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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Biological pilot plant studies were conducted at Radford Army Ammunition Plant (RAAP) on wastewaters originating from the manufacturing of single-base propellants and nitroglycerine. These wastes were treated with a complete mix activated sludge system, a rotating biological disc treatment system, and an aerated waste stabilization (dispersed growth) system. Extensive studies indicated that the complete mix activated sludge system tested was unstable on a long-term basis, unless very close control was main-

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tained over waste composition and loading rates on a continuous basis, conditions not possible to meet at RAAP. The rotating biological disc treatment system was evaluated for a period of over three months and found to be very stable and to provide excellent treatment. A short study conducted using the aerated waste stabilization (dispersed growth) system indicated this to be a highly efficient waste treatment system.

The complete mix activated sludge system was not recommended as an acceptable waste treatment process for RAAP. The rotating biological disc treatment system was recommended as an acceptable wastewater treatment process for RAAP with the aerated waste stabilization (dispersed growth) system recommended as an acceptable alternative treatment method.

PREFACE

Prior to this study no information was available on the treatment of munitions wastes with conventional biological systems. Available chemical or physical methods of treatment were both more expensive and unsuited to the volumes of aqueous waste to be treated. This study was performed in order to evaluate the efficacy of munitions waste treatment using conventional activated sludge, rotating disc, and dispersed growth treatment processes, and to generate design criteria for a full-scale treatment plant for those systems found to be effective in treating the Radford munitions manufacturing waste.

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I. INTRODUCTION

Radford Army Ammunition Plant (RAAP) is a 4,200 acre munitions manufacturing complex located on the New River near Radford, Virginia. A wide variety of explosive and propellant materials are produced at this facility. RAAP was constructed in 1941 to meet the urgent munitions requirements of the Second World War. At that time very little attention was given to the conservation and optimization of water usage in the manufacturing and facilities design. During periods when the plant was operating at its maximum production rate, water usage in excess of 80 million gallons per day was required for manufacturing operations, steam generation, building cleanup, fire protection, and other uses.

In 1968 and 1969, the United States Army Environmental Hygiene Agency conducted several field surveys at RAAP and found that the manufacturing facility was discharging large quantities of nitrates, sulfates, insoluble sludge, ashes, waste solvents, and waste propellant ingredients into Stroubles Creek and the New River. In June of 1969, the Virginia State Water Control Board reviewed the findings of the United States Army Environmental Hygiene Agency and recommended that pollution abatement measures be taken at RAAP to eliminate the degradation of the Stroubles Creek and the New River.

In 1971, Hercules, Incorporated conducted an extensive survey of water utilization and wastewater flows and characteristics from the 1,700 buildings in the RAAP manufacturing facility*. In conjunction with this survey, the Sanitary Engineering Department at Virginia Polytechnic Institute and State University conducted a study characterizing the major wastewater streams and their susceptibility to standard waste treatment processes. The wastes that would require physiochemical treatment and those wastes that could possibly be biologically treated were identified in this study. A later study conducted by Hercules, Incorporated in 1972 developed methods for the improvement of water utilization which resulted in a 60 percent reduction in water usage**. RAAP continued to

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*Smith, L. L., and R. L. Dickenson. 1972. Biological and engineering investigations to develop optimum control measures to prevent water pollution. Final Engineering Rpt., P.E. 249 (Phase I). Radford Army Ammunition Plant, Radford, Virginia.

**Evans, J. L., and R. L. Dickenson. 1973. Improvement of Water Utilization at Radford Army Ammunition Plant. Final Engineering Rpt., P.E. 290, (Phase II). Radford Army Ammunition Plant, Radford, Virginia.

discharge wastes through several outfalls even though a reduction in water usage was achieved. The United States Environmental Protection Agency issued a NPDES Permit (VA 0000248) effective July 28, 1974 for the RAAP facilities. Of primary interest for this report was the effluent requirements for the major waste streams which will be collected and discharged through a new outfall to be designated relocated outfall No. 16. This portion of the permit has an effective period beginning July 1, 1977 and lasting through August 1, 1979. Table 1 shows the effluent limitations and monitoring requirements of NPDES No. VA 0000248 for relocated outfall No. 16. The controlling effluent limitations are the average and maximum BOD and COD concentrations in the effluent.

The effluent limitations that must be met after August 1, 1979 are unknown at this time, but will probably be more stringent than those in the existing NPDES Permit. Some idea of the future effluent limitations may be determined be reviewing a United States Environmental Protection Agency publication, "Development Document for Interim Final Effluent Limitations Guidelines and Proposed New Source Performance Standards for the Explosvies Manufacturing Point Source Category," dated March 1976. The water quality standards for the New River must also be maintained as water quality may be the controlling factor.

Pilot plant studies were initiated in July of 1975 to determine the biological treatability of the predicted wastewater from relocated outfall No. 16. This wastewater will consist of a combination of pretreated nitroglycerine waste along with water dry waste from the production of single-base propellants. Biological pilot plants were operated by personnel from Hercules Incorporated with technical supervision provided by the United States Army Natick Research and Development Command. Jones, Olson & Associates, Inc. (JOA) served as consultants to assist in the technical supervision of the operation of the pilot plants and to develop design criteria for the proposed full scale treatment system.

The activated sludge process was first evaluated utilizing an existing biological denitrification pilot plant which was modified for this purpose. This modified pilot plant was not totally suited for use in the activated sludge studies and further modifications were required as the pilot plant testing proceeded. The activated sludge system, during its operation from July through December 1975, provided efficient treatment for only relatively short periods of time, and was very sensitive to changes in operating conditions. The biological solids

TABLE 1. Effluent Limitations and Monitoring Requirements

During the period beginning July 1, 1977 and lasting through August 1, 1979, the permittee is authorized to discharge from outfall(s) serial number(s) 016.

Such discharges shall be limited and monitored by the permittee as specified below:

Effluent Characteristics	Discharge Limitations kg/day (lbs/day) Daily Average	Discharge Limitations kg/day (lbs/day) Daily Maximum	Discharge Limitations Other Units (Specify) Daily Average	Discharge Limitations Other Units (Specify) Daily Maximum	Monitoring Requirements Meas. Freq.	Monitoring Requirements Sample Type
Flow-m^3/day (MGD)	-	-	-	-	Continuous	Recorded
BOD_5	1541 (3390)	6302 (13865)	60 mg/l	120 mg/l	1/week	24 hr. Composite
Chemical Oxygen Demand	3996 (8726)	7427 (16340)	195 mg/l	290 mg/l	1/week	24 hr. Composite

The pH shall not be less than 6.0 standard units nor greater than 9.0 standard units and shall be monitored continuously and recorded.

There shall be no discharge of floating solids or visible foam in other than trace amounts.

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s): At Outfall 16*.

*Wherever Outfall 16 is relocated.

in the aeration system during this period tended to be dispersed and created problems with maintaining an adequate MLSS concentration. Pilot plant studies were temporarily discontinued on December 22, 1975.

In February 1976, the second phase of the biological pilot plant treatment studies was begun using a rotating biological disc treatment system. The four stage rotating biological disc system that was used initially was soon modified into a three stage configuration in order to obtain better mixing and distribution of the waste load throughout the stages. Using this configuration, excellent treatment efficiencies were obtained.

On May 11, 1975, further activated sludge studies were initiated in order to observe the system's performance in parallel with the rotating biological disc pilot plant. These activated sludge studies were continued until May 24th when the activated sludge pilot plant was modified into an aerated waste stabilization system to simulate the operation of an aerated surge basin and evaluate its ability to pretreat this waste. On June 9th, both pilot plants were modified so that the effluent from the aerated waste stabilization pilot plant would flow through the rotating biological disc pilot plant creating a two-stage treatment system. This system was operated for only five days and on June 14th, pilot plant studies at Radford Army Ammunitions Plant were concluded.

II. WASTE CHARACTERIZATION

Wastewaters treated in the pilot plant studies originated from the manufacturing of single-base propellants and nitroglycerine. The manufacturing of single-base propellants involves mixing alcohol-wet nitrocellulose with a solvent mixture of ether and alcohol to convert nitrocellulose to a colloidal mass. After this dough-like mixture is pressed into strands, it is dried and then washed in heated water (60°C) at the solvent recovery area. This wastewater from the solvent recovery process is termed water dry waste. The organic concentration of this waste varies considerably from approximately 500 to 28,000 mg/l COD. The significant components of the water dry waste are ethyl alcohol, diethyl ether, and dinitrotoluene (DNT). The major portion of the dissolved solids in this wastewater is DNT. Further waste characterization is provided in Table 2*.

Nitroglycerine is manufactured using the continuous Biazzi Process (NG-2) and also using a batch process (NG-1) at the Radford Army Ammunition Plant. After the glycerine, nitric acid and sulfuric acid are mixed and nitrification is complete, excess acid is removed. The nitroglycerine is then washed in a soda ash solution and two fresh water baths to remove residual acids and impurities. Nitroglycerine is mixed with an emulsifying solution for storage. Upon removal, the emulsifying solution is discharged to settling tanks where some residual nitroglycerine settles out. The waste from the acid separation, soda ash solution bath, water baths, and emulsifying solutions are treated by a denitration process prior to discharge. This treatment breaks the glycerine-nitrate bond of the residual nitroglycerine in the waste. A characterization of the pretreated nitroglycerine waste is provided in Table 3.

The nature of the manufacturing operations at RAAP makes it extremely difficult to predict future waste flow and composition. The variation in production rates of the ammunition plant is significant depending upon the demand for the many products which the plant is capable of manufacturing. New prodcution technology and modifications to existing processes to reduce wastewater discharge or increase production efficiency has a significant effect on a future wastewater flow and composition.

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*Smith, L. L. and R. L. Dickenson. 1974. Engineering investigation to develop optimum control measures to prevent water polltuion. Final Engineering Rpt., P. E. 249, (Phase II). Radford Army Ammunition Plant. Radford, Virginia.

Hercules, Incorporated performed an extensive in-plant wastewater survey which was utilized by Simons-Eastern and Reynolds, Smith and Hills to predict the future wastewater flow and composition. These predict the future waste flows and composition and have been modified slightly by Hercules, Incorporated to reflect any process changes that have occurred since their in-plant wastewater survey that will affect the wastewater flow and composition. The average wastewater flow is expected to be 1.25 MGD while the average composition of this waste is expected to be 454 mg/l of COD, 182 to 272 mg/l of BOD, 25 mg/l of suspended solids, 350 to 700 mg/l of NO_3 and a pH of between 6.5 to 7.5. This is the predicted average daily flow and composition of the wastewater expected to enter the biological treatment system following any necessary pretreatment and was used for the design of the recommended full scale treatment systems.

Wide variations in both wastewater flow and composition are expected. Although RAAP has the capacity of continuous operation, at present, the production rate is very low. During weekends and at night there may be essentially no influent wastewater. Since many of the processes are batch wasted, the peak flow rates could be several times the average flow.

The water dry waste provides most of the organic content of the waste. Obviously, the production rate of single-base propellants will significantly affect the organic concentration of the waste. Similarly, the production rates for nitroglycerine will determine the amount of nitrates in the wastewater. Although a great deal of variation is expected in wastewater flow and composition, no precise definition of these variations has been developed.

TABLE 2. Water Dry Waste Characteristics

	Min	Ave	Max
Temperature	155	160	165
pH	6.55	7.26	7.75
COD (mg/l)	593	7295	28,000
TOC (mg/l)	96	1011	3525
Nitrates (mg/l)	5	19	45
Sulfates (mg/l)	9	40	75
Alkalinity (mg/l $CaCO_3$)	20	25	31
Spec. Cond. (umhos/cm)	79	152	252
Susp. Solids (mg/l)	0.5	5.6	28
Dissolved Solids (mg/l)	107	152	287
Total Solids (mg/l) @ 600 C	108	159	296
Volatile Solids (mg/l) @ 600 C	23	54	105
Color (units)	10	47	100

TABLE 3. Pretreated Nitroglycerine Waste Characteristics

	Min	Ave	Max
pH	12.3	12.6	12.9
Alkalinity (mg/l as $CaCO_3$)	2920	4882	7520
Spec. Cond. (umhos/cm)	5800	9776	11,990
Turbidity (JUT)	0.4	25	100
BOD (mg/l)	44	115	240
COD (mg/l)	78	533	817
TOC (mg/l)	140	170	200
Total Solids (mg/l)	16,020	35,124	53,420
Suspended Solids (mg/l)	33	131	672

III. ROTATING BIOLOGICAL DISC

Operation-Results

The Autotrol Rotating Biological Disc (RBD) used for the wastewater studies at Radford Army Ammunition Plant consisted of a series of 36 corrugated polyethylene discs (18.62 inches in diameter) rotating slowly (12 RPM) with the lower 35 percent of each disc submerged in the wastewater (see Figure 1). The semicircular aluminum tank with the discs in place and with a nominal amount of biomass had a volume of approximately 30 gallons and was initially divided into four stages separated by bulkheads. The bulkhead between the first and second stage was removable. The pilot plant was housed in a small building in order to protect it from the weather and to maintain the reactor at a temperature above 55^oF.

Wastewater was pumped into a feed chamber where it was picked up by buckets on feed arms which rotated with the disc. As the arms rotated, wastewater was lifted into the small circular openings at the bottom of each bulkhead and out the overflow pipe located at the end of the fourth stage. Microorganisms produced from the decomposition of the wastewater attached and grew on the polyethylene discs utilizing soluble organic matter for energy and further cell production. Excess biomass sheared from the discs and was kept in suspension by rotational mixing forces until the hydraulic flow carried it out of the reactor. The pilot plant did not have a clarification unit as part of the process, however, in order to evaluate the effect of clarification following the pilot plant treatment, individual samples were allowed to settle for 30 minutes before the supernatant was drawn off for analysis. Therefore, unless otherwise noted, all effluent suspended solids were determined on the supernatant of samples which had settled 30 minutes.

The combined waste used for the rotating biological disc studies consisted of water dry waste, pretreated NG-1 or NG-2 wastes, fire water and a small amount of settled sewage. THe fire water, which is simply filtered river water used for fire protection, and the water dry waste were blended to achieve a COD of approximately 400 mg/l except for several occasions from May 30th to June 15th when slug loadings from 700 to 800 mg/l COD were used for further evaluation. The use of sewage in the combined waste was discontinued on April 20th when Hercules, Incorporated decided that domestic sewage would not be treated in the proposed waste treatment plant in order to eliminate the need for the effluent to be chlorinated.

A separate nutrient feed system was used throughout the rotating biological disc studies. Ammonium nitrate was used as a source of nitrogen until it became apparent that the NG-1 wastes contained more than a sufficient amount of nitrates. Bisodium phosphate and later phosphoric acid were added to supply the phosphorus requirements for the system. Nutrient solutions were pumped into the feed well where they mixed with the influent wastewater.

A rather variable relationship was found to exist between BOD and COD for the high alcohol wastes treated by the rotating biological disc system (Figure 2). BOD to COD ratios generally ranged between 0.4 to 0.6. The variation in the BOD/COD relationship is the result of variations in wastewater composition and analytical techniques.

The hydraulic loading on the rotating biological disc reactor from its initial operation in early February to May 13th was approximately 500 GPD. The hydraulic loading on the media surface was 2.0 GPD/ft^2, while the detention time was approximately 90 minutes. During rotating biological disc operations at 2.0 GPD/ft^2, the pH levels in the reactor normally ranged between 7.0 to 7.8 while the influent waste pH tended to be more acidic. The dissolved oxygen level usually ranged between 1.8 to 3.0 mg/l in the first stage, but on infrequent occasions, dropped as low as 1.0 mg/l during warmer weather. The dissolved oxygen concentrations in the second, third and fourth stages were understandably higher than that mentioned in the first stage and was indicative of the decreased amount of biomass and lower oxygen uptake rates in the latter stages of the process.

Light colored biomass grew rapidly on the first stage disc after initial operation began while growth was somewhat less on the second stage disc. Very little growth appeared on the third and fourth stage discs. Soluble BOD removal efficiency (Figure 3) increased as biomass built up on the discs. During March, soluble BOD removal averaged above 90 percent, and by April 4th was averaging better than 95 percent. Total BOD removal efficiency averaged about 92 percent during the latter part of March. Soluble COD removal efficiency which was averaging 84 percent in early March reached as high as 95 percent on March 31st. Total COD removal efficiency averaged about 4 percent lower than soluble COD removal efficiencies during March and increased to above 85 percent by April 4th (Figure 4). Effluent suspended solids concentrations averaged approximately 50 mg/l until March 20th when they decreased substantially resulting in an immediate increase in total BOD and COD removal efficiencies (see Figure 4). From March 22nd until June 9th, the effluent suspended solids concentration remained at the low level of approximately 25 mg/l. It should be kept in mind that all effluent analyses were conducted on samples which had been settled for 30 minutes.

The amount of soluble BOD and COD removal by each stage of the rotating biological disc reactor is represented in Figures 5 and 6. From the initial start-up of the rotating biological disc pilot plant in February of 1976 until April 4th, the first stage removal rate varied considerably from as low as 8 lbs COD/1000/ft^2/day (4 lbs BOD/1000 ft^2/day) to as high as 40 lbs COD/1000 ft^2/day (23 lbs BOD/1000 ft^2/day). Although the system did not have sufficient time to stabilize in the four stage configuration, the first stage showed great flexibility in treating the major portion of the fluctuating waste loads. The amount of soluble organics removed by the second stage during this same period varied from 1 to 10 lbs COD/1000 ft^2/day (0.5 to 5 lbs BOD/1000 ft^2/day), while the amount removed by the third stage varied from less than 1 to 4 lbs COD/1000 ft^2/day (0.2 to 3 lbs BOD/1000 ft^2/day).

On April 4th, the bulkhead between the first and second stages was removed and a gravity recirculation line was placed between the enlarged first stage and the feed well. These changes were made in order to increase the media area in the first stage and improve mixing characteristics. These modifications were very effective in reducing the loading on the first stage. The result of these modifications was the development of a heavy filamentous growth on the enlarged first stage (first and second stage combined) and a thin growth on the third stage disc. The fourth stage disc continued to be sparsely covered. The increase in the size of the first stage reduced the loading rate per surface area in half and because of the increase in biomass, produced a more stable system.

During the period from April 5th to May 11th in which the three stage configuration was more or less stabilized at the hydraulic loading of 2.0 GPD/ft^2, the first stage removed an average of 87 percent of the soluble COD and 78 percent of the soluble COD (see Figure 7). During the same period, the first stage removed 81 percent of the total BOD and 71 percent of the total COD (see Figure 8). The third stage removed only 7 percent of both the soluble BOD and COD, but did provide 13 percent of the total BOD and COD removal. The fourth stage provided very little treatment. The overall treatment provided by the rotating biological disc pilot plant during this period of constant hydraulic and organic loadings was very good.

Soluble BOD removals averaged 96 percent and the soluble COD removals averaged 89 percent. Removal efficiencies for this same period of time were 94 percent for total BOD and 86 percent for total COD. The effluent produced during this period was of very high quality containing an average of only 11 mg/l total BOD, 58 mg/l total COD and 25 mg/l suspended solids.

From April 4th until May 13th, the first stage removed a slightly higher percentage of the organic waste load while the removal efficiency by the third and fourth stages decreased slightly. Obviously, the amount of biomass on the first stage would continue to increase until it reached an equilibrium point for any particular hydraulic and organic loading condition. During this period, the first stage removed approximately 7 lbs of soluble BOD/1000 ft^2/day and approximately 12 lbs of soluble COD/1000 ft^2/day. In contrast to the high removal rates of the first stage, the third stage removed only 1 lb of soluble BOD/1000 ft^2/day and 2 lbs of soluble COD/1000 ft^2/day. It is evident that up until May 13th the first stage provided the substantial part of the organic removal while the third and fourth stages polished the first stage effluent. The relationship between the soluble BOD and COD removal rate and loading rate for the first stage during the period from April 4th to May 11th when the rotating biological disc system was relatively stabilized is defined in Figures 9 and 10. This relationship was found to be approximately 0.8 for both soluble BOD and COD.

On May 13th the hydraulic loading was increased to 1,000 GPD which resulted in a media loading of 4 GPD/ft^2 and a detention time of approximately 45 minutes. Immediately a sloughing off of biomass attached near the influent of the first stage occurred. This possibility was due to the hydraulic force of the influent flow. Biomass sloughed off other parts of the first stage disc but was quickly replaced. Growth on the expanded first stage disc reached a thickness of between one-quarter to one-half an inch, while an appreciable increase was visible on the third stage disc.

The increased hydraulic loading of May 13th caused the soluble BOD removal efficiency of the rotating biological disc pilot plant to drop from the 96 percent level it had achieved after stabilizing at 500 GPD to a low of 78 percent on May 18th before increasing to 86 percent on May 29th. Total BOD removal efficiency for the system dropped as low as 51 percent on May 20th before increasing to 85 percent on May 27th. The soluble COD removal efficiency decreased as a result of the increased hydraulic loading from 89 percent to a low of 46 percent on May 20th before increasing to 84 percent on May 27th. Total COD removal efficiency reached a low of 41 percent on May 16th, but then increased steadily until it had reached 81 percent on May 27th.

The amount of organics applied to the rotating biological disc system was substantially increased when the hydraulic loading was increased from 2 GPD/ft^2 to 4 GPD/ft^2. There was an insufficient amount of biomass on the discs and an insufficient detention time to effectively treat this increased organic loading, therefore, the effluent organic concentrations increased significantly. The increase in effluent BOD and COD after May 13th are reflected in Figure 10. The effluent soluble COD concentration increased from 34 mg/l on May 17th to 208 mg/l on May 20th while the effluent soluble BOD concentration increased from 4 mg/l on May 13th to 40 mg/l on May 19th. However, by May 27th a sufficient amount of biomass had built up on the discs for effluent concentrations to have decreased to 55 mg/l soluble COD and 25 mg/l soluble BOD. The operation of the rotating biological disc pilot plant was not affected by this rapid loading increase. When the hydraulic loading was increased, the first stage which was already heavily loaded provided some additional organic removal while the third and fourth stages began providing an increased amount of organic removal. The first stage soluble BOD removal rate increased from approximately 7.0 lbs/1000 ft^2/day to approximately 9 lbs/1000 ft^2/day while the soluble COD removal rate increased from approximately 12 to 15 lbs/1000 ft^2/day. The removal rates for the third stage increased from 2 to 6 lbs COD/1000 ft^2/day and from 1 to 3 lbs BOD/1000 ft^2/day. The fourth stage treatment increased from approximately 1 to 5 lbs COD/1000 ft^2/day.

The performance of the entire rotating biological disc treatment system both while stabilized at 2 GPD/ft^2 (500 GPD) and during loading variations is characterized in Figure 11. During late April and early May there was a fairly constant relationship between the soluble BOD and COD applied and removed. Ten days after the hydraulic loading was doubled, the rotating biological disc pilot plant was removing approximately 9 lbs COD/1000 ft^2/day, whereas, it had been removing approximately 6 lbs COD/1000 ft^2/day previously. The rate of BOD removal increased from approximately 3 lbs/1000 ft^2/day to approximately 5 lbs/1000 ft^2/day during the same period.

A slug loading in which the influent COD concentration was increased to approximately 700 mg/l (300 mg/l BOD) occurred between May 30th and June 4th. This caused the soluble BOD removal efficiency to drop to 38 percent on June 2nd before increasing to 80 percent on June 3rd. The soluble COD removal efficiency dropped off to 52 percent on June 1st due to the effects of the slug loading and had increased only to 60 percent on June 4th when both the hydraulic and organic loadings were decreased. Total COD removal efficiency decreased from

81 percent on May 27th to 29 percent on June 1st before increasing to 55 percent on June 3rd. During the period from May 30th to June 4th, the soluble effluent COD concentration increased to as high as 345 mg/l and the soluble effluent BOD concentration increased to 100 mg/l. It should be remembered that the slug loading occurred before the system had an opportunity to stabilize at the hydraulic loading of 4 GPD/ft^2 (1,000 GPD). The increased hydraulic and slug loadings resulted in an organic loading on May 30th which was four times greater than it had been on May 15th.

The slug loading caused a further increase in the amount of organics being removed by each stage. During this period, the first stage soluble BOD removal rate increased to approximately 12 lbs/1000 ft^2/day accompanied by a soluble COD removal rate increase to approximately 19 lbs/1000 ft^2/day. The first stage was not able to exhibit the same treatment flexibility during this slug loading that it had shown in adjusting to the increased loads earlier during March. The third stage removal rate was quite variable during this period reaching as high as 23 lbs COD/1000 ft^2/day (12 lbs BOD/1000 ft^2/day) on June 2nd.

The slug loading of May 30th caused the COD removal rate for the entire rotating biological disc system to increase from approximately 9 to 13 lbs/1000 ft^2/day and the BOD removal rate to increase from approximately 5 to 10 lbs/1000 ft^2/day within a four day period. Since the reactor did not have sufficient time to stabilize at this high organic loading before the hydraulic and organic loads were reduced, higher overall removal rates should be feasible.

Discussion

The rotating biological disc treatment system was very effective in treating the high alcohol waste once a sufficient amount of biomass had been developed in the system. After operating for a period of several weeks, a sufficient amount of biomass had attached itself to the discs to remove more than 90 percent of the soluble BOD. The amount of biomass on the disc continued to increase for almost three months. A long period of operation was necessary before the biomass reached an equilibrium at the 2 GPD/ft^2 (400 mg/l COD) loading rate. COD removal efficiency increased slowly over this period as the microorganisms developed the ability to metabolize more chemical constituents of the wastewater.

Microscopic examination of the biomass and wastewater were performed on several occasions. The biomass was found to contain a large number of bacteria, several types of filamentous organisms, and both attached and free swimming ciliates and protozoa. The free swimming ciliates and protozoa were indicative of the high energy state of the system.

Except for the first six weeks of operation, the rotating biological disc reactor system produced sludge that settled well. The biological solids appeared densely clumped although filamentous in nature. Effluent suspended solids varied somewhat, occasionally increasing as high as 80 mg/l and frequently decreasing as low as 6 mg/l. In general, the rotating biological disc effluent was quite clear. Neither the increased hydraulic loadings in the latter part of May, nor the increase in organic loadings at the end of May appreciably affected the effluent suspended solids concentration.

During the period from April 5th through May 11th, the operation of the rotating biological disc reactor was essentially stabilized at a loading of 2 GPD/ft^2. A sufficient amount of biomass had been previously built up on the discs to provide a high level of treatment efficiency. Average organic removal efficiencies of 94 percent total BOD, 96 percent soluble BOD, 86 percent total COD, and 89 percent soluble COD were achieved during this period. The effluent that was produced contained only 11 mg/l BOD, 58 mg/l COD, and 25 mg/l suspended solids.

The hydraulic loading of 2 GPD/ft^2 (500 GPD) of the approximately 400 mg/l COD alcohol waste produced organic loadings of about 3.5 lbs soluble BOD/1000 ft^2/day and 7 lbs soluble COD/1000 ft^2/day on the system. The rotating biological disc pilot plant removed 94 percent of BOD applied and 96 percent of COD applied and due to the small amount of biomass on the third and fourth stage appeared somewhat underloaded. The increased hydraulic loading of 4 GPD/ft^2 (1000 GPD) produced organic loadings of approximately 7 lbs soluble BOD/1000 ft^2/day and 14 lbs soluble COD/1000 ft^2/day. After a period of two weeks, operation at 4 GPD/ft^2/day, the rotating biological disc system was beginning to accumulate sufficient biomass to adequately handle this loading. The system was not operated at the 4 GPD/ft^2 loading for a sufficient amount of time to determine if the same high treatment efficiencies obtained at 2 GPD/ft^2 could also be achieved at 4 GPD/ft^2.

Varying hydraulic and organic loading conditions did not cause any upset in the operation of the rotating biological disc system. At the loading rate of 2 GPD/ft^2 the system was able to provide increased treatment capacity during sizeable hydraulic and organic loading increases.

The amount of organics applied to the rotating biological disc system was increased substantially by increasing the hydraulic loading rate or concentration of the wastewater on several occasions. The organic removal rate is partially a function of the amount of biomass on the disc. During substantial instaneous loading increases, the loading rate on the system surpassed the maximum organic removal rate achievable for the amount of biomass present in the system and the wastewater received only partial treatment. This did not have any affect on the operation of the rotating biological disc system. During loading conditions as high as 50 lbs soluble COD/1000 ft^2/day, there was no problem maintaining a sufficient oxygen concentration in the critical first stage.

The rotating biological disc pilot plant was very easy to operate and required a minimum of operator attention. Since the system is not easily upset and requires no recycle, the operator's main duties involved checking influent wastewater flows, nutrient solution flows, pH and dissolved oxygen concentrations in the reactor, and assuring that all mechanical equipment was functioning properly.

Conclusions

1. The rotating biological disc treatment process provided excellent treatment of the combined wastewater (approx. 400 mg/l COD) at a loading of 2 GPD/ft^2.

2. BOD removal efficiencies of greater than 94 percent and COD removals of greater than 85 percent were achieved from April 5, 1976 to May 11, 1976. At a loading of 2 Gal/ft^2 (COD of approximately 400 mg/l) effluent concentrations over this period were 11 mg/l BOD, 58 mg/l COD, and 25 mg/l suspended solids.

3. The first stage of the rotating biological disc system was able to achieve peak removal of as high as 40 lbs soluble COD/1000 ft^2/day (20 lbs soluble BOD/1000 ft^2/day) and sustained removal rates of 19 lbs soluble COD/1000 ft^2/day (12 lbs soluble BOD/1000 ft^2/day).

4. The rotating biological disc pilot plant was able to maintain a sufficient concentration of oxygen in the first stage at loadings as high as 40 lbs soluble COD/1000 ft^2/day (20 lbs soluble BOD/1000 ft^2/day).

5. Substantial increases in hydraulic and organic loading rates did not affect the rotating biological disc reactor, although peak loading passed through the system only partially treated.

6. The biological sludge produced by the rotating biological disc system was visibly filamentous in nature, had good settling properties, and was not noticeably affected by loading variations.

IV. ACTIVATED SLUDGE

Operation-Results

The pilot plant (see Figure 13) used for the activated sludge studies was originally a biological denitrification pilot plant and was modified to be used in this project. The modified pilot plant was not totally suited for activated sludge pilot plant studies, however, in order to conserve funds it was necessary that the modified denitrification plant be used. The modified system consisted of a 3,000 gallon combined waste holding tank, a 1,400 gallon aeration tank and a 600 gallon clarifier. The holding tank was used to blend and store the combined waste until it was fed into the aeration tank. During winter months, an electric heater in the holding tank was used to maintain a desired temperature. The holding tank was equipped with a mechanical mixer which was used to blend the waste. The aeration tank was equipped with a mechanical mixer and an aeration system consisting of a diffuser and a positive displacement blower. The diffused air system was capable of maintaining an adequate oxygen concentration in the reactor at all loading conditions evaluated. The aeration tank, which was previously the sludge conditioning tank in the denitrification system, had to be raised approximately eight feet in the air and placed on a platform in order to achieve gravity flow between the aeration tank and the clarifier. The detention time in the clarifier was too long for the hydraulic loading rates studied and created intermittent problems throughout the testing period.

The combined waste for the activated sludge pilot plant studies consisted of water dry waste, NG-1 or NG-2 wastes, fire water and at times a small amount of settled sewage. Because of the extreme variations in organic concentration of the water dry waste experienced during the testing (500 to 28,000 mg/l COD), a varying amount of fire water was used in an attempt to dilute the combined waste to the desired concentration of 400 mg/l. The organic concentration of the water dry waste decreased substantially during storage due to the evaporation of ethyl alcohol and diethyl ether. It became necessary to perform COD analysis on the water dry waste daily in order to be able to obtain the proper dilutions.

On July 30, 1975, the activated sludge pilot plant was started-up using biomass from previous pilot plant operations. This material had an initial suspended solids concentration of only 450 mg/l, was dispersed and proved unsuitable for pilot plant start-up. By August 16th, the aeration tank had a MLSS concentration of only 60 mg/l, the dissolved oxygen uptake rate was quite low and the system was overloaded at 3 to 4 lbs COD/lb MLSS/day. Although the system was obviously not operating as an activated sludge process by August 16th, it was still removing 70 percent of the total COD. This was due to the highly degradable characteristics of the alcohol waste and the ability of the microorganisms to function at high food to microorganisms loadings in the dispersed phase.

On August 21st, the pilot plant was restarted using activated sludge from the Blacksburg sewage treatment plant. However, the sludge was obtained by mistake from an aerobic digester and it was not until August 27th that the MLSS level in the aeration tank was adjusted to a reasonable concentration of between 2,000 and 3,000 mg/l. In the period from August 27th through September 11th, the organic loading was fairly stable at from 0.3 to 0.4 lbs COD/lb MLSS/day. See Figures 14 through 17 for results of the activated sludge pilot plant operation. The effluent COD and suspended solids concentrations were low during this period indicating reasonably stable and efficient operation. Also, the mixed liquor concentration increased noticeably and sludge wasting was required. During this period, the hydraulic loading of 6 GPD resulted in a reactor detention time of only 4 hours. The O_2 uptake on September 11th was 16.8 mg/l/hr. This two week interval was the first period of stable operation and indicated that the activated sludge system could operate satisfactorily at least for short periods at relatively low loading rates and low reactor detention times.

The period from September 11th through September 22nd was characterized by rapid loading changes and the subsequent failure of the activated sludge process. Between September 10th to September 12th the loading was increased from 0.37 to 0.84 lbs COD/lb MLSS/day and by September 14th the system was heavily loaded at approximately 1.35 lbs COD/lb MLSS/day. During these rapid loading changes there was a decrease in the MLSS concentration from approximately 2,200 mg/l on September 12th to 200 mg/l on September 22nd. Accompanying the decrease in MLSS concentration was an increase in effluent suspended solids and COD concentrations and the eventual failure of the system to operate as an activated sludge process. It should be noted that the MLSS concentration decreased sharply from September 17th to 18th after the reactor detention time had been increased from 6 to 34 hours in an attempt to stabilize the process. This failure was caused by the rapid loading changes that occurred and the high reactor detention times used in attempting to stabilize the process.

Following the failure of the activated sludge process, sludge was again obtained from the Blacksburg sewage treatment plant. By September 27th, the system had stabilized at a loading rate of approximately 0.2 to 0.3 lbs COD/lb MLSS/day (0.1 lbs BOD/lb MLSS/day). From September 27th through October 18th, the pilot plant operated at high removal efficiencies while the effluent suspended solids, COD, and BOD were all quite low averaging 42, 60, 7.0 mg/l, respectively. Toward the latter portion of this period, sludge wasting was required on a daily basis at a rate of approximately 0.4 lbs MLSS/ln BOD/day indicating a good bacterial growth rate when taking in consideration the fact that a portion of the BOD was lost due to air stripping. A reactor detention time of 12 hours was used during this period.

On October 18th and 19th, the effluent from the clarifier became increasingly cloudy. This indicated that the system after performing exceptionally well for three weeks was becoming unstable. On October 20th in an effort to restabilize the system and to prevent the system from losing solids, the loading rate was decreased from 0.15 to 0.05 lbs BOD/lb MLSS/day. This caused the detention time in the aeration tank to increase from 12 to 19.2 hours. This reduction in loading rate did not stabilize the system but caused a significant reduction in BOD and COD removal efficiencies. The effluent suspended solids increased significantly causing the MLSS concentration to decrease.

Attempts were made to stablize the system by discontinuing the influent flow to the system for 24 hours, by feeding sewage without process waste to the system and by maintaining a high level of nutrients within the system. None of these had a beneficial effect on the system and on

October 27, 1975 the decision was made to discontinue operation of the system and make needed repairs to the pilot plant facilities.

The sludge return pump was modified to pump at high rates, but on an interval basis controlled by a time clock. The pump had been operating on a continuous basis at a low flow rate. This resulted in periodic clogging of the sludge return line. The clarifier was modified by increasing the depth of the center feed well two feet to decrease the turbulence near the effluent weir.

The pilot plant was again restarted by obtaining activated sludge from the Blacksburg sewage treatment plant. The period from October 28th to November 4th was a period of acclimation during which the effluent COD, BOD and suspended solids were relatively high. However, by November 5th the system had become stabilized and the COD removal efficiency had increased to 85 percent and the BOD removal efficiency to 98 percent.

From November 4th through November 26th, the system was operated at organic loadings varying between 0.14 to 0.36 lbs COD/lb MLSS/day, hydraulic loadings varying between 1.5 to 3.2 GPM, and aeration tank detention times varying from 7.5 to 16 hours. During this period, the MLSS concentration stabilized around 2,000 mg/l, while the removal efficiencies averaged 78 percent for total COD and 91 percent for total BOD.

The MLSS concentration decreased from 2,000 to 1,100 mg/l from October 26th to December 9th for no apparent reason. Neither loading rate, reactor detention time or any waste characteristic was changed during this period. BOD removal efficiency decreased from 85 percent on October 26th to 63 percent on December 9th and averaged 74 percent during this period. COD removal efficiency continued to average approximately 78 percent. Also, effluent suspended solids increased noticeably. Oxygen uptake rates remained essentially unchanged at approximately 10 mg/l/hr. During this period which was characterized by a significant decrease in MLSS concentration, the activated sludge system was operating at the same loadings and aeration tank detention times that it had been from September 25th to October 20th when the system was producing excess solids. It is evident that although long aeration tank detention times and rapid loading rate changes promote the production of dispersed solids, other factors associated with the treatment of the specific wastewater are causing the system to not perform satisfactorily on a continuing basis. Microscopic examination of the activated sludge showed microorganisms to be in a healthy condition with a prevalence of rotifers and stalked ciliates. This indicated a lack of any toxic effects from the waste. No free swimming ciliates were found indicating a low energy state. Therefore, it was decided to further increase loading on the system through a series of hydraulic and organic loading increases.

The COD loading was increased rapidly from 0.58 lbs/lb MLSS/day on December 9th to 1.10 lbs/ln MLSS.day on December 11th, while the hydraulic loading rate increased from 2.0 to 3.0 GPM which decreased the detention time from 12 to 8 hours. These loadings resulted in an increase in effluent COD from 61 mg/l on December 9th to 132 mg/l on December 11th, and an accompanying decrease in total COD removal efficiency from 82 to 68 percent. The effluent BOD averaged 30 mg/l during this period. A decrease of 15 F in the aeration tank temperature that took place between December 8th and 10th because of cold weather was probably a factor in the decrease in COD removal efficiency.

From December 11th through 16th, the loading rate was maintained at approximately 1.0 lb COD/lb MLSS/day (0.65 lbs BOD/lb MLSS/day). The aeration detention time was reduced to 5 hours during this period. The problems of dispersed growth and decreasing mixed liquor concentration were overcome during this period with the MLSS concentration increasing from approximately 1,100 mg/l to 1,500 mg/l. The system performed quite well at the higher loading rate and reduced detention time with BOD and COD removal efficiencies averaging 82 and 91 percent, respectively.

Between December 16th and 19th, the COD loading rate was substantially increased from 1.28 to 2.71 lbs/lb MLSS/ day with the BOD loading rate increasing from 0.60 to 2.20 lbs/lb MLSS/day. The result of this extremely high and rapid loading increase was the formation of filamentous bacteria in the mixed liquor. Although the effluent suspended solids concentration increased to 237 mg/l on December 19th, the treatment efficiency remained high. The total effluent BOD increased from 7 mg/l to 42 mg/l during this period, however, a significant percentage of the increase was due to suspended solids in the effluent rather than an increase in soluble BOD. The effluent suspended solids remained high during the next few days averaging over 200 mg/l. In an attempt to eliminate the filamentous growth which was still prevalent in the mixed liquor on December 22nd, an anaerobic condition was maintained in the aeration tank for a period of eight hours. When this treatment was not successful, the system was shut down on December 22nd for the Christmas holidays.

The activated sludge pilot plant was not restarted until May 11, 1976 because of funding problems. Activated sludge was obtained from the Roanoke sewage treatment plant to start the pilot plant. The waste fed to the pilot plant consisted of water dry waste, pretreated NG-2 waste and sufficient fire water to produce a COD of approximately 400 mg/l. This mixture was a projection of the composition of the actual combined waste to be treated by the proposed waste treatment plant. Phosphoric acid was added directly to the aeration tank in order to avoid any past problems with denitrification in the holding tank. Sufficient nitrogen was present in the NG-2 waste tp provide the required nitrogen. The system was operated as a complete mix activated sludge process from May 11, 1976 until May 24, 1976. The BOD and COD loading rates averaged 0.1 lbs BOD/lb MLSS/day and 0.23 lbs COD/lb MLSS/day, respectively. The detention time in the aeration tank was approximately 12 hours. The MLSS concentration declined from 3,700 mg/l on May 11th to 2,950 mg/l on May 19th, but had increased back to 3,600 mg/l on May 24th. The production of excess solids by the system from May 19th to 24th were achieved at essentially the same loading conditions as from October 26th to December 9th when the system was losing solids and from September 25th to October 20th during which time the system was producing excess solids. The only difference in the system's operation during May from the two earlier abovementioned time periods was that settled sewage was not being added to the combined waste. The soluble BOD removal efficiency for the thirteen days the activated sludge system was run averaged 92 percent while the soluble COD removal efficiency averaged only 75 percent. But by May 24th, the system was removing 91 percent of the soluble COD. The activated sludge system performed satisfactorily and produced excess solids during this period.

On May 24th, the activated sludge system was modified into an aerated waste stabilization (dispersed growth) system (see Figure 13) in order to be able to characterize the behavior of the proposed aerated surge basin and its ability to pretreat the waste. In order to accomplish this process modification the influent flow rate was lowered to 0.5 GPM (48 hours aeration tank detention time) and the clarifier was eliminated from the system. The MLSS concentration immediately dropped from 3,600 mg/l to 1,300 mg/l after only one day and stabilized at approximately 100 mg/l after six days time.

The dispersed growth system provided efficient soluble BOD and COD treatment at high loading rates achieving an average of 95 percent soluble BOD removal and 85 percent soluble COD removal from May 24th to June 10th. The average MLSS concentration was 121 mg/l for this period. The waste stabilization system maintained a high treatment efficiency during rapid loading increases. During the four day period from May 27th to 31st in which the loading rate increased from 0.64 to 3.76 lbs COD/lb MLSS/day, there was an increase in the soluble COD removal efficiency from 89 to 94 percent. Later during the period from June 8th to 10th in which the loading rate was substantially increased from 3.07 to 8.7 lbs COD/lb MLSS/day, the soluble COD removal rate dropped only from 93 to 79 percent.

Beginning on June 9th, the activated sludge pilot plant operating without the clarifier (dispersed growth system) and the rotating biological disc pilot plant were operated in series (see Figure 18). This was done in order to simulate the operation of the proposed treatment facility using an aerated surge basin for pretreatment of the combined waste prior to its entering the rotating biological disc reactor. Another objective was to determine if the dispersed solids from the aeration tank would settle after contact in the rotating biological disc reactor. The short time (five days) that the systems were run in series was insufficient to provide this information.

To connect the two pilot plants, a line was run from the effluent pipe on the activated sludge aeration tank to the feed well of the rotating biological disc reactor. The influent flow rate into the aeration tank was increased from 0.5 GPM to 1.0 GPM in order to obtain a 24-hour detention time. The hydraulic loading on the rotating biological disc reactor was thus increased from 500 GPD to 1,440 GPD. The same combined waste as mentioned earlier was fed to the waste stabilization-rotating biological disc system although the organic loadings were somewhat higher (600 to 750 mg/l COD).

The COD removal efficiencies of both the waste stabilization and rotating biological disc reactors dropped off immediately after the system began operating because the hydraulic loading was increased from 0.5 to 1.0 GPM to the aeration tank and from 500 to 1,440 GPD to the rotating biological disc while the organic loading to both reactors was doubled. Within a period of five days, the combined system was obtaining 92 percent soluble COD removal with the waste stabilization reactor accounting for 78 percent of that reduction.

It would seem likely that the combined system would stabilize at the loading ranges used with the aeration tank providing better than 90 percent of the treatment. This degree of treatment would be substantially reduced if phosphates were not added to the aeration tank.

Discussion

The complete mix activated sludge system proved to be unable to provide an adequate treatment efficiency on a continuing basis. This inability to provide an adequate treatment efficiency was directly related to the systems inability to maintain an adequate MLSS concentration in the aeration tank. Although the system did provide excellent treatment efficiencies for several weeks in a row, the system would soon begin to lose solids into the effluent resulting in a reduced MLSS and a loss of efficiency. This loss of solids was caused by the production of a dispersed biomass in the aeration tank which was washed from the system as it could not be settled in a clarifier and returned to the aeration system.

Many factors were considered as possible causes of this instability including lack of adequate nutrients, and rapid changes in temperature and loading rates. Although these parameters seem to aggravate the problem at times, the data shows no direct correlation with any of them. The lack of stability of the activated sludge process appears to be directly related to the type of wastewater being treated.

It was noted that the system did not perform well when the detention times were greater than 12 hours. At no time when the detention time exceeded 12 hours was the system capable of producing an acceptable treatment efficiency as the MLSS quickly became dispersed and were quickly washed from the system. On occasions when detention times were in the range from 6 to 12 hours, the system performed exceptionally well over a wide range of loading rates (0.1 to 1.0 lbs BOD/lb MLSS/day) while at other times the MLSS were lost due to a dispersed biomass. The most consistent results were realized when the detention time was from 3.0 to 6.0 hours.

At no time was there evidence of any toxic effects from the wastewater. Microscopic examinations were made on several occasions even when the MLSS had been reduced to less than 100 mg/l. At all times a healthy biota was evident by the presence of free swimming ciliates and rotifers.

It may be possible under certain controlled conditions to achieve excellent BOD and COD removal efficiencies while treating the type wastewater in question. During a period of several weeks in October 1975, the total BOD and total COD removal efficiencies averaged 96 percent and 85 percent, respectively. During the same time period, the soluble BOD and COD removal efficiencies averaged 98 and 90 percent, respectively. The loading rate during this period was relatively stable and may have played an important part in the activated sludge system achieving such a high degree of treatment during that period.

One of the major problems, however, at RAAP is that the wastewater flow and composition is expected to be anything but stable. The major source of organic matter (the water dry waste) results from batch systems whose COD concentrations are known to vary from 500 to greater than 28,000 mg/l. Many of the manufacturing processes run intermittently on an as needed basis, some of these being batch processes while others are sources of continuous discharge. At present, manufacturing operations are performed on a normal 40 hour work week. However, during war time, operation will most likely be 24 hours a day, 7 days a week. Even with extensive equalization, it is doubtful whether sufficient control over the hydraulic and organic loading rates could be achieved to assure that the activated sludge system would operate effectively. Therefore, the conventional types of activated sludge processes cannot be recommended for use at RAAP.

The obvious system to consider is the aerated waste stabilization process which is normally a dispersed growth system. This system was tested and proved capable of providing a high degree of treatment efficiency even during sizeable variations in loading rates. Although this dispersed growth system was not tested extensively, it should be considered as a viable and effective treatment system for the wastewater at RAAP.

Conclusions

1. The complete mix activated sludge process proved unable to provide an adequate treatment efficiency on a continuous basis.

2. The primary cause of the system's inability to produce an adequate treatment efficiency was the development of a dispersed biota in the aeration tank. The cause of the dispersed growth was not determined.

3. At times under controlled conditions, the system was capable of BOD and COD removal efficiencies of 95 and 98 percent, respectively.

4. The actual loading rate on the system was lower than the calculated value because of the loss of volatile organics through air stripping.

5. The complete mix activated sludge process cannot be recommended as an acceptable wastewater treatment process for RAAP.

6. The aerated waste stabilization system proved to be a highly efficient treatment system and because of its normally dispersed growth, should be considered as an alternative method of wastewater treatment at RAAP.

V. AEROBIC DIGESTION

A batch aerobic digestion study was performed on sludge from the rotating biological disc pilot plant. This was done in order to determine the degree of solids reduction possible and to develop some qualitative information on the dewatering properties of the aerobically digested sludge.

Several days accumulation of biological solids from the rotating biological disc pilot plant were placed in a 50-gallon vat and aerated (diffused aeration) continuously for a period of 21 days. The vat was covered from the weather but had sufficient open space for free air passage. The test was performed at a constant volume with evaporation losses being replaced daily. Temperature during this period ranged from 60 to 70 F. Dissolved oxygen concentrations averaged between 5.5 to 7.6 mg/l except for a period from the second through the fourth days when a high degree of digestion caused oxygen concentrations to be substantially lower.

Five grab samples were taken weekly and analyzed for COD, total solids, and total volatile solids. There was a large degree of variation in solids and COD results obtained. This was part due to improper sampling procedures. The aerobically digesting solids were not thoroughly hand mixed before sampling and since the diffused aeration alone was insufficient to keep all of the solids in suspension, not all samples were representative.

Figures 19 and 20 show the reductions in solids and COD concentrations respectively achieved during the digestion period. Initially the rate of digestion was very high. Total solids concentration which was almost 4,000 mg/l at the beginning of the aerobic digestion tests dropped to approximately 3,000 mg/l during the first three days while volatile solids concentration decreased from 3,000 to 2,300 mg/l. After 16 days digestion, the total solids concentration had decreased to about 2,000 mg/l where it remained through the end of the study period. Volatile solids concentration decreased to approximately 1,450 mg/l by the 17th day and remained at this level. The COD concentration dropped from an initial value of approximately 3,200 mg/l to 1,200 mg/l by the end of the study period.

The aerobic digestion process reduced both the total solids and volatile solids concentrations approximately 50 percent while the COD concentration was reduced approximately 60 percent. This study indicated that the digestion process was essentially complete after 16 days. After 21 days of digestion, the mixed liquor had a sludge volume of 770 mg/l after 30 minutes and 315 mg/l after 120 minutes of settling in a one liter graduated cylinder.

Aerobically digested sludge was placed on a fine sand bag to determine its dewatering characteristics. Approximately 18 inches of this sludge dewatered in a period of several days leaving a thin layer of dense adhesive sludge. A sample of this aerobically digested sludge left unaerated for a period of a week did not become anaerobic.

VI. AIR STRIPPING

Air stripping of the high alcohol content wastewater (water dry waste) was investigated in some detail to determine its value as a pretreatment process and to develop information on its influence on the efficiency of biological waste treatment processes. The water dry waste contained both ethyl alcohol and diethyl ether, which can be air stripped although diethyl ether air strips much more rapidly than ethyl alcohol.

Twenty-four hour batch air stripping tests were performed in the aeration tank of the activated sludge pilot plant to determine the degree of air stripping that could potentially occur during the activated sludge process. The same wastewater used during the activated sludge pilot plant studies was air stripped in these tests. The first air stripping test was run at 13 C and resulted in a COD concentration reduction of only 15 percent (see Figure 21). The heater in the aeration tank was used during the second test to evaluate air stripping at elevated temperatures. During this test at temperatures that varied between 21 C to 28 C, a COD reduction of 30 percent was achieved (see Figure 22). Alcohol concentrations were measured during the second test and a 22 percent reduction in the alchol concentration was achieved. These two air stripping tests showed that temperature was a definite factor in the air stripping processes as would be expected. The higher the temperature the higher the quantity of alcohol and ether stripped from the waste during any given time period.

A laboratory air stripping test under controlled conditions was performed on a sample of concentrated water dry waste (6,100 mg/l COD) to more fully document the effects of temperature on the air stripping process. Two-liter beakers of water dry waste were aerated for 24 hours at 8 C, 27 C, and 38 C and samples were taken at various time intervals for COD analysis. The results of these three tests are presented in Figure 23. The water dry waste that was air stripped at 8 C decreased in COD concentration from 6,100 to 5,040 mg/l while the water dry waste that was air stripped at 27 C decreased in COD concentration to 2,800 mg/l. The largest decrease in COD concentration (6,100 to 1,660 mg/l) occurred in the sample that was air stripped at the highest temperature (38°C). The increased amount of air stripping occurring at higher temperatures is readily evident with COD reductions of only 18 percent achieved at 8°C as compared to a 74 percent reduction obtained at 38°C. To determine if the relationship between air stripping and temperature was linear in nature, the percent COD reduction was plotted against (air stripping) temperature (Figure 2) and the relationship does appear to be linear for the water dry waste studied.

VII. RECOMMENDED DESIGNS

Rotating Biological Disc Treatment System

The rotating biological disc wastewater treatment system (see Figure 25) was recommended for use at Radford Army Ammunition Plant. The design criteria for the major components of that system are presented in this section.

Significant variations are expected in both the wastewater flow and composition on both a short term (hourly) and on a long term basis (monthly). Therefore, the equalization basin must serve to equalize both the hydraulic variations and the chemical composition of the wastewater. There is no information available on the expected variations of the wastewater, therefore, the following assumptions were made:

1. The equalization basin should be capable of handling a hydraulic surge equivalent to 50 percent of the average daily flow without increasing the hydraulic loading rate on the rotating biological disc system.

2. The equalization basin should be able to handle a spill of 12,000 gallons of water with a COD of 28,000 mg/l over a two-hour period without increasing the COD in the influent to the rotating biological disc units by over a factor of 2.0.

Based on the above assumptions, it is necessary for the equalization basin to have a minimum volume of 716,000 gallons and a hydraulic surge capacity of an additional 625,000 gallons. Therefore, when the surge basin is completely filled, the total volume would be approximately 1.35 MGD. See Figure 26 for a schematic diagram of the surge basin.

The equalization basin may develop a dispersed growth even without the addition of nutrients. Therefore, sufficient aeration (mixing) should be provided to not only mix the basin and prevent sedimentation of suspended solids, but to provide adequate aeration to satisfy an oxygen uptake rate of 10 mg/l/hr. This is equivalent to approximately 50 H.P. for slow speed surface aerators or 70 H.P. for high speed surface aerators depending upon the aerators selected. It is recommended that the minimum water depth in the basin be eight feet and the maximum depth be 14 feet. Consideration should be given to the installation of a bar screen preceding the surge basin to protect the aerators and pumps.

Sufficient nitrogen is present in the waste so that the only nutrient which must be added is phosphorus. Phosphorus should be added in the form of phosphoric acid. The phosphoric acid feed system should consist of a storage tank and acid feeding pumps. The maximum nutrient required is not expected to exceed 160 lbs of H_3PO_4 per day assuming 100 percent acid. The size of the acid storage tank depends upon the concentration of acid available in the area and the minimum volume which must be purchased at any one time.

Automatic controls for feeding phosphoric acid were considered but rejected. It is recommended that phosphoric acid be controlled manually by feeding into the surge basin and measuring ortho-phosphate in the influent to the rotating biological disc units and effluent to the clarifiers once each shift. The operator can run ortho-phosphate colorometrically and manually adjust the H_3PO_4 feed rate.

The overall loading on the rotating biological disc units should be 2 gallons/day/ft^2 of surface area at the design flow and concentration. This requires a total rotating biological disc surface area of approximately 625,000 ft^2. There should be two separate rotating biological disc systems, each containing one-half of the total surface area or approximately 312,500 feet each. Each of these two systems should be divided into three cells with the first cell containing 50 percent of the surface area of the unit or approximately 156,250 ft^2. The remaining two cells should contain 25 percent of the surface area of the unit or approximately 78,125 ft^2 each. Consideration should be given to allow varying the rotation rate of the disc.

The feed rate to the rotating biological disc units should be as nearly constant as possible. This means selecting pumps which can pump at a relatively constant rate from the surge basin without creating hydraulic surges through the system. Hercules Incorporated has stated that the minimum flow rate will be a zero flow. It is desirable to maintain a minimum flow rate through the rotating biological discs, therefore, a minimum pumping rate of approximately 1.0 gallons/day/ft^2 of rotating biological disc surface in use should be maintained. To prevent the surge basin from being lowered beyond its minimum depth of 8 feet, a flow recycle system should be installed. This system as shown in Figure 27 would take treated waste from a diversion box and return it by gravity to the surge basin. A float control at the surge basin would operate a valve to allow the recycle stream to operate only when the surge basin is approaching minimum depth. A flow splitting device should be installed ahead of the rotating biological disc units to allow a varying percentage of the flow to be discharged to each rotating biological disc unit. This would allow one rotating biological disc unit to be taken out of service or varying hydraulic load to be placed on the units.

Two clarifiers should be installed each 40 feet in diameter with a minimum depth of 12 feet. A conventional bottom scrapper should be used as there will be no sludge return. A surface skimmer should be installed and and a peripherial weir used.

Pilot plant data showed that at the recommended design loading rate approximately 135 mg/l of suspended solids could be expected to be discharged to the clarifier. At the design flow of 1.25 MGD and assuming 100 percent suspended solids removal in the clarifiers, approximately 1,407 lbs of sludge each day would be wasted to the sludge digesters. Therefore, sludge pumps should be designed to handle approximately 1,407 lbs of sludge/day at 1.0 percent solids. Consideration should be given for peak sludge flows and that one clarifier may have to be taken out of service for repair.

Sludge digestion should be provided by aerobic digestion based on a 20-day detention time assuming a 2.0 percent sludge concentration in the digesters. Based on these assumptions, the approximate volume of the aerobic digesters should be 168,700 gallons. This volume should be divided between two tanks 32 feet in diameter with a maximum water depth of 14 feet.

Aeration should be provided by diffused aeration. Blowers should be selected to provide for an expected average oxygen uptake rate of 50 lbs/hr and a maximum oxygen uptake of 70 lbs/hr in the digester system (25 lbs/hr average, 35 lbs/hr maximum each tank).

Provision should be made so that when the aeration in the digesters is shut off, the sludge may be thickened by removing supernatant back to the surge basin. The digesters should be piped so they can be operated in series or parallel.

The volume of sludge to be handled from the aerobic digesters is based on the assumption that 1,407 lbs/day of 90 percent volatile sludge will be wasted to the digester. Based on pilot plant data, at least 40 percent reduction in volatile solids can be expected. Therefore, approximately 900 lbs.day of sludge at 2.0 percent must be handled from the aerobic digesters. This is approximately 5,400 gallons of digested sludge which must be handled each day.

The potentially viable methods of sludge handling and disposal are: 1) sand bed dewatering and landfill of dried sludge; 2) mechanical sludge dewatering and landfill of dried sludge; or 3) land spreading of liquid sludge. Hercules Incorporated has stated that they will provide for landfill disposal of dried sludge and emergency disposal of liquid sludge.

Information gathered from several sewage treatment plants in the area indicated that during the summer months it took four to six weeks for anaerobically digested sludge to dry on sand beds. However, from October through March, essentially no drying can be expected. This means that for approximately six months during the year sand beds could provide only storage for sludge and no drying.

It is recommended that facilities be installed for emergency hauling of liquid sludge. Sludge dewatering should be provided by a continuous belt filter press capable of handling 25 GPM of digested sludge at 2.0 percent solids. This capacity would allow one shift operation of the filter press five days each week.

Consideration was given to recommending sand beds as a backup system when the filter press was undergoing maintenance. Due to the high cost and the lack of drying during six months of the year, it is recommended that sand beds not be used but that a sludge lagoon be installed capable of holding at least three months of waste sludge volume or approximately 500,000 gallons. Provision should be made to remove supernatant from the sludge lagoon back to the surge basin and to pump sludge to either the continuous belt filter press or to truck hauling. A second continuous belt filter press could be substituted for the sludge lagoon as a backup system. This continuous belt filter press would also have to be capable of handling 25 GPM of digested sludge at 2.0 percent solids.

Aerated Waste Stabilization Treatment System

The extensive activated sludge studies indicated that the complete mix activated sludge system tested was unstable on a long term basis and not acceptable as a wastewater treatment process for RAAP. The aerated waste stabilization (dispersed growth) system proved to be a highly efficient treatment system and should be considered as an alternative method of wastewater treatment. This system is capable of meeting the NPDES permit requirements as shown in Table 1. The aerated waste stabilization treatment system recommended consists primarily of four waste stabilization ponds, two of which are aerated (see Figure 27). At the average design flow ([illegible]5 MGD), the system will have a hydraulic detention time of six days.

The first and second ponds are aerated waste stabilization ponds and should be in series and each have a volume of approximately 2,500,000 gallons. It is recommended that the maximum water depth in the aerated ponds be 12 feet. The unaerated ponds need to be only 8 feet deep. A bar screen should be installed preceding the first aerated stabilization pond and the gravity bypass line (see Figure 27). Surface aerators are recommended capable of satisfying an oxygen uptake rate of 10 mg/l/hr. This is equivalent to approximately 100 H.P. for slow speed surface aerators or 140 H.P. for high speed surface aerators for each of the 2,500,000 gallon ponds. The actual H.P. required will depend upon the specific type of aerator installed.

The only nutrient addition that is necessary is phosphorus which should be added in the form of phosphoric acid. The phosphoric acid should be fed into the wastewater influent line at a point preceding the gravity bypass line. The maximum phosphoric acid requirement should not exceed 160 lbs H_3PO_4 (100 percent acid) per day. The feeding of phosphoric acid should be controlled manually. The orthophosphate concentration in the effluent can be measured colorometrically and the operator can adjust the phosphoric acid feed rate accordingly.

The two waste stabilization ponds should each have a volume of approximately 1,250,000 gallons and be designed in parallel. Each pond should have a maximum water depth of 8 feet deep. A flow splitting device should be installed on these stabilization ponds to allow a varying percentage of the wastewater to be discharged to each pond.

A gravity bypass line (see Figure 27) should be installed in order to bypass any one of the ponds if repairs or cleaning becomes necessary. Flow measurements should be made before the effluent is discharged.

VIII. APPENDICES

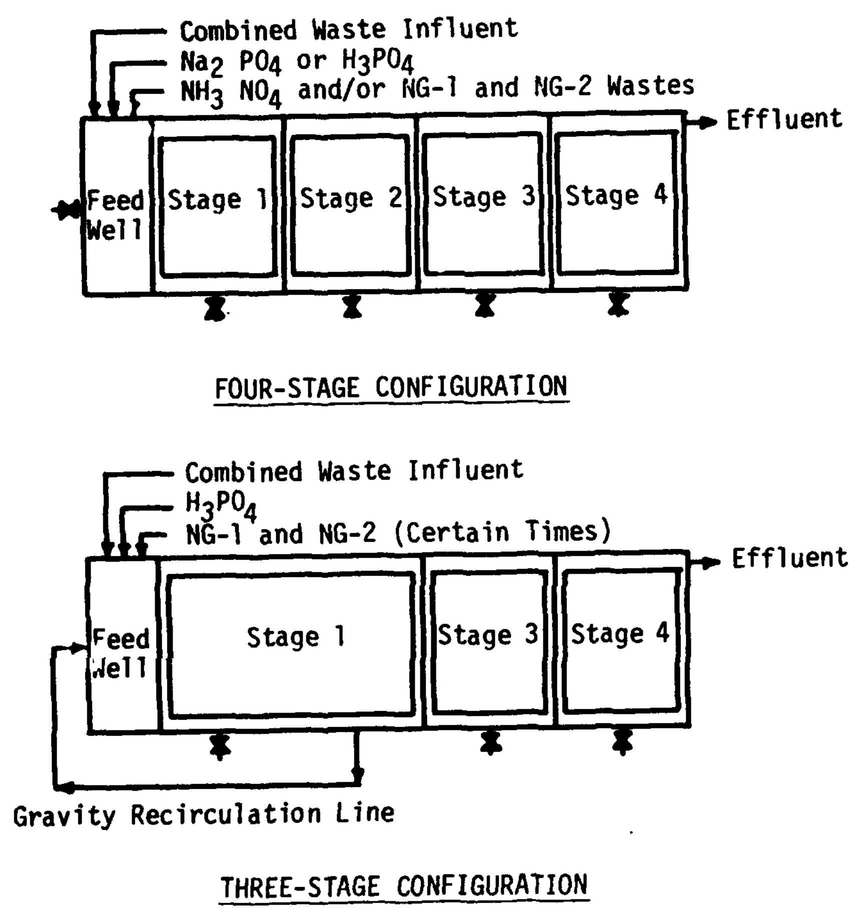


FIGURE 1. Schematic Diagram of the Four Stage and Three Stage Rotating Biological Disc (RBD) Pilot Plants. The Change From Four to Three Stages was Made on April 4, 1976.

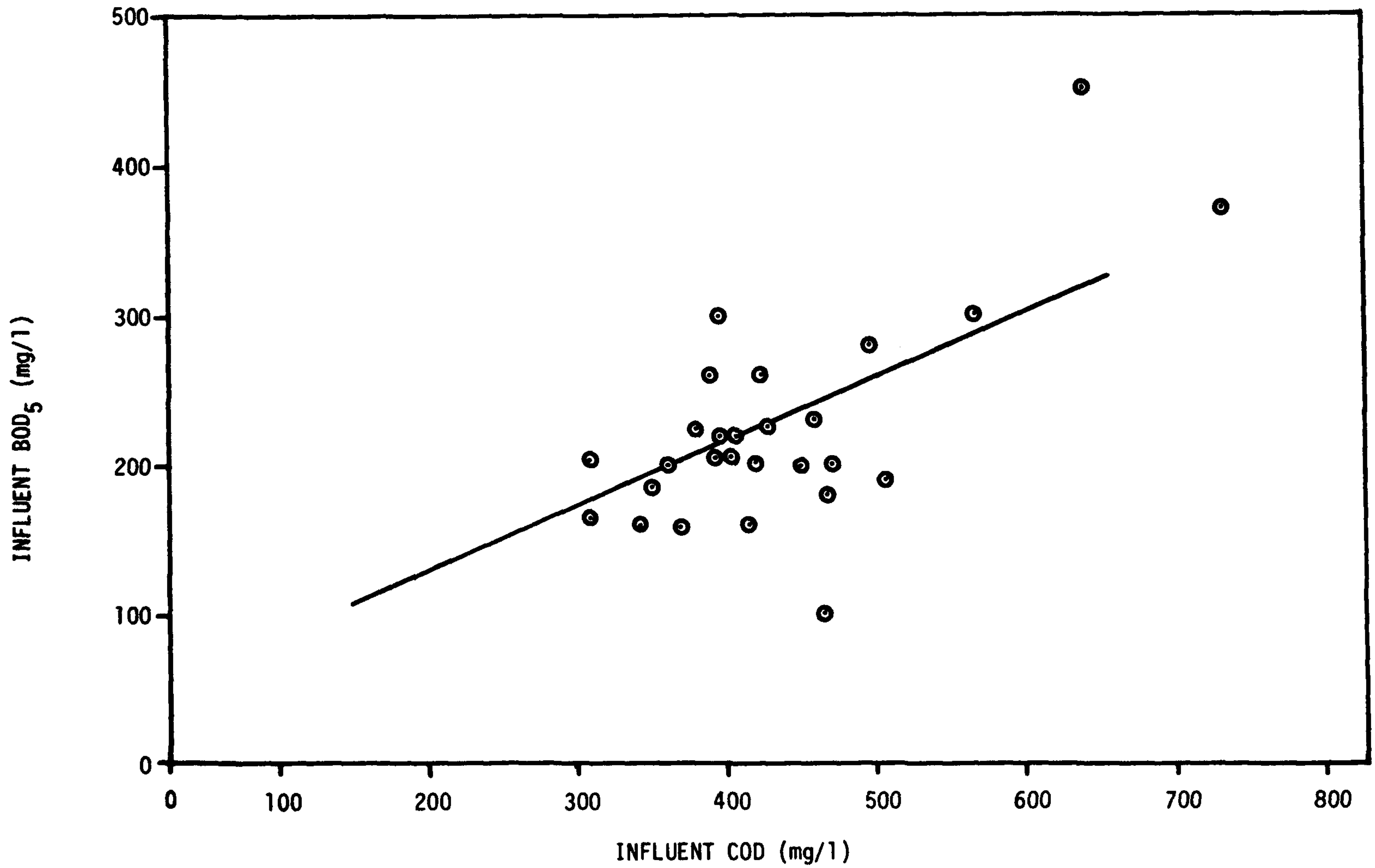


FIGURE 2. Influent BOD Versus Influent COD For The Combined Waste.

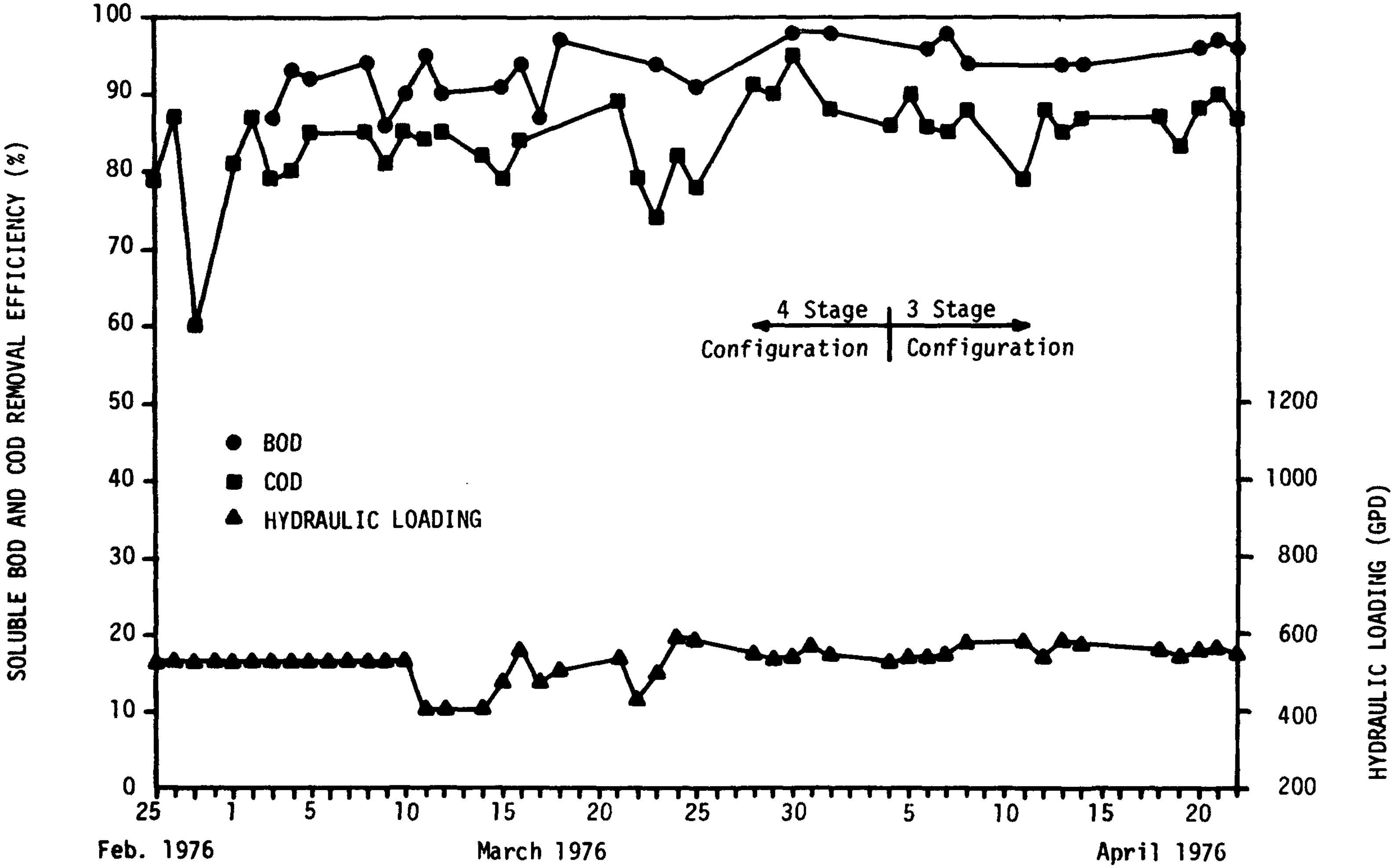


FIGURE 3. The Relationship Between Soluble BOD and COD Removal Efficiency and Hydraulic Loading for the Rotating Biological Disc Treatment System

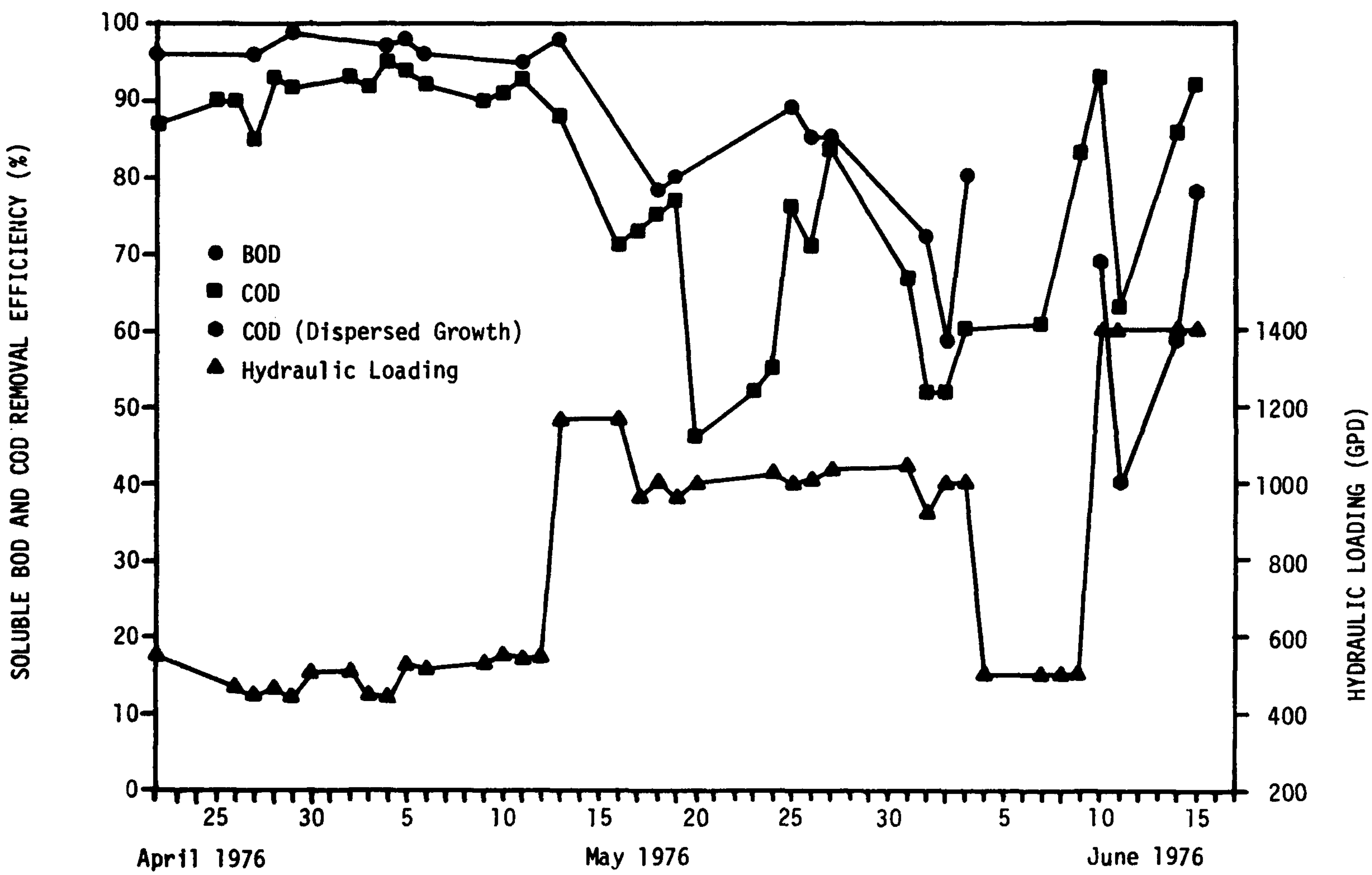


FIGURE 3. The Relationship Between Soluble BOD and COD Removal Efficiency and Hydraulic Loading (Cont.) for the Rotating Biological Disc Treatment System

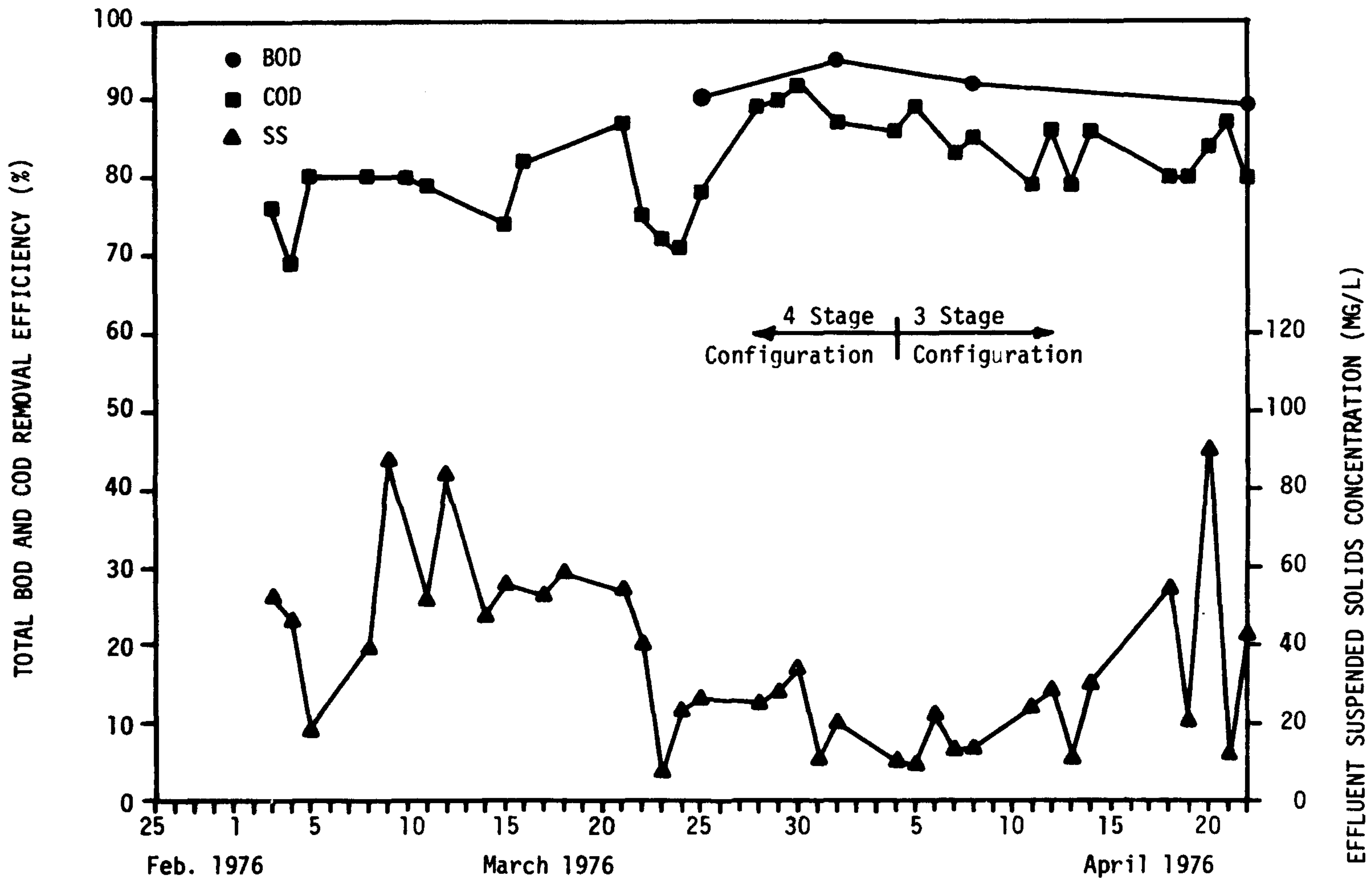


FIGURE 4. The Relationship Between Total BOD and COD Removal Efficiency and Effluent Suspended Solids Concentration for the Rotating Biological Disc Treatment System

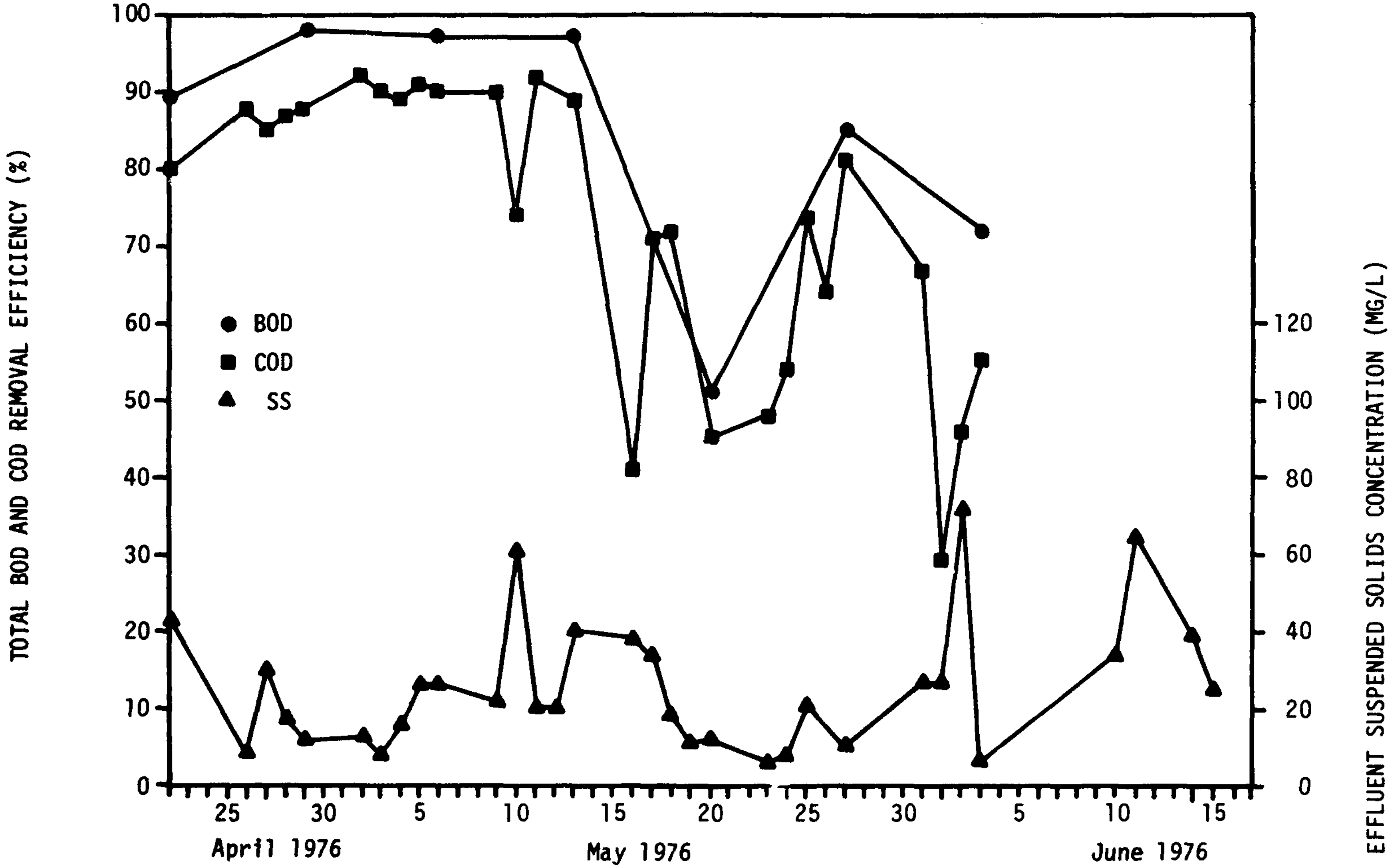


FIGURE 4. (Cont.) The Relationship Between Total BOD and COD Removal Efficiency and Effluent Suspended Solids Concentration for the Rotating Biological Disc Treatment System

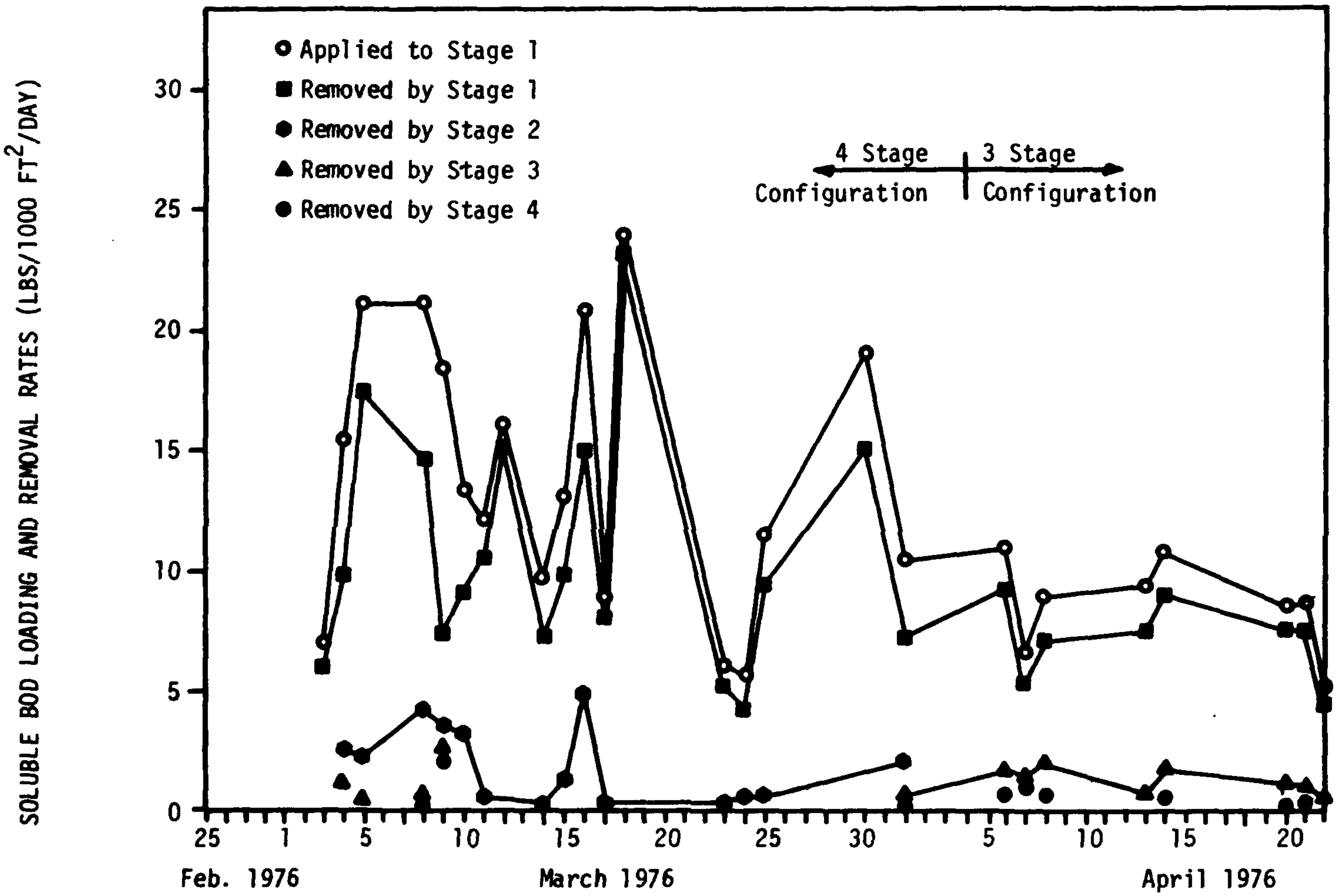


FIGURE 5. The Relationship Between the Soluble BOD Loading and Removal Rates for Each Stage of the Rotating Biological Disc Treatment System

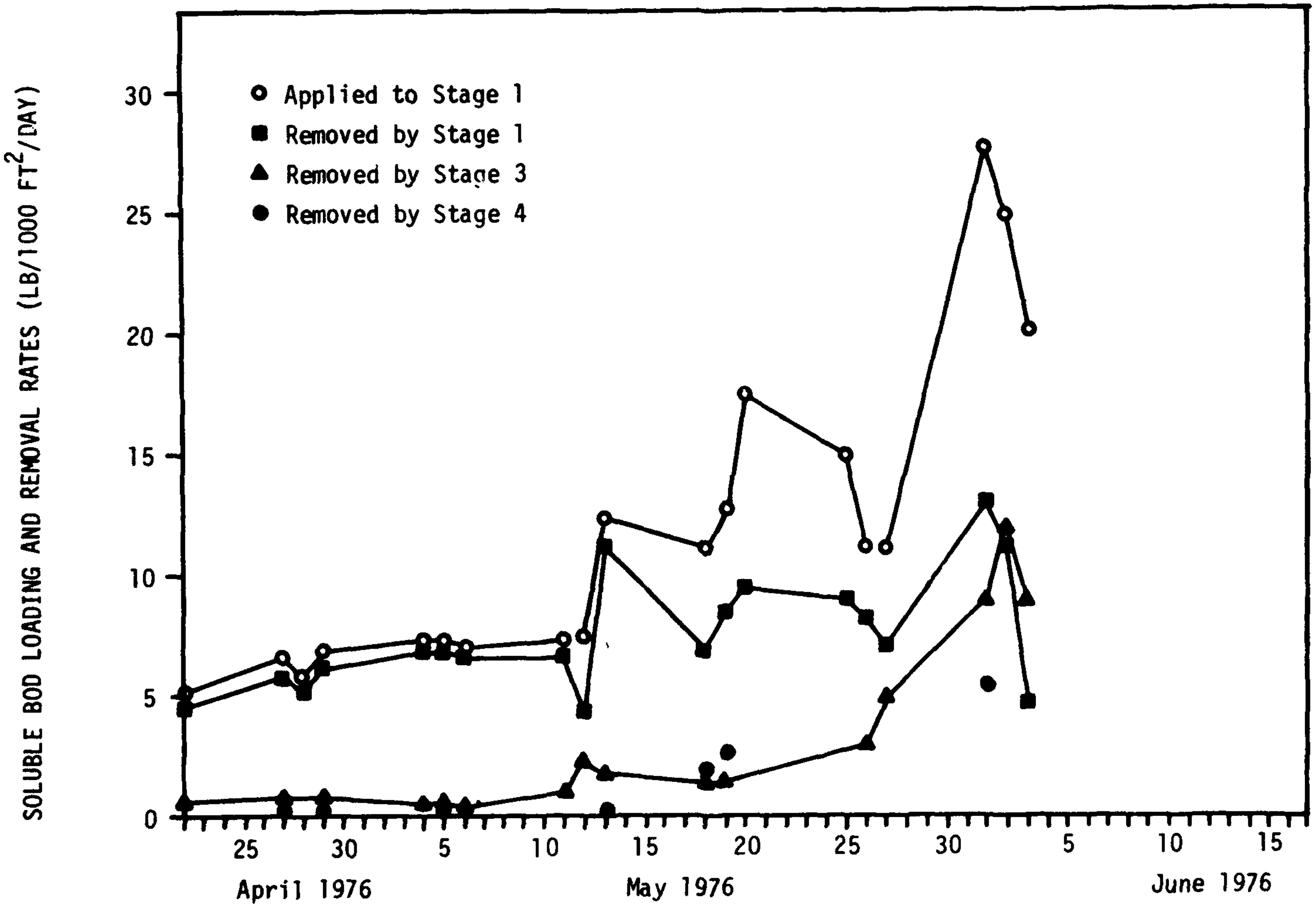


FIGURE 5. (Cont.) The Relationship Between the Soluble BOD Loading and Removal Rates for Each Stage of the Rotating Biological Disc Treatment System

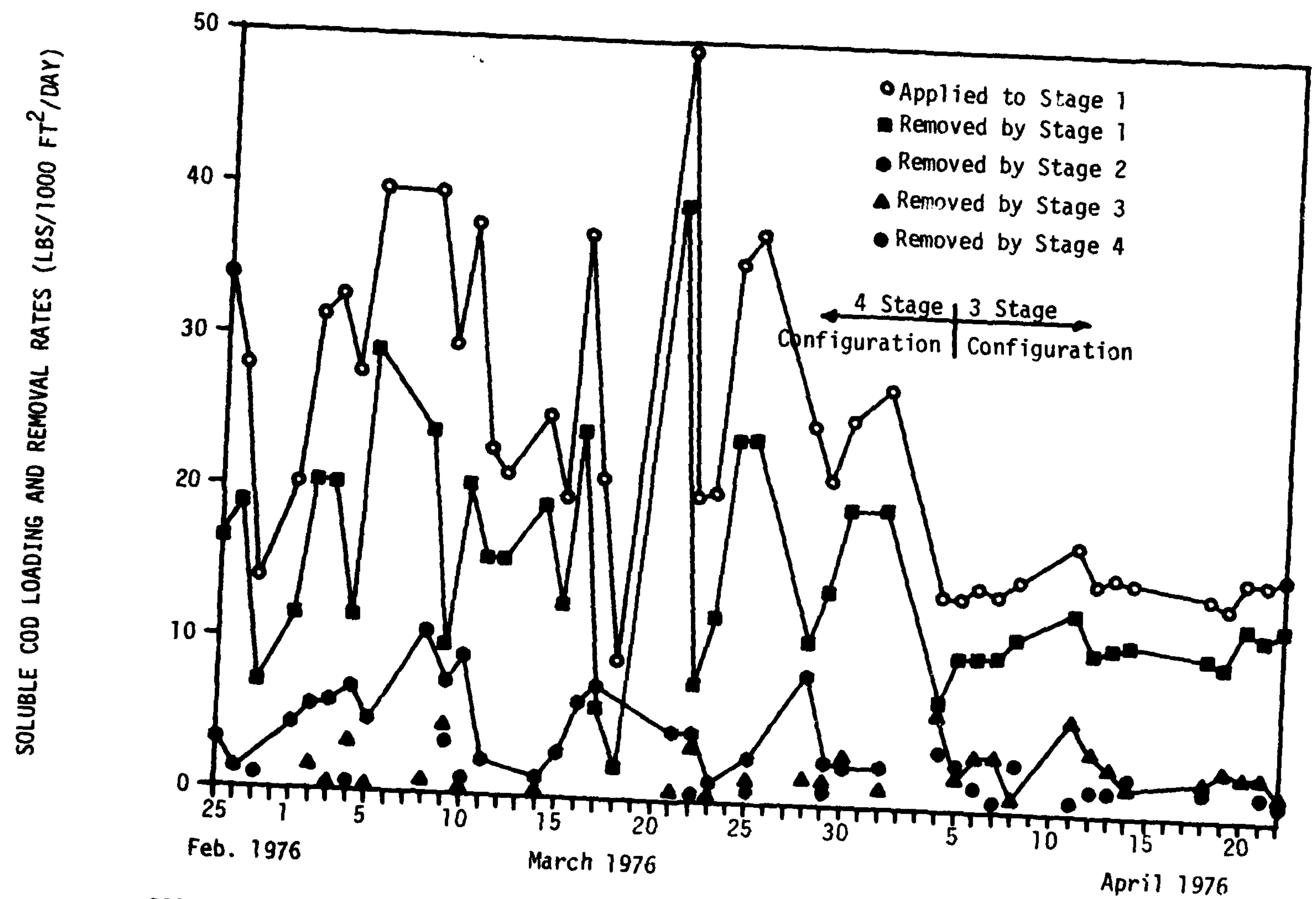


FIGURE 6. The Relationship Between Soluble COD Loading and Removal Rates for Each Stage of the Rotating Biological Disc Treatment System

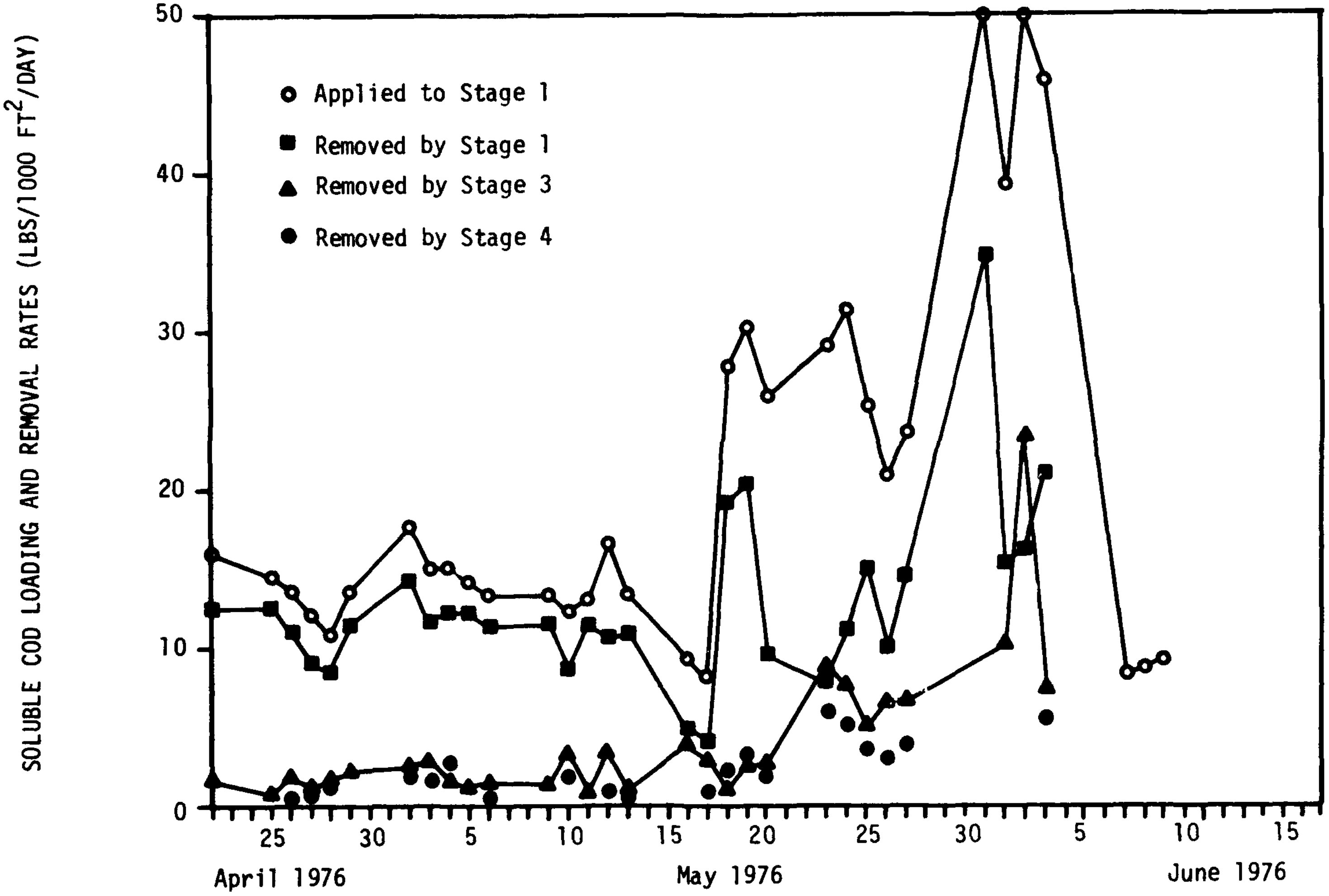


FIGURE 6. (Cont.) The Relationship Between the Soluble BOD Loading and Removal Rates for Each Stage of the Rotating Biological Disc Treatment System

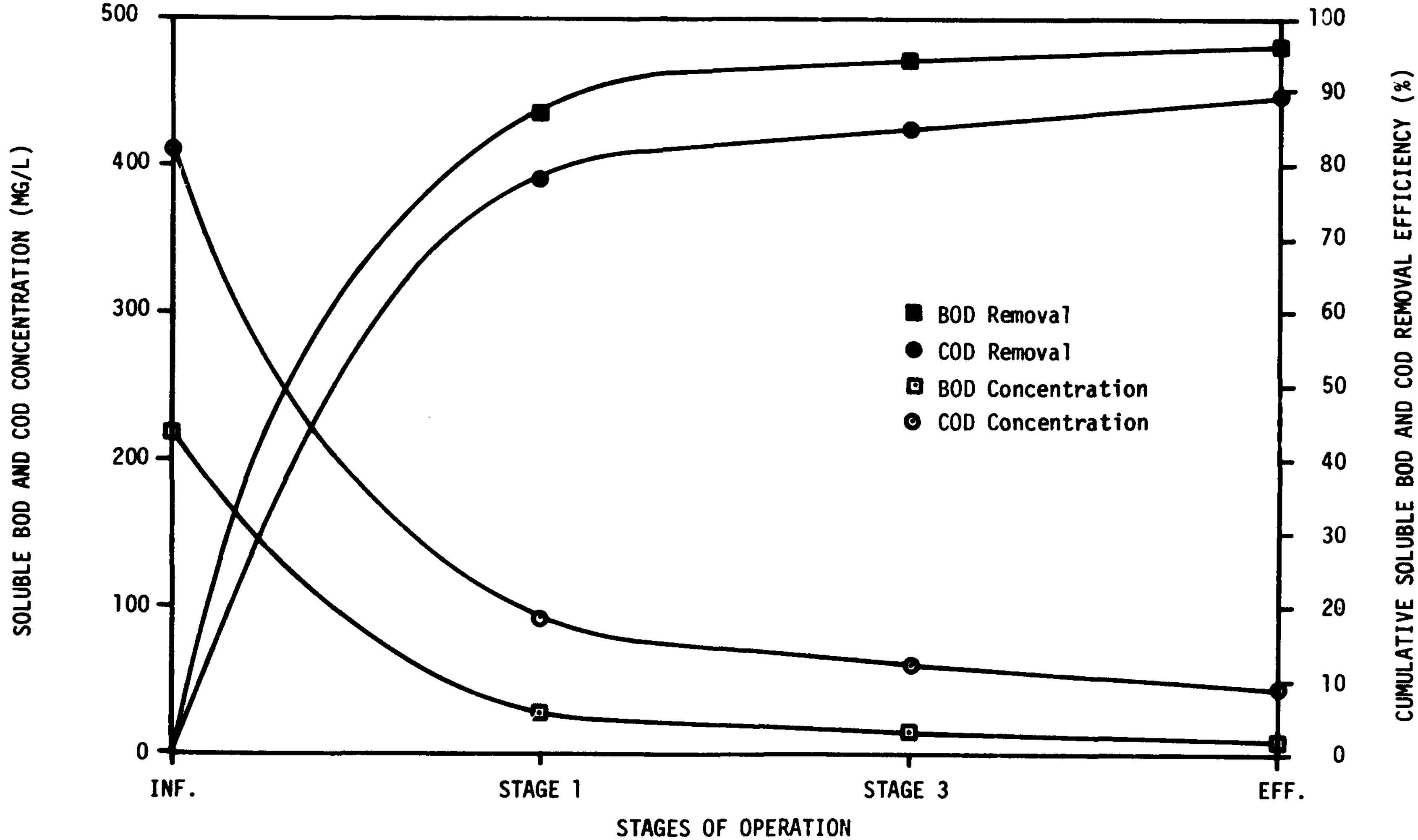


FIGURE 7. The Average Cumulative Soluble BOD and COD Removal Efficiency for each Stage of the Rotating Biological Disc Treatment System During the Period From April 4, 1975 to May 11, 1976

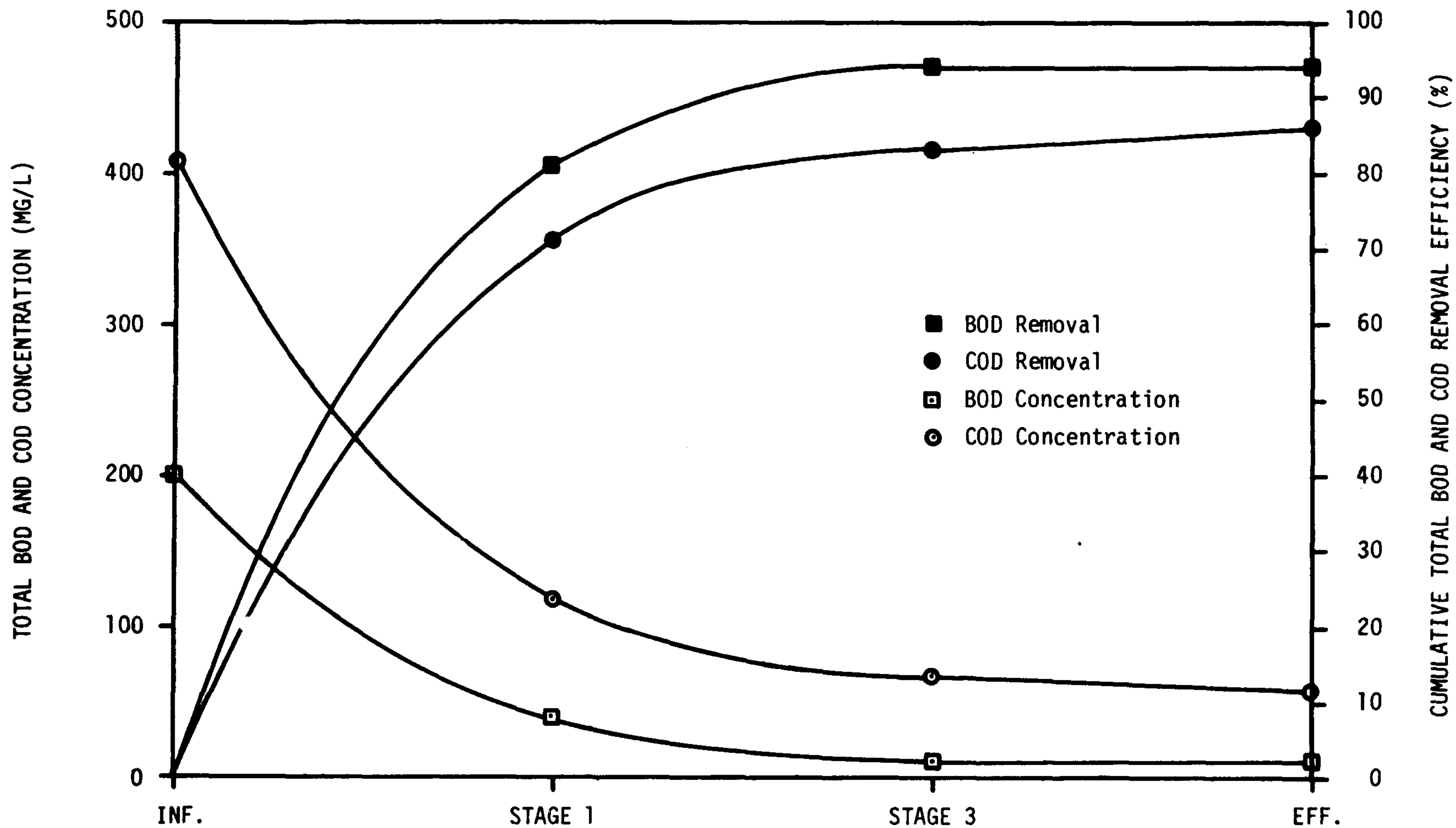


FIGURE 8. The Average Cumulative Total BOD and COD Removal Efficiency for each Stage of the Rotating Biological Disc Treatment System During the Period of From April 4, 1976 to May 11, 1976

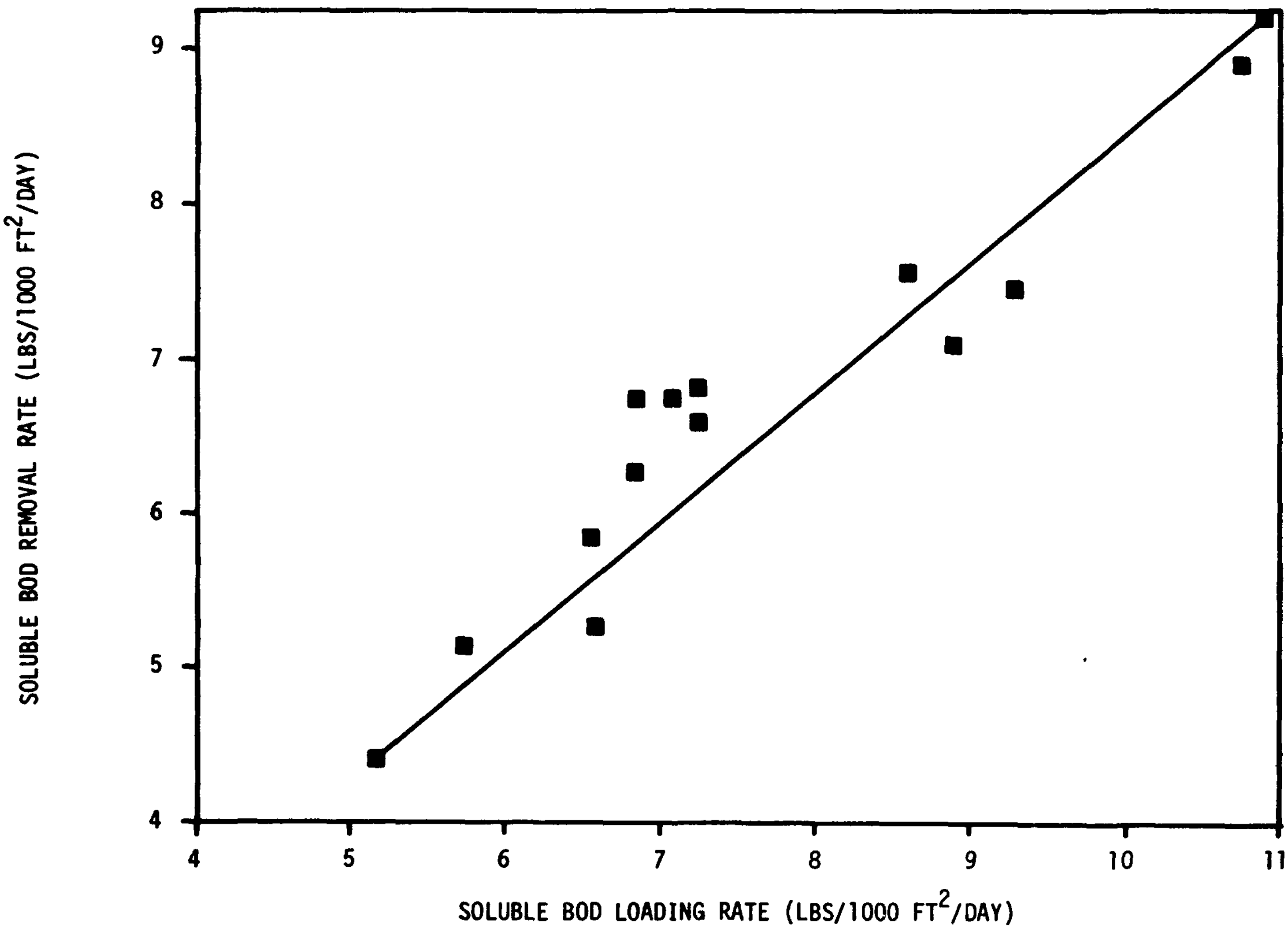


FIGURE 9. The Relationship Between Soluble BOD Loading Rate and Soluble BOD Removal Rate For The Rotating Biological Disc Treatment System During the Period From April 5, 1976 to May 11, 1976.

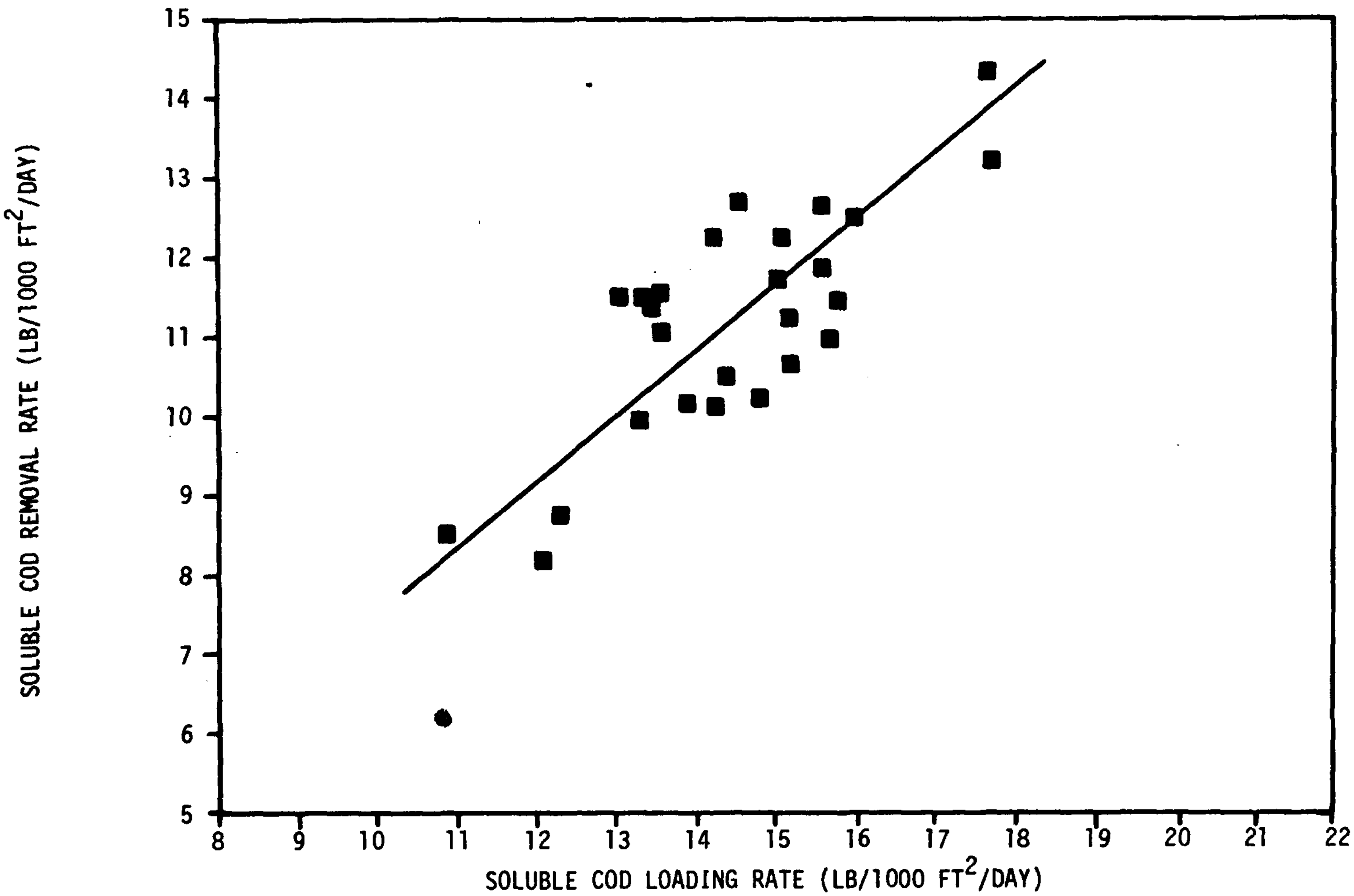


FIGURE 10. The Relationship Between Soluble COD Loading Rate and the Soluble COD Removal Rate for the Rotating Biological Disc Treatment System During the Period From April 5, 1976 to May 11, 1976

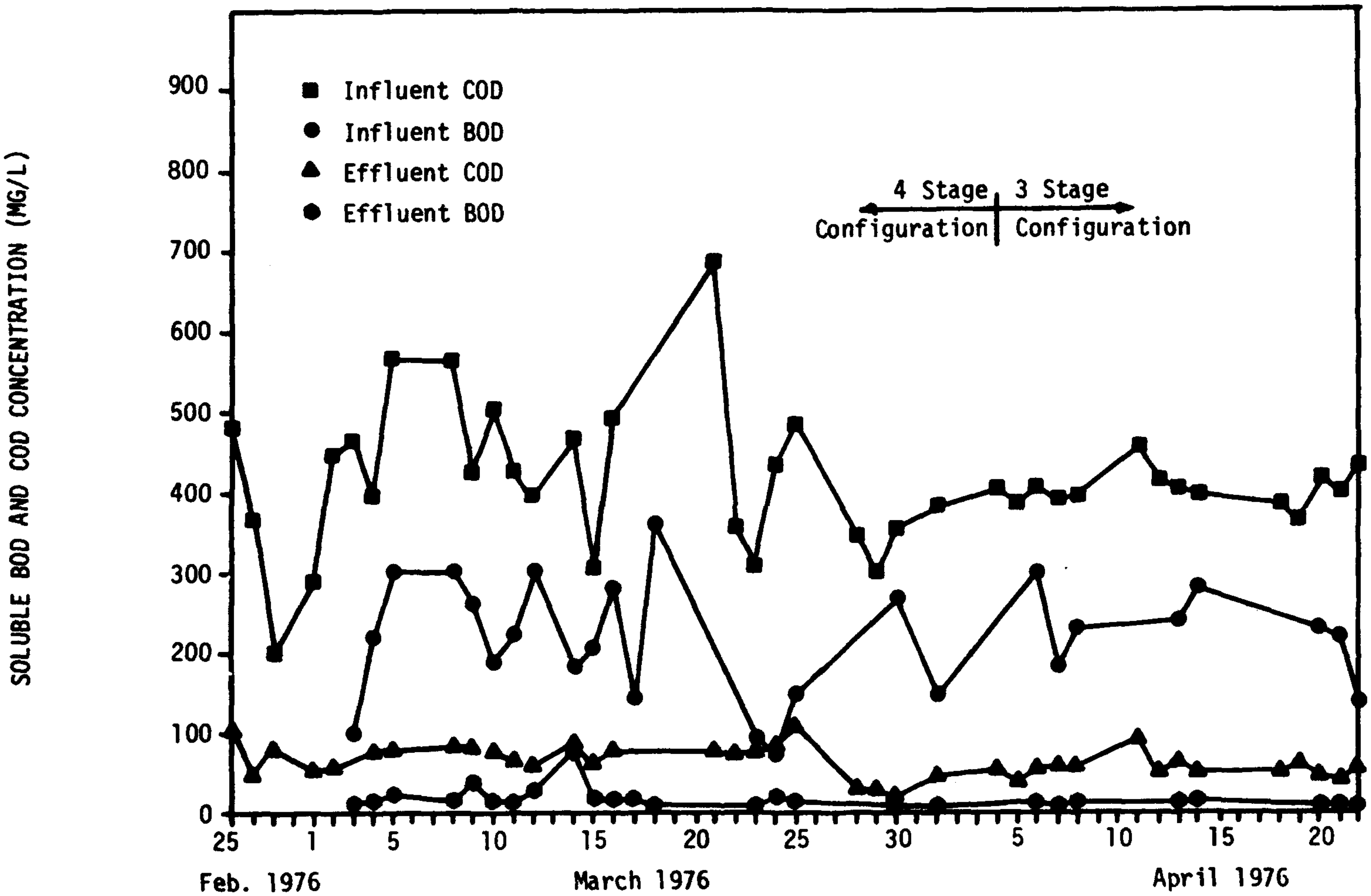


FIGURE 11. The Relationship Between Soluble BOD and COD Influents and Effluents for the Rotating Biological Disc Treatment System

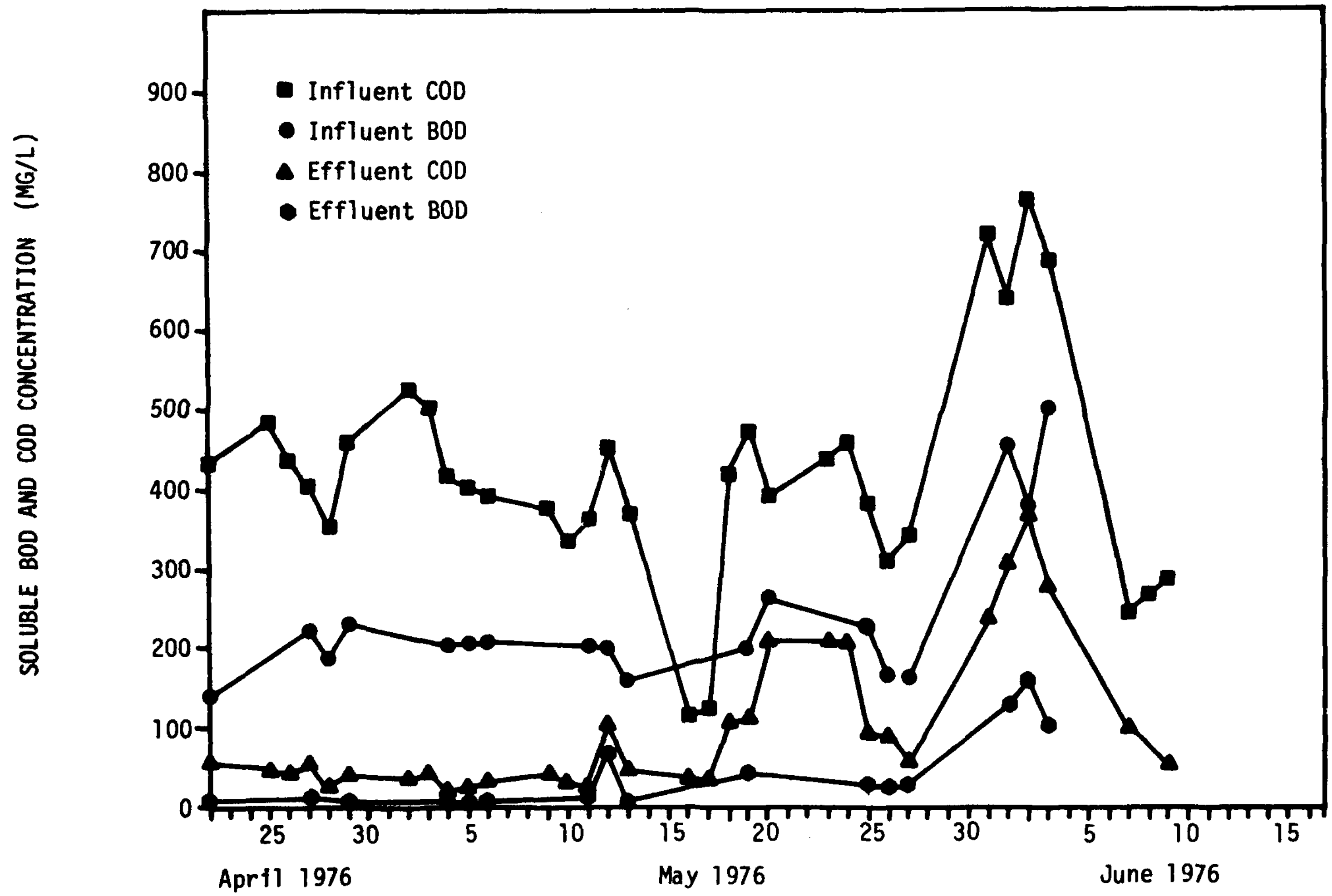


FIGURE 11. (Cont.) The Relationship Between Soluble BOD and COD Influents and Effluents Concentrations for the Rotating Biological Disc Treatment System

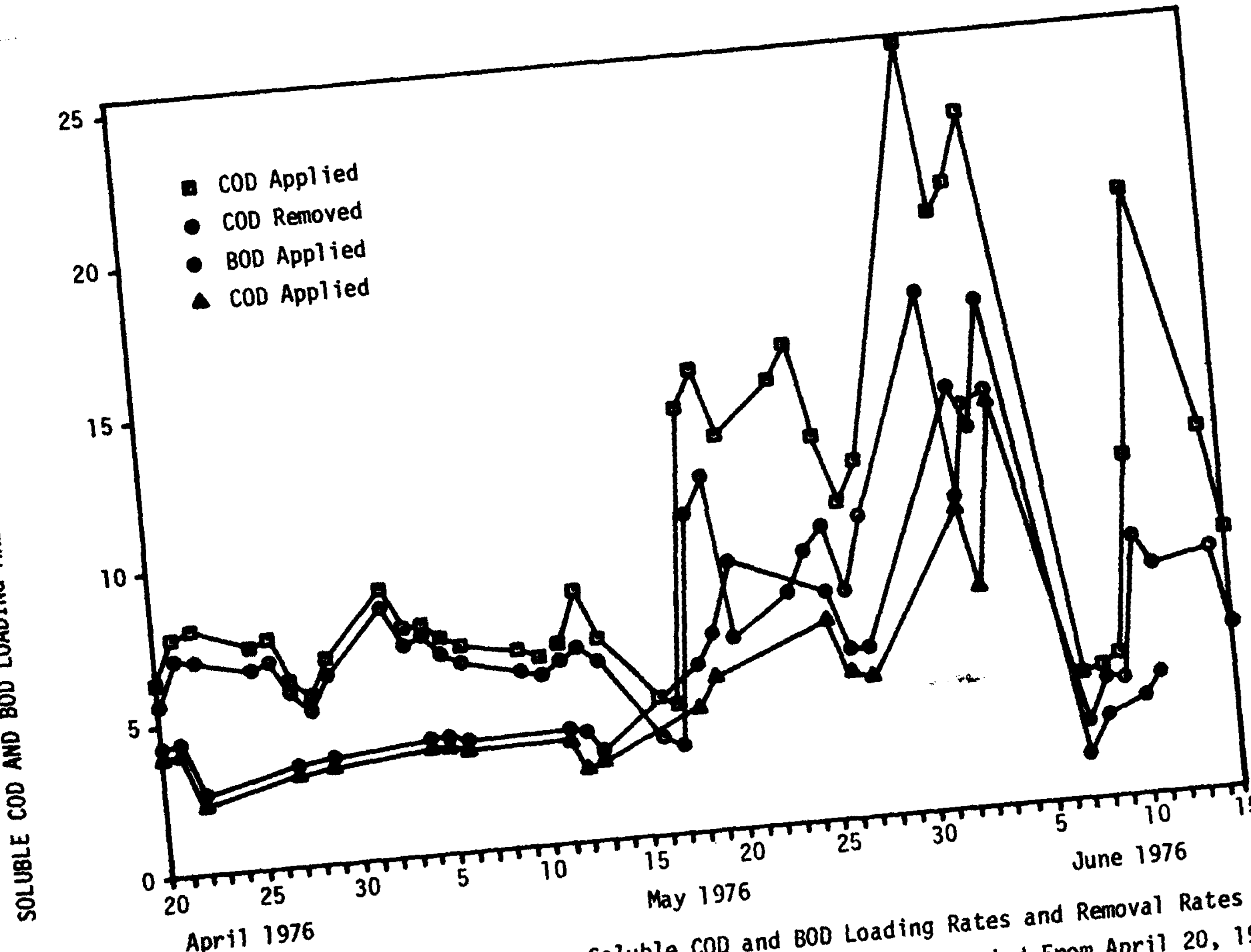
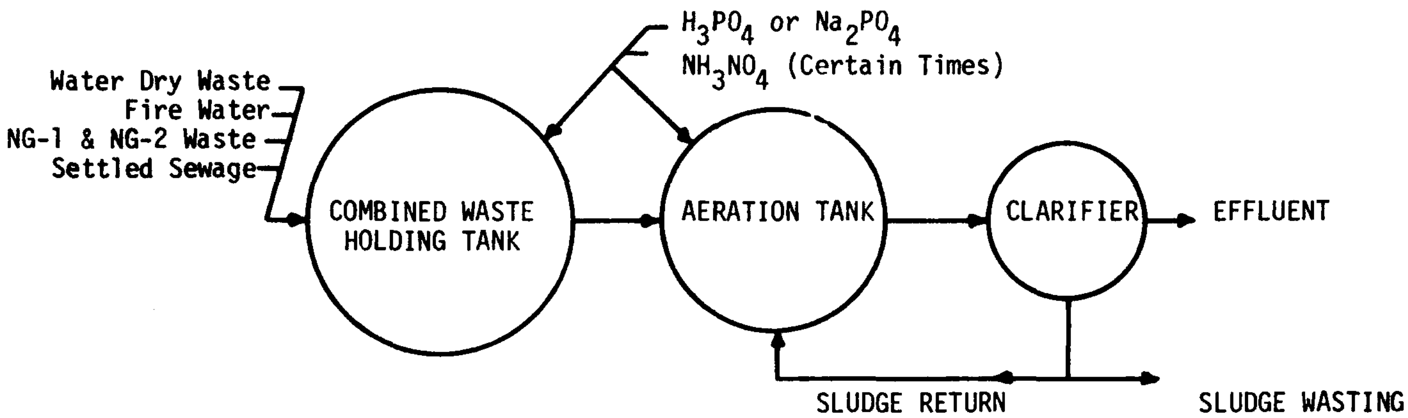
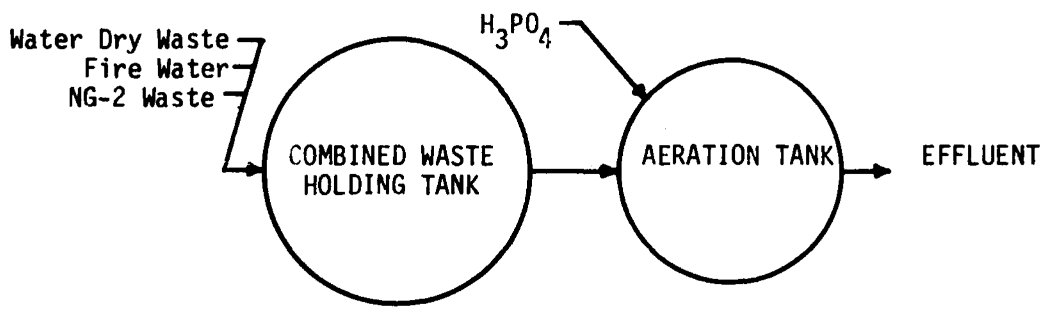


FIGURE 12. The Relationship Between Soluble COD and BOD Loading Rates and Removal Rates for the Rotating Biological Disc Treatment System during the Period From April 20, 1976 to June 15, 1976



ACTIVATED SLUDGE SYSTEM



AERATED WASTE STABILIZATION (DISPERSED GROWTH) SYSTEM

FIGURE 13. Schematic of Activated Sludge Pilot Plant and Aerated Waste Stabilization (Dispersed Growth) Pilot Plant

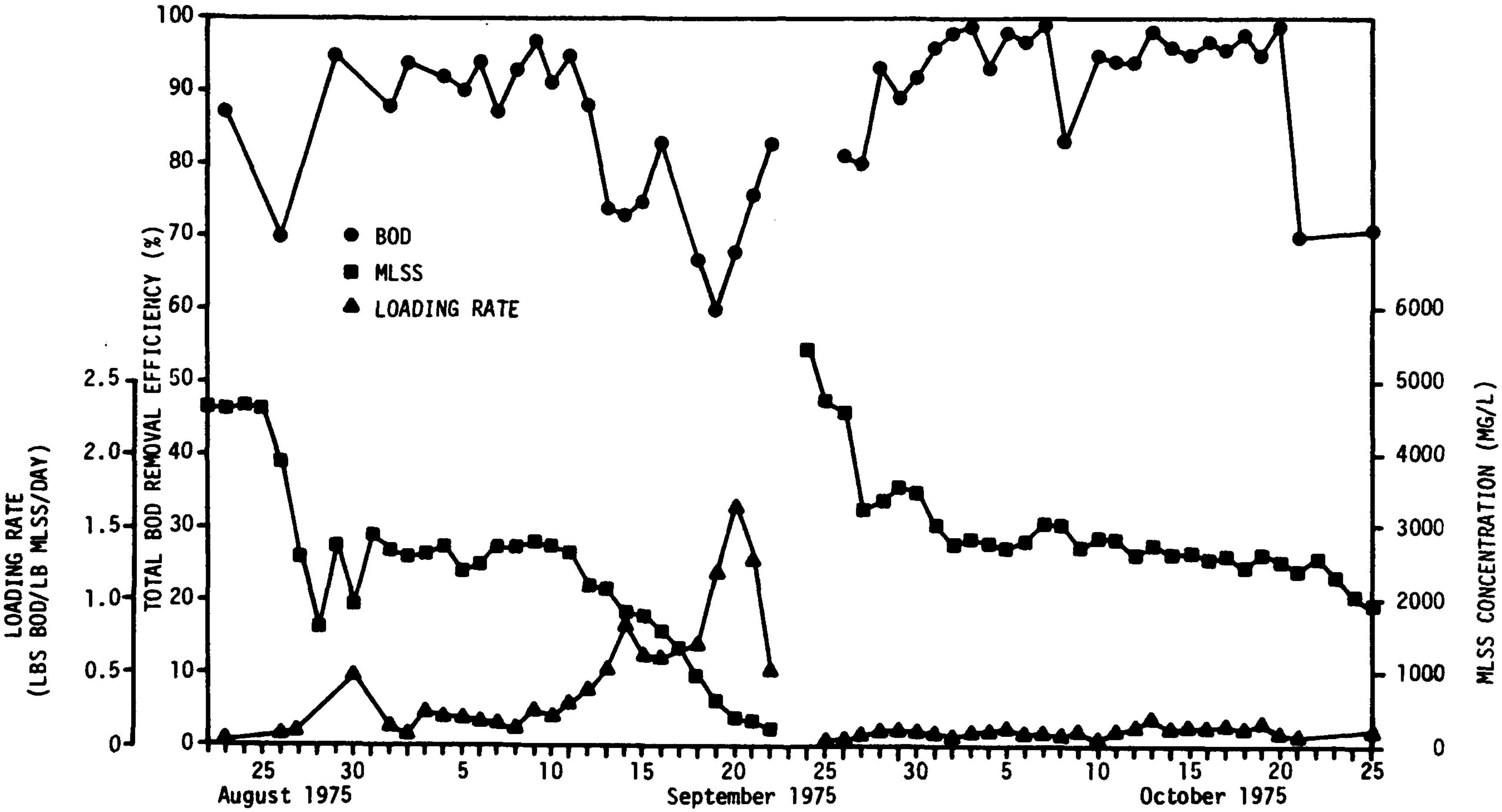


FIGURE 14. The Relationship Between Total BOD Removal Efficiency, Mixed Liquor Suspended Solids Concentration and Loading Rate for the Activated Sludge System

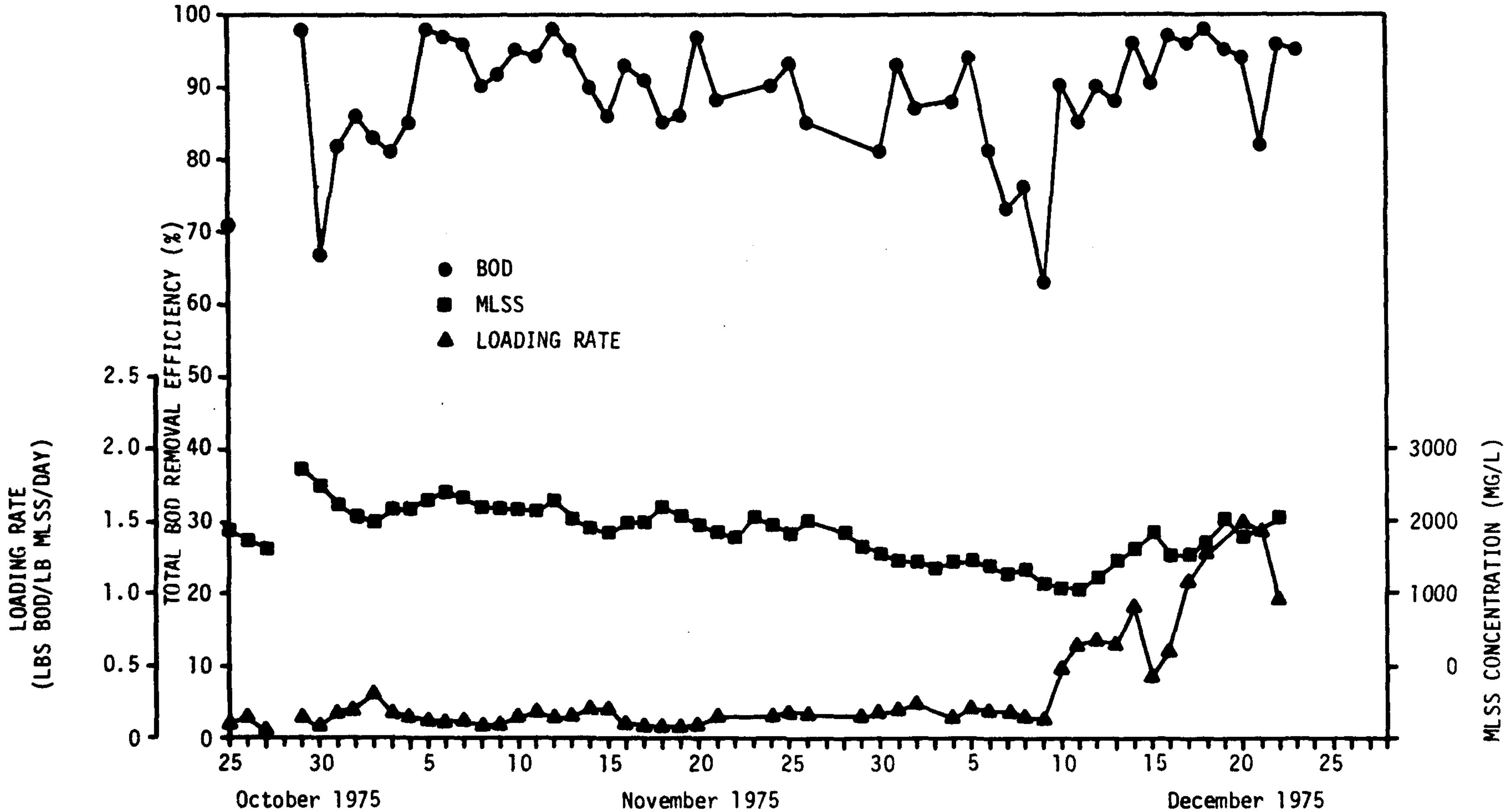


FIGURE 14. (Cont.) The Relationship Between Total BOD Removal Efficiency, Mixed Liquor Suspended Solids Concentration and Loading Rate for the Activated Sludge System

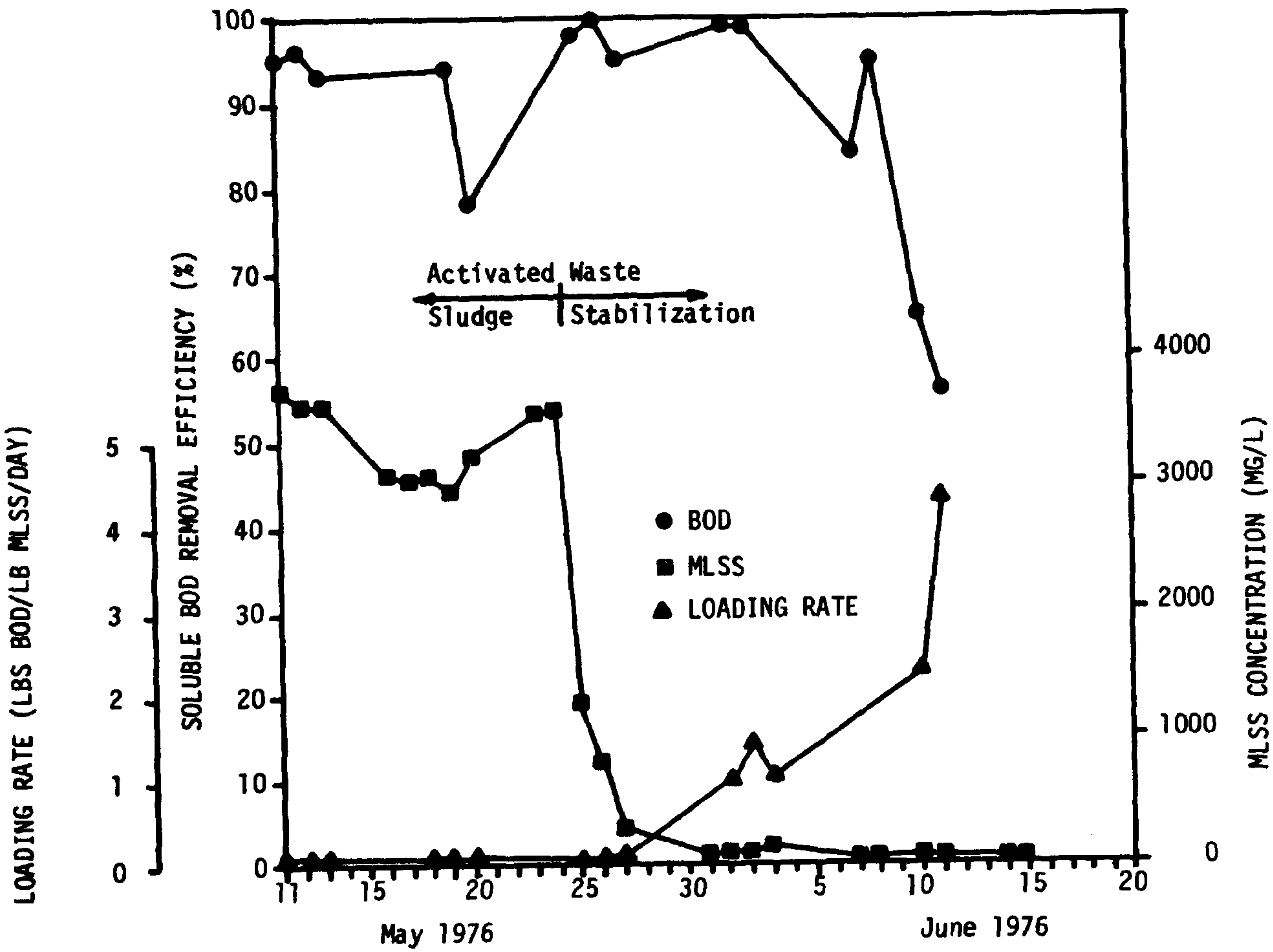


FIGURE 14. (Cont.) The Relationship Between Soluble BOD Removal Efficiency, Mixed Liquor Suspended Solids concentration and Loading Rate for the Activated Sludge and Aerated Waste Stabilization (Dispersed Growth) Systems

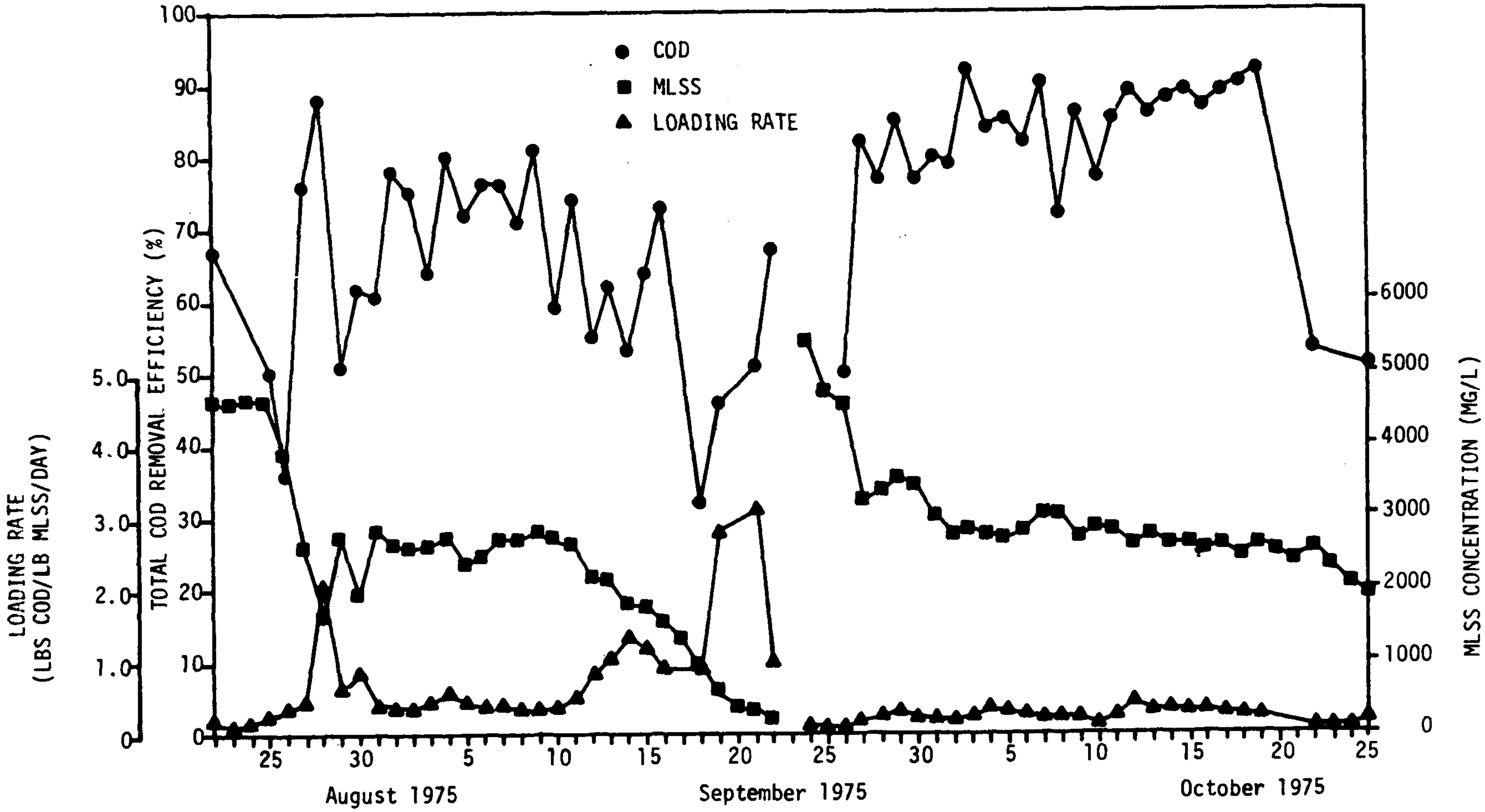


FIGURE 15. The Relationship Between Total COD Removal Efficiency, Mixed Liquor Suspended Solids Concentration and Loading Rate for the Activated Sludge System

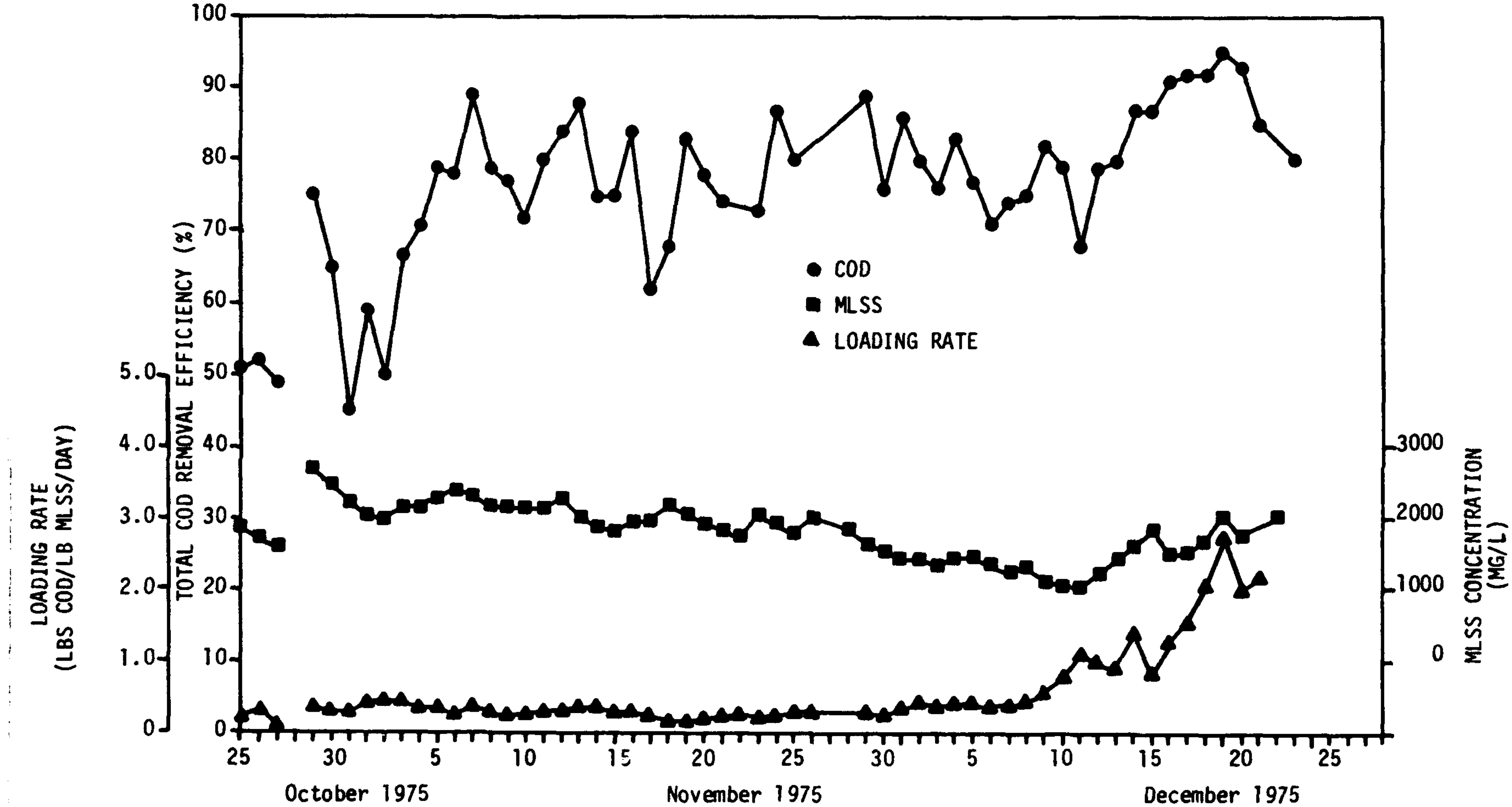


FIGURE 15. (Cont.) The Relationship Between Total COD Removal Efficiency, Mixed Liquor Suspended Solids Concentration and Loading Rate for the Activated Sludge System

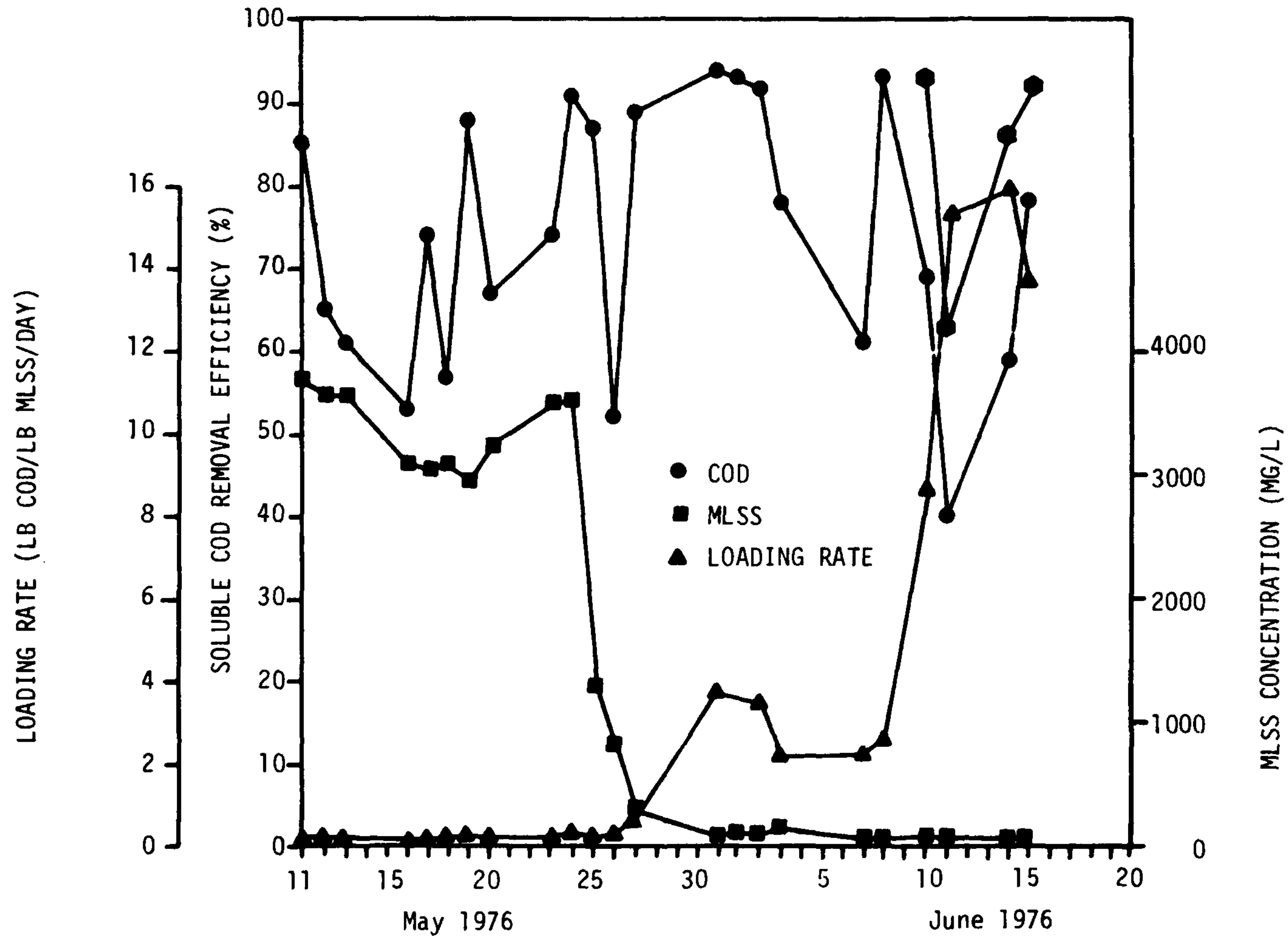


FIGURE 15. (Cont.) The Relationship Between Soluble COD Removal Efficiency, Mixed Liquor Suspended Solids and Loading Rate for the Activated Sludge System

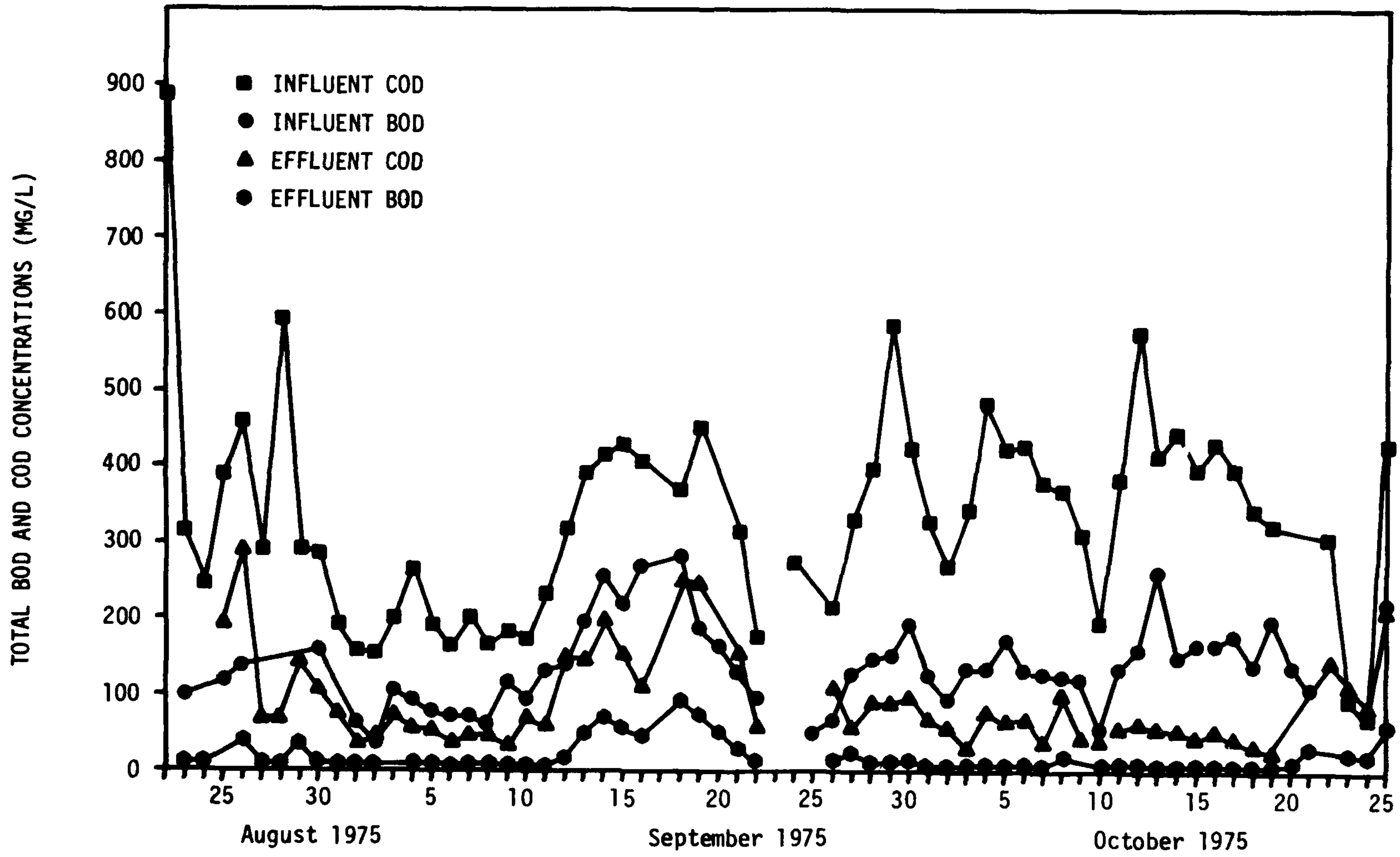


FIGURE 16. The Relationship Between Total BOD and COD Influents and Effluents for the Activated Sludge System

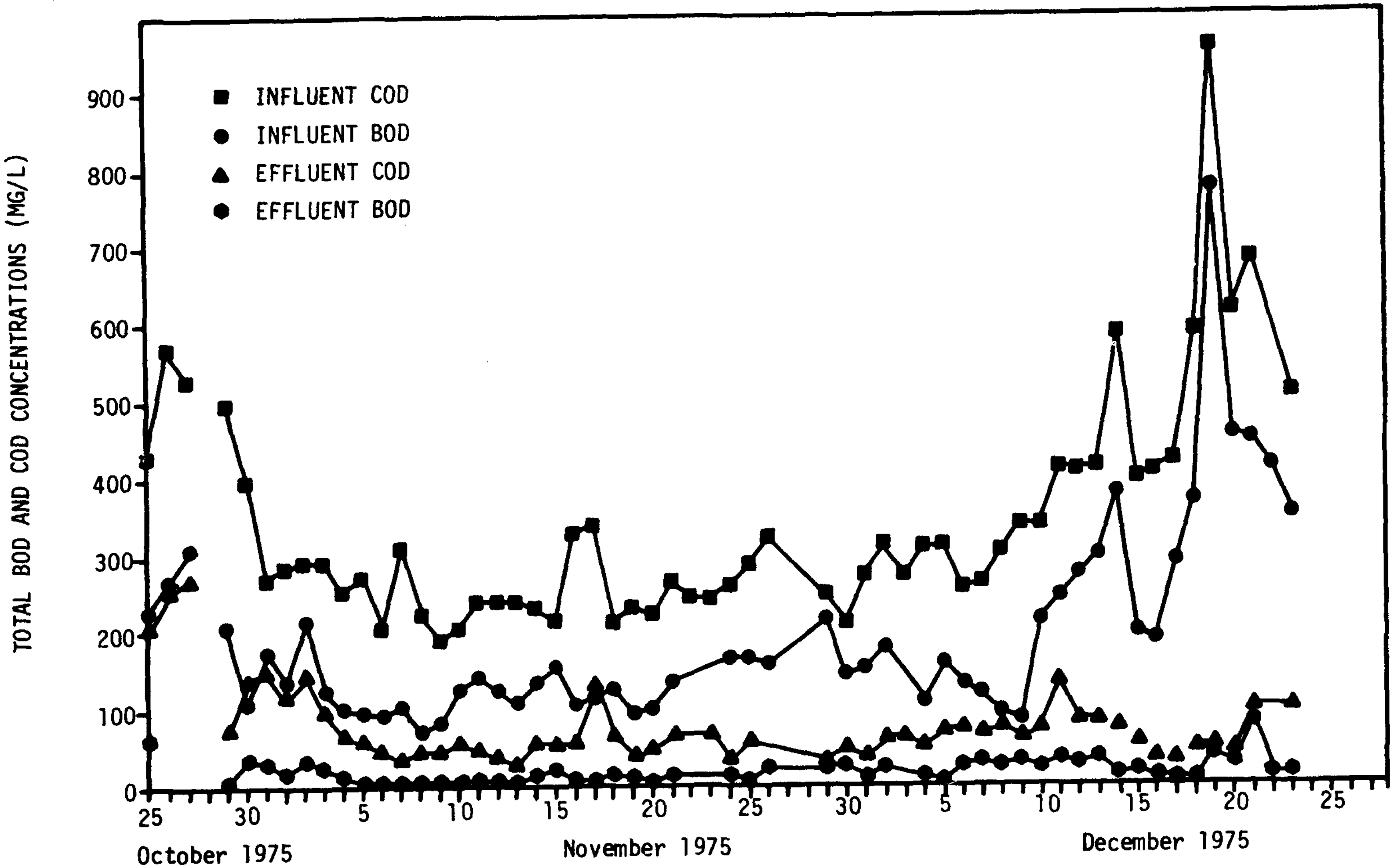


FIGURE 16. (Cont.) The Relationship Between Total BOD and COD Influents and Effluents for the Activated Sludge System

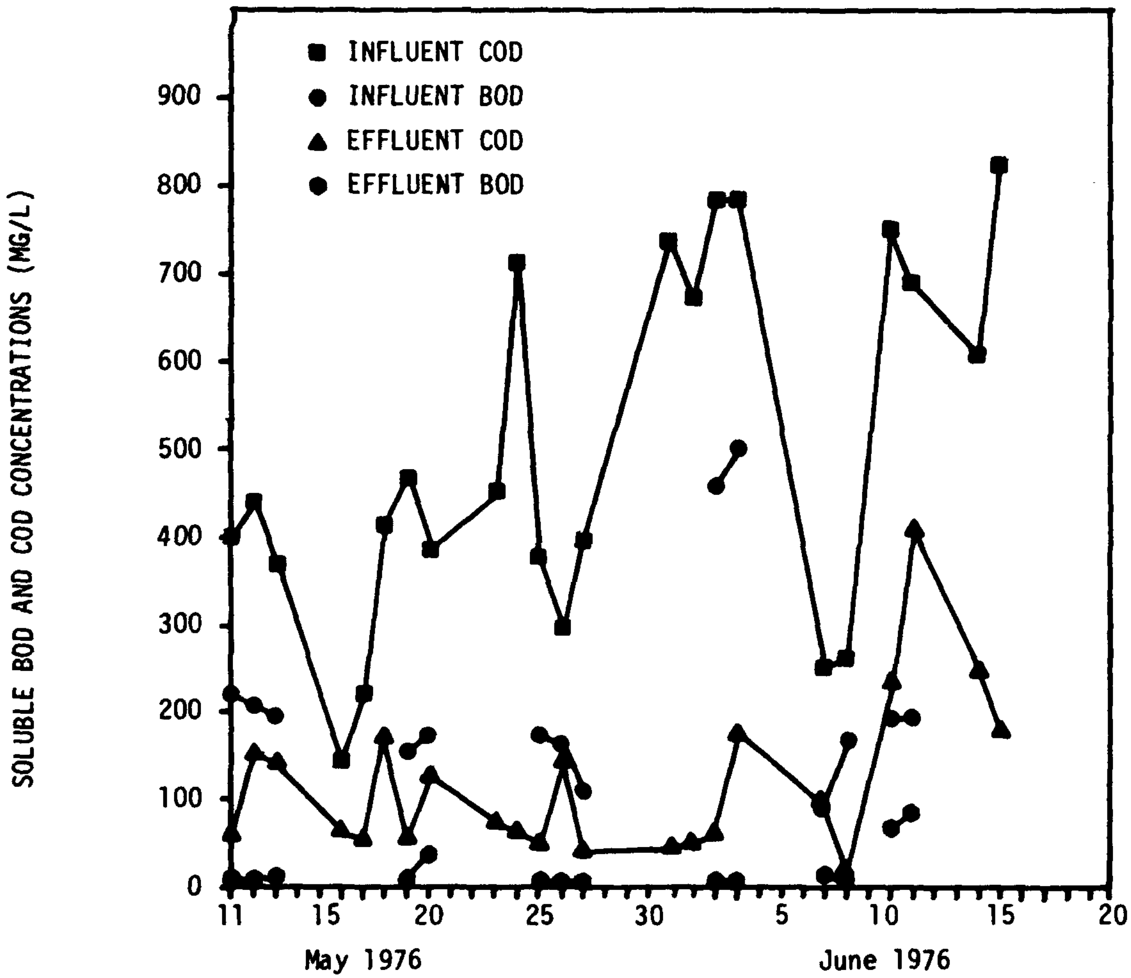


FIGURE 16. (Cont.) The Relationship Between Soluble BOD and COD Influents and Effluents for the Activated Sludge System

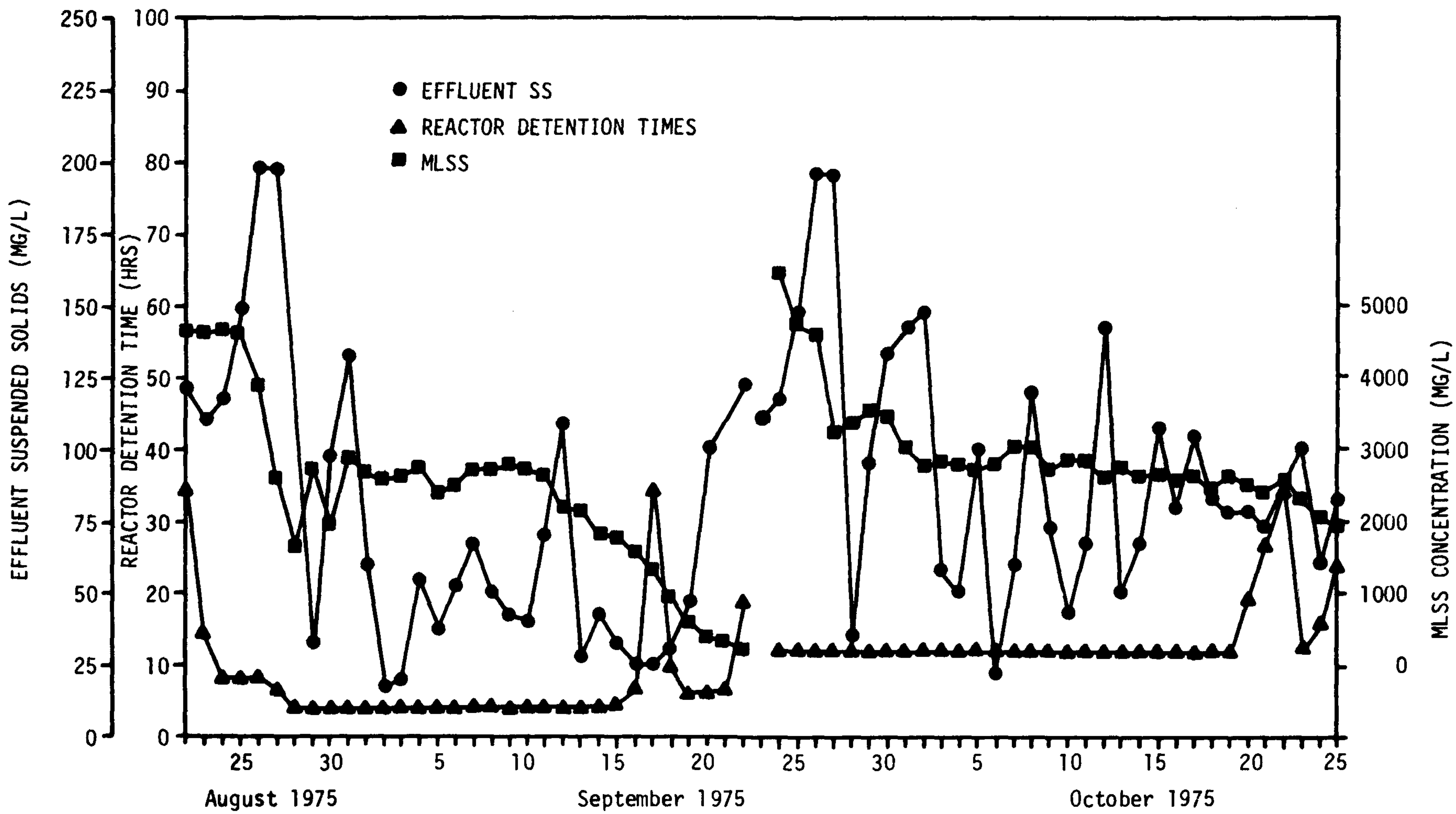


FIGURE 17. The Relationship Between Effluent Suspended Solids Concentration, Reactor Detention Time, and Mixed Liquor Suspended Solids Concentration for the Activated Sludge System

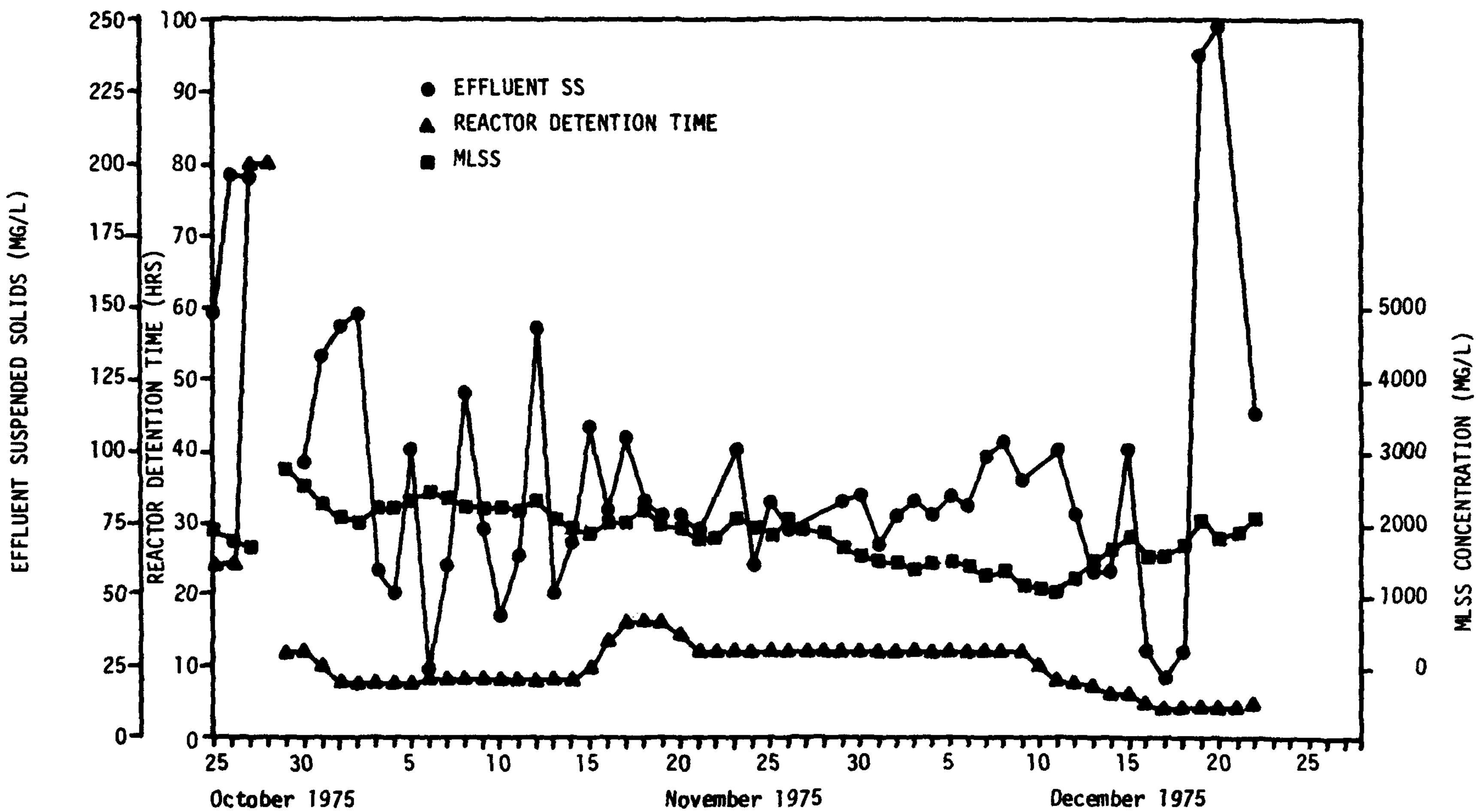


FIGURE 17. (Cont.) The Relationship Between Effluent Suspended Solids Concentration, Reactor Detention Time, and Mixed Liquor Suspended Solids Concentration for the Activated Sludge System

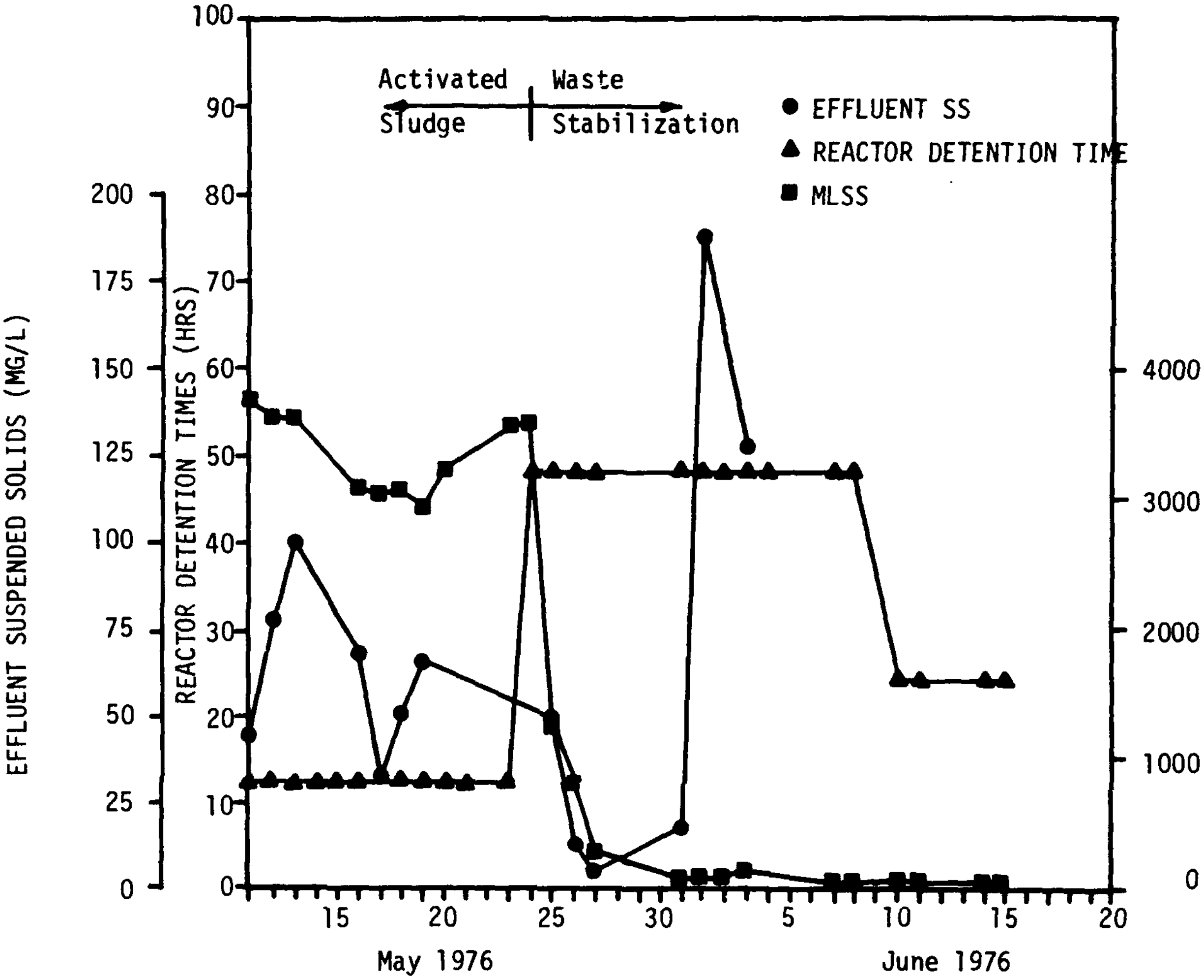


FIGURE 17. (Cont.) The Relationship Between Effluent Suspended Solids Concentration, Reactor Detention Time, and Mixed Liquor Suspended Solids Concentration for the Activated Sludge System

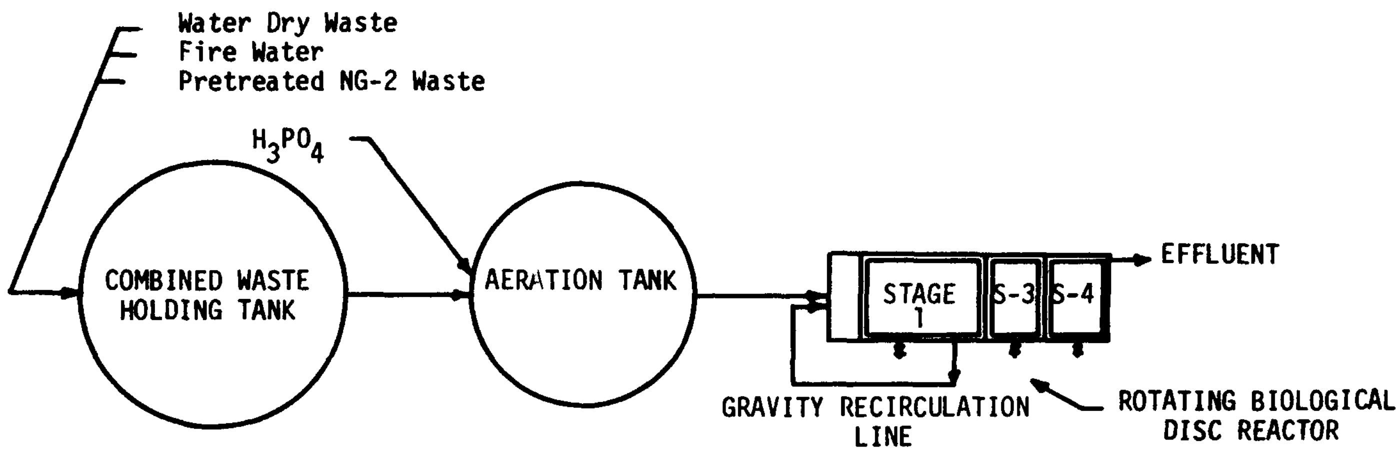


FIGURE 18. Schematic Diagram of the Combined Waste Stabilization (Dispersed Growth) and Rotating Biological Disc Treatment System

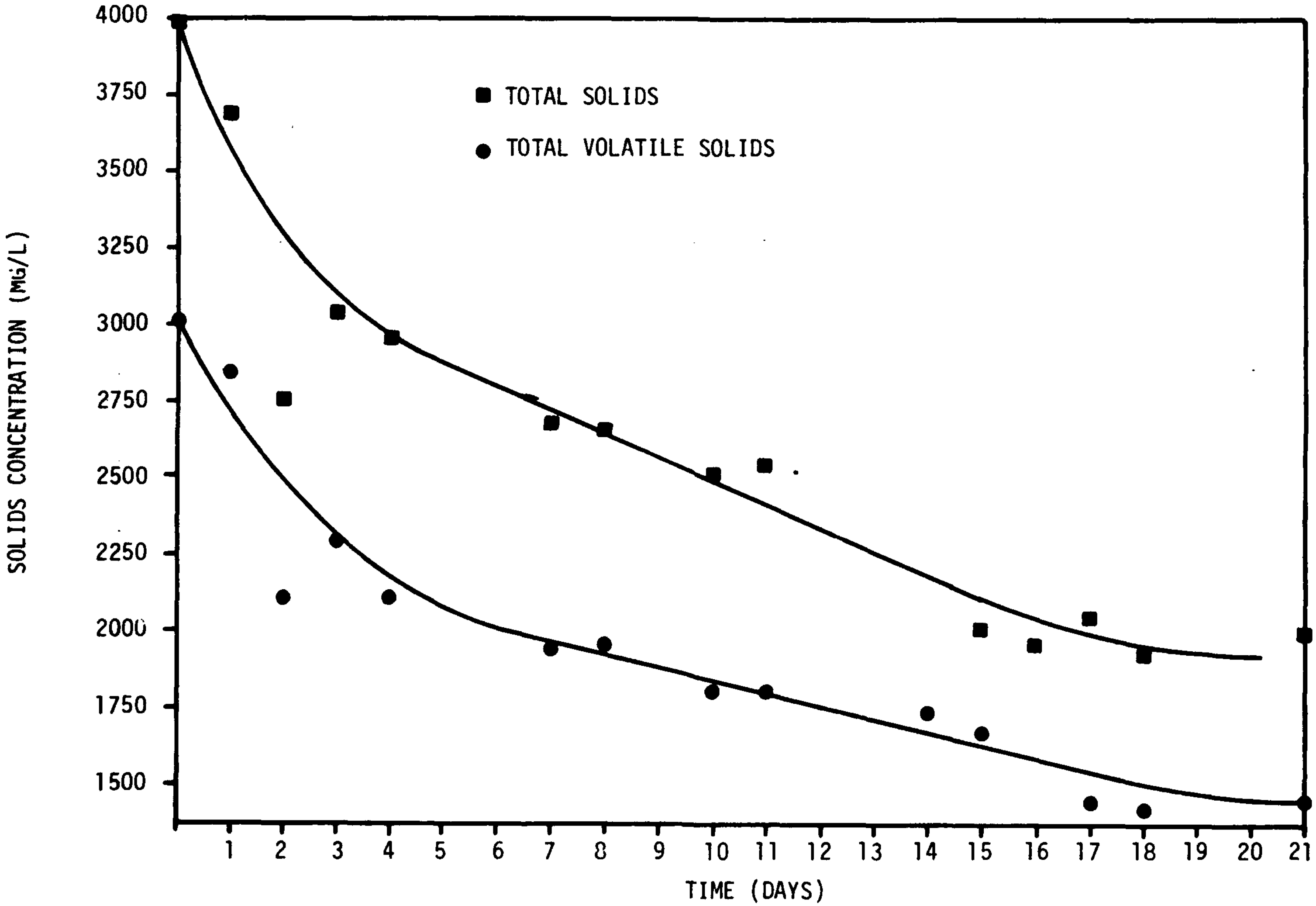


FIGURE 19. The Reduction in Total and Volatile Solids Concentration Through Aerobic Digestion Over A Twenty-Four Day Period

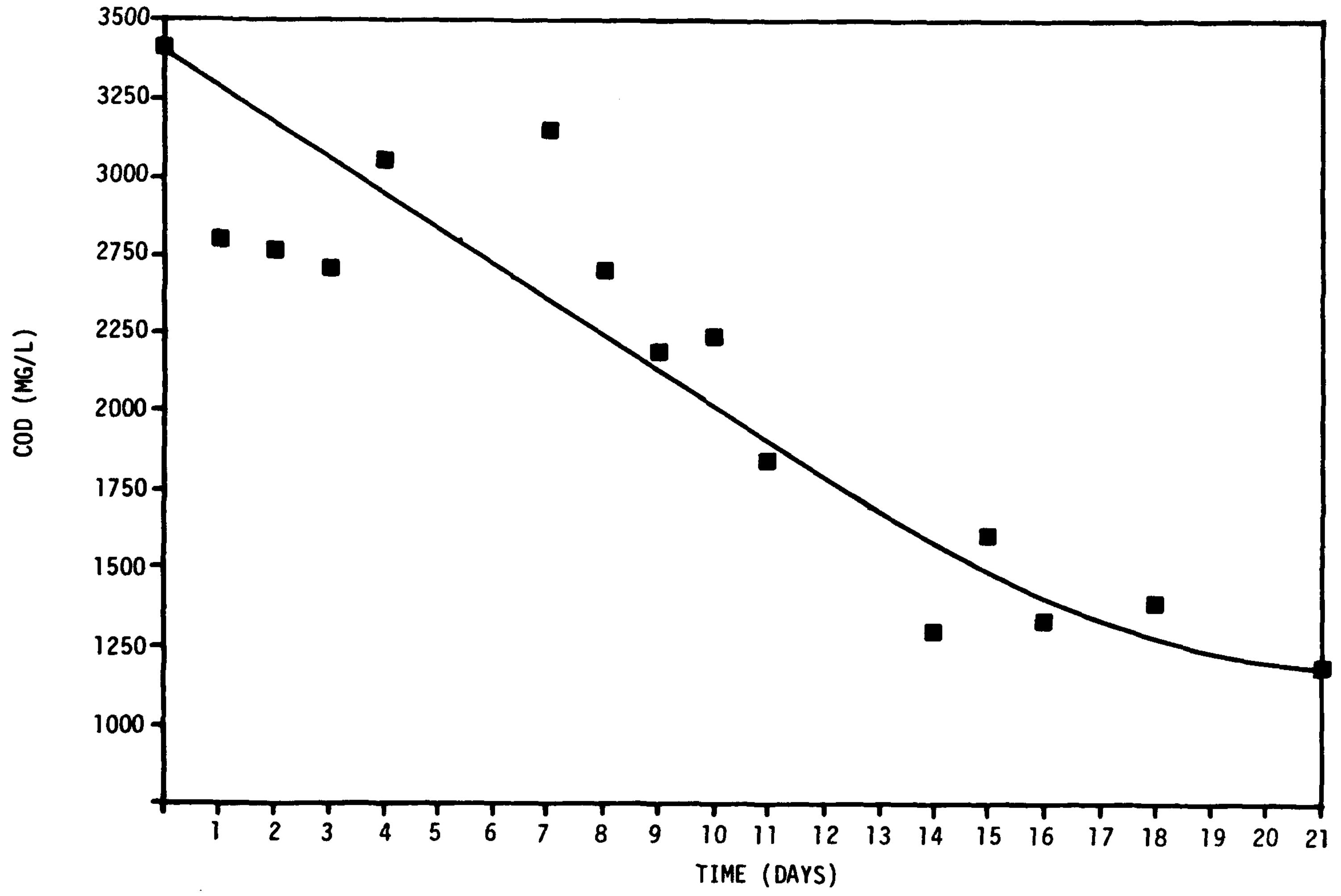


FIGURE 20. The Reduction in COD Concentration Through Aerobic Digestion Over a Twenty-One Day Period

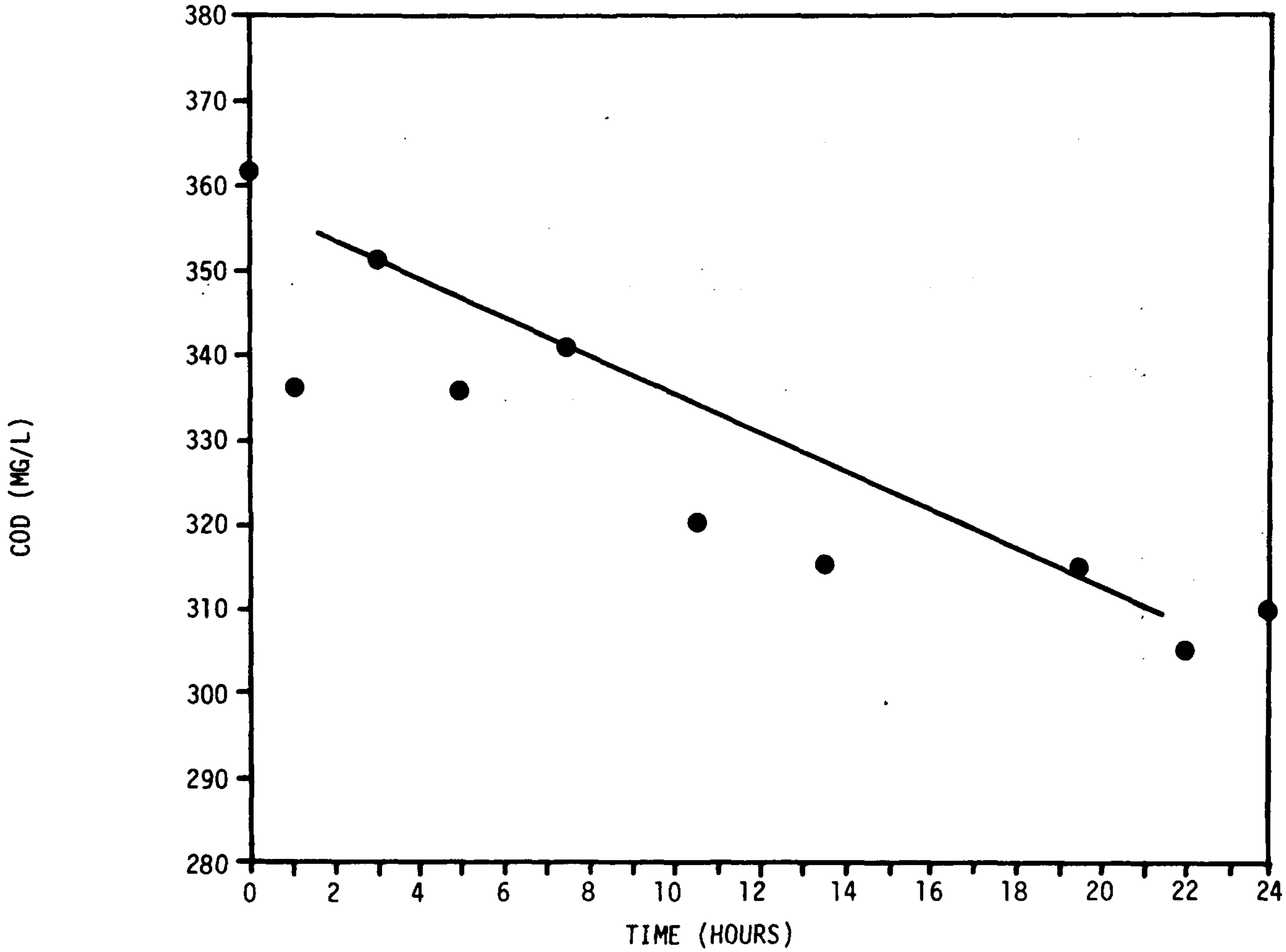


FIGURE 21. The Reduction in COD Concentration of the Combined Waste Through Air Stripping in the Activated Sludge Aeration Tank Over a Twenty-Four Hour Period

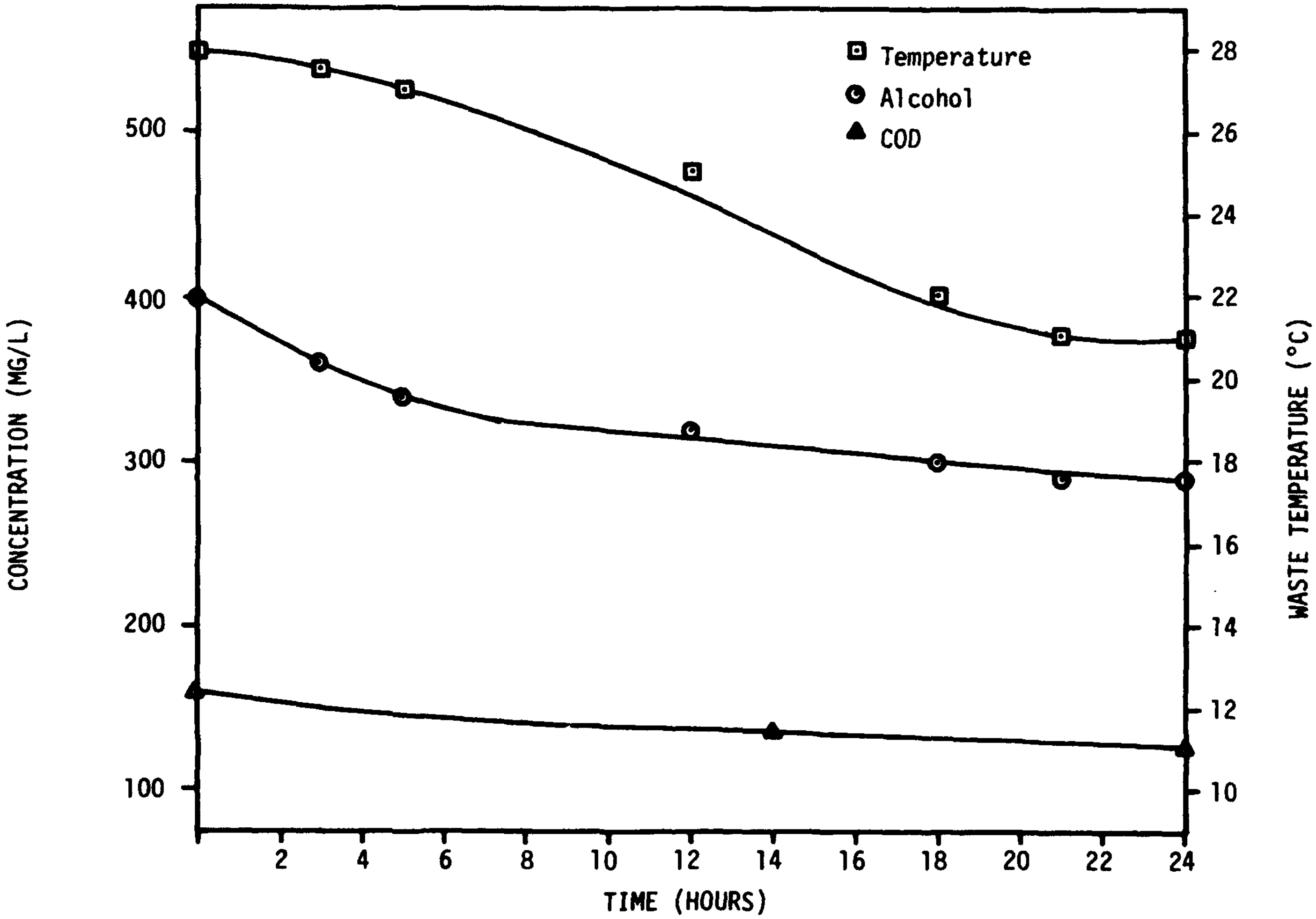


FIGURE 22. The Reduction of COD and Alcohol Concentrations of the Combined Waste Through Air Stripping in the Activated Sludge Aeration Tank

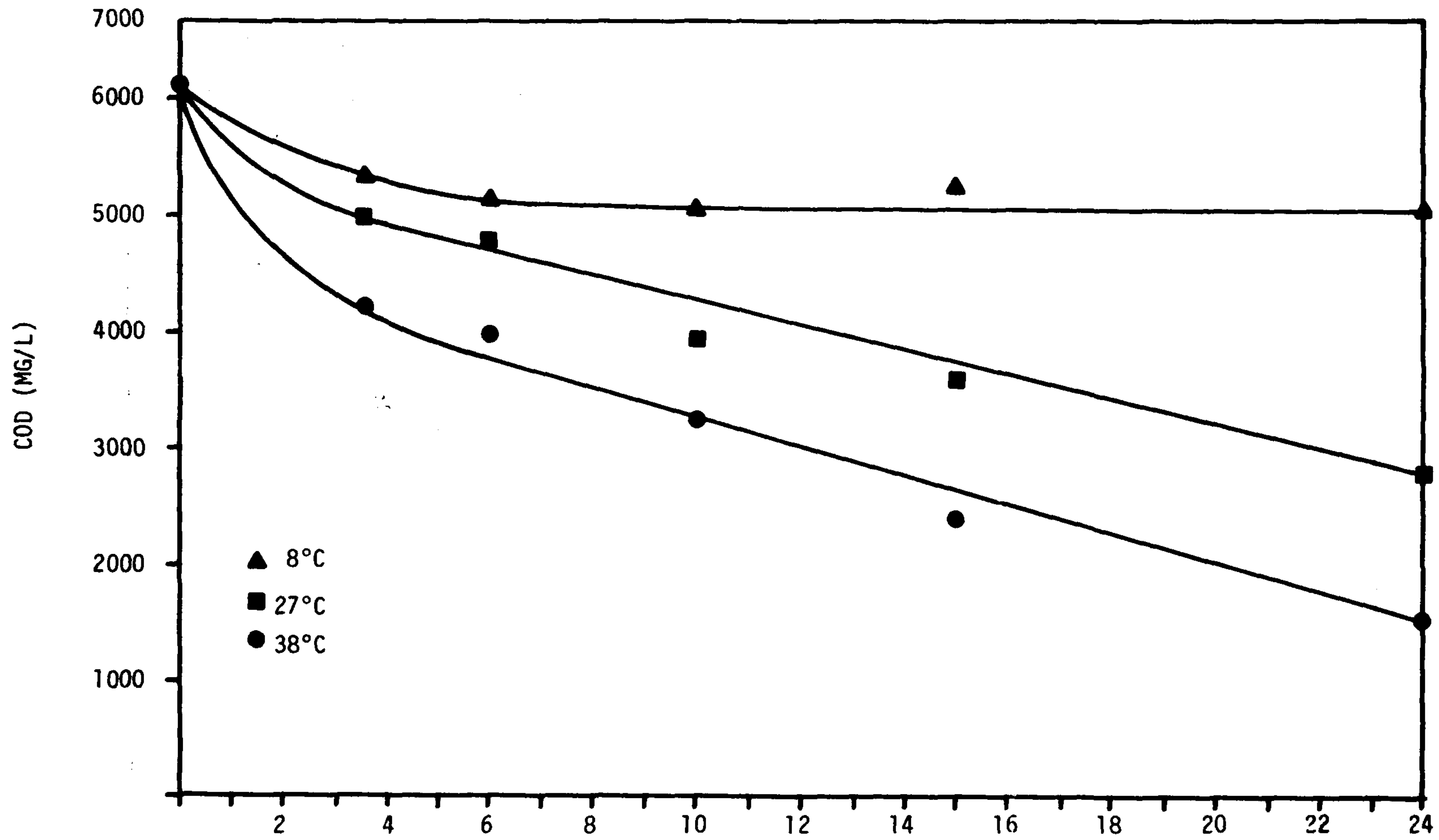


FIGURE 23. The Reduction in COD Concentrations of Water Dry Waste by Laboratory Batch Air Stripping at Controlled Temperatures

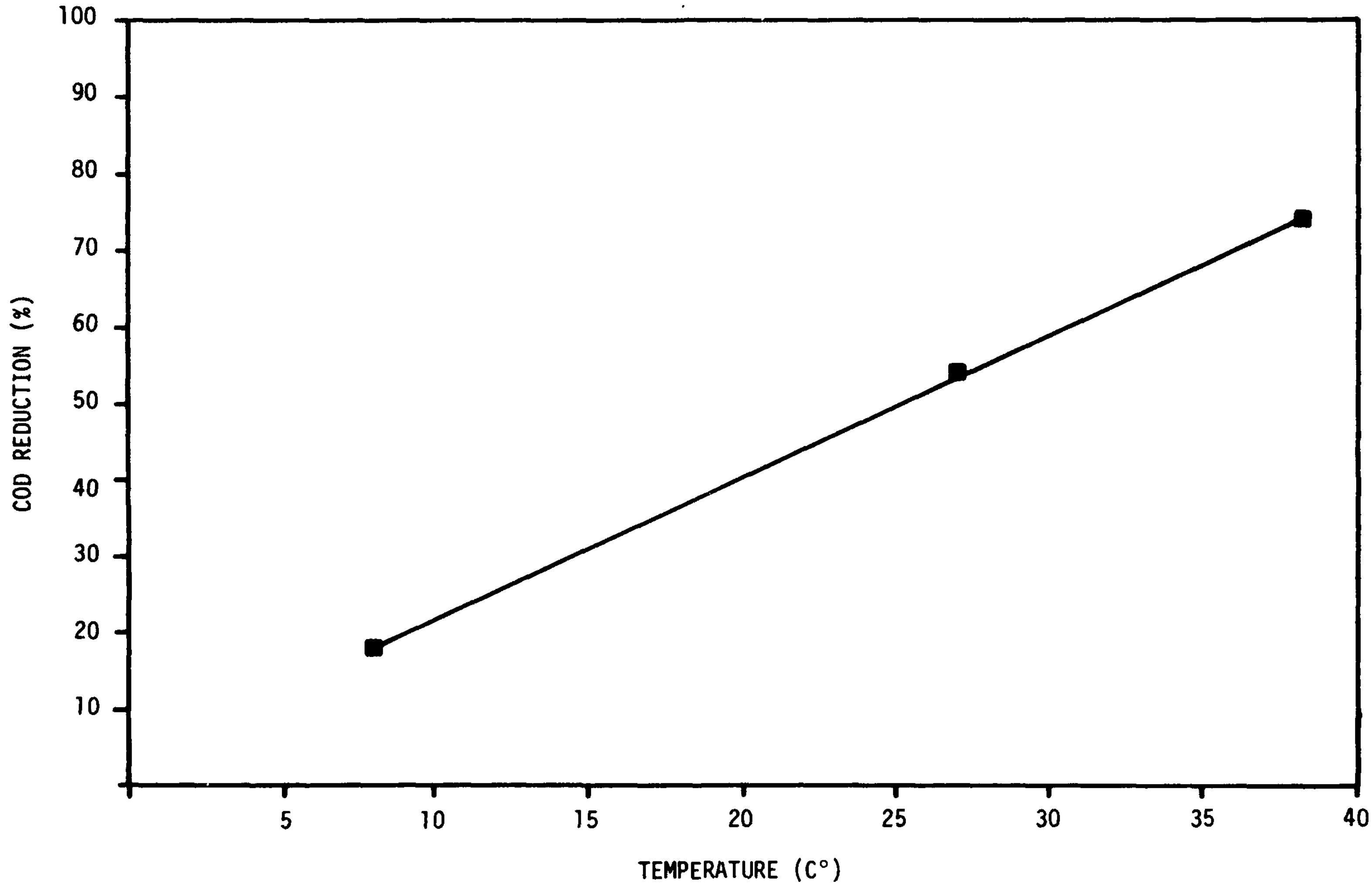


FIGURE 24. The Relationship Between Temperature and COD Reduction for Laboratory Batch Air Stripping Analysis

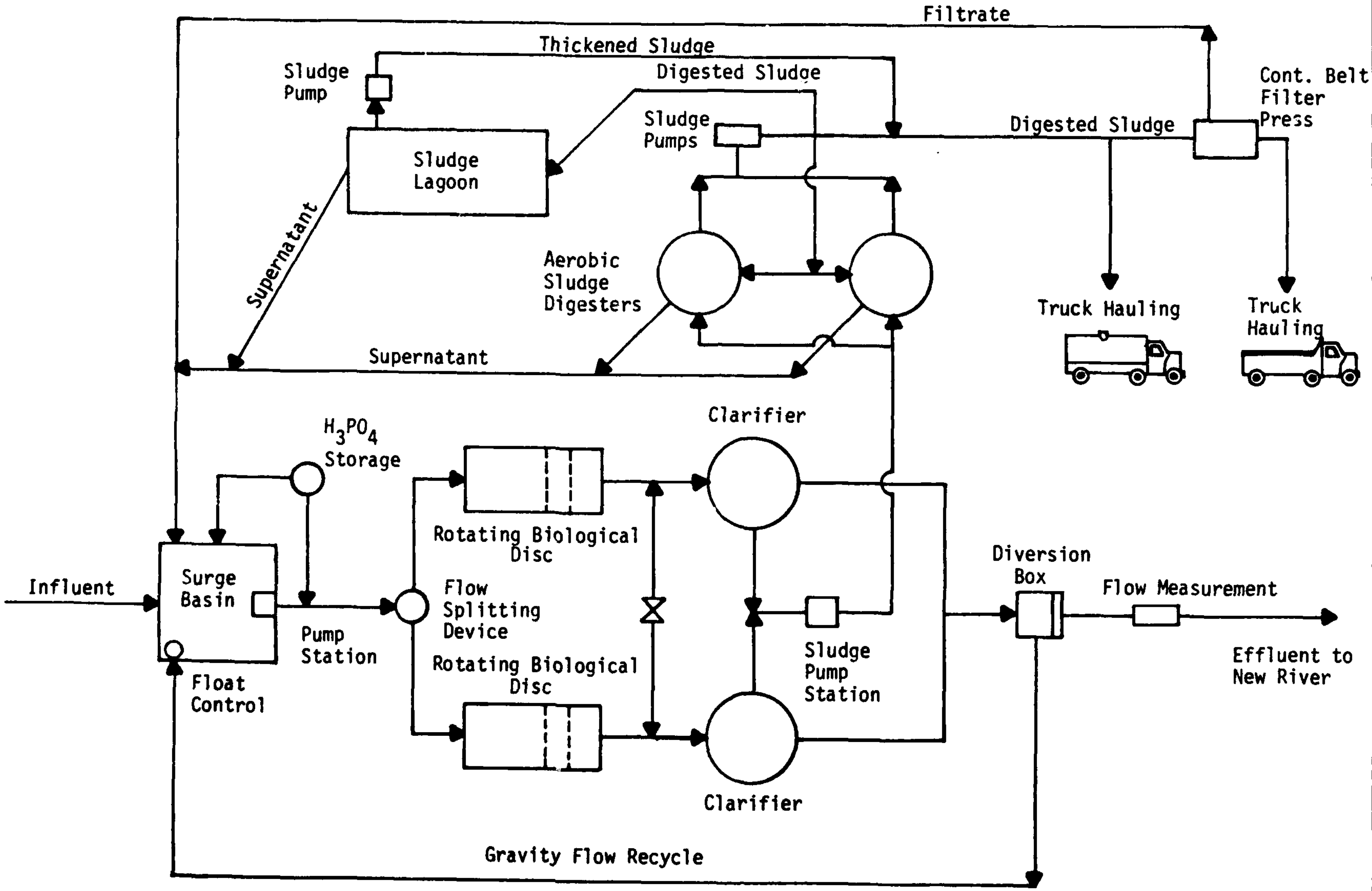


FIGURE 25. Schematic Diagram of Rotating Biological Disc Treatment System

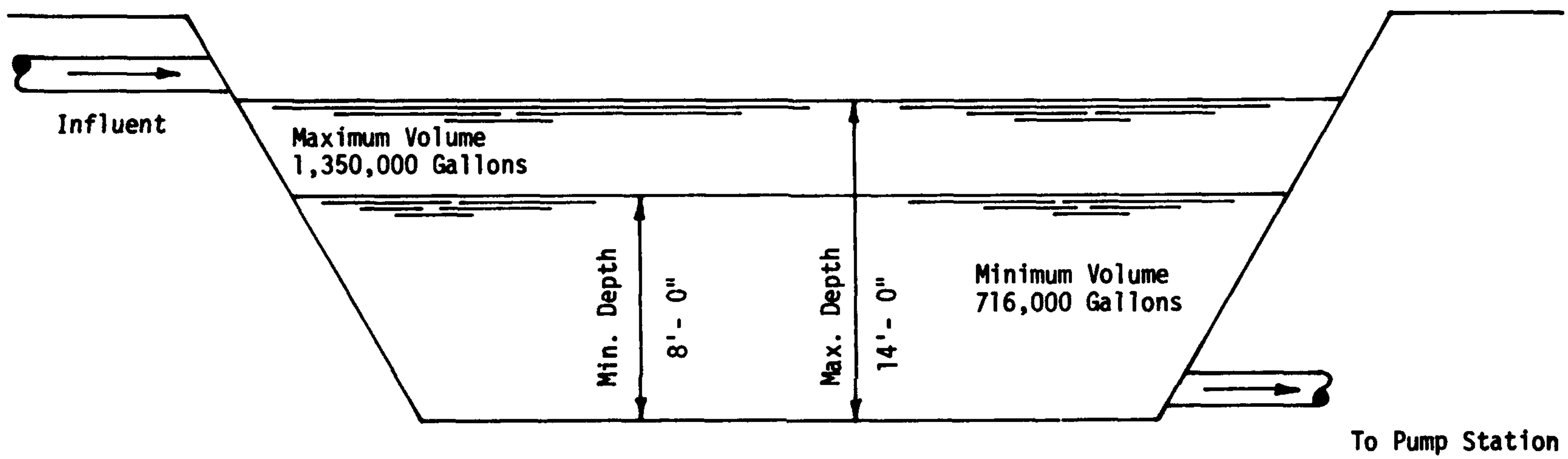


FIGURE 26. Schematic Diagram of the Surge Basin for the Rotating Biological Disc Treatment System

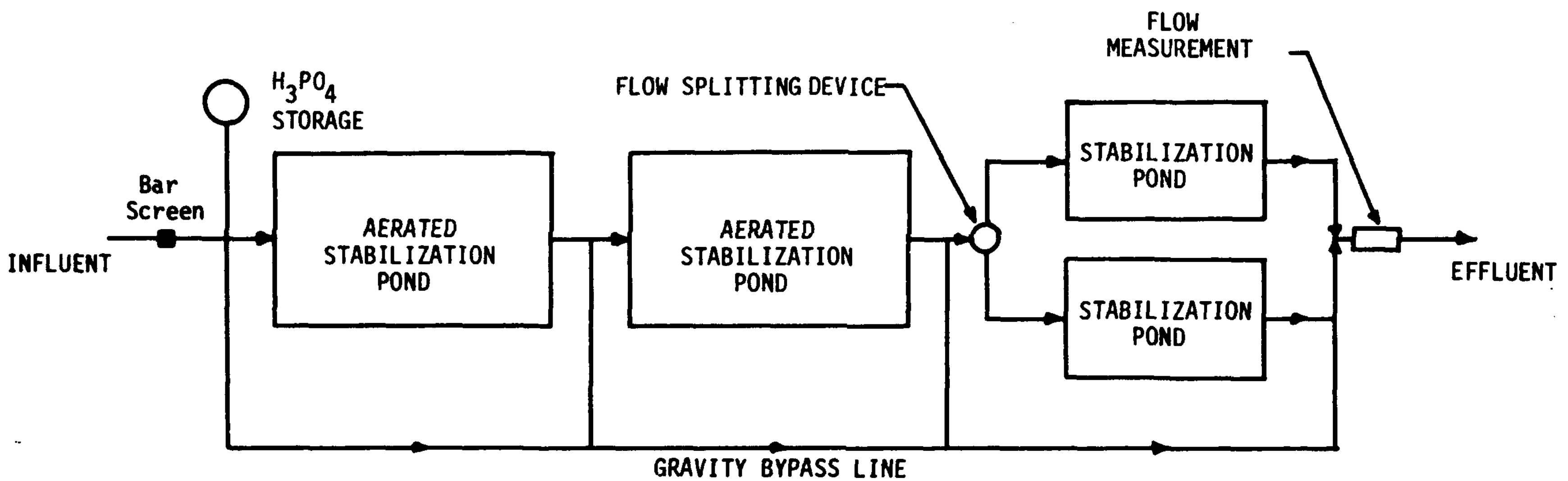


FIGURE 27. Schematic Diagram of Aerated Waste Stabilization (Dispersed Growth) Treatment System