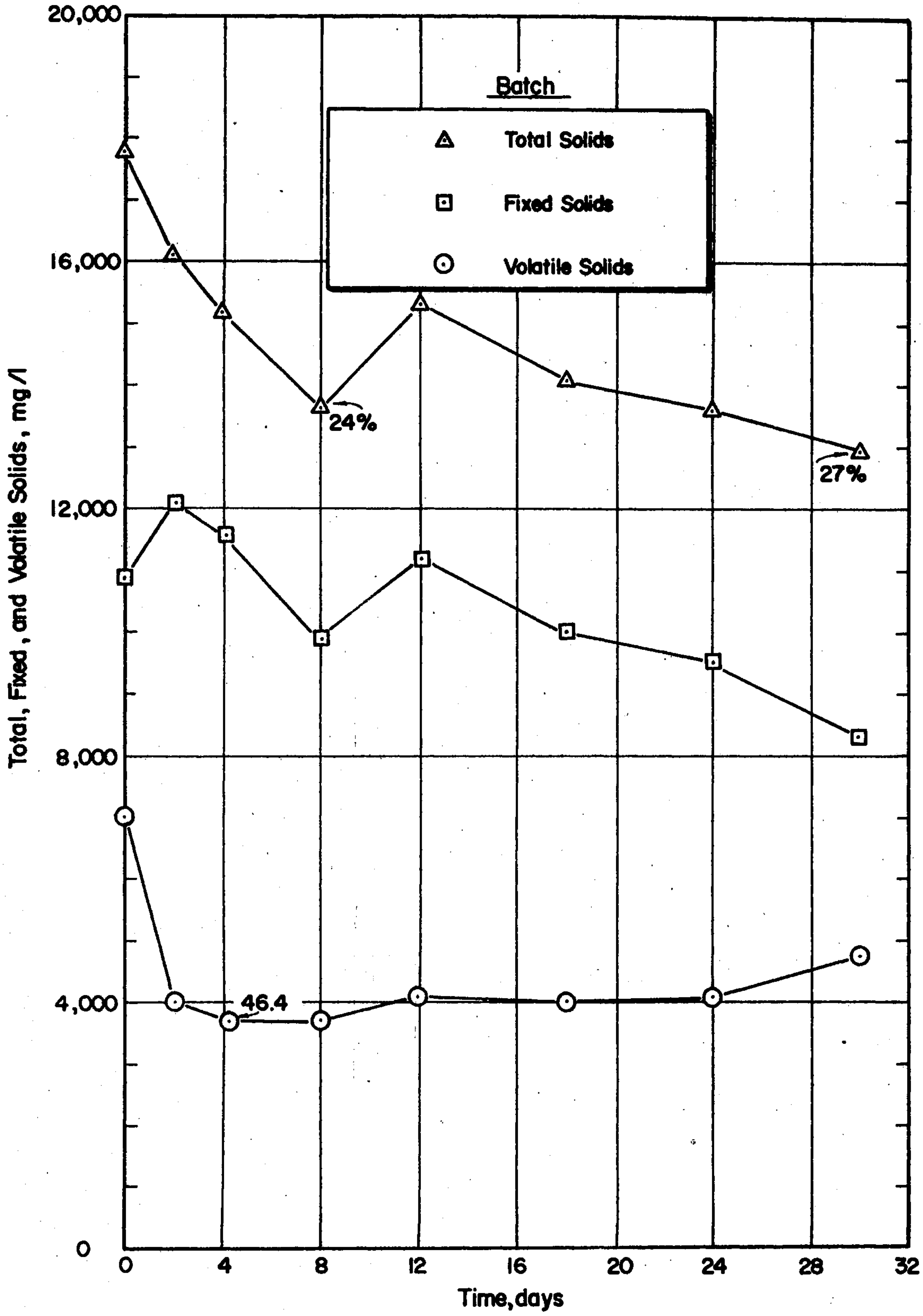

Figure 14 - Comparison of Total Solids, Fixed Solids, and Volatile Solids After 4-hour Settling. Composition of Sludge Applied to Drying Beds for Dewatering.

TABLE I

CHEMICAL AND PHYSICAL CHARACTERISTICS AND EFFLUENT QUALITY OF AEROBICALLY DIGESTED SLUDGE APPLIED TO DRYING BEDS FOR DEWATERING STUDY - BATCH EXPERIMENT

Analysis	Raw	Detention Time (Days)						
		2	4	8	12	18	24	30
Total Solids	29,375	18,250	19,125	21,250	25,125	23,750	13,375	13,250
Volatile Solids	7,125	4,500	5,125	6,250	8,000	7,500	3,875	4,500
Fixed Solids	22,250	13,750	14,000	15,000	17,125	16,250	9,500	8,700
% Volatile Solids	24.30	24.70	26.70	29.40	31.80	31.60	28.90	33.90
% Moisture	97.10	98.15	98.05	97.85	92.50	97.60	98.30	98.65
% Settleability	63	80	76	53	43	49	99	99
Filterability sec	374	395	487	447	450	460	367	304
PO_4	ND	ND	120	ND	6	ND	ND	12
Ammonia N	ND	ND	59	ND	20	ND	ND	27
Nitrate N	ND	ND	7	ND	2	ND	ND	ND
COD	ND	ND	4,573	ND	1,480	ND	ND	1,303

All analyses are expressed in mg per liter unless otherwise indicated. Physical values are based on four-hour settled sludge; chemical values are based on drying bed effluents. (ND - No determination)

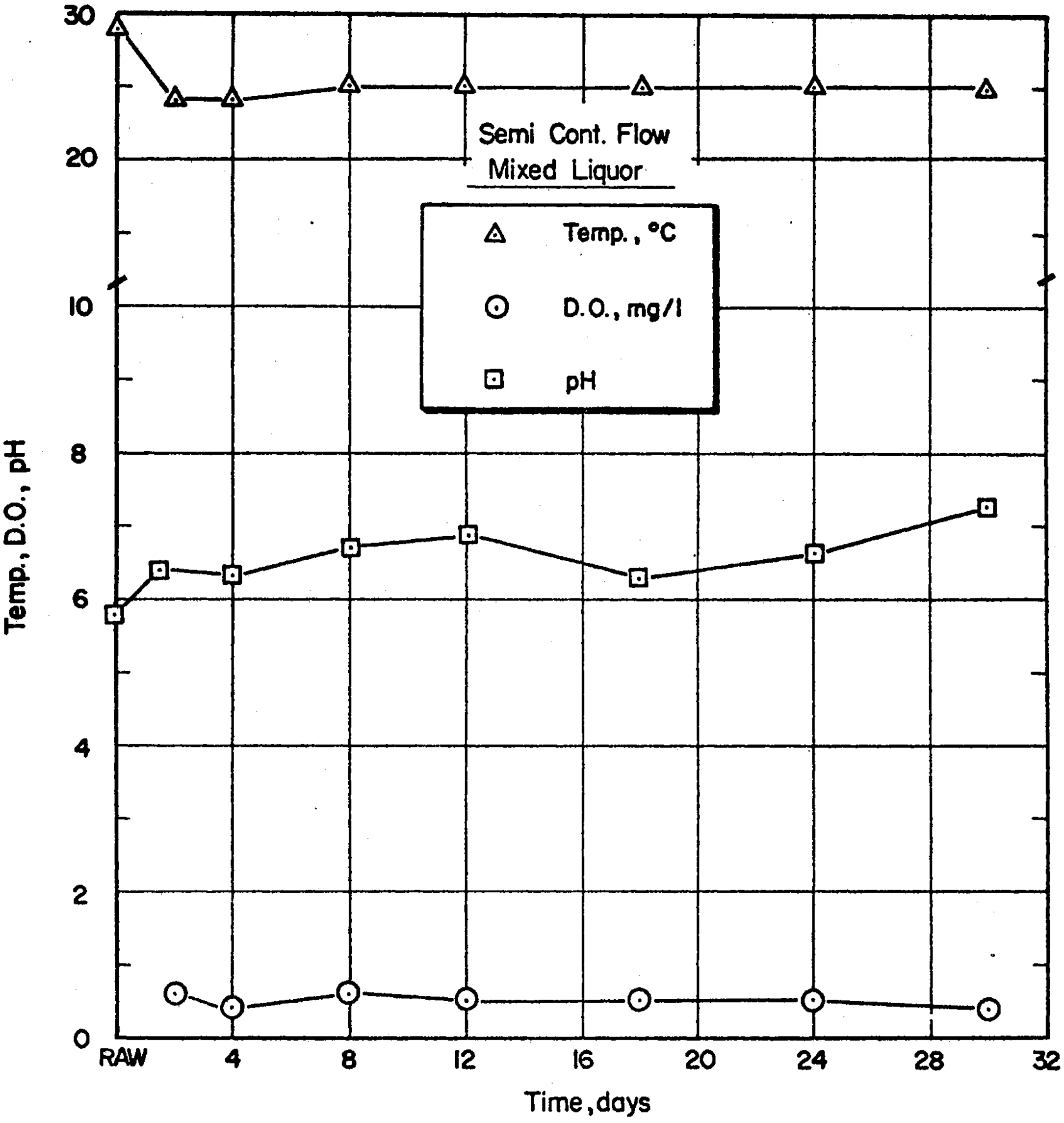

Figure 15 - Comparison of pH, Temperature, and Dissolved Oxygen in Semi-continuous Completely Mixed Reactor for Various Detention Times.

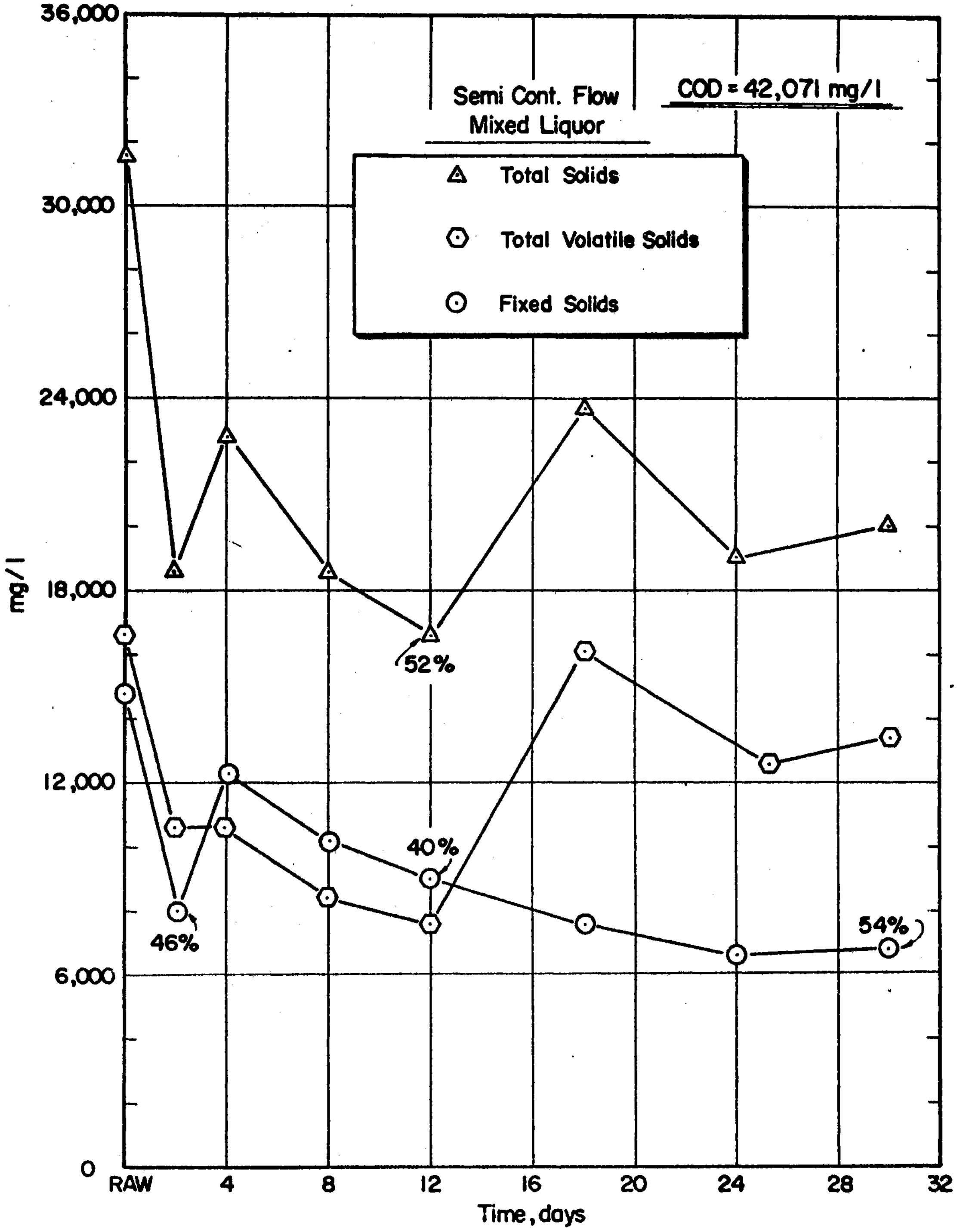

Figure 16. Overall Average for All Experiments of Total Solids, Fixed Solids, and Volatile Solids in Semi-continuous Completely Mixed Reactor at Various Detention Times.

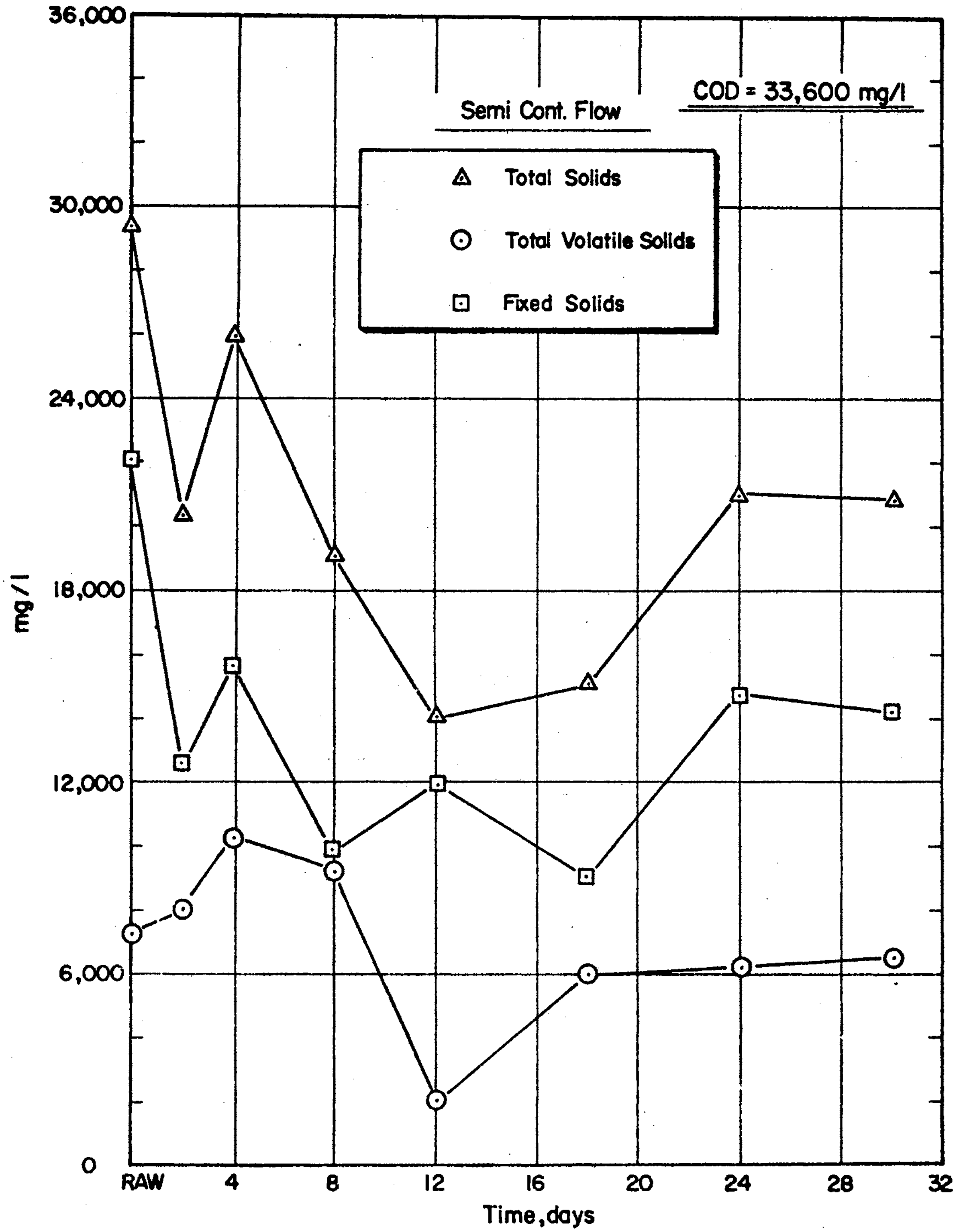

Figure 17 - Comparison of Total Solids, Fixed Solids, and Volatile Solids During Experimental Phase No. 1. Semi-continuous Completely Mixed Study.

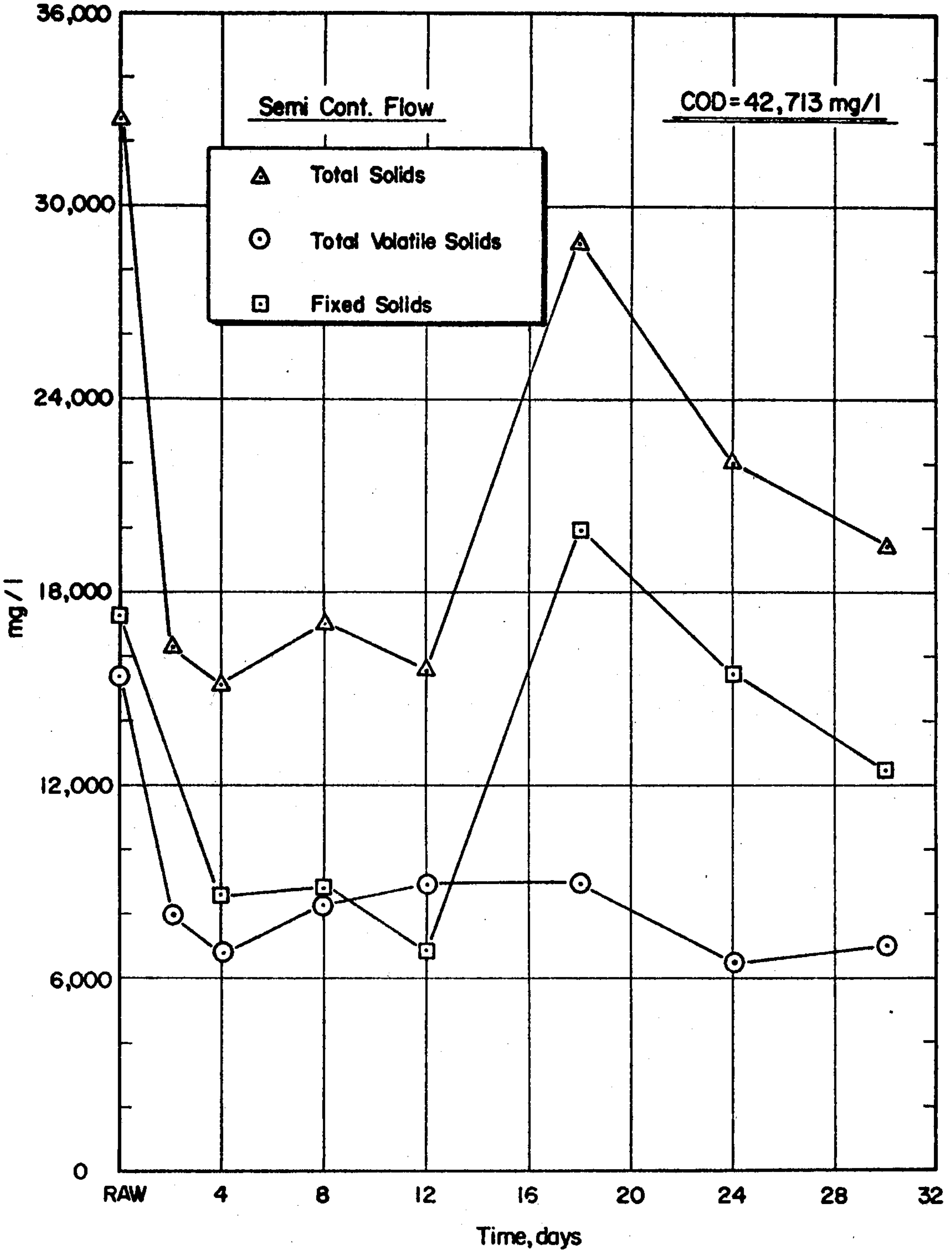

Figure 18 - Comparison of Total Solids, Fixed Solids, and Volatile Solids During Experimental Phase No. 2. Semi-continuous Completely Mixed Study.

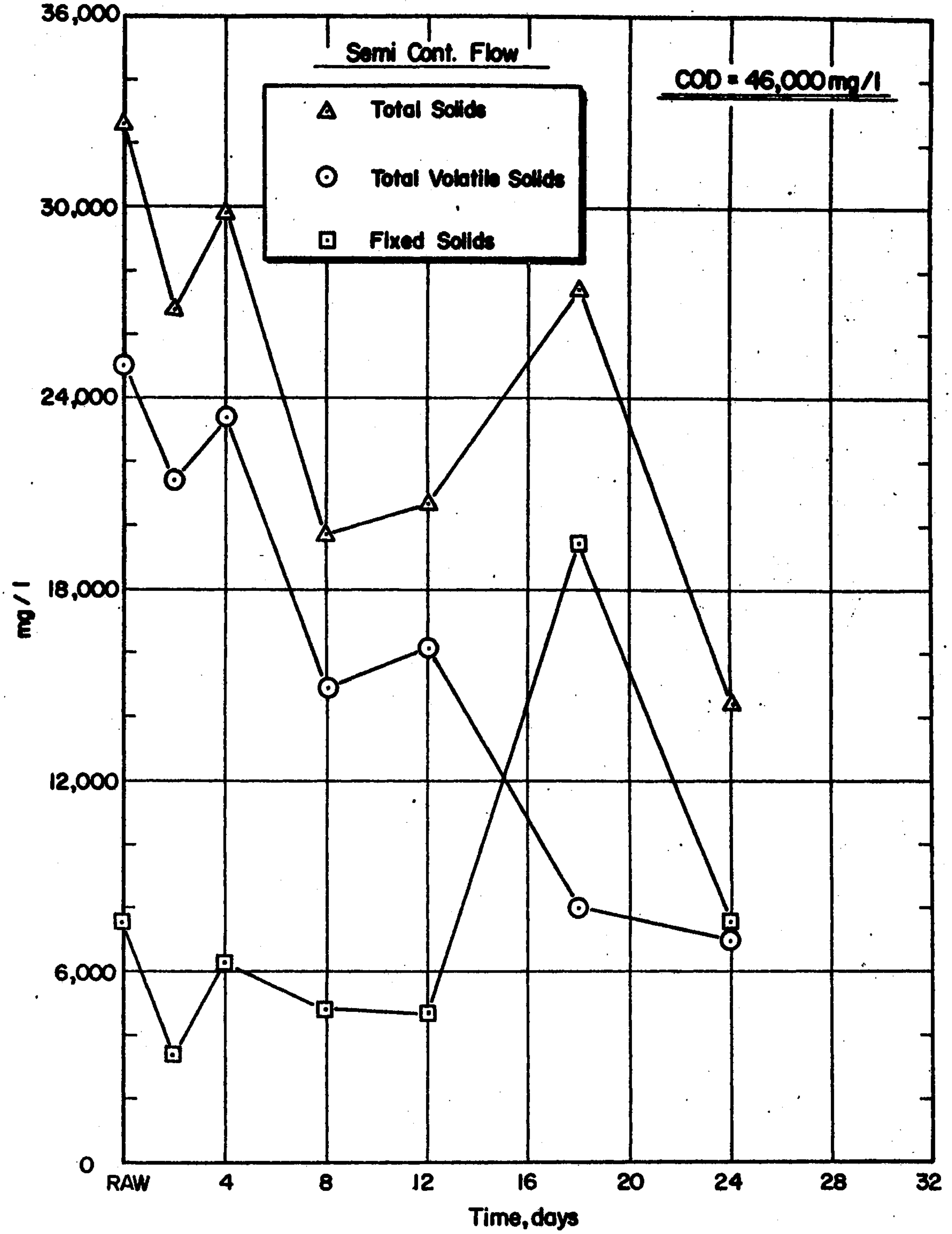

Figure 19 - Comparison of Total Solids, Fixed Solids, and Volatile Solids During Experimental Phase No. 3. Semi-continuous Completely Mixed Study.

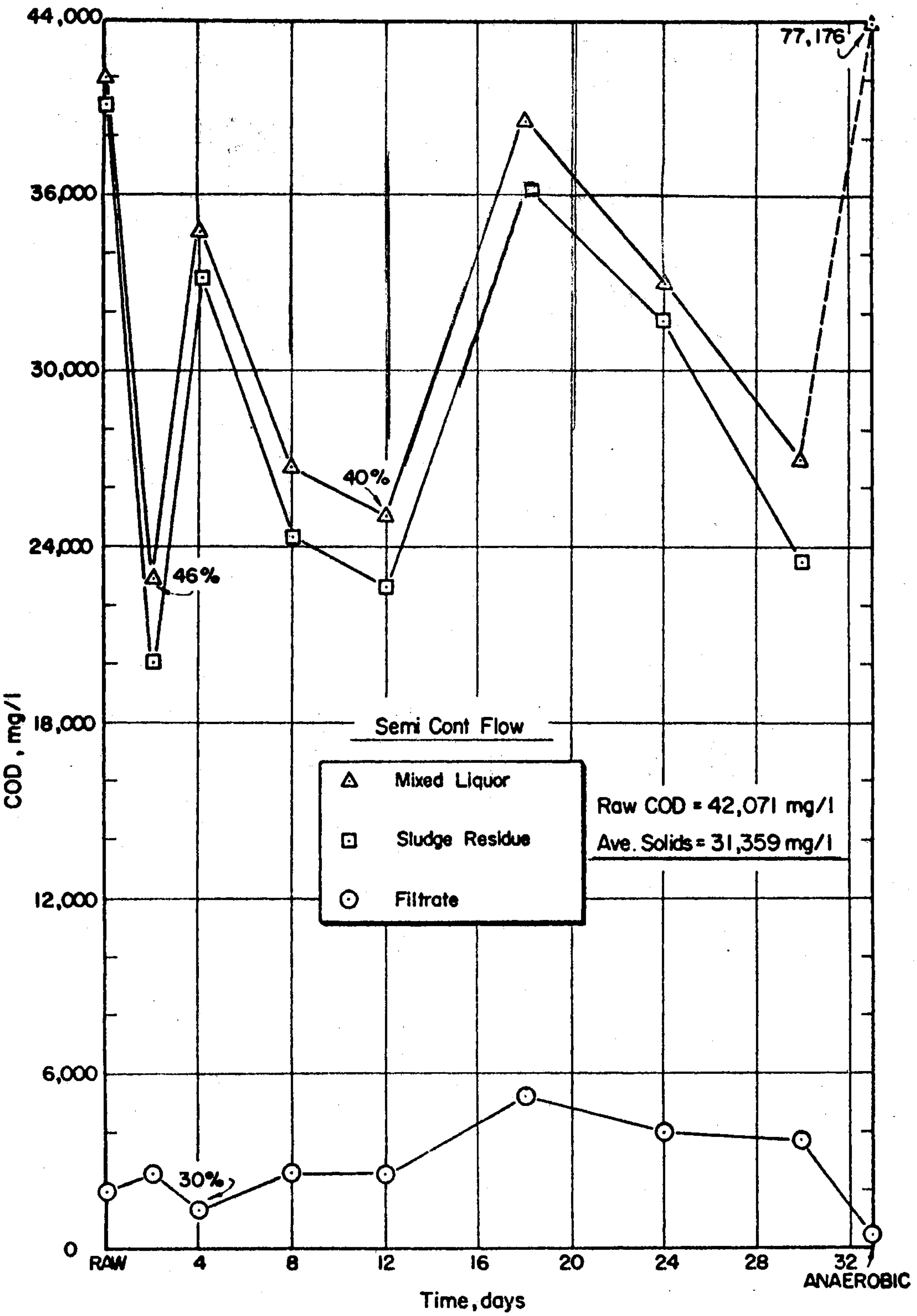

Figure 20 - Overall Average for All Experiments of COD Values for Semi-continuous Completely Mixed Reactor at Various Detention Times.

changes in COD at various detention times.

Figures 21, 22, and 23 show plots of COD at various detention times for each experimental run. In Figure 20, the mixed liquor COD at the 2-day detention time is significantly lower than the mixed liquor COD in the raw sludge. The 2-day detention time showed the higher reduction in COD over all other detention times. In the filtrate the highest reduction in COD was shown at the 4-day detention time.

In Figure 24, the BOD of the filtrate is plotted for various detention times. A decrease in BOD at the 2- and 4-day detention times are shown followed by an increase at 8 and 12 days. Eighteen, 24, and 30 days showed decreasing values; the minimum BOD value was shown at the 30-day detention time. The maximum BOD value was found at the 12-day detention time.

Figure 25 shows BOD and COD comparison in the filtrate at various detention times.

Figure 26 shows an overall average of the response of ammonia nitrogen to aerobic digestion at the various detention times. Ammonia nitrogen in the mixed liquor showed decreasing values with time. Ammonia in the filtrate followed the same pattern, except for a slight increase in the ammonia nitrogen content at the 30-day detention time.

Figures 27 and 28 show the response of ammonia to aerobic digestion for two different experimental runs.

Figure 29 shows the response of nitrate to aerobic digestion at various detention times. Very little change is shown in the nitrate value of the filtrate with increased detention times. The nitrate value in the mixed liquor, however, decreased at the 2-day detention time, increased at 4 days, and reached its lowest level at 8 days. It

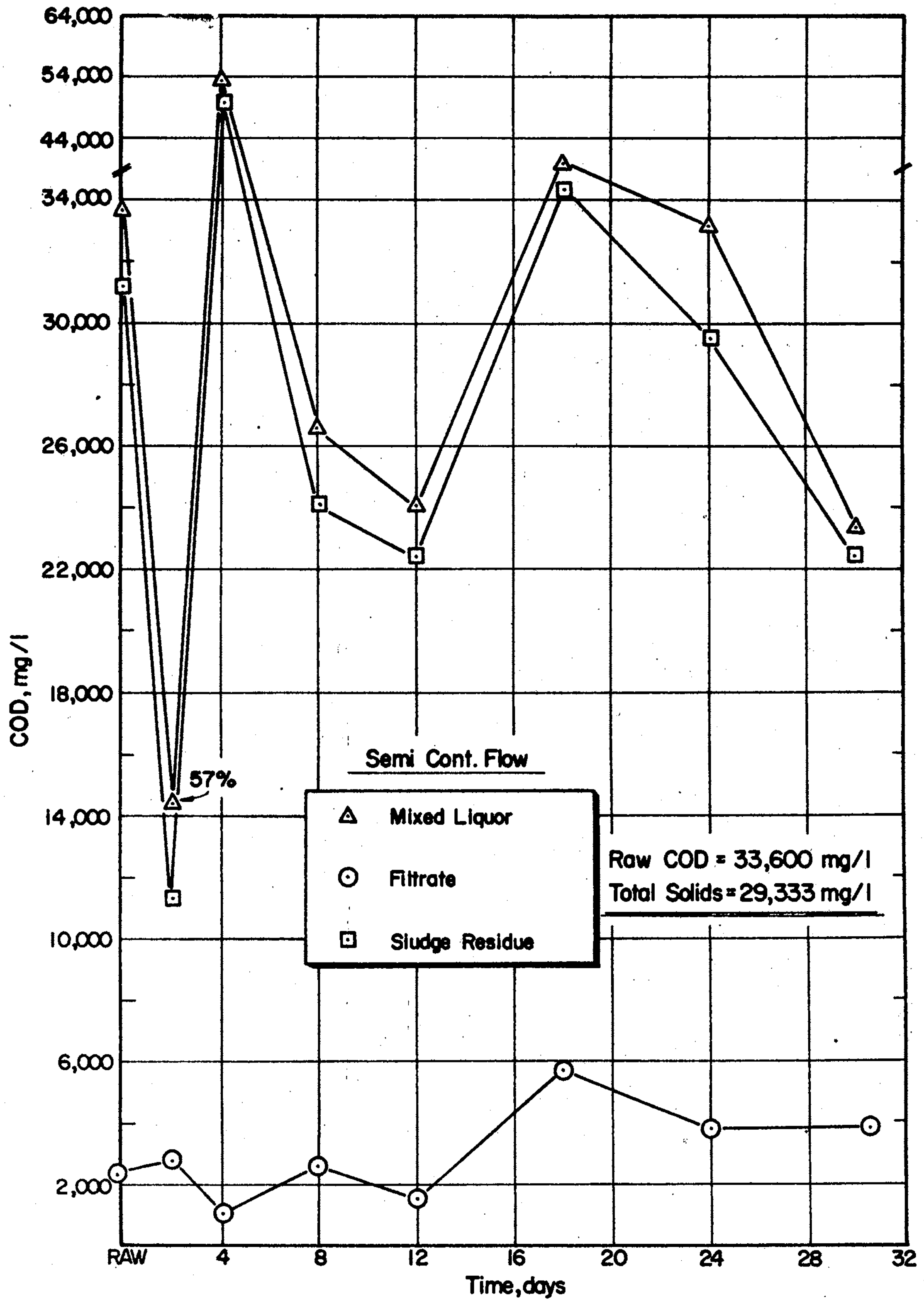

Figure 21 - Comparison of COD Values During Experimental Phase No. 1. Semi-continuous Completely Mixed System.

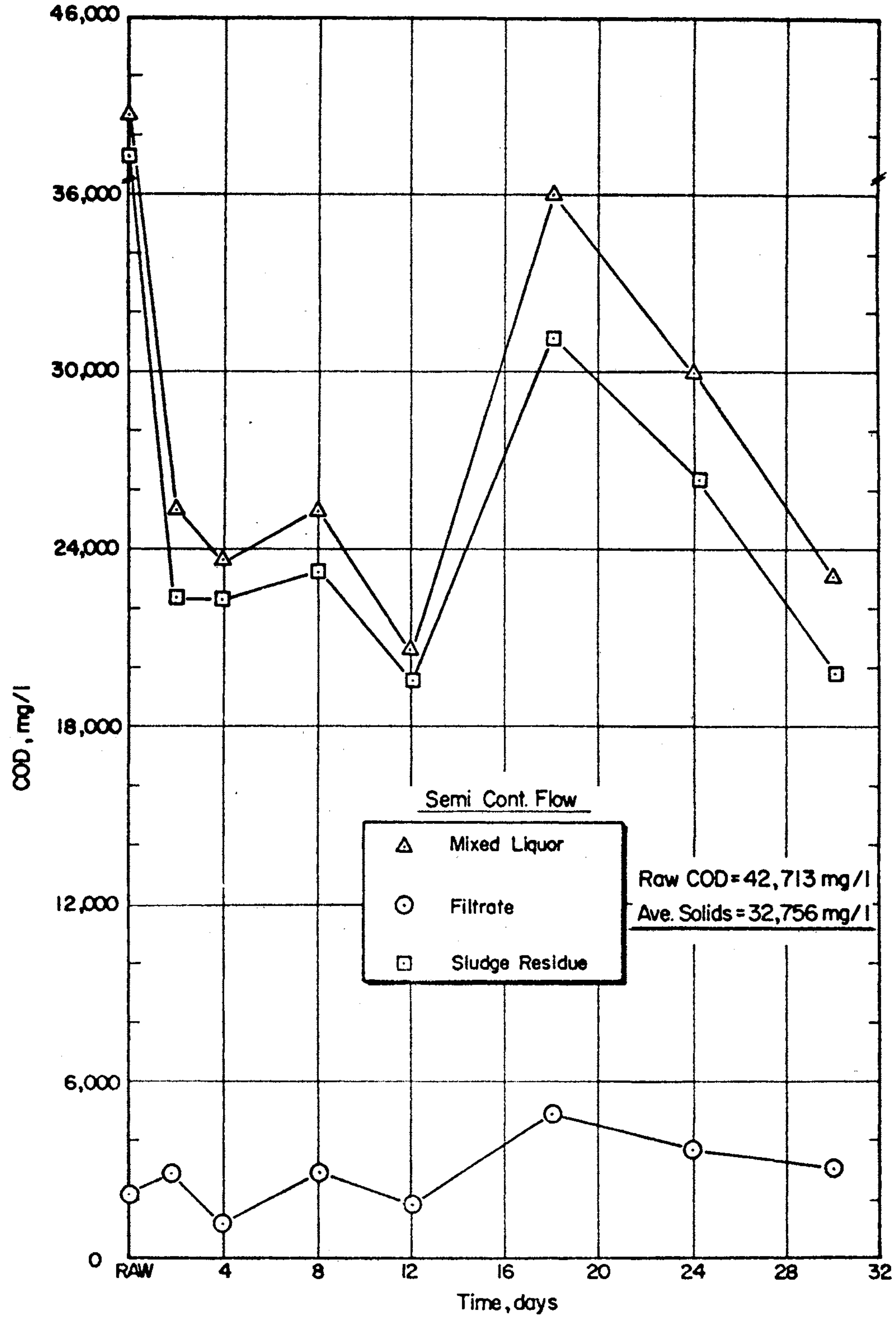

Figure 22 - Comparison of COD Values During Experimental Run No. 2. Semi-continuous Completely Mixed System.

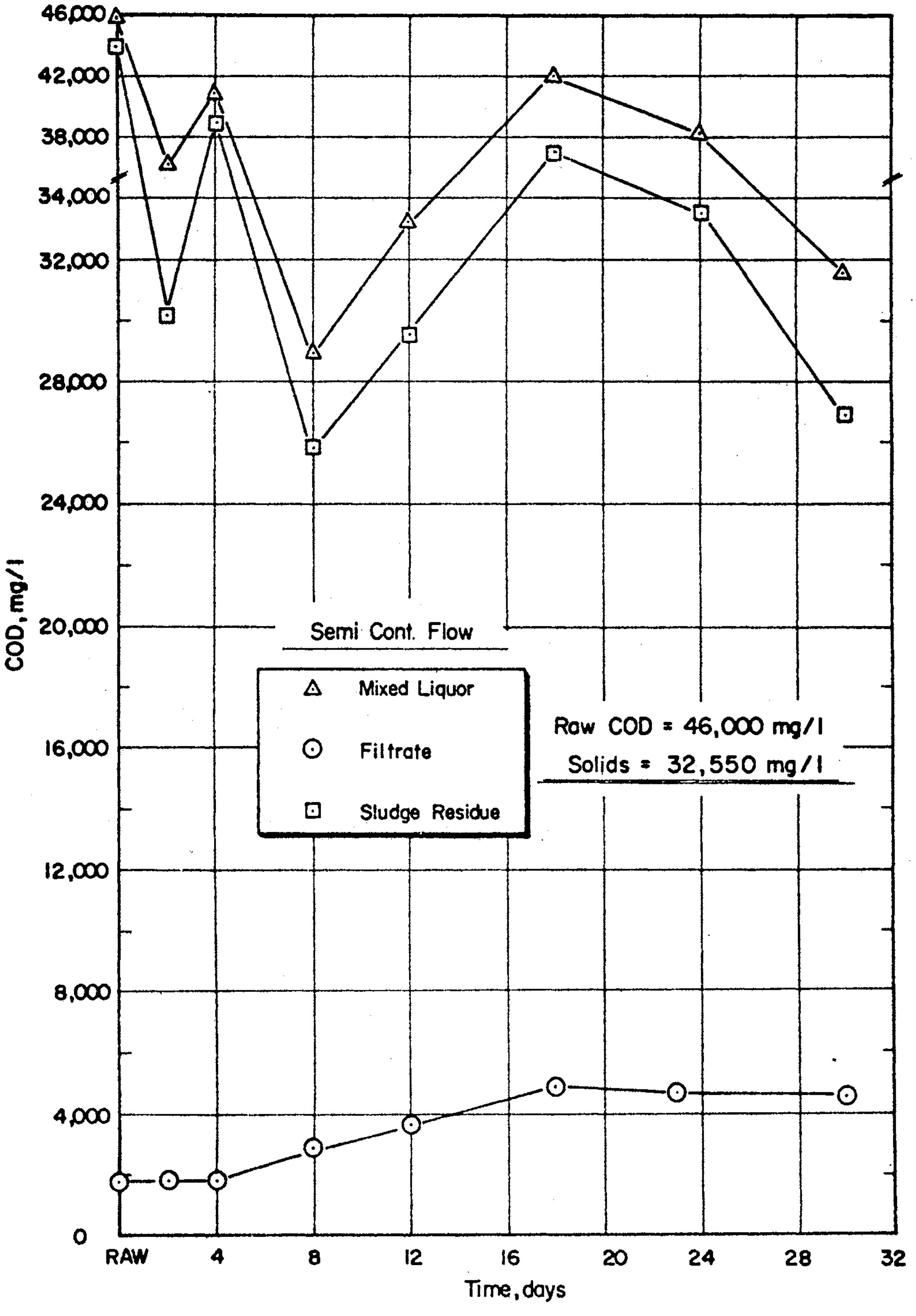

Figure 23 - Comparison of COD Values During Experimental Run No. 3. Semi-continuous Completely Mixed System.

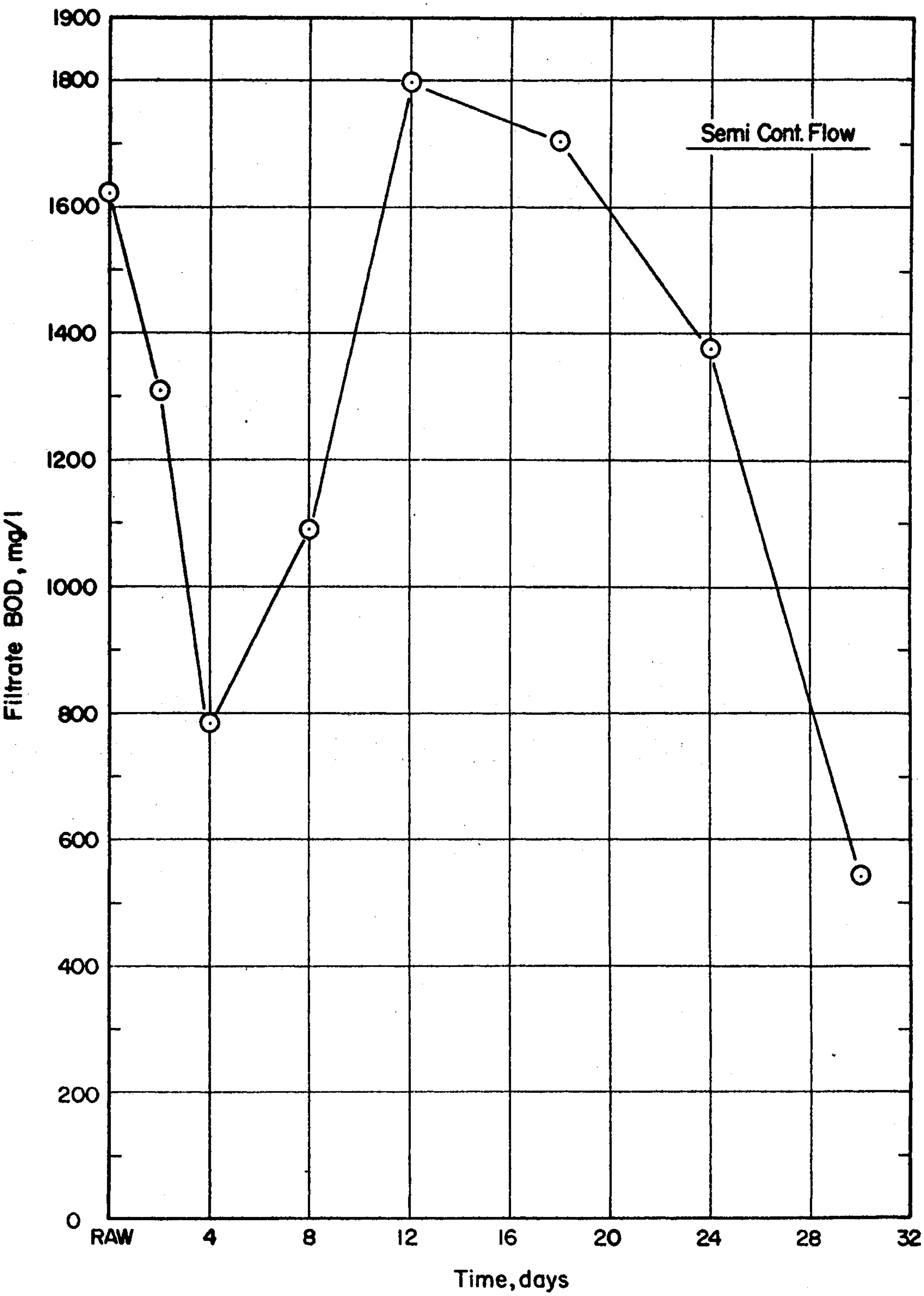

Figure 24 - Comparison of BOD Values for Semi-continuous Completely Mixed Reactors at Various Detention Times.

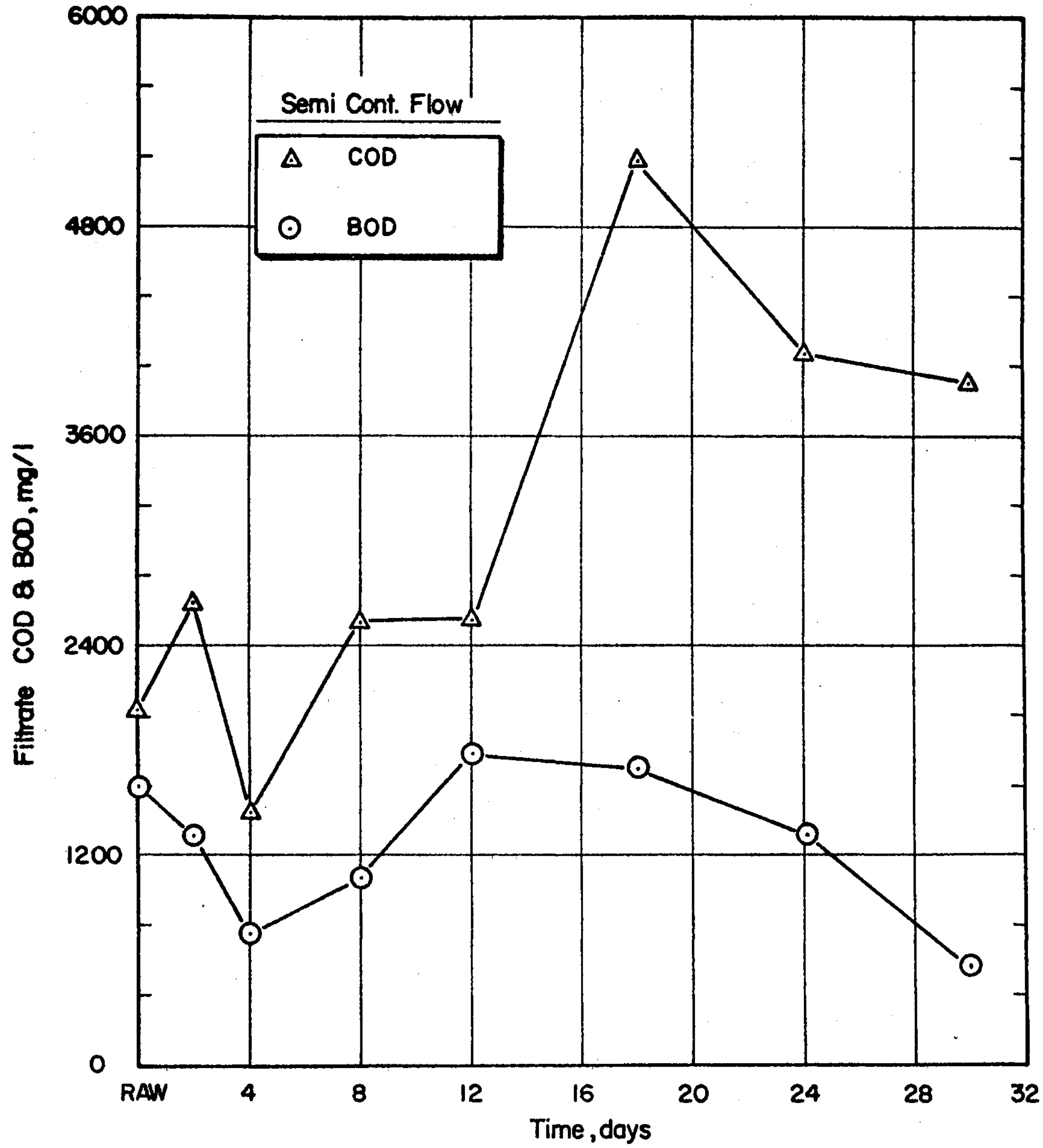

Figure 25 - Comparison of Filtrate COD and BOD Values for Semi-continuous Completely Mixed Reactor at Various Detention Times.

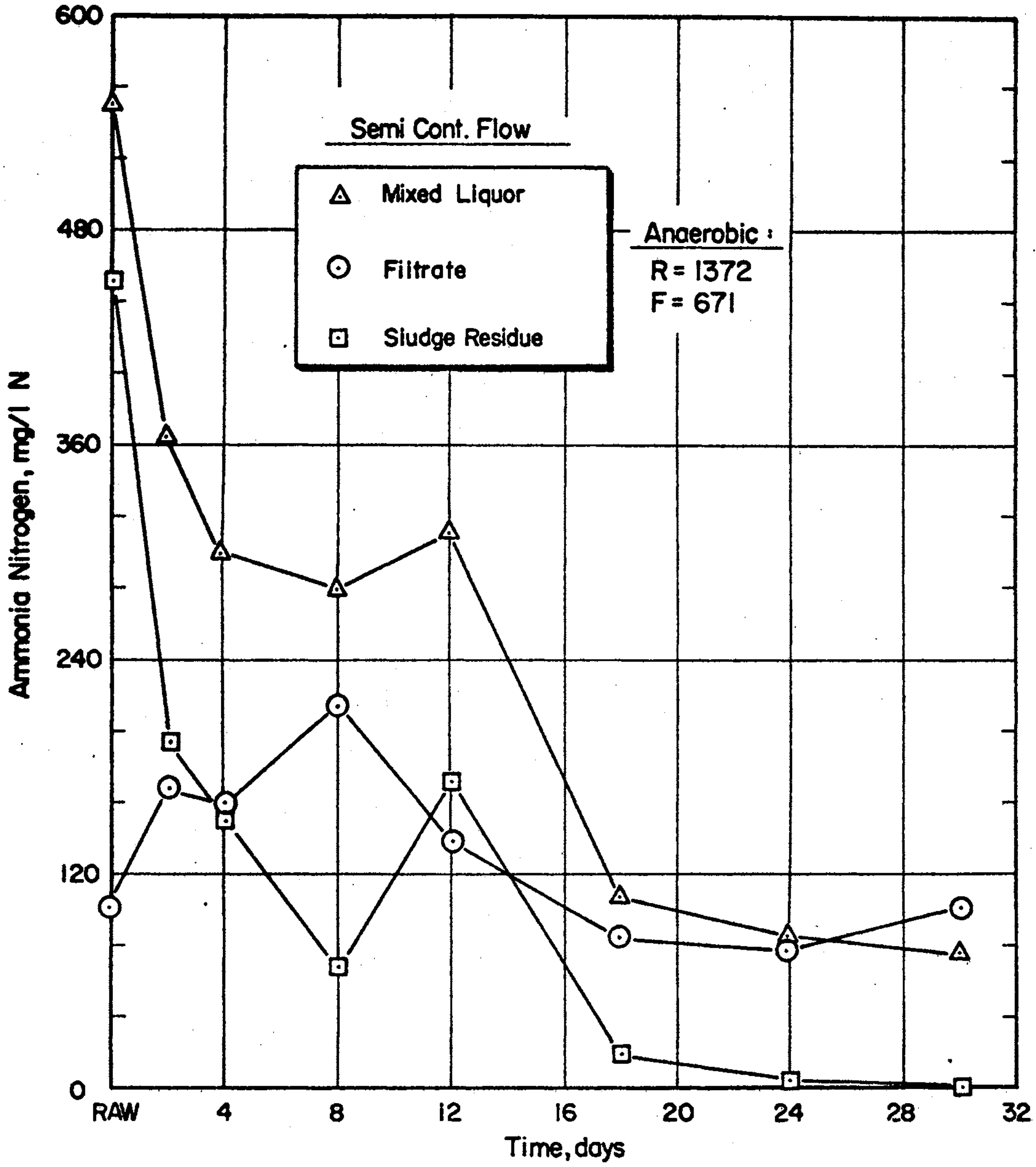

Figure 26 - Overall Average for All Experiments of Ammonia Nitrogen Values for Semi-continuous Completely Mixed Reactor at Various Detention Times.

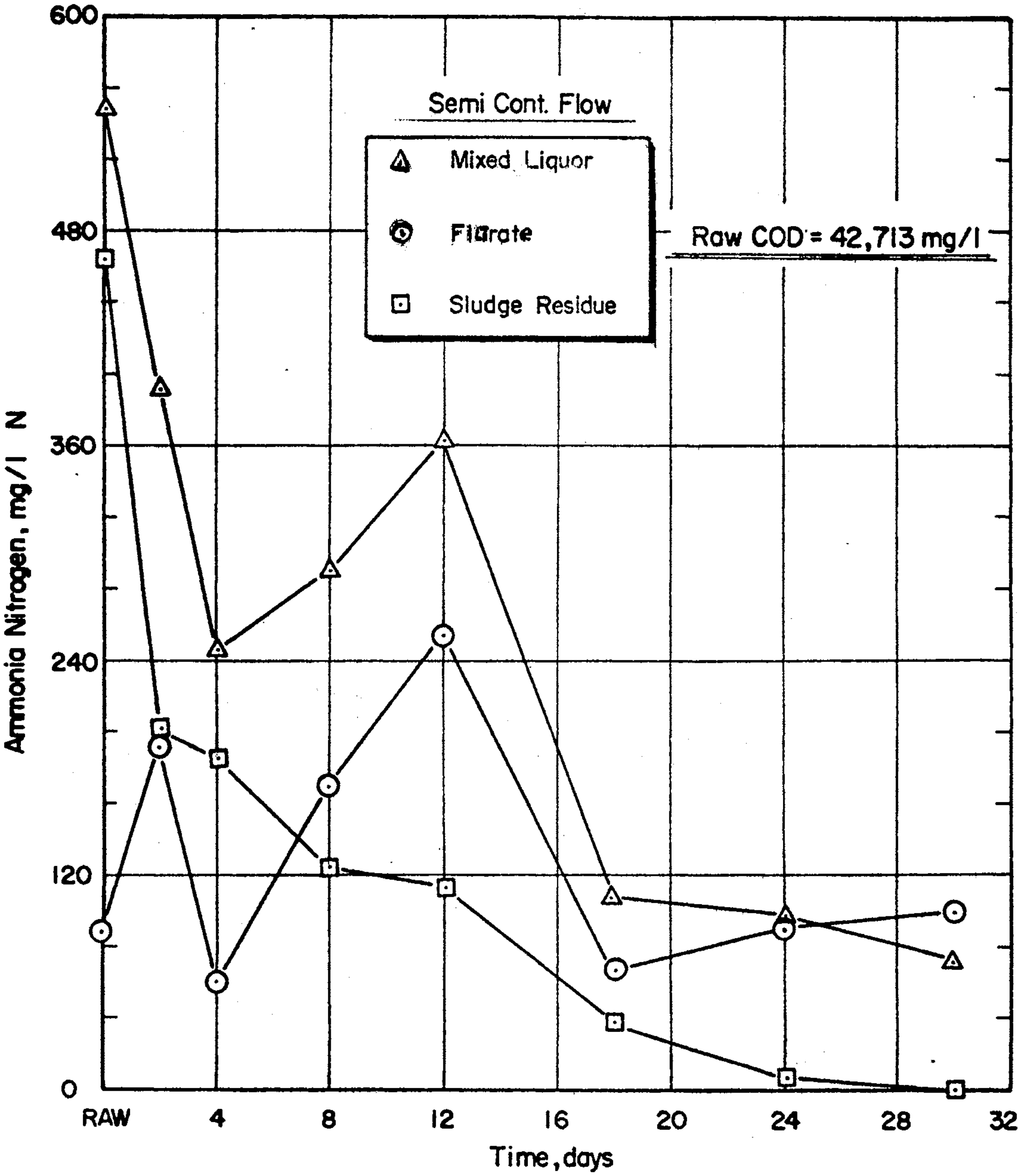

Figure 27 - Comparison of Ammonia Nitrogen Values for Experimental Phase No. 2. Semi-continuous Completely Mixed System.

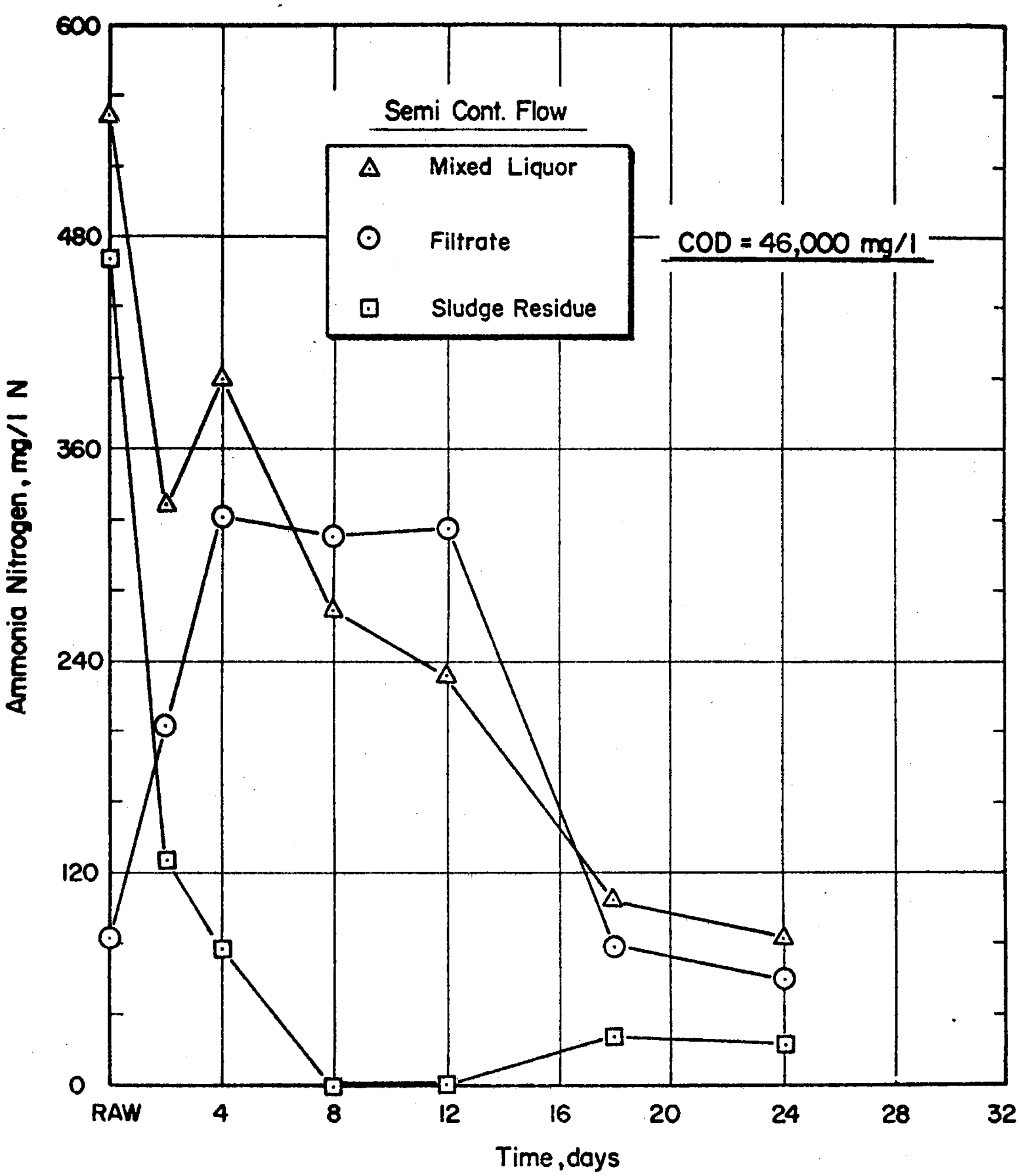

Figure 28 - Comparison of Ammonia Nitrogen Values for Experimental Phase No. 3. Semi-continuous Completely Mixed System.

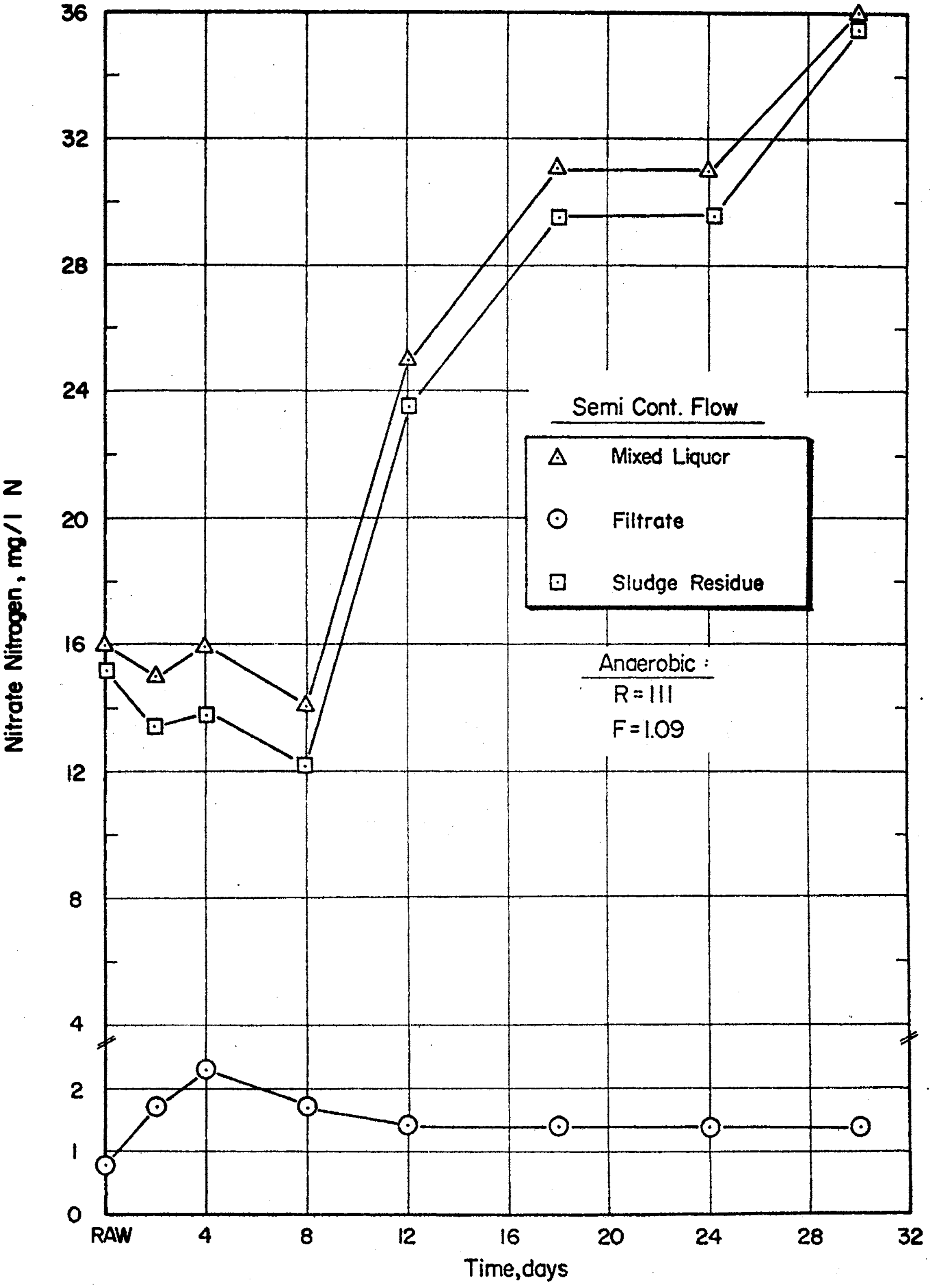

Figure 29 - Overall Average for All Experiments of Nitrate Values for Semi-continuous Completely Mixed Reactors at Various Detention Times.

then increased significantly at 12 days, followed by another rather significant increase at 18 days. The nitrate values leveled between 18 and 24 days, followed by a significant increase at the 30-day detention time.

Figures 30 and 31 show the results of changes in nitrate with time for two experimental runs.

Figure 32 shows a plot of the total phosphate in the mixed liquor, filtrate, and sludge residue at various detention times. The total phosphate in the filtrate increased through the 8-day detention period. It reached its lowest level at 12 days. This was followed by a significant increase at 18 days, followed by decreasing values at 24 and 30 days. The total phosphate in the mixed liquor reached its lowest level at a 2-day detention time. This was followed by an increase at 4 days, a decrease at 8 and 12 days, followed by a significant increase at the 18-day detention time. The PO_4 dropped slightly between 18 and 24 days, then leveled through 30 days.

Figures 33, 34, and 35 show the phosphate results for each experimental run.

Figure 36 shows the plot of the percent volatile solids for each detention time. The overall averages and the results from each experimental run are plotted on one graph. Two out of the three experimental runs showed similar patterns. In these two similar runs, the greatest reduction in percent volatile solids occurred at the 18-day detention time. In the other experiment, the greatest reduction occurred at the 12-day detention time.

Figure 37 shows the filtrate quality for three different parameters at various detention times. The parameters being considered were ammonia nitrogen, total phosphate, and nitrate nitrogen. There was no definite

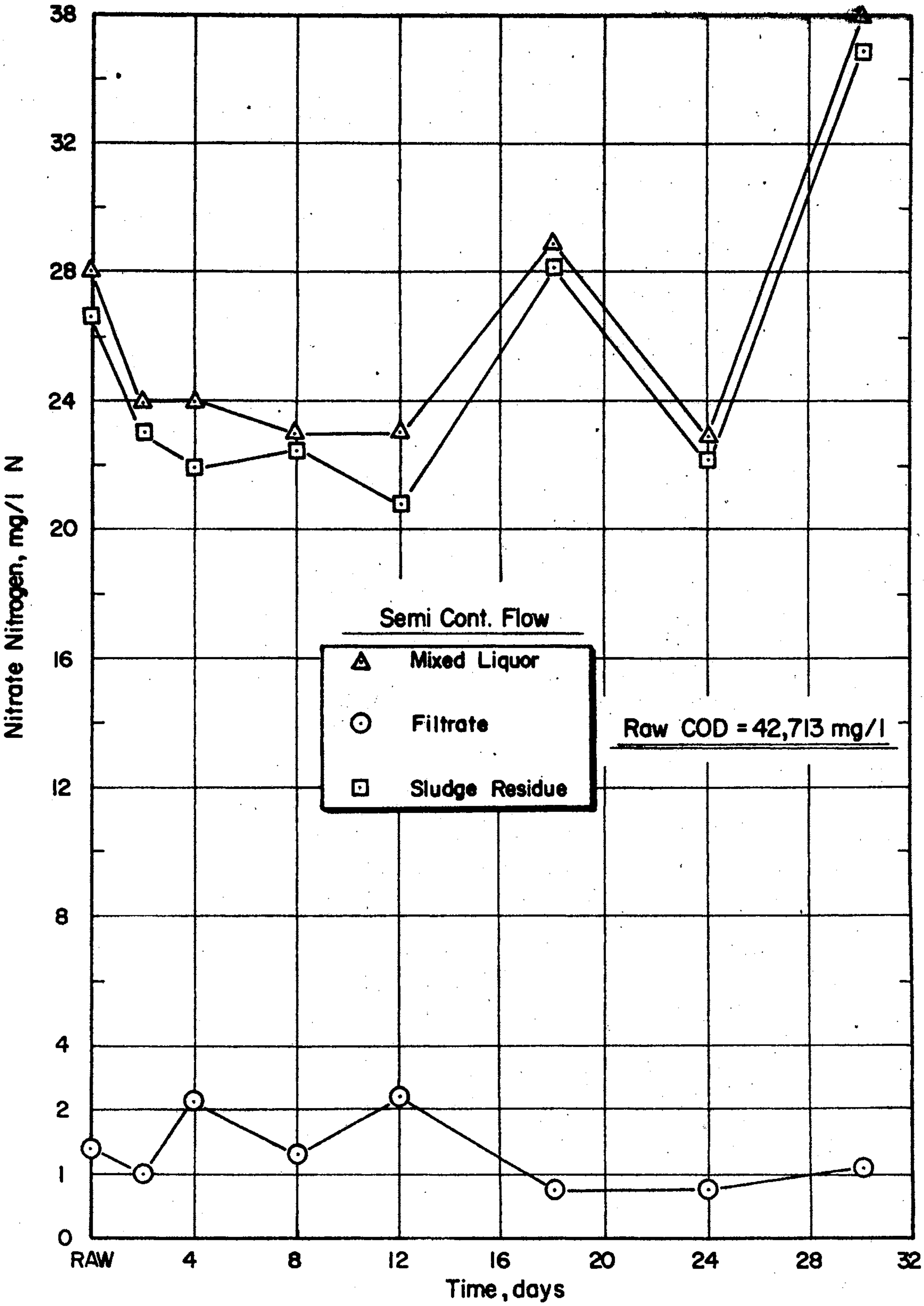

Figure 30 - Comparison of Nitrate for Experimental Phase No. 2. Semi-continuous Completely Mixed System.

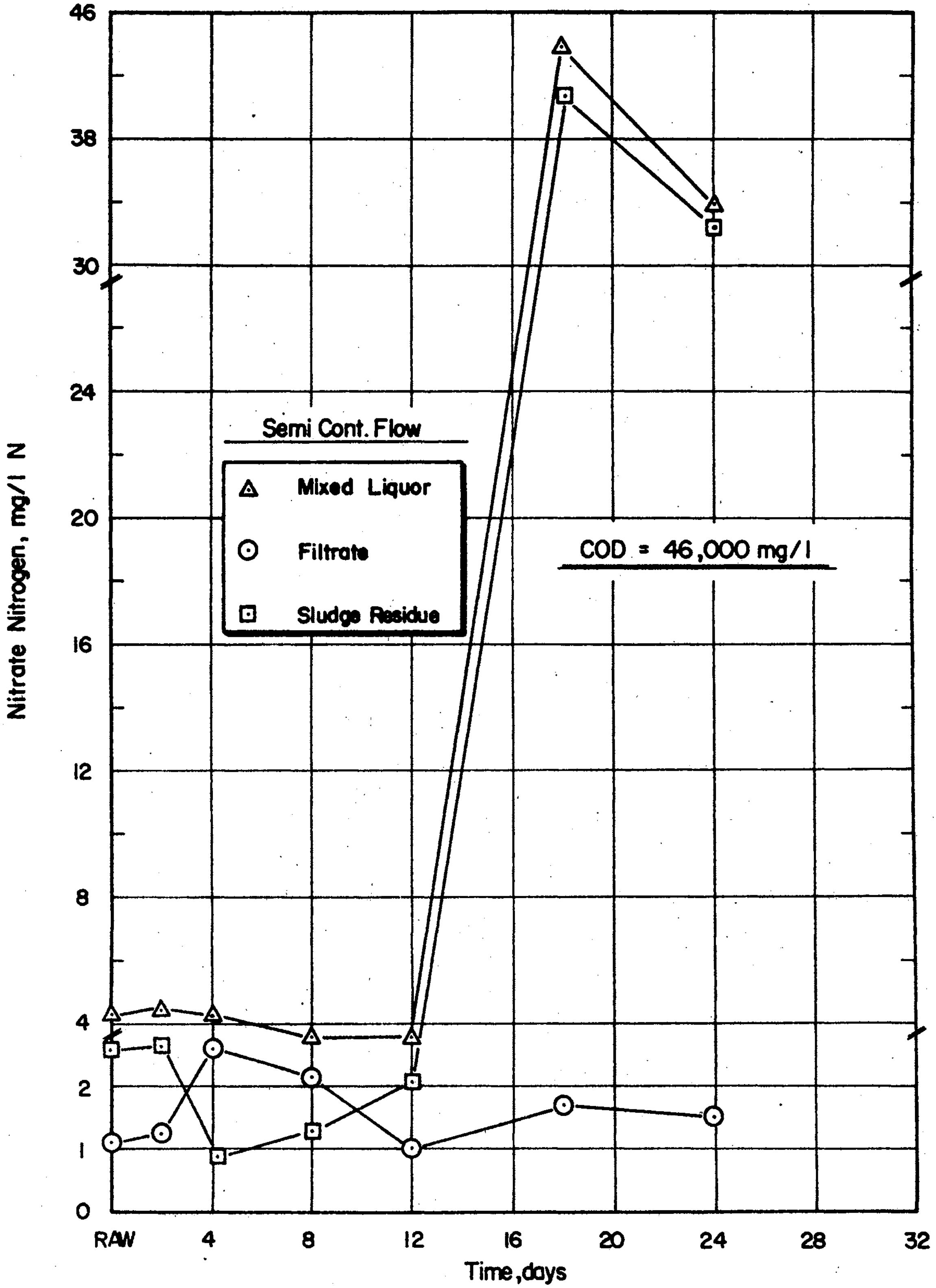

Figure 31 - Comparison of Nitrate Experimental Phase No. 2. Semi-continuous Completely Mixed Reactor.

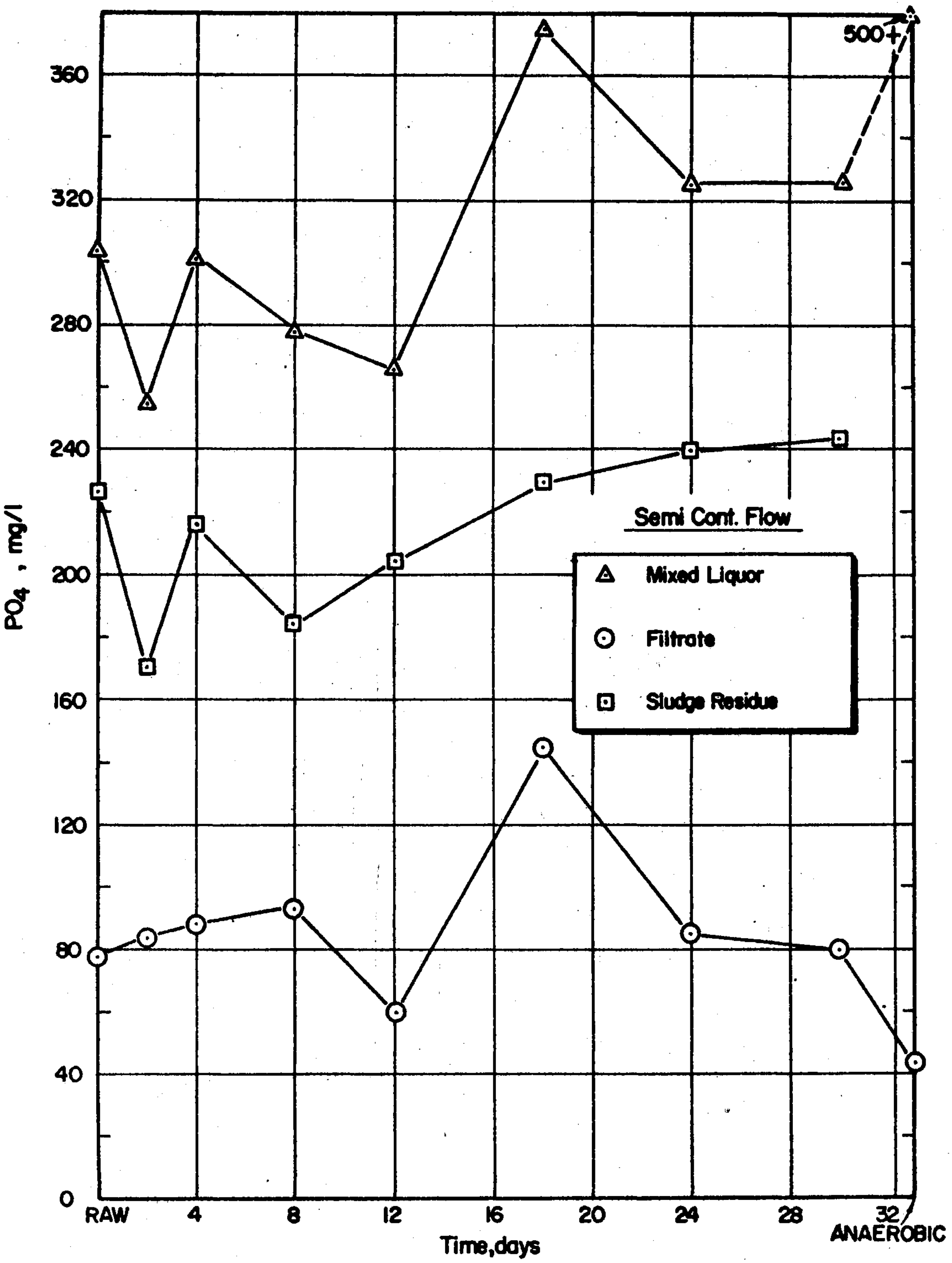

Figure 32 - Overall Comparison of Phosphate Value for Semicontinuous Completely Mixed Reactor at Various Detention Times.

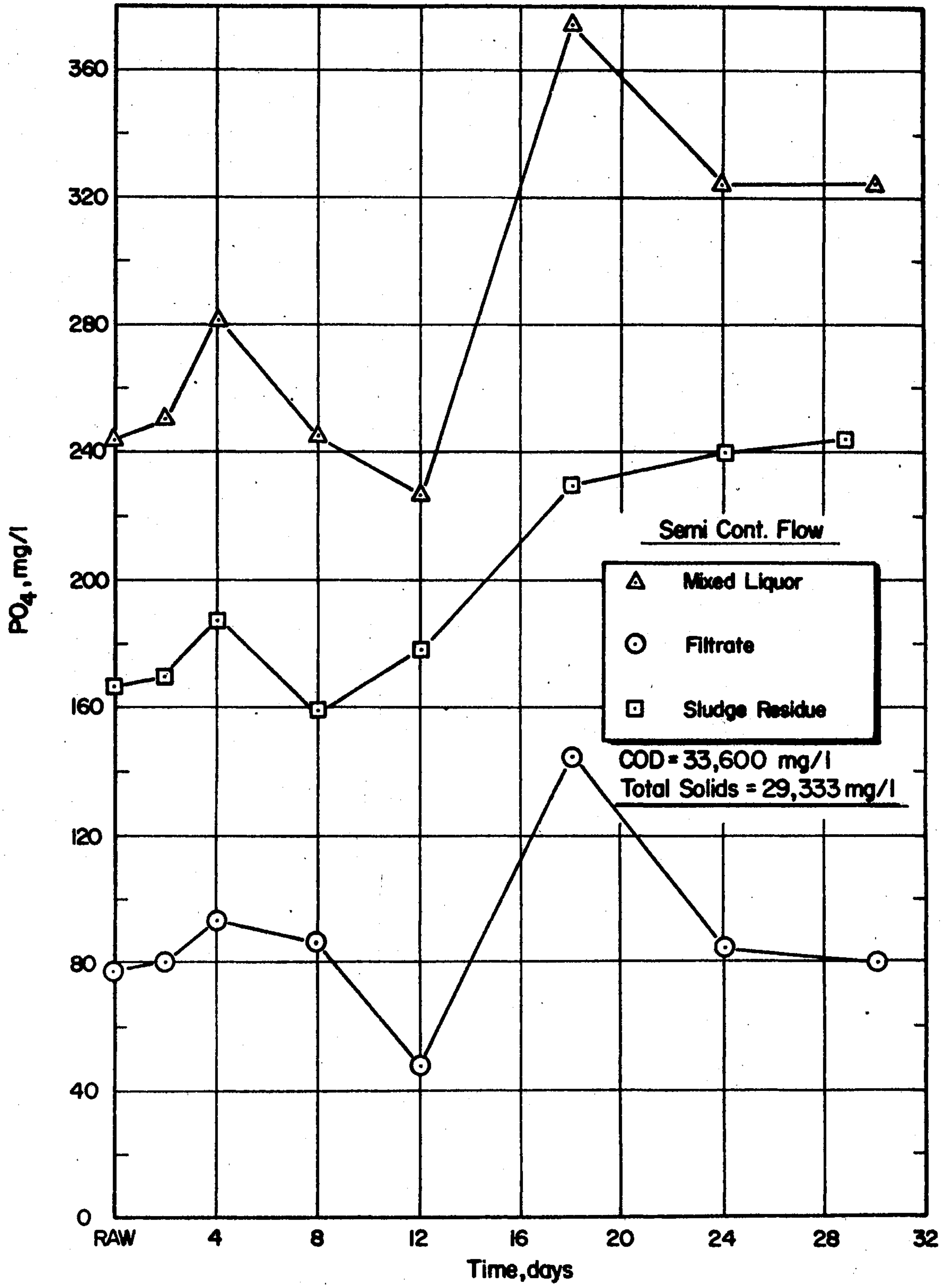

Figure 33 - Comparison of Phosphate Values for Experimental Phase No. 1. Semi-continuous Completely Mixed Reactor.

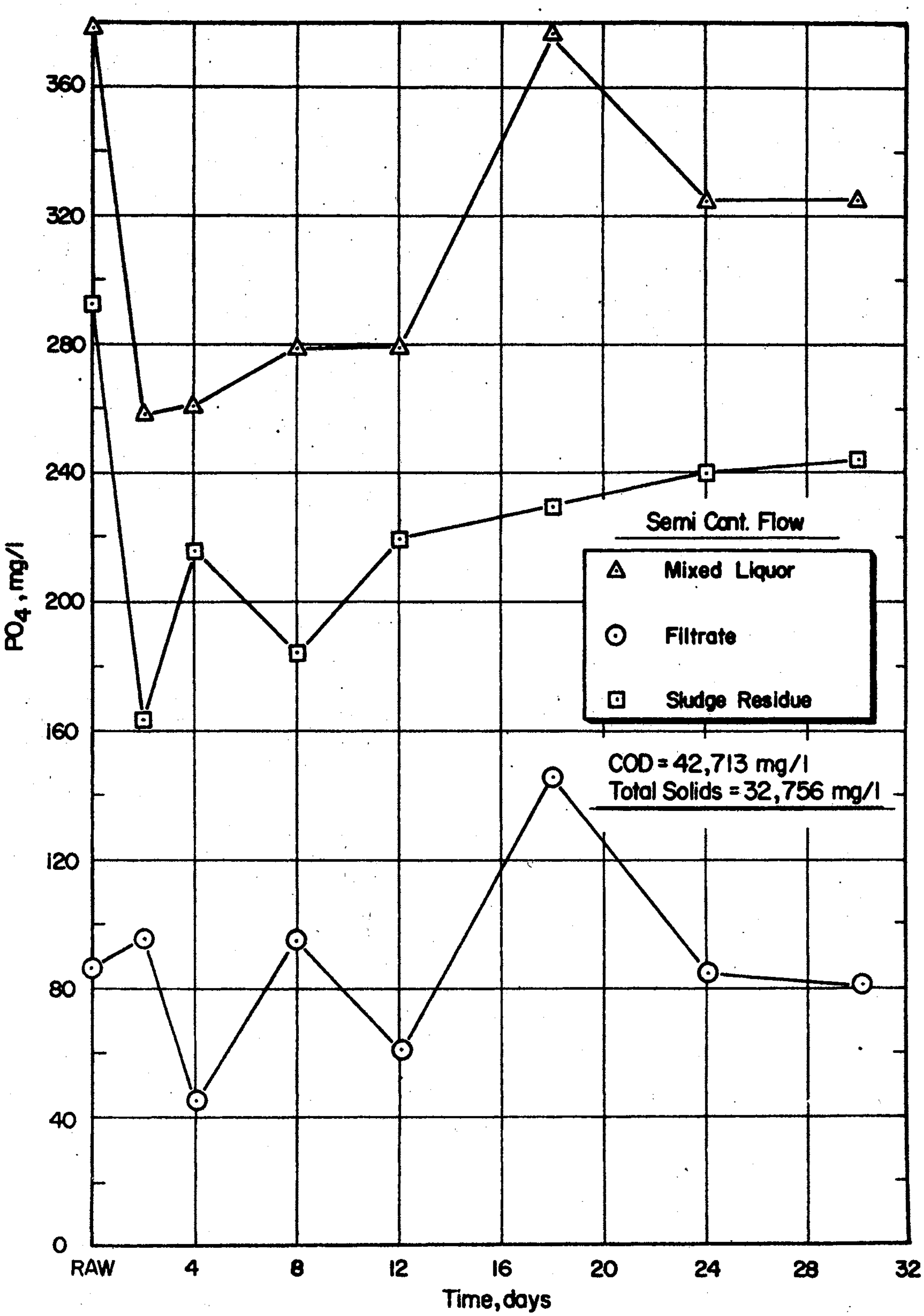

Figure 34 - Comparison of Phosphate Values for Experimental Phase No. 2. Semi-continuous Completely Mixed Reactor.

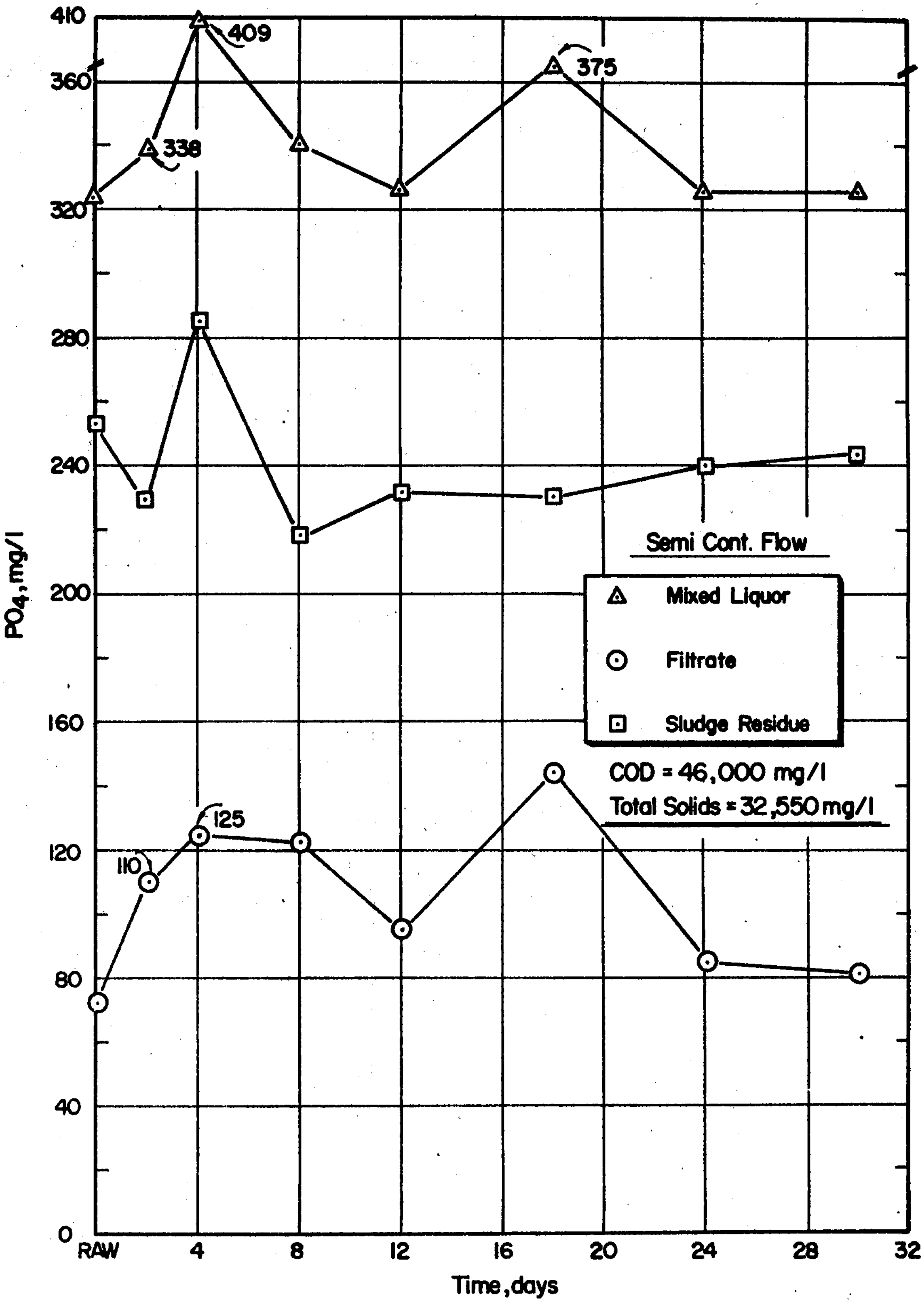

Figure 35 - Comparison of Phosphate Values for Experimental Phase No. 3. Semi-continuous Completely Mixed Reactor.

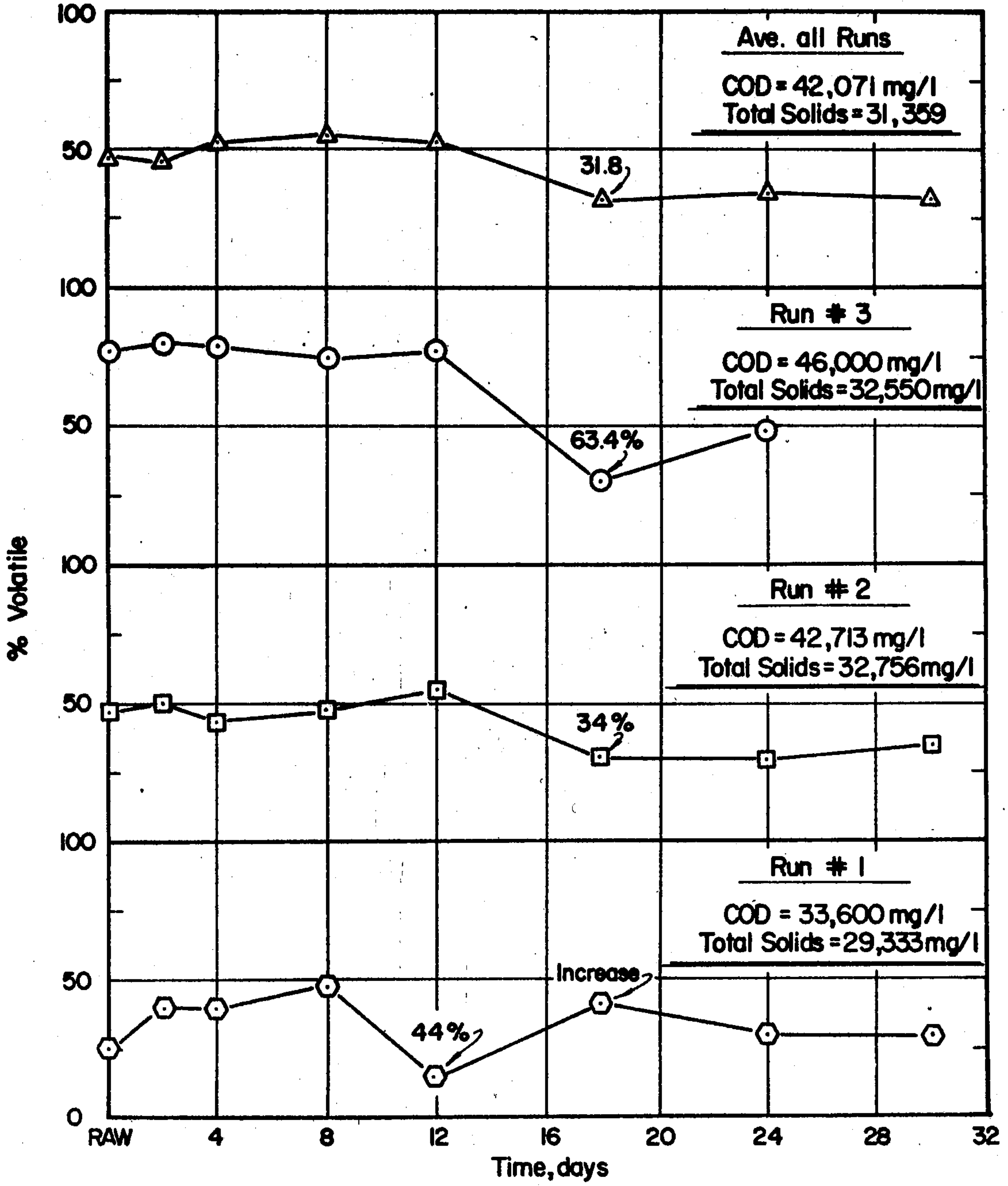

Figure 36 - Comparison of Percent Volatile Solids Values for Semi-continuous Completely Mixed Reactor at Various Detention Times Shows Overall Average Experimental Phases Nos. 1, 2, and 3.

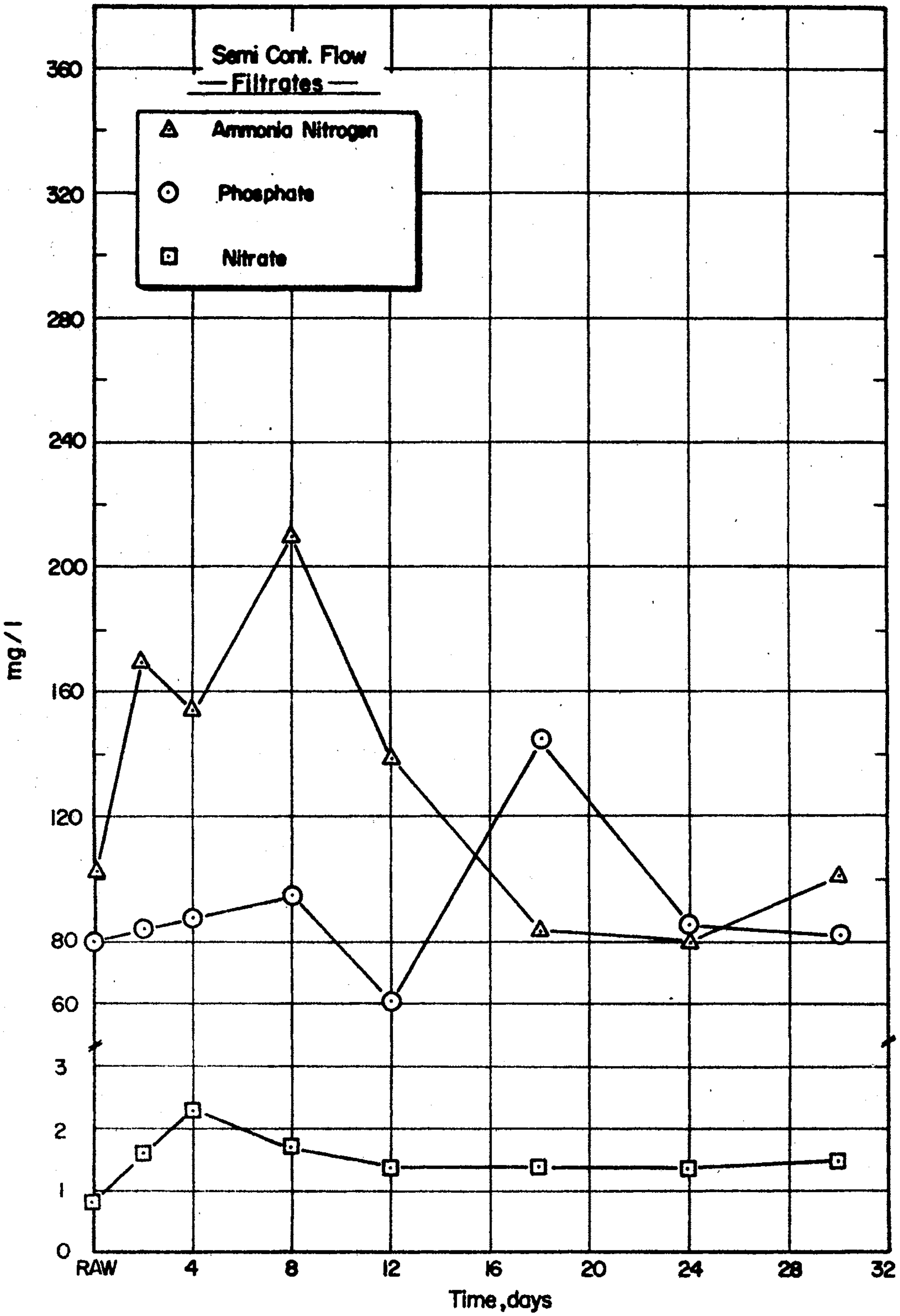

Figure 37 - Comparison of Filtrate Values for Ammonia, Nitrate, and Phosphate for Completely Mixed Semi-continuous Reactor at Various Detention Times.

relationship established.

Figure 38 shows the same information plotted on the mixed liquor. Again there was no definite relationship shown between the parameters being considered.

Figure 39 shows on a single graph a plot of the mixed liquor, COD, total solids, and volatile solids at various detention times. Here a relationship can be established. A decrease in COD is followed by a decrease in total solids, followed by a decrease in volatile solids. An increase in COD is followed by an increase in volatile solids.

Dewatering characteristics of the sludge were also investigated and reported elsewhere (14).

Table II shows the overall average of the chemical and physical characteristics of the sludge applied to the sludge drying beds, as well as the chemical characteristics of the effluent waste.

Tables III, IV, and V show the same information for each of the three experimental runs.

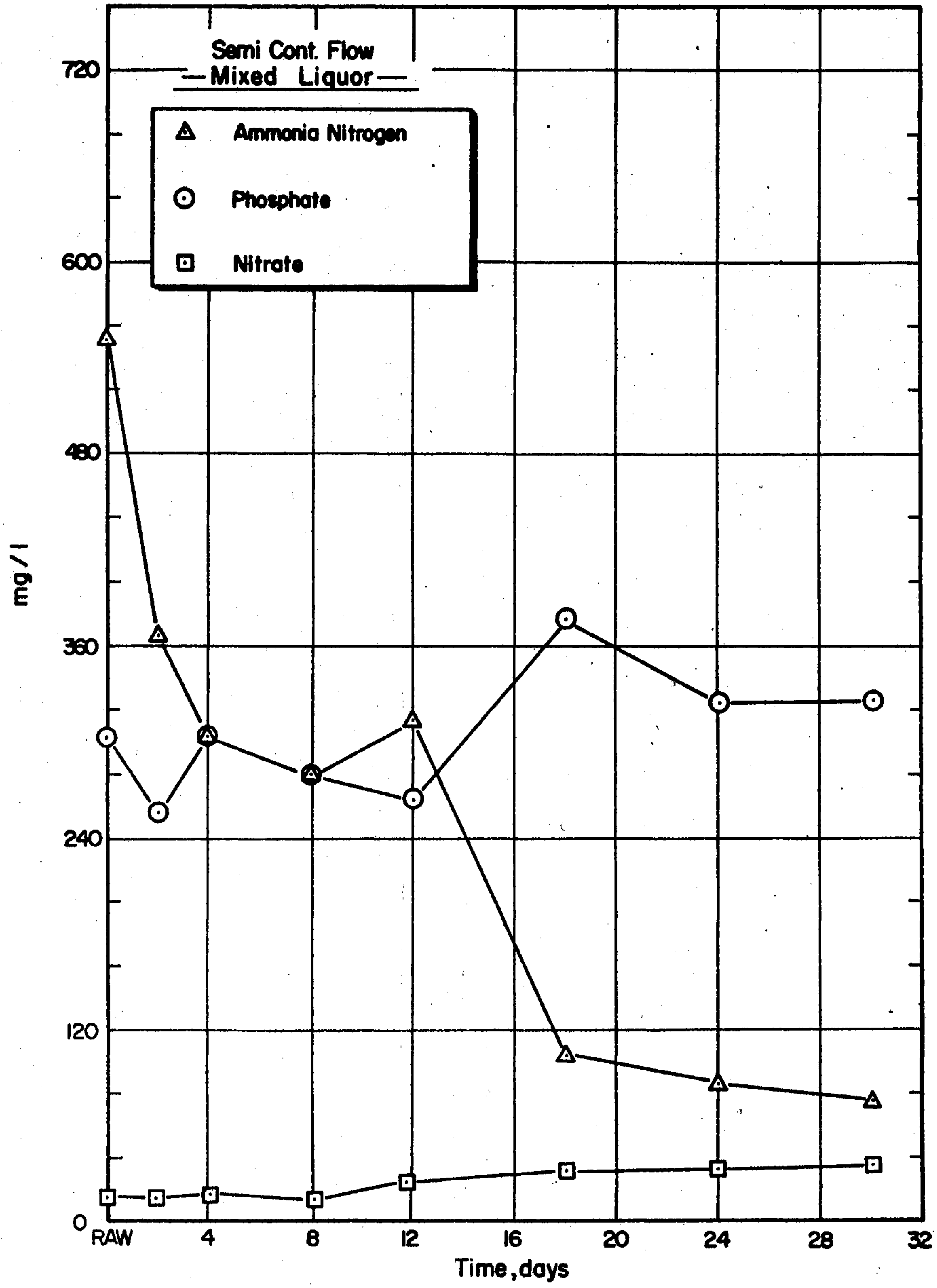

Figure 38 - Comparison of Ammonia, Nitrate, and Phosphate in Mixed Liquor for Semi-continuous Completely Mixed Reactor at Various Detention Times.

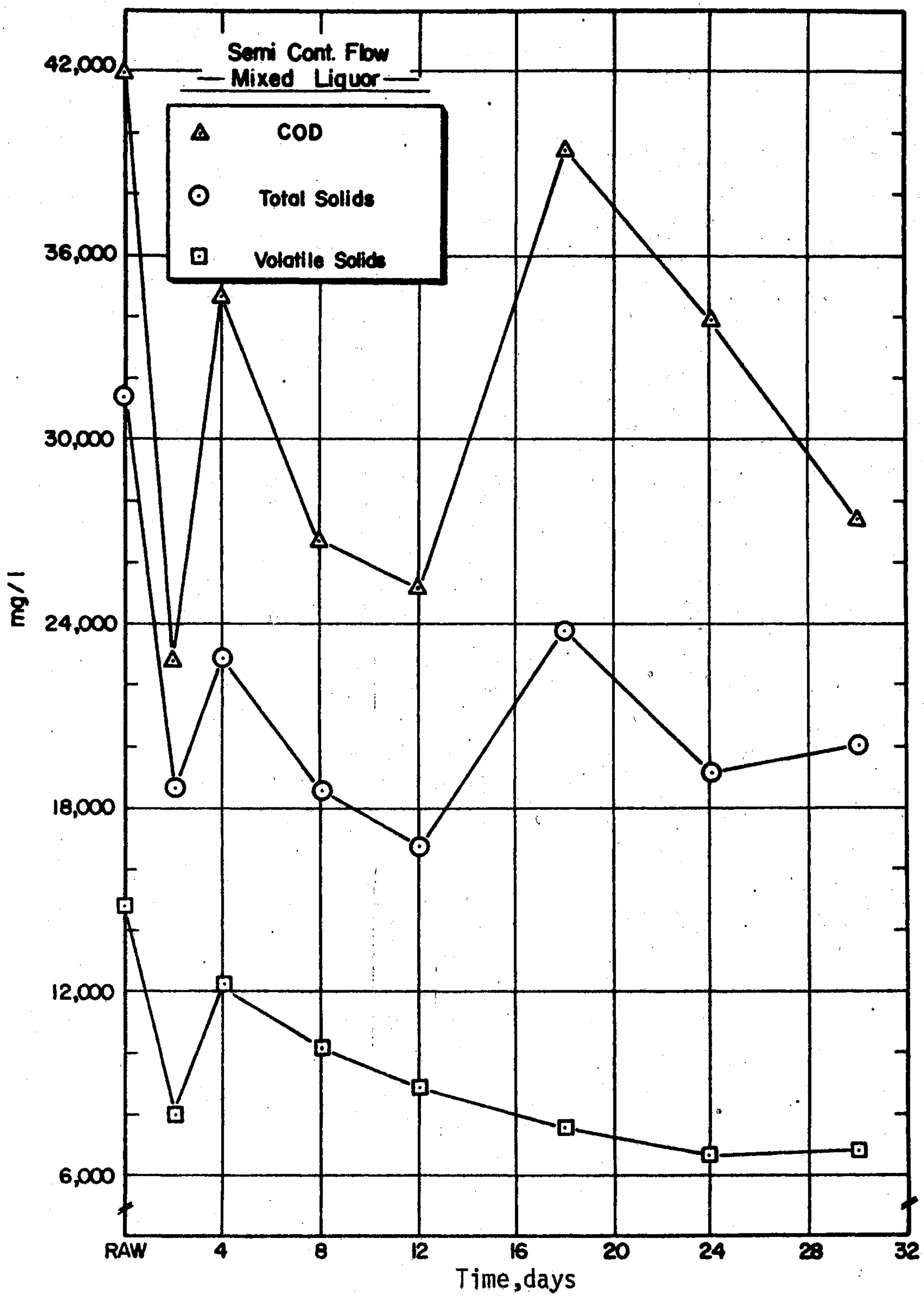

Figure 39 - Comparison of Mixed Liquors, COD, Total Solids, and Volatile Solids for Semi-continuous Completely Mixed Reactor at Various Detention Times.

TABLE II

CHEMICAL AND PHYSICAL CHARACTERISTICS AND EFFLUENT QUALITY OF AEROBICALLY DIGESTED SLUDGE APPLIED TO DRYING BEDS FOR DEWATERING STUDY - COMPLETELY MIXED SEMI-CONTINUOUS FLOW STUDY

		Detention Time (Days)						
Analysis	Raw	2	4	8	12	18	24	30
Total Solids	35,060	57,847	34,015	30,971	25,482	32,000	35,500	29,750
Volatile Solids	16,612	23,681	15,808	15,565	13,342	9,417	12,000	11,250
Fixed Solids	18,448	34,166	18,207	15,406	12,140	22,583	23,500	18,500
% Moisture	96.50	94.25	96.69	96.92	97.48	97.25	96.85	ND
% Volatile	47.38	40.94	46.47	50.25	52.36	29.43	33.80	37.81
Filterability sec	143	520	513	482	392	571	592	523
% Settleability	89	52	61	61	69	79	49	61
PO_4	ND	66	56	60	108	95	30	ND
Ammonia N	ND	149	175	222	226	62	16	68
Nitrate N	ND	3	4	5	2	3	3	3
COD	ND	3,408	3,949	3,986	2,960	5,685	4,220	4,100

All analyses are expressed in mg per liter unless otherwise indicated. Physical values are based on four-hour settled sludge; chemical values are based on drying bed effluents. (ND - No determination)

TABLE III

CHEMICAL AND PHYSICAL CHARACTERISTICS AND EFFLUENT QUALITY OF AEROBICALLY DIGESTED SLUDGE APPLIED TO DRYING BEDS FOR DEWATERING STUDY - COMPLETELY MIXED SEMI-CONTINUOUS FLOW STUDY

		Detention Time (Days)						
Analysis	Raw	2	4	8	12	18	24	30
Total Solids	32,000	28,000	32,000	26,000	22,000	27,500	31,500	ND
Volatile Solids	15,000	6,000	9,000	9,000	5,000	8,000	10,000	ND
Fixed Solids	17,000	22,000	23,000	17,000	17,000	19,000	21,500	ND
% Moisture	96.8	97.2	96.8	97.4	97.8	97.3	96.9	ND
% Volatile	46.9	21.4	28.1	34.6	22.7	29.1	31.7	ND
Filterability sec	149	649	551	428	440	608	586	ND
% Settleability	89	64	64	70	62	88	51	ND
PO_4	ND	ND	ND	ND	110	95	30	ND
Ammonia N	118	149	95	165	171	74	12	ND
Nitrate	ND	3	5	5	2	3	2	ND
COD	ND	ND	ND	ND	ND	ND	ND	ND

All analyses are expressed in mg per liter unless otherwise indicated Physical values are based on four-hour settled sludge; chemical values are based on drying bed effluents. (ND - No determination)

TABLE IV

CHEMICAL AND PHYSICAL CHARACTERISTICS AND EFFLUENT QUALITY OF AEROBICALLY DIGESTED SLUDGE APPLIED TO DRYING BEDS FOR DEWATERING STUDY - COMPLETELY MIXED SEMI-CONTINUOUS FLOW STUDY

		Detention Time (Days)						
Analysis	Raw	2	4	8	12	18	24	30
Total Solids	40,340	91,008	37,635	30,798	22,591	32,500	37,000	30,500
Volatile Solids	13,260	35,385	15,254	13,585	11,400	9,250	13,000	11,000
Fixed Solids	27,080	55,623	22,381	17,213	11,191	23,250	24,000	19,500
% Moisture	96.0	91.0	96.3	97.0	97.8	ND	ND	ND
% Volatile	32.9	38.9	40.5	44.1	50.4	28.5	35.1	36.1
Filterability sec	144	391	538	493	278	582	537	482
% Settleability	87.0	25.7	33.0	58.0	86.7	88.0	56.0	62.0
PO_4	ND	51	62	37	105	ND	ND	ND
Ammonia N	ND	ND	336	336	336	ND	ND	85
Nitrate	ND	ND	3	4	2	2	ND	1
COD	ND	3,408	3,624	4,020	2,660	6,230	3,560	3,610

All analyses are expressed in mg per liter unless otherwise indicated. Physical values are based on four-hour settled sludge; chemical values are based on drying bed effluents. (ND - No determination)

TABLE V

CHEMICAL AND PHYSICAL CHARACTERISTICS AND EFFLUENT QUALITY OF AEROBICALLY DIGESTED SLUDGE APPLIED TO DRYING BEDS FOR DEWATERING STUDY - COMPLETELY MIXED SEMI-CONTINUOUS FLOW STUDY

Analysis	Raw	Detention Time (Days)						
		2	4	8	12	18	24	30
Total Solids	30,200	ND	30,600	36,200	33,300	36,000	38,000	29,000
Volatile Solids	23,000	ND	23,450	25,000	24,500	11,000	13,000	11,500
Fixed Solids	7,200	ND	7,150	11,200	8,800	25,000	25,000	17,500
% Moisture	97.0	96.3	97.0	96.4	96.7	ND	ND	ND
% Volatile	76.2	ND	76.6	69.1	73.6	30.6	34.2	39.7
Filterability sec	134	ND	418	545	492	524	653	563
% Settleability	96	ND	95	40	61	62	43	60
PO_4	ND	73	53	72	ND	ND	ND	ND
Ammonia N	ND	ND	ND	ND	ND	50	20	50
Nitrate	ND	ND	ND	ND	2	3	5	4
COD	ND	ND	4,600	3,920	3,560	5,140	4,880	4,590

All analyses are expressed in mg per liter unless otherwise indicated. Physical values are based on four-hour settled sludge; chemical values are based on drying bed effluents. (ND - No determination)

CHAPTER V

DISCUSSION

A. Batch Studies

Most of the information available in the literature was obtained from laboratory type batch units. It was the purpose of this investigation to run a batch study on a larger scale to have information as to how this might compare with results obtained from semi-continuous completely mixed pilot studies. The batch unit was placed into operation as described in the materials and methods section. Samples were taken beginning with time zero and continuing through selected time intervals of 2, 4, 8, 12, 18, 24, and 30 days. Samples were withdrawn and run in triplicate, and the averages of these were recorded and plotted.

Figure 4 shows a plot of the temperature, pH, and dissolved oxygen at various detention times. The pH in the batch unit decreased initially through 4 days (Figure 4) and then began to increase with time until a maximum pH of 8.0 was reached at the end of 30 days. This type of trend is expected in a study such as this, and seems to indicate rather conclusively that the system is responding to aerobic treatment. It should, however, be pointed out that Lawton and Norman (3) concluded in their experiments utilizing various pH values that a small change in pH did not affect digestion efficiencies. Even in environments in which the pH values were as low as 5, efficiencies were not significantly affected. The system also showed an increase in DO with aeration time. This is to be expected in a system where no additional feed is being added. As the sludge became more stable, there was less demand for oxygen. Consequently, the dissolved oxygen level had a tendency to rise. The maximum total solids reduction during this study was 28 per cent, which occurred at 30 days. However, it must be noted that a 24 per cent reduction occurred in 8 days. From a design viewpoint, aeration beyond 8 days is not justified so far as reduction in solids is concerned. However, other parameters must be considered in making final judgment. The maximum volatile solids reduction of 46 per cent occurred at 4 and 8 days. This, too, is an important design criterion. The COD and BOD data point out that the system yielded a maximum overall reduction in COD of 65 per cent, and a maximum BOD reduction of 22 per cent. It is interesting to note that after 36 days of aeration time, the COD increased significantly, while the BOD seemed to decrease significantly. The increase in COD might logically be explained by a starving system undergoing cell lysis. The lytic material is then put back into the system as substrate; consequently, there is an increase in COD. The fact that BOD continued to decrease might be because the lytic material was not biodegradable or readily biodegradable, therefore there was no increase in oxygen demand (BOD), or there might be a period of acclimation needed before BOD exertion appears. It is also interesting to note that there is no significant overall reduction in COD through 12 days of aeration. The sum of the mixed liquor COD and filtrate COD is practically the same through this time period. This seems to indicate that at these time periods there is no conversion of organic material to CO_2 and H_2O, but a change from an insoluble to a soluble form of organic material (degradation). It was also possible that some cell lysing was taking place at this time and there was no net change in COD. The latter is considered to be more theoretical than practical.

The system's response to changes in nitrogen content was about what was to be expected. Free ammonia nitrogen stripped from the system rather rapidly, and very little change in nitrate nitrogen was shown. This indicates that nitrification did not take place. Jaworski, et al. (2) showed basically the same type relationship between ammonia, nitrates and nitrites. However, they did show nitrate values as high as 600 ppm after 60 days of aeration.

It will be noted that the greatest portion of the phosphates was tied up in the mixed liquor. It should be noted also that there was a 48 per cent reduction in filtrate PO_4 after 30 days, and a 58 per cent reduction after 36 days of aeration time. The only other time a reduction in filtrate PO_4 occurred was at the 2-day detention period. The reduction noted at 30 and 36 days might be due to PO_4 utilization in synthesis of new cells.

Many researchers have shown a great interest in percent volatile solids reduction. Figure 12 points out what occurred to volatile solids during this particular study. The volatile solids content at time zero was 39.2 per cent. This value appeared to be rather low, and suggests that a large portion of test material was inert and nondegradable. However, a maximum volatile solids reduction of 37.3 per cent did occur after 4 days of aeration.

Figure 13 is a chart showing the chemical characteristics of the filtrate so that one might get a better insight as to what was taking place in the system biochemically, and the quality of effluent being discharged. As always with a study of this nature, one objective was that of pollution control with high effluent quality.

During this same study, dewatering characteristics of the aerobically digested sludge were studied. As a matter of procedure, the samples were collected and allowed to set for 4 hours, then the clear liquid layer was decanted and the thickened sludge applied to drying beds and dewatering characteristics noted. This information was reported in another paper (14). However, Figure 14 shows what happens to the solids concentration of the sludge after 4 hours settling. The data show that the mixed liquor compacted well with a significant increase in solids. The solids concentration increased from 17,875 to 29,375 ppm at time zero.

Table I gives the average overall characteristics of the sludge applied to the drying beds for dewatering, as well as chemical characteristics of its effluent waste. It will be noted that the PO_4 and ammonia content in the effluent from the drying beds was slightly lower than that of the filtrate, and that the COD value was slightly higher. The nitrates again were very insignificant.

B. Experimental Results From Semi-continuous Completely Mixed Study

Before giving an interpretation of analytical data, it might be well to mention some of the operational problems encountered in feeding the digester reactors. Pump stoppage eventually became an ever-present problem. During experimental run No. 2, pumps had to be cleaned almost daily, and sometimes twice a day. Because of this problem, the reactors were switched to hand-feeding for experimental run No. 3. Reactors were hand-fed twice a day--once at 12 noon, and again at 7 P. M. The amount of feed was based upon detention time. For the 2-day detention time, 45 gallons of waste was fed twice a day at the specified times. For the 4-day detention time, 22.5 gallons was fed; for 8 days, 11.25 gallons; for 12 days, 7.5 gallons; for 18 days, 5.0 gallons; for 24 days, 3.75 gallons; and for 30 days, 3.0 gallons. It was also noted that during the early experiments the pH of the feed material was rather low. This could perhaps be explained by the fact that the feed line leading from the primary clarifier to the feed reservoir was quite long, and held an estimated volume of 100 gallons. While the reactors were being fed from the reservoir, this large volume was laying in the line and, perhaps, some degradation was occurring. This condition could lead to low pH's. However, at no time did the feed itself exhibit a septic odor, nor were gas bubbles noted in the reservoir. pH control was not used during the study. These facts, along with the fact that the nature of the sludge itself changed daily might account for some of the irregularities that appear to exist in the analytical data. Because of this, also included are actual results in table form of all chemical analyses for each experimental run at various detention times. (Tables VI to XXVI are attached as appendices to this report.) The tables may be used to study overall characteristics of the sludge, and to note different changes in compositions of the sludge at various detention times.

It may be necessary to consider also that the sewage treatment plant at Stillwater receives all of the waste from the Oklahoma State University, which has a current enrollment in excess of 18,000. The influence of the college population on the characteristics of the waste utilized for this study must be considered in trying to interpret the analytical data.

There were times, perhaps, when the university was out for vacation and on weekends, when many students would leave the campus, and thus the reactors were receiving a fairly weak feed. Then there were times when school was in session and the reactors were under severe organic shock loading conditions. These types of conditions had an important influence on how the reactors responded to aerobic treatment. All of the above mentioned conditions must be considered in evaluating the data.

Figure 15 is a plot of the results of pH, DO, and temperature at various detention times (2, 4, 8, 12, 18, 24, and 30 days).

The study was to be conducted at a controlled temperature of 25°C. Problems with the temperature control mechanism occurred, and consequently early in the study the temperatures for the 2-day and 4-day detention times were less than 25°C. The problem was resolved, and the temperature for all detention times in all reactors was 25°C. The fact that the DO in the reactor reached a maximum of only 0.6 ppm will lead to a great deal of discussion by many researchers as to the efficiency and capacity of the aerators used. This should be a study in itself. As the investigator, it was felt that air supply was adequate, and good mixing and oxygen transfer were taking place and enough oxygen was present during all detention periods so as not to have oxygen limitations.

It has been recommended by many investigators that in an aerobic system at least 1-2 ppm DO be maintained at all times in order that oxygen does not become limiting. Certainly (2ppm) DO is desirable, but many aerobic systems respond with high efficiencies with DO of less than 1 ppm.

Figures 16, 17, 18, and 19 show plots of total solids, volatile solids, and fixed solids with time. It can be seen that the greatest reduction in total solids occurred at 12 days. A reduction of 52 per cent is shown. Maximum volatile solids reduction occurred at 30 days, i.e., 54 per cent. However, a significant reduction of 40 per cent is shown at 12 days, and a 46 per cent reduction is shown at a low detention time of 2 days. It would appear from a standpoint of total solids and volatile solids reduction, the 12-day detention time is best. It is interesting to note that there was not much change in the total solids content, but the changes in volatile material for each experimental run were quite different.

Figures 20, 21, 22, and 23 show plots of COD values for various detention times for each set of experiments. The maximum COD reduction in the mixed liquor occurred at the 2-day detention time. A 46 per cent reduction is shown. A 40 per cent reduction occurred at 12 days. COD in the filtrate showed increases over raw filtrate for all times studied except 4 days, which shows a 30 per cent reduction in filtrate COD. All three experimental runs responded in the same manner, the only difference being the degree of response. The lower the COD in the effluent, the higher the efficiency. Where the influent COD was 33,600, the maximum efficiency removal at 2 days was 57 per cent. When the COD increased to 46,000 in experiment No. 3, the efficiency was reduced to 22 per cent for the same detention time.

Figure 25 shows the comparison between BOD and COD values. Although a significant decrease in BOD and COD are shown for the 4-day detention time, it might be pointed out that at no time during this study was a flocculating microbial mass developed. This would indicate that the system was still not completely oxidized. It is believed that at no time was the system operating in the endogenous phase. Exogenous materials were still available as substrate. It appears that the main process taking place was aerobic degradation without synthesis.

Figures 26 through 29 show what occurs to ammonia with increasing detention times. The filtrate shows gradual increases in ammonia up to 8 days, followed by a gradual decrease through 24 days. The ammonia content in the filtrate dropped below that of the raw filtrate after an 18-day detention time.

Stabilization of free ammonia in the mixed liquor seemed to be adequate, but filtrate ammonia contents were still too high if one planned to discharge it to a receiving stream. We were still quite a way from removing all of the nutrient value from the filtrate.

Irgens and Halvorson in their studies reported nitrate and ammonia content of supernatant fluids of less than 1 ppm. In the same study they also reported that in all cases nitrogen contents were less in the treated sludge than in raw sludge.

The nitrates in the filtrate in this study were less than 4 ppm. The phosphate contents in Figures 33 to 35 indicate that most of the PO_4 is tied up in the mixed liquor. No significant change is noted in the filtrate phosphate.

Figure 36 shows a plot of volatile solids reduction. The reduction in volatile solids was as high as 63.4 per cent for the 18-day detention time.

CHAPTER VI

CONCLUSIONS

The more efficient control facilities from the standpoint of degradation of organic material per unit time have been those using aerobic mechanisms. Both the trickling filter plant and the activated sludge plant depend on some form of aeration. In both of these processes there is an additional requirement for anaerobic digesters to reduce the bulk waste collected in the primary and secondary treatment. The use of anaerobic digesters has met with a measure of success, but the standard units now in operation require heating and detention times up to 30 days.

Time has now become a valuable commodity and is given prime consideration in developing new processes for waste disposal. One purpose of this research was to determine if time could be saved by utilizing aerobic digestion of organic sludge in lieu of anaerobic digestion. Before discussing the conclusions reached from this study, one must first establish ground rules and set the objective function. The objective function may simply be stated as: to maximize efficiency and minimize time. The guideline then is to produce an acceptable aerobically digested waste that can be disposed of readily. The material must not be a health hazard or be offensive, and must exhibit good dewatering characteristics. Effluent quality, then, is not the prime consideration.

The theoretical equation for judging this process may be written as:

Organic matter + O_2 + NH_3 + cells ⟶ sludge cells + CO_2 + H_2O + disposable organic waste.

The question now becomes: At what detention time in the aerobic digestion of an organic primary waste is an acceptable sludge generated?

From the results of this study, the following conclusions can be made:

1. Aerobic digestion of primary waste sludge is feasible.
2. Aerobic digestion of primary sludge to an acceptable end product can be accomplished at a 12-day detention time.
3. Maximum reduction in total solids and volatile solids in the mixed liquor occurs at a 12-day detention time.
4. COD reductions up to 40 per cent can be obtained at a 12-day detention time.
5. Sludge digested for 12 days showed satisfactory drainability characteristics.
6. Free ammonia was stripped from the mixed liquor after a 12-day detention time.
7. There were no significant changes in phosphate or nitrate in the mixed liquor for any of the time periods investigated.
8. In the batch study, the total solids and volatile solids reduction was a function of digestion time.
9. Semi-continuous completely mixed studies should be used for design rather than batch studies.
10. Filtrate liquors from the aerobic digestion showed higher COD values when compared to anaerobic digester filtrate.

CHAPTER VII

SUGGESTIONS FOR FUTURE WORK

The following future investigations would be of interest:

1. Pilot studies on the response of various mixes of primary and secondary sludges to aerobic digestion.

2. Pilot studies where some parameter other than temperature be controlled, for example, pH.

3. Studies utilizing two-stage aerobic digesters.

4. Further studies of the pilot type are needed to evaluate the results of these experiments.

5. Other methods of sludge disposal need to be investigated.

6. Further batch studies are needed to substantiate the response of aerobic digestion of primary and/or secondary sludges under controlled conditions.

7. Pilot studies utilizing pure oxygen rather than diffused air as the oxygen source.

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APPENDIX

Tables VI - XXVI

Physical and Chemical Characteristics of Aerobically Digested Sludge for Each Experimental Run at Each Detention Time Investigated.

TABLE VI

AVERAGE OF EXPERIMENTAL RUN NO. 1
OCT., NOV., DEC., 1970
2 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	33,600	2,464	14,400	2,768	11,308	ND	ND
BOD	ND	2,563	ND	1,500	ND	ND	ND
Total PO_4	244	78	250	80	170	500+	45
Ammonia N	551	116	392	146	246	ND	ND
Nitrate N	28.00	0.67	24.00	2.30	22.00	111.00	1.00
PH	5.79		6.50			7.03	
D O	ND		0.34			ND	
Total Solids	29,333		20,250			102,559	
Volatile Solids	7,333		8,000			42,256	
Fixed Solids	22,000		12,250			60,303	
% Moisture	97.1		98.5			89.7	
% Volatile	25					41	
Temperature	29		17			ND	
Filterability (Sec)	235		477			ND	
Settleability	88.6					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE VII

AVERAGE OF EXPERIMENTAL RUN NO. 2
JAN., 1971
2 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	42,713	2,200	25,333	2,976	22,357	77,176	304
BOD	ND	1,392	ND	1,276	ND	ND	ND
Total PO_4	379	87	258	95	163	500+	42
Ammonia N	ND	88	328	192	136	1,232	666
Nitrate N	4.00	1.36	5.00	0.99	4.01	ND	1.62
PH	5.75		6.28			6.99	
D O	ND		0.44			ND	
Total Solids	32,756		16,321			147,295	
Volatile Solids	15,438		7,996			11,470	
Fixed Solids	17,318		8,325			135,825	
% Moisture	96.8		98.4			96.8	
% Volatile	47.13					0.08	
Temperature	29		24				
Filterability (Sec)	169		481			531	
% Settleability	87					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE VIII

AVERAGE OF EXPERIMENTAL RUN NO. 3
FEB., 1971
2 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	46,000	1,978	ND	ND	ND	ND	557
BOD	ND	ND	ND	ND	ND	ND	ND
Total PO_4	324	72	ND	ND	ND	500+	ND
Ammonia N	ND	82	ND	ND	ND	1,512	679
Nitrate N	ND	0.78	ND	ND	ND	ND	1.09
PH	5.76					6.87	
D O	ND		0.64			ND	
Total Solids	32,550					67,250	
Volatile Solids	25,000					30,950	
Fixed Solids	7,550					3,630	
% Moisture	96.8					93.3	
% Volatile	77					54	
Temperature	29		24			ND	
Filterability (Sec)	170					697	
% Settleability	96					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE IX

AVERAGE OF EXPERIMENTAL RUN NO. 1
OCT., NOV., DEC., 1970
4 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	33,600	2,464	54,400	1,168	53,272	ND	ND
BOD	ND	2,563	ND	860	ND	ND	ND
Total PO_4	244	78	282	94	188	500+	45
Ammonia N	551	116	243	146	97	ND	ND
Nitrate N	28.00	0.67	18.00	2.07	15.93	111.00	1.00
PH	5.79		6.20			7.03	
D O	ND		0.40				
Total Solids	29,333		26,000			102,559	
Volatile Solids	7,333		10,333			42,256	
Fixed Solids	22,000		15,667			60,303	
% Moisture	97.1		97.5			89.7	
% Volatile	25					41	
Temperature	29		19			ND	
Filterability (Sec)	235		478			ND	
% Settleability	88.6					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE X

AVERAGE OF EXPERIMENTAL RUN NO. 2
JAN., 1971
4 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	42,713	2,200	23,548	1,200	22,348	77,176	304
BOD	ND	1,392	ND	712	ND	ND	ND
Total PO_4	379	87	260	44	216	500+	42
Ammonia N	ND	88	399	60	399	1,232	666
Nitrate N	4.0	1.4	4.0	2.1	1.9	ND	1.6
PH	5.75		7.16			6.99	
D O	ND		0.44			ND	
Total Solids	32,756		15,199			147,295	
Volatile Solids	15,438		6,717			11,470	
Fixed Solids	17,318		8,482			135,825	
% Moisture	96.8		98.5			96.8	
% Volatile	47.13					0.08	
Temperature	29		23			ND	
Filterability (Sec)	169		645			531	
% Settleability	87					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XI

AVERAGE OF EXPERIMENTAL RUN NO. 3
FEB., 1971
4 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	46,000	1,978	41,600	1,980	39,620	ND	577
BOD	ND	ND	ND	ND	ND	ND	
Total PO_4	324	72	409	125	284		
Ammonia N	ND	82	ND	322	ND	500+	679
Nitrate N	ND	0.78	ND	3.18	ND	ND	1.09
PH	5.96		5.52			6.87	
D O	ND		0.29				
Total Solids	32,550		29,900			67,250	
Volatile Solids	25,000		23,550			30,950	
Fixed Solids	7,550		6,350			3,630	
% Moisture	96.8		98.1			93.3	
% Volatile	77					54	
Temperature	29		25				
Filterability (Sec)	170		447			697	
% Settleability	96					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XII

AVERAGE OF EXPERIMENTAL RUN NO. 1
Oct., Nov., Dec., 1970
8 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	33,600	2,464	26,700	2,666	24,034	ND	ND
BOD	ND	2,563	ND	948	ND	ND	ND
Total PO_4	244	78	245	86	159	500+	45
Ammonia N	551	116	293	194	99	ND	ND
Nitrate N	28	0.67	23.00	1.60	21.40	111.00	1.00
PH	5.79		6.8			7.03	
D O	ND		0.50				
Total Solids	29,333		19,000			102,559	
Volatile Solids	7,333		9,250			42,256	
Fixed Solids	22,000		9,750			60,303	
% Moisture	97.1		98.2			89.7	
% Volatile	25					41	
Temperature	29		23				
Filterability (Sec)	235		453			ND	
% Settleability	88.6					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XIII

AVERAGE OF EXPERIMENTAL RUN NO. 2
Jan., 1971
8 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	42,713	2,200	25,365			77,176	304
BOD	ND	1,392	1,228			ND	ND
Total PO_4	379	87	279			500+	42
Ammonia N	---	88	266			1,232	666
Nitrate N	4.00	1.36	4.00				1.62
PH	5.75		6.62				6.99
D O	ND		6.73				
Total Solids	32,756		17,101			147,295	
Volatile Solids	15,438		8,249			11,470	
Fixed Solids	17,318		8,852			135,825	
% Moisture	98.8		98.7			96.8	
% Volatile	47.13					0.08	
Temperature	29		25				
Filterability (Sec)	169		527			531	
% Settleability	87					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XIV

AVERAGE OF EXPERIMENTAL RUN NO. 3
Feb., 1971
8 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	36,000	1,978	28,000	2,981	25,819	ND	577
BOD	ND	ND	ND	ND	ND	ND	ND
Total PO_4	324	72	340	122	218	500+	
Ammonia N		82		311	ND	1,512	679
Nitrate N		0.78	ND	2.33	ND	ND	1.09
PH	5.96		6.46			6.87	
D O	ND		0.215				
Total Solids	32,550		19,750			67,250	
Volatile Solids	25,000		14,950			30,950	
Fixed Solids	7,550		4,800			3,630	
% Moisture	96.8		98.1			93.3	
% Volatile	77					53	
Temperature	29		25				
Filterability (Sec)	170		763			697	
% Settleability	96					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XV

AVERAGE OF EXPERIMENTAL RUN NO. 1
Oct., Nov., Dec., 1970
8 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	33,600	2,464	24,000	1,592	22,408	ND	304
BOD	ND	2,563	ND	1,848	ND	ND	ND
Total PO_4	244	78	226	48	178	500+	45
Ammonia N	441	116	ND	29	ND	ND	ND
Nitrate N	28	0.67	ND	0.92	ND	111	1.0
PH	5.79		6.96			7.03	
D O	ND		0.48				
Total Solids	29,333		19,000			102,559	
Volatile Solids	7,333		2,000			42,256	
Fixed Solids	22,000		12,000			60,303	
% Moisture	97.1		98.6			89.7	
% Volatile	25		14			41	
Temperature	29		25				
Filterability (Sec)	235		285			ND	
% Settleability	88.6					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XVI

AVERAGE OF EXPERIMENTAL RUN NO. 2
Jan., 1971
12 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	42,713	2,200	20,626	1,968	19,658	77,176	304
BOD	ND	1,392	ND	1,870	ND	ND	ND
Total PO_4	379	87	279	60	219	500+	42
Ammonia N	ND	88	364	252	112	1,232	666
Nitrate N	4.00	1.36	23.00	2.17	20.83		1.62
PH	5.75		7.40				
D O	ND		0.48				
Total Solids	32,756		15,683			147,295	
Volatile Solids	15,438		8,822			11,450	
Fixed Solids	17,318		6,861			135,825	
% Moisture	96.8		98.5			96.8	
% Volatile	47.13		56.25			0.08	
Temperature	29		25				
Filterability (Sec)	169		315			531	
% Settleability	87					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XVII

AVERAGE OF EXPERIMENTAL RUN NO. 3
FEB., 1971
12 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	46,000	1,978	33,200	3,585	29,615	ND	577
BOD	ND	ND	ND	1,975	ND	ND	ND
Total PO_4	324	72	327	95	232	500+	ND
Ammonia N	ND	82	231	317	0.0	1,512	679
Nitrate N	ND	0.78	3.60	1.48	2.12	ND	1.09
PH	5.96		6.03				
D O	ND		0.48				
Total Solids	32,550		20.750		67,250		
Volatile Solids	25,000		16,100		30,950		
Fixed Solids	7,550		4,650		3,630		
% Moisture	96.8		98.0		93.3		
% Volatile	77		78		54		
Temperature	29		25				
Filterability (Sec)	170		515		697		
% Settleability	96				100		

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XVIII

AVERAGE OF EXPERIMENTAL RUN NO. 1
OCT., NOV., DEC., 1971
18 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	33,600	2,464	40,245	5,780	34,465	ND	ND
BOD	ND	2,563	ND	1,625	ND	ND	ND
Total PO_4	244	70	375	145	230	500+	45
Ammonia N	551	116	102	109	0.0	ND	ND
Nitrate N	28	0.67	22.00	1.70	20.30	111.00	1.00
PH	5.79		6.2			7.03	
D O	ND					ND	
Total Solids	29,333		15,000			102,559	
Volatile Solids	7,333		6,000			42,256	
Fixed Solids	22,000		9,000			60,303	
% Moisture	97.1		97.9			89.7	
% Volatile	25		40			41	
Temperature	29		25				
Filterability (Sec)	235		600			ND	
% Settleability	88.6					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XIX

AVERAGE OF EXPERIMENTAL RUN NO. 2
JAN., 1971
18 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	42,713	2,200	36,130	4,950	31,180	77,176	304
BOD	ND	1,392	ND	1,773	ND	ND	ND
Total PO_4	379	87	ND	ND	ND	500+	42
Ammonia N	ND	88	105	67	38	1,232	667
Nitrate N	4.00	1.36	29.00	0.8	28.20	ND	1.62
PH	5.75		6.30			6.99	
D O	ND		0.40			ND	
Total Solids	32,756		29,000			147,295	
Volatile Solids	15,430		9,000			11,470	
Fixed Solids	17,318		20,000			135,825	
% Moisture	96.8		93.65			96.80	
% Volatile	47.13		31.00			0.08	
Temperature	29		25			ND	
Filterability (Sec)	169		574			531	
% Settleability	87					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XX

AVERAGE OF EXPERIMENTAL RUN NO. 3
FEB., 1971
18 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			**Anaerobic Mixed Liquor**	**Anaerobic Filtrate**
			Mixed Liquor	Filtrate	Sludge Residue		
COD	46,000	1,978	42,110	4,880	37,230	ND	577
BOD	ND	ND	ND	1,725	ND	ND	ND
Total PO_4	324	72	ND	ND	ND	500+	ND
Ammonia N	ND	82	105	78	27	1,512	6.79
Nitrate N	ND	0.78	43.00	1.70	41.30	ND	1.09
PH	5.96		6.40			6.87	
D O	32,500		ND			ND	
Total Solids	25,000		27,500			67,250	
Volatile Solids	7,550		8,000			30,950	
Fixed Solids	96.8		19,500			3,630	
% Moisture	77					93.3	
% Volatile	29					54	
Temperature	170					ND	
Filterability (Sec)	96		555			697	
% Settleability						100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XXI

AVERAGE OF EXPERIMENTAL RUN NO. 1
OCT., NOV., DEC., 1971
24 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	33,600	2,464	33,335	3,870	29,465	ND	ND
BOD	ND	2,563	ND	1,384	ND	ND	ND
Total PO_4	244	78	325	85	240	500+	45
Ammonia N	551	116	70	92	ND	ND	ND
Nitrate N	28.00	0.67	35.00	1.90	33.10	111.00	1.00
PH	5.79		6.2			7.03	
D O	ND		0.5			ND	
Total Solids	29,333		21,000			102,559	
Volatile Solids	7,333		6,250			42,256	
Fixed Solids	22,000		14,750			60,303	
% Moisture	97.1					89.7	
% Volatile	25		30			41	
Temperature	29					ND	
Filterability (Sec)	235		633			ND	
% Settleability	88.6					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XXII

AVERAGE OF EXPERIMENTAL RUN NO. 2
JAN., 1971
24 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	42,713	2,200	30,040	3,650	26,390	77,176	304
BOD	ND	1,392	ND	1,667	ND	ND	ND
Total PO_4	379	87	ND	ND	ND	500+	42
Ammonia N	ND	88	98	92	6	1,232	666
Nitrate N	4.00	1.36	23.00	0.80	22.20	ND	1.62
PH	5.75		7.00			6.99	
D O	ND					ND	
Total Solids	32,756		22,000			147,295	
Volatile Solids	15,438		6,500			11,470	
Fixed Solids	17,318		15,500			135,825	
% Moisture	96.8		98.5			96.8	
% Volatile	47.13		29.5			0.08	
Temperature	29		25			ND	
Filterability (Sec)	129		506			531	
% Settleability	87					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TALBE XXIII

AVERAGE OF EXPERIMENTAL RUN NO. 3
FEB., 1971
24 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	46,000	1,978	38,350	4,700	33,650	ND	577
BOD	ND	ND		1,576	ND	ND	ND
Total PO_4	324	72	ND	ND	ND	500+	ND
Ammonia N	ND	82	84	59	25	1,512	679
Nitrate N	ND	0.78	34	1.5	32.5	ND	1.09
PH	5.96		6.6			6.87	
D O	ND					ND	
Total Solids	32,500		14,500			61,250	
Volatile Solids	25,000		7,000			30,950	
Fixed Solids	7,550		7,500			3,630	
% Moisture	96.8					93.3	
% Volatile	77		48			53	
Temperature	29					ND	
Filterability (Sec)	170		681			697	
% Settleability	96					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XXIV

AVERAGE OF EXPERIMENTAL RUN NO. 1
OCT., NOV., DEC., 1970
30 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	33,600	2,464	27,365	3,970	23,465	ND	
BOD	ND	2,563	ND	354	ND	ND	
Total PO_4	244	78	325	81	244	500+	
Ammonia N	551	116	77	ND	ND	ND	
Nitrate N	28	0.67	34	ND	ND	111	
PH	5.79					7.03	
D O	ND						
Total Solids	29,333					102,559	
Volatile Solids	7,333					42,256	
Fixed Solids	22,000					60,303	
% Moisture	97.1					89.7	
% Volatile	25					41	
Temperature	29					ND	
Filterability (Sec)	235					ND	
% Settleability	88.6					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XXV

AVERAGE OF EXPERIMENTAL RUN NO. 2
JAN., 1971
30 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	42,713	2,200	23,140	3,170	19,970	77,176	304
BOD	ND	1,392		606	ND	ND	ND
Total PO_4	379	87	ND	ND	ND	500+	42
Ammonia N	ND	88	77	101	0.0	1,232	666
Nitrate N	4.00	1.36	38.00	1.10	36.90	ND	1.62
PH	5.75		7.40			6.99	
D O	ND					ND	
Total Solids	32,756		19,500			147,295	
Volatile Solids	15,438		7,000			11,470	
Fixed Solids	17,318		12,500			135,825	
% Moisture	96.8		97.9			96.8	
% Volatile	47.13		35.90			0.08	
Temperature	29		25			ND	
Filterability (Sec)	169		530			531	
% Settleability	87					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

TABLE XXVI

AVERAGE OF EXPERIMENTAL RUN NO. 3
FEB., 1971
30 DAY DETENTION

Analysis	Raw Mixed Liquor	Raw Filtrate	Aerobic Sludge			Anaerobic Mixed Liquor	Anaerobic Filtrate
			Mixed Liquor	Filtrate	Sludge Residue		
COD	46,000	1,978	31,590	4,630	26,960	ND	
BOD	ND	ND	ND	560	ND	ND	
Total PO_4	324	72	325	ND	ND	500+	
Ammonia N	ND	82	ND	ND	ND	1,512	
Nitrate N	ND	0.78	ND	ND	ND	ND	
PH	5.96		7.10			6.87	
D O	ND					ND	
Total Solids	32,550					67,250	
Volatile Solids	25,000					30,950	
Fixed Solids	7,550					3,630	
% Moisture	96.8					93.3	
% Volatile	77					54	
Temperature	29					ND	
Filterability (Sec)	170					697	
% Settleability	96					100	

All analyses expressed in mg per liter unless otherwise indicated. PH expressed in units. ND = No Determination.

VITA

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Master of Science

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