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# Pilot Plant Installation for Fungal Treatment of Vegetable Canning Wastes


U.S. ENVIRONMENTAL PROTECTION AGENCY

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# *Pilot Plant Installation for Fungal Treatment of Vegetable Canning Wastes*

*by*

THE GREEN GIANT COMPANY
LeSuer, Minnesota 56058

*for the*

ENVIRONMENTAL PROTECTION AGENCY

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# ABSTRACT

The use of the imperfect fungus, *Trichoderma viride,* to treat corn and pea canning wastes has been tested in continuous fermentation systems at the 10,000-gallon scale. Both a pool unit with a 2-hp floating aerator and an oxidation ditch with a 3-ft rotary brush aerator were tested. The pH was controlled to approximately 3.7 and ammonium nitrogen and inorganic phosphate were added. The average residence time was about 20 hours. An aerated lagoon was also operated to compare with the two fungal systems.

In the fungal systems, about 96-percent removal of 5-day biochemical oxygen demand ($BOD_5$), 88-percent removal of chemical oxygen demand (COD) and 93-percent removal of total organic carbon (TOC) was achieved on corn canning wastes. Performance on pea canning wastes was about 95-percent $BOD_5$ removal, 81-percent COD removal, and 87-percent TOC removal. Essentially zero levels of ammonia nitrogen and inorganic phosphate could be attained in the effluent stream. Organic phosphate levels were decreased by 80 percent.

Mycelium yields were equivalent, on a dry-weight basis, to about 50 percent of the $BOD_5$ of the feed. The nitrogen content of the dry mycelium was equivalent to about 50-percent protein. The most promising fungal recovery system was a vibrating screen for bulk harvest and a sand filter to remove materials passing the vibratory screen.

Costs are estimated at 4.9 cents per pound of $BOD_5$. Sale of mycelium as feed could decrease this to 3.1 cents per pound of $BOD_5$. Operation on a year-around basis with sale of the mycelium as a feed (assuming simplified filtration requirements) would decrease costs to about 1.1 cents per pound of $BOD_5$. Direct feeding of the mycelium without drying could further reduce the net cost significantly, to about 0.8 cents per pound of $BOD_5$.

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## SECTION I

## CONCLUSIONS

1. The use of *Fungi Imperfecti* in treating corn and pea canning wastes was investigated on a pilot-plant scale. Pilot units used were a plastic swimming pool holding 10,000 gallons of waste and an aerated ditch holding 11,000 gallons. The pool was aerated with a 2-hp floating aerator and the ditch with a 3-foot cage rotor. The installations were made at the Green Giant plant at Glencoe, Minnesota. The pool was operated in the latter part of the 1969 season, and through the 3-1/2 months of the 1970 canning season. The ditch was operated during the corn canning season of 1970.

2. Both units were operated as continuous fermentations with average residence times of 18 to 22 hours, although longer residence times were used experimentally during part of the season. Sulfuric acid was added automatically as required to maintain the pH at about 3.7. Ammonium sulfate and sodium dihydrogen phosphate were added continuously at rates believed needed for vigorous growth and production of a mycelium of high protein content. Inoculation was with *Trichoderma viride*.

3. The rationale for the use of *Fungi Imperfecti* was one of converting dissolved and suspended organic matter into a mycelium that not only has a high enough protein content to have value as an animal feed, but also is large enough to be readily recovered by simple filtration or screening. Laboratory studies had indicated that fungi could be maintained as the dominant microorganisms if used as an inoculum and if the pH was kept in the range of 3 to 4. Criteria of successful operation include lowering of biochemical oxygen demand ($BOD_5$) to low levels in the effluent stream, low levels of nitrogen and phosphate in the effluent stream, ease of harvest of the mycelium, high yields of mycelium, high protein levels in the mycelium, economy of operation, and stability of microbial flora.

4. $BOD_5$ removal from corn canning wastes was about 96 percent, to yield an effluent stream of about 50 mg per liter $BOD_5$. COD removal was about 88 percent. Removal of total organic carbon (TOC) was about 93 percent. These performances could be improved to decrease residues by about one quarter by more complete clarification of the effluent. Performance on pea canning wastes was about 95 percent $BOD_5$ removal, 81 percent COD removal, and 87 percent TOC removal.

5. On corn wastes, it was possible to produce an effluent stream with lower levels of ammonia nitrogen and inorganic phosphate than could be detected by the analytical methods. The detection limits were about 1 mg per liter of nitrogen and 0.2 mg per liter of phosphate. Levels of organic phosphorous in the effluent stream were about 2.5 mg per liter. Levels in the feed stream were about 12 mg per liter. Excellent nitrogen and phosphate removals were attained only during part of the season because of inadvertent over-feeding with these nutrients. Nitrogen and phosphate removal were not investigated on pea wastes.

6. Mycelium yields were judged to be satisfactory and were equivalent on a dry-weight basis to about half the $BOD_5$ level of the feed stream.

7. Harvest of mycelium in the pilot plant was considerably more difficult than in the laboratory because a finer mycelium was obtained. One reason for the finer mycelium may be the more violent mechanical action of the aerators, although it has not been proven that this is the case. Another reason has been the appearance of fungal species other than *T. viride* with very small fine flocs. There was some evidence that low temperatures contributed to a finer mycelium during part of the season. The mycelium could not be efficiently recovered on a stationary screen as had been possible in the laboratory. About two-thirds of the mycelium could be recovered on a vibratory screen unit manufactured by the Sweco Company at a flow rate of about 6 gallons per square foot of filter area per minute. Several ways of recovering the material that passed through the vibratory screen unit were identified, with the most promising being the use of a sand bed filter. Twenty bed volumes of material could be filtered at flow rates above 2 gallons per minute per square foot of surface. The mycelium could be readily recovered by back-washing. The effluent from the sand bed had a turbidity of about 50 by the Jackson candle test. Once the mycelium had been obtained in relatively concentrated form, it could be dewatered on a vacuum filter to yield a cake of 20 percent solids content. Further drying could be accomplished at temperatures up to 100°C to yield a product of light brown color and little taste. Layers of drying fungal material had to be kept thin to avoid surface hardening.

8. Protein levels in the mycelium were examined only by analysis for total nitrogen. By this measure they were in the neighborhood of 50 percent.

9. The microbial flora remained fungal in type, but underwent shifts away from dominance by *Trichoderma viride*. On corn wastes, the pool remained *T. viride*, but the ditch changed to as high as 70 percent *Geotrichum* during midseason. It later gradually returned to a greater percentage of *T. viride*. It is speculated that oversupplying nitrogen and phosphorus could have had a role in these shifts. Laboratory studies strongly suggested that changes occurring in waste temporarily stored in the receiving lagoon were deleterious to *T. viride*. The pea waste fermentation quickly became dominated by a *Fusarium*, which matched laboratory experience with this waste stream.

10. Several factors increased costs of operation over those estimated from laboratory experience. One was higher oxygen requirements. The oxygen requirement is now estimated at 0.7 pound per pound of $BOD_5$ removed. There remains a degree of uncertainty in this estimate. Another factor increasing costs was higher sulfuric acid requirements. This is a function of water hardness, fermentation in the receiving lagoon, and $BOD_5$ concentration. Avoiding long residences in the receiving lagoon and a more concentrated waste stream would lower this cost per unit of

$BOD_5$ significantly. A third, and very important factor, was the increased investment in harvesting equipment needed to accommodate the finer mycelium. Our present estimates of treatment costs are 4.9 cents per pound of $BOD_5$. Sale of the product might lower the costs to 3.1 cents per pound of $BOD_5$. In making these calculations, a 3-month-per-year operating season has been assumed. Operating on a year-around basis would spread investment costs over a greater waste volume and lower estimates of treatment costs with sale of the recovered solids, to about 1.1 cents per pound of $BOD_5$. Elimination of the drying step could reduce the net cost to about 0.8 cents per pound of $BOD_5$. It is obvious that further economies could be achieved by use of a more concentrated waste stream, or use of softer water. Some economy could be achieved by use of shorter retention times, and we have no evidence that we were approaching the lower limits of retention time except when temperatures were below 15°C.

11. It is concluded that the *Fungi Imperfecti* system has performed credibly on a pilot-plant scale in yielding a purified effluent stream, but that costs of operation are higher than desired. Several possibilities of lowering costs are visualized and several applications can be recognized where costs would be lower, even without substantative improvements in the system.

12. An aerated lagoon was constructed late in the corn canning season and was operated along with the fungal systems. Although the lagoon covered only a partial season, performance efficiency based on $BOD_5$ removal per horsepower per day showed 92 percent. This corresponded to 95 percent $BOD_5$ removed in the fungal systems.

## SECTION II

## RECOMMENDATIONS

This study had as its objectives the determination of the feasibility of using selected imperfect fungal strains for the degradation of vegetable canning wastes, harvesting the fungal solids, and employing the fungus as the protein component in animal feed formulations.

With the establishment of the feasibility of these objectives, both in previous laboratory studies and in the studies reported here, recommendations are made for further development of this important process.

1. A larger-scale (50,000 gallon) pilot plant should be built to operate for at least ten months of the year.

2. Studies should be carried out on start-up procedures employing laboratory and pilot development of dried fungal inoculum. This material might be held in cold storage as spores or mycelium dried in vegetable waste substrate.

3. Storage survival studies are needed to ensure the viability of the dried inoculum for process start-up.

4. Necessity for, and means of, smoothing out the variations in composition of a mixed vegetable waste stream, in salt concentration, and in flow should be explored.

5. The effects of the methods of harvesting and drying on mycelium quality must be determined by studies to permit use of the final harvested solids as the protein component in animal feeds. Such a use would allow recycling of the organic waste materials and convert carbohydrate-containing wastes tc useful materials.

6. Applications to waste from other food or nonfood processes should be sought. These might include wet corn milling, meat processing, potato processing, tomato canning, paper manufacturing, and others.

7. Studies to determine the feasibility of harvesting large quantities of crude enzymes; *e.g.*, amylases, celluloses, proteases, and lipases, should be conducted.

## SECTION III

## INTRODUCTION

Investigation of a possible role for organisms of the *Fungi Imperfecti* class for treating food processing wastes was undertaken on the hypothesis that the fungi would be efficient in converting dissolved and suspended organic matter into a mycelium which could be readily recovered and which would have value as an animal feed. Laboratory studies[1] using wastes from corn canning and from soy protein isolation gave further encouragement that these hopes could be realized. Over 98-percent removal of $BOD_5$ was achieved in a 20-hour retention time. The equivalent of over 50 percent of the $BOD_5$ was recovered as mycelium. The mycelium had a favorable amino acid pattern and gave good growth of rats in limited feeding trials.

The present investigations were undertaken to determine if the promise shown in the laboratory studies could be corroborated in a field installation and with commercial equipment. Pilot-plant operation has extended over two operating seasons, but had a very late start the first season. Pea wastes were included in the second season of operation.

An aerated lagoon was operated in conjunction with the fungal pilot plants for comparative purposes.

Funding for the investigation was supplied by EPA, the Green Giant Company, the Wisconsin Canners and Freezers Association, the Minnesota Canners Association, and the National Canners Association.

# SECTION IV

# METHODS

## Physical Facilities

Pilot-plant installations were made at the Green Giant canning plant at Glencoe, Minnesota. Two types of aeration systems were used: a floating aerator installed in a plastic swimming pool, and a cage rotor installed in a circular ditch. The floating aerator was manufactured by Richards of Rockford, and was equipped with a 2-hp motor. During part of the first season the floating aerator was equipped with an impeller intended to reduce its output to one hp. An impeller which reduced output to the 1.5-hp level was used while operating on pea and silage wastes in the second season. Aeration of the ditch was accomplished with a 3-ft cage rotor aerator of 5-hp capacity, manufactured by Lakeside Engineering Company.

The pool was 23.6 feet in diameter and was filled to a depth of 3.2 feet. At this depth, it held approximately 10,000 gallons. The ditch was sized to hold 11,000 gallons. It was V-shaped in cross section and was a circle of 100-ft center-line circumference. The liquid level was 3.1 feet, and the *V* was about 8 feet across, at the surface of the liquid. The ditch was lined with rubber sheeting. In both installations, feed rate of plant effluents was regulated by a constant head tank discharged through calibrated orifices. Exit was by overflow. The feed intake for the pilot facilities was from the first of a series of lagoons in which the plant wastes are normally treated. The intake was initially 100 feet from the plant outlet, but later in the season it was moved to a position within 10 feet of the outlet. The lagoon receiving the plant waste held 13 million gallons and had an average retention time during the operating season of 4 to 15 days.

Other units in the physical plant were plastic storage tanks and metering pumps to provide input of ammonium and phosphate salt solutions, and plastic storage tanks and a recording pH meter which actuated a metering pump for acid addition. The installation is indicated in Figure 1. The ditch and pool units are pictured in Figures 2 and 3.

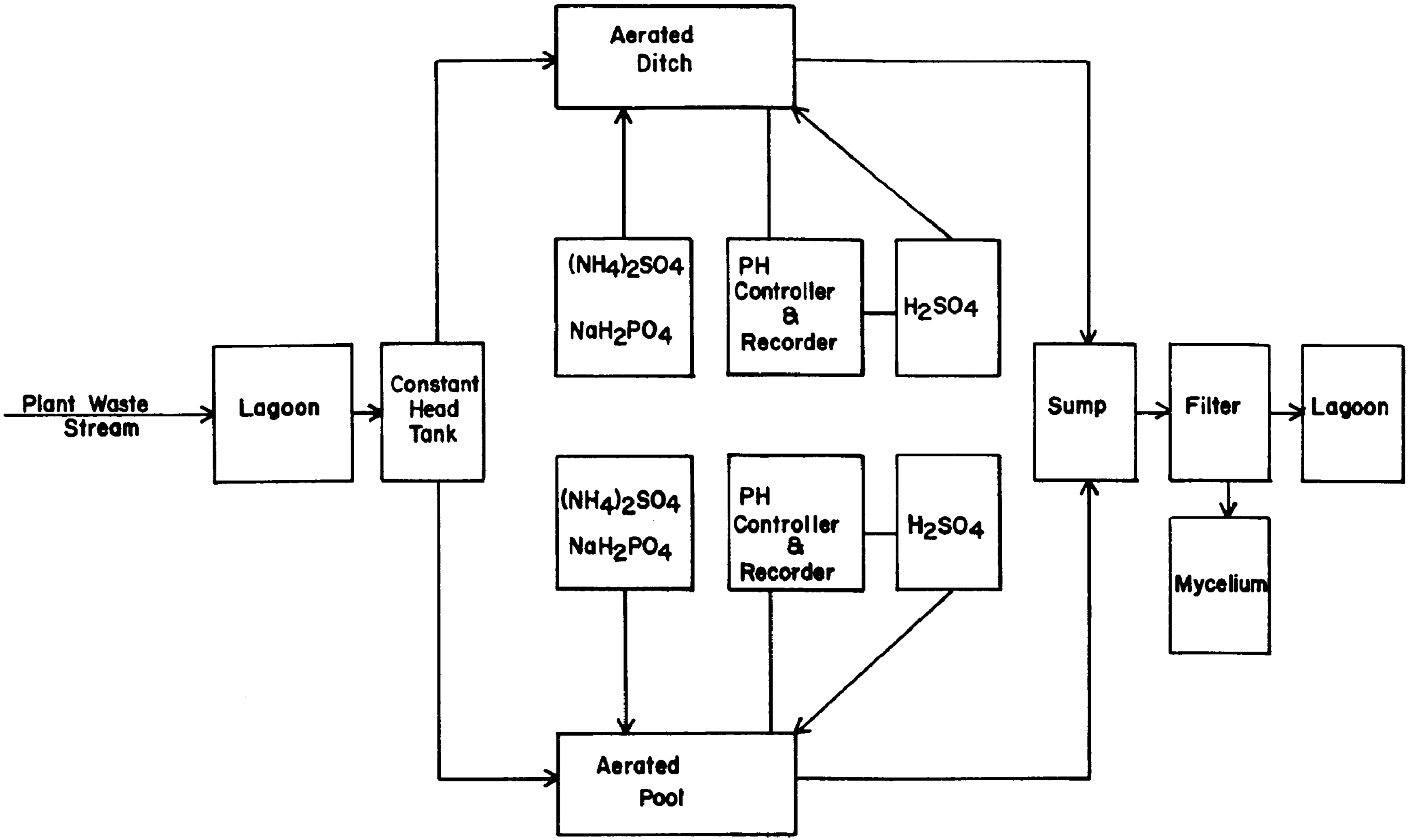



Figure 1. Schematic Diagram of the Pilot Plant Flow System

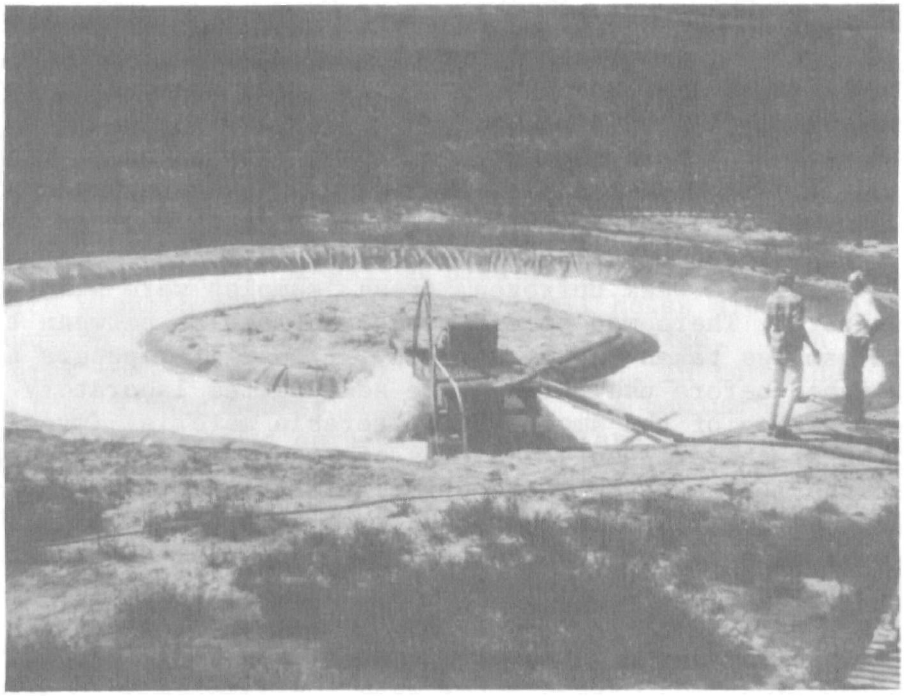


Figure 2. Aerated Ditch Used for Treatment of
Corn Canning Waste

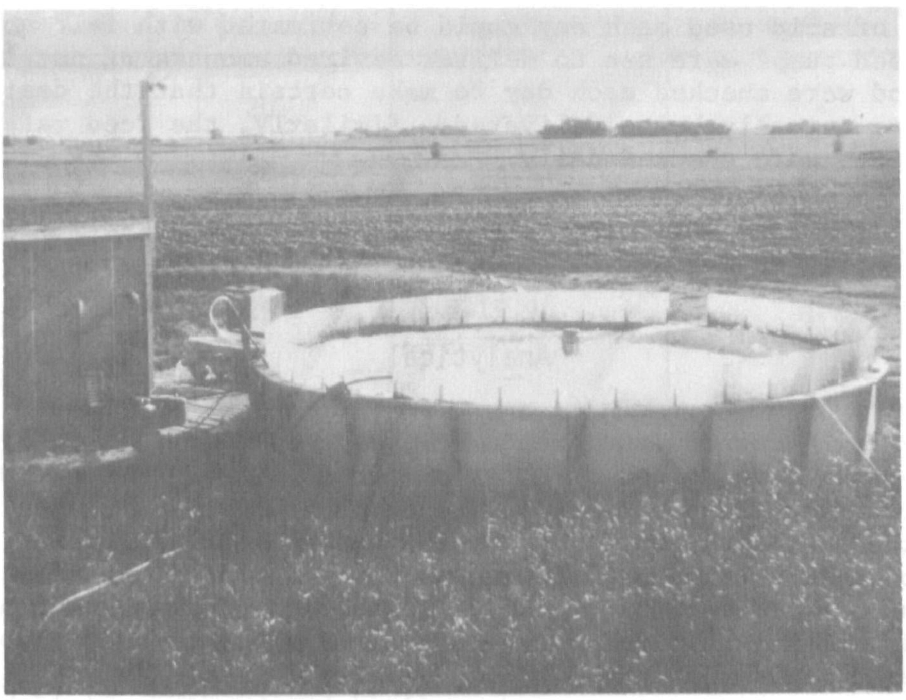


Figure 3. Aerated Pool Used for Treatment of
Corn Canning, Pea Canning and Silage Wastes

## Sampling Procedures

A technician was at the pilot-plant site for eight hours each day (three hours on Sunday) to make observations and to take samples. Samples of feed and effluent from both the ditch and pool were taken at the same time each day (11: a.m. during pea canning, 2:00 p.m. during corn canning). The effluent samples were filtered through Whatman No. 4 filter paper and frozen until they could be transported to the laboratory for analysis. Twice a week unfrozen, fresh, samples were also processed in the laboratory. There was no difference in results between the frozen and unfrozen samples taken on the same day. The filter papers had been dried and weighed before use. They were sent to the laboratory to permit determination of the amount of filterable material (mycelium) in a known volume of the effluent. Samples of feed were also frozen for transport to the laboratory without prior filtration. Since the feed was drawn from a receiving lagoon rather than directly from the plant outlet, it was believed to be adequately mixed so that single samples were representative.

Readings of dissolved oxygen (DO) levels and temperature were taken with a Yellow Springs Model 54 oxygen meter when the samples were drawn. Routinely, the probe was placed two feet from the edge of the pool, at a depth of 1.5 feet. In the ditch, it was placed just upstream of the cage rotor at a depth of two feet. At intervals in the course of the investigations, a recording dissolved-oxygen meter was available so that readings could be made around the clock. The pH was constantly monitored and recorded. The sulfuric acid storage tanks were calibrated so that the amount of acid used each day could be estimated with fair accuracy. Nutrient feed pumps were set to deliver desired amounts of nutrient solution and were checked each day to make certain that the desired amounts were actually being delivered. Similarly, the feed rates of incoming waste were checked daily.

At least every third day samples of unfiltered effluent were drawn and taken to the laboratory for microscopic examination.

## Analytical

Chemical oxygen demand measurements were made as described in *Standard Methods for the Examination of Water and Waste Water*.[2] Measurements of $BOD_5$ were carried out according to standard methods.[2] Nitrogen determinations on the wastewater were made by the Conway micro-diffusion method.[3] This method involves release of ammonia following addition of strong alkali, and is useful only for the determination of ammonium ion. However, it was suitable for determination of the amount of ammonium sulfate needed to supply the nitrogen requirements of the fungi. The nitrogen content of mycelium was determined by the micro-Kjeldahl method.[4] Phosphates were determined by the method of Fiske and Subbarow,[5] applied with and without prior acid hydrolysis. Without acid hydrolysis, the method measures only inorganic phosphorus; after acid hydrolysis, it measures total phosphate as phosphorus.

## Inoculation

Inoculation was, in each case, effected by use of a culture of *Trichoderma viride* I-23 grown in four 32-gallon plastic garbage cans. The cans were equipped with plastic pipe inserts with small holes along their length for introduction of air from a compressed air source. Each of the cans was inoculated from a shake-flask culture which, in turn, had been inoculated from a test tube slant culture. The medium used for growth of the inoculum was ground corn plus appropriate amounts of ammonium sulfate, sodium dihydrogen phosphate, and sulfuric acid. Successive additions of this nutrient were made as fungal growth occurred. Successive additions were made richer in total nutrient. In this way, a final inoculum of 80 gallons containing 5.6 grams of mycelium (dry weight) per liter was attained in four days. Steps in the growth cycle of the inoculum for each can are shown in Table 1.

Table 1. Growth of Inoculum

| Hours after Inoculation | Additions | | Dry Weight Fungal Mass* (g/liter) |
|---|---|---|---|
| | Volume (liters) | Concentration Solids (g/liter) | |
| 0 | 20 | 1.1 | -- |
| 24 | 20 | 2.3 | 0.8 |
| 48 | 20 | 10.7 | 1.4 |
| 72 | 20 | 19.1 | 2.9 |
| 112 | 20 | -- | 5.6 |

*To some degree the fungal mass included suspended solids from the ground corn.

The pool and ditch each contained about 4500 gallons of canning waste at the time of inoculation. Feed was either started very slowly or delayed until the culture became established.

One variant of this procedure was the use of equal amounts of ground peas and corn to prepare inoculum for pea canning wastes.

Another variant used in the first season was to use corn canning wastes as the medium for inoculum propagation; a continuous culture was simulated by dipping out part of the culture at regular intervals during growth. and replacing the volume removed with fresh corn wastes to which the required inorganic nutrients had been added.

## Harvesting

A Sweco, Inc. Model LC-18-C-333 filter unit, with a one-square-foot filter surface, was used on-line during part of the season. Other mycelium recovery techniques were tried on a laboratory scale during the same period.,

## Operating Calender

The pool unit was operated on corn canning wastes during the 1969 canning season (September 12 until October 13). The canning operation ended on September 20, so subsequent operation depended entirely on wastes held in the receiving lagoon. In 1970, the pool unit was operated on pea canning wastes from June 22 until August 8. Silage juice supplemented the peas wastes from July 26 until August 8. The pool was operated on corn canning wastes from August 31 until September 29. Two failures of pH control instruments rendered pool operations ineffective between August 8 and August 31. The ditch unit was operated in 1970 on corn canning wastes from August 9 to October 2. Canning plant operation ceased on September 22.

# SECTION V

# RESULTS

## Corn Waste

The bulk of the detailed results on treatment of wastes was obtained during the second season of operation. Except as otherwise noted, the data reported are taken from the second season.

### Operating Parameters

Variables which might affect the operation of the waste treatment system are:

- Nature of the feed
- Organism used for inoculation
- pH control
- Temperature
- Retention time
- Inorganic nutrient addition
- Oxygen level
- Stirring

Some of these variables were controlled by the operator; some were not.

Some of the characteristics of the feed are indicated by measurements made on a composite sample composed of equal aliquots from frozen and thawed samples obtained from the heart of the operating season (from August 19 to September 20). Results of the examination are shown in Table 2.

The temperature pattern encountered during the operating season is shown in Figure 4. Measurements were made at 2 p.m. each day. It should be noted that the temperature of the ditch was characteristically about one degree higher than that of the pool. This is thought to be caused by the protection provided by its sunken position.

The effect of variations in retention time was investigated; the time was also altered occasionally in response to other events. It was deliberately maintained high (a low flow rate) immediately after inoculation. Also, at day 21, the retention time in the ditch was reduced for two days because a failure of the pH control equipment had allowed the pH to drop

Table 2. Characteristics of Composite Sample of Corn Waste

| | Mg/1 |
|---|---|
| COD | 2536 |
| $BOD_5$ | 1564 |
| TOC | 1632 |
| Total solids | 2520 |
| Filterable solids (suspended) | 210 |
| Volatile solids | 1490 |
| Ash | 923 |
| pH | 6.9 |
| Ammonium nitrogen | 35 |
| Phosphate, as P | 8.5 |
| Acid to titrate to pH 3.7 ($H_2SO_4$) | 450 |

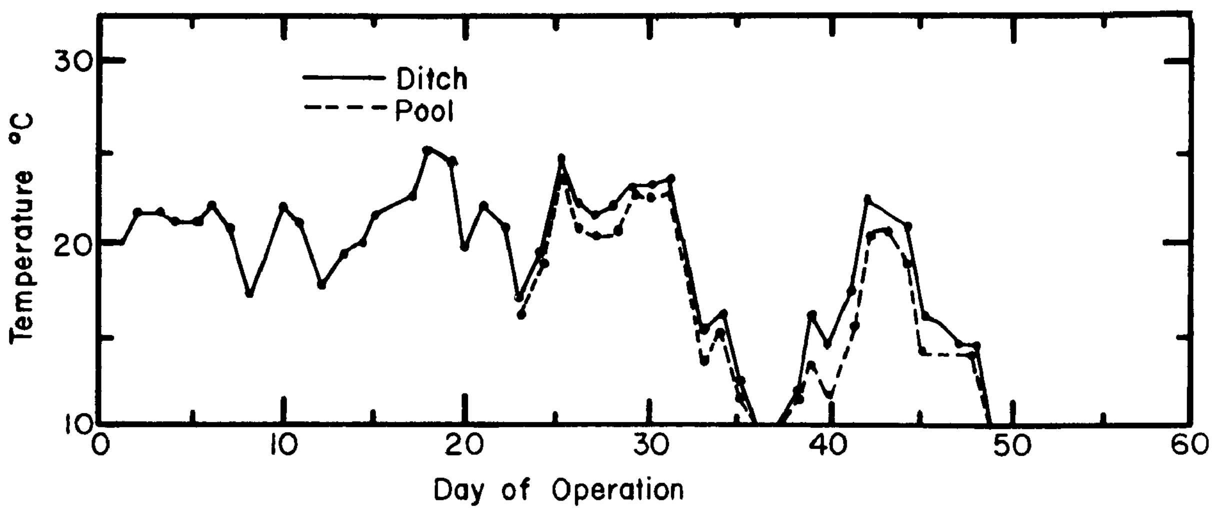



Figure 4. Temperature of Corn Waste Treatment System Measured at 2 p.m. Each Day

to levels that impaired culture performance. The pool was operated at longer retention times than desired during part of the season because of partial failure of a sump pump. (The retention times are represented in Figure 5.) The retention times, together with the COD or $BOD_5$ levels, governed the daily loading, which are shown in Figure 6 for the ditch and in Figure 7 for the pool.

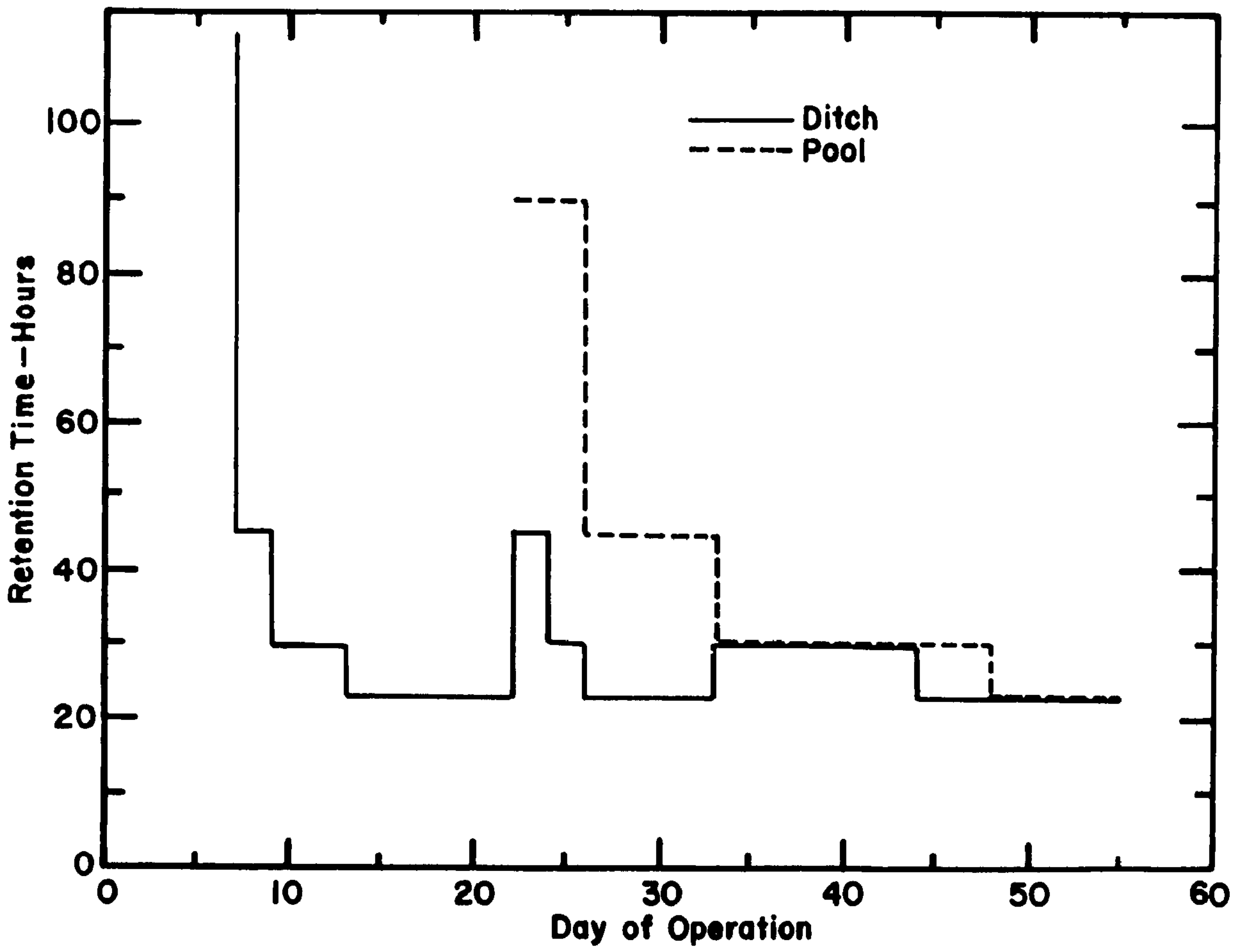



Figure 5. Retention Time of Corn Waste in the Ditch and in the Pool

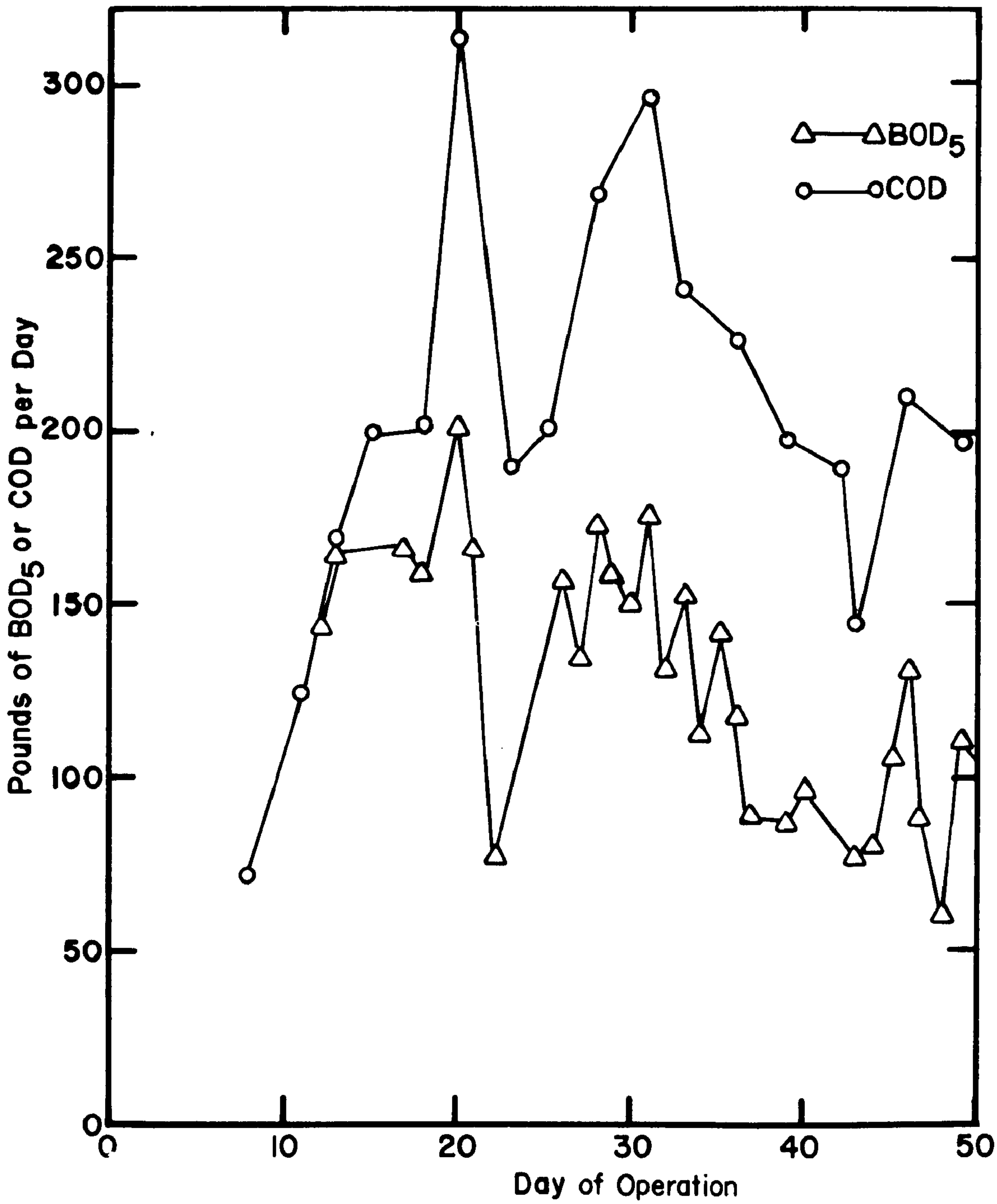



Figure 6. Total Loading of Ditch in Pounds of $BOD_5$ or COD per Day During Operation on Corn Canning Wastes

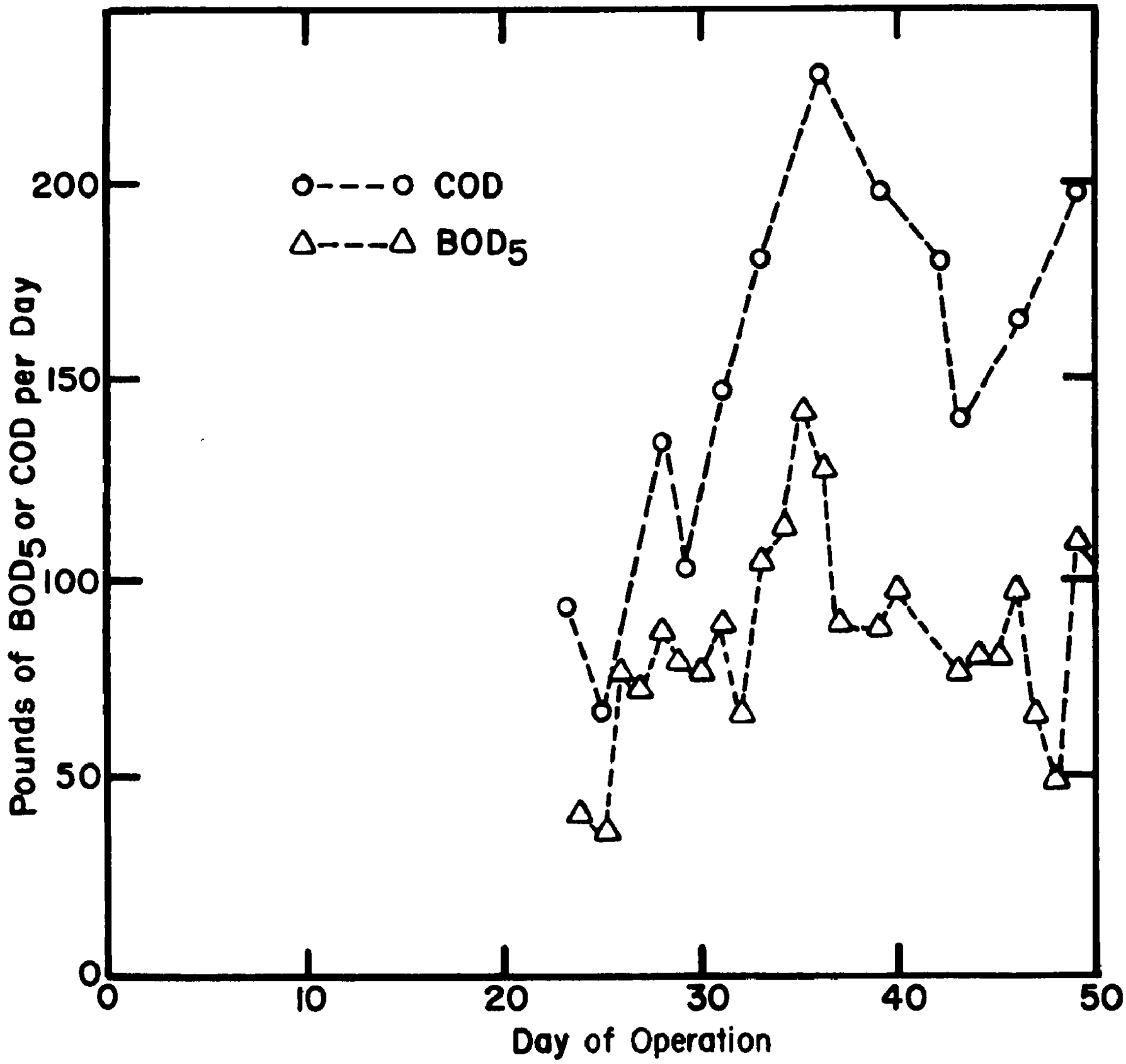



Figure 7. Total Loading of Pool in Pounds of $BOD_5$ or COD per Day During Operation on Corn Canning Wastes

Ammonium sulfate and sodium dihydrogen phosphate were added in amounts required, based on prior experience. Alterations were made as feed rates were changed; as the average COD changed; and as excesses or possible deficiencies occurred as indicated by analyses of the effluent. The amounts of inorganic nutrients used are indicated in pounds per 1000 gallons of corn waste feed in Figure 8 for the ditch and in Figure 9 for the pool.

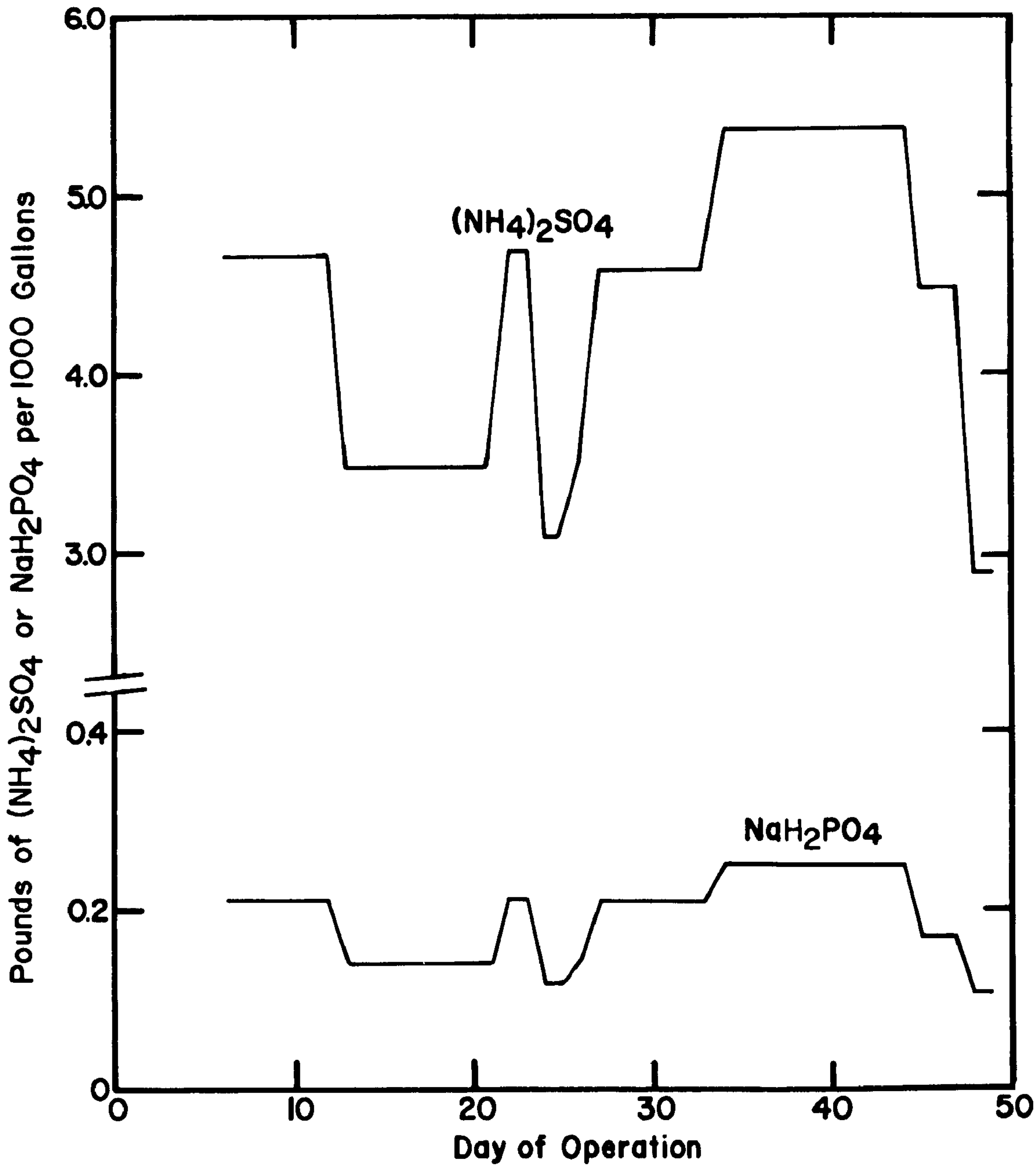



Figure 8. Ammonium Sulfate and Sodium Dihydrogen Phosphate Additions to Ditch in Pounds per 1000 Gallons of Corn Feed

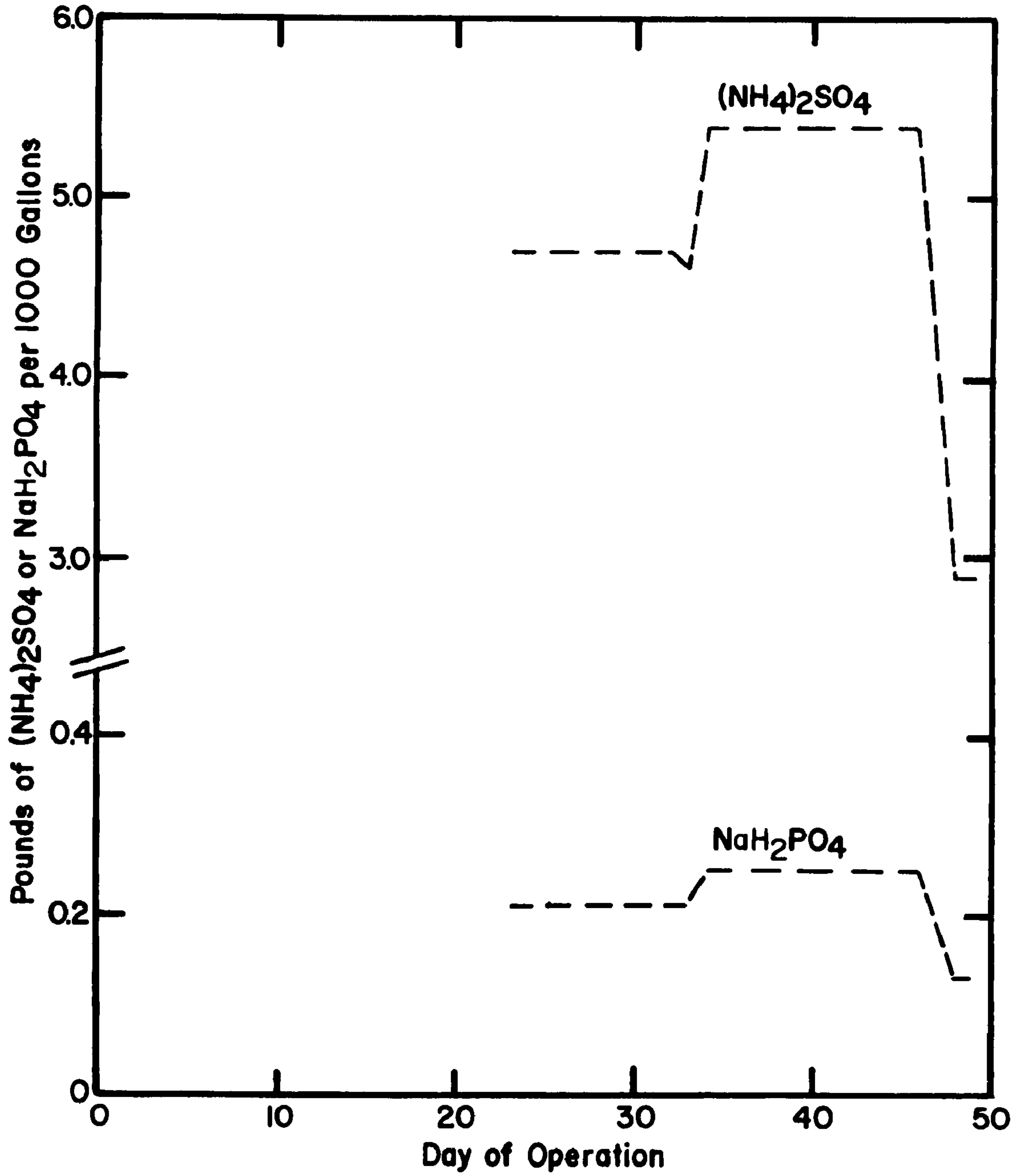



Figure 9. Ammonium Sulfate and Sodium Dihydrogen Phosphate Additions to Pool in Pounds per 1000 Gallons of Feed

The pH control was set at 3.5, and that pH was maintained within ±0.1 unit, with few exceptions. A major exception in the ditch occurred on the twenty-first day, when the acid pump failed to turn off and the pH dropped to 1.8. The pH control failures occurred in the pool because of a loose pH probe connection. The pH meter showed the pH to be in the proper range when actually it was below 2.0. This destroyed operations in the pool twice during the first 20 days of the corn canning season. The amount of sulfuric acid required to maintain the pH is indicated in Figure 10. The amount of acid averaged about four pounds per 1000 gallons of feed. Titrations of the well water used in the canning operations showed an acid requirement of about 2.9 pounds per 1000 gallons to bring the pH to 3.5. Titrations of the plant waste directly from the corn canning operations showed a similar requirement. Titrations of plant waste drawn from the receiving lagoon, however, showed a requirement of six pounds of acid per 1000 gallons.

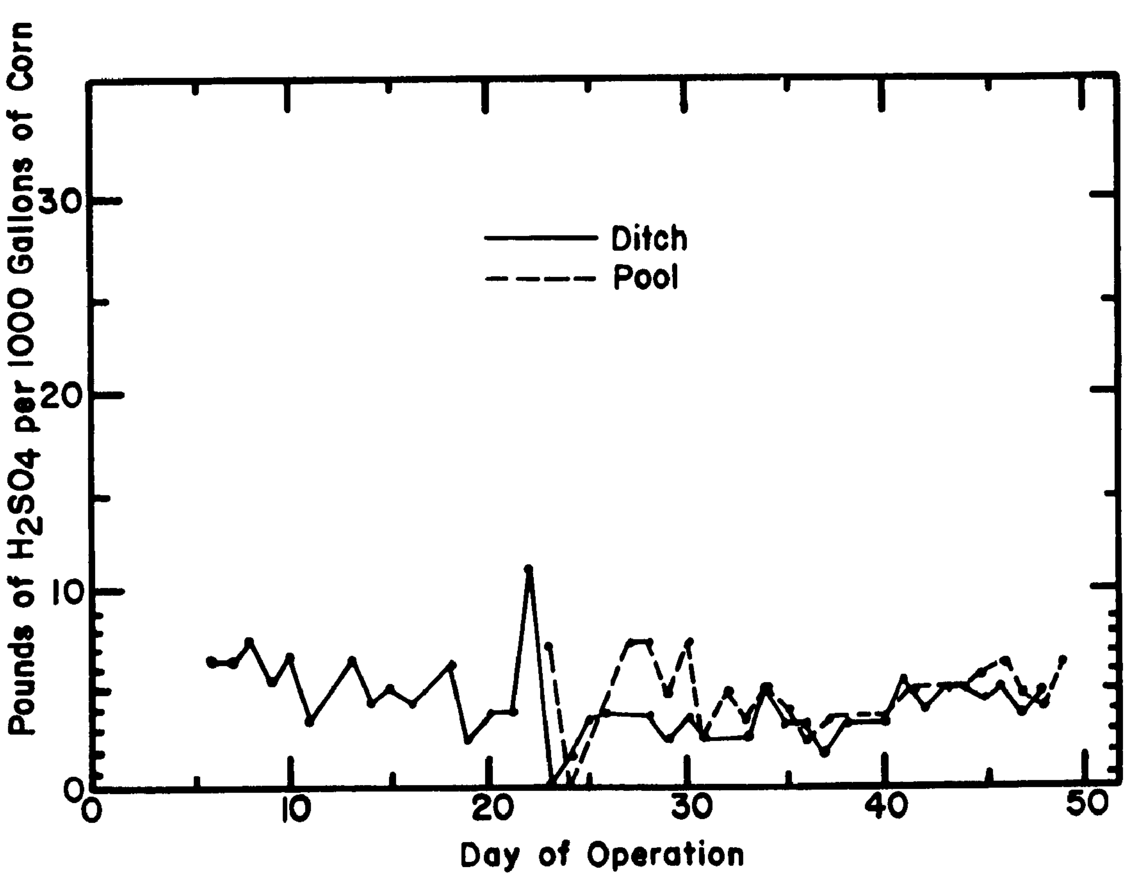



Figure 10. Sulfuric Acid Additions Required to Maintain pH at About 3.7 During Operation on Corn Canning Wastes

## Removal of Organic Matter

The performance of the ditch and pool in removing COD and $BOD_5$ are shown in Figures 11 through 14. These data were taken from Whatman Number 4 filtered effluent samples. COD removal during favorable periods of operation of the ditch (for example, between Days 25 and 36) was about 89 percent. The high effluent COD on Day 21 followed failure of pH control with a fall of pH to 1.8. The peak on Days 37 and 38 occurred when the temperature in the ditch and pool dropped to below 10°C. $BOD_5$ removal was about 97 percent during periods of favorable operation. $BOD_5$ levels in the effluent vacillated between about 40 and 90, with a mean of about 50, except during upsets caused by extremes of acidity or temperatures. It is to be noted that the decreased COD removal caused by extreme acidity on Day 21 is also reflected by a peak in effluent $BOD_5$. The increase in COD levels in the effluent during the period of low temperature on Days 37 and 38 is not reflected by a corresponding increase in effluent $BOD_5$. Effluent COD and $BOD_5$ levels from the pool show slightly higher values than those of the ditch; particularly COD values.

COD values of the feed showed more variation from day to day than did $BOD_5$ values. COD and $BOD_5$ values were initially close together, but by Day 20, had separated appreciably. The ratio of $BOD_5$ to COD values in the feed from Day 20 to Day 50 averaged 0.55. The ratio of $BOD_5$ to COD values in the effluent averaged about 0.24, with extremes of 0.12 and 0.44.

## Yield of Mycelium

The yield of mycelium as recovered from daily effluent samples on Whatman No. 4 filter paper varied from about 0.55 gram per liter to 0.8 gram per liter. Values are shown graphically in Figure 15. In both the ditch and the pool the dry weight of recovered mycelium averaged 50 percent of the weight of $BOD_5$ removed. The amount of mycelium recovered was relatively constant. The spikes on Days 6 and 9 for the ditch are thought to be caused by imperfect sampling procedures.

## Oxygen Consumption

The dissolved oxygen levels in the pool and ditch at a common time each day are shown in Figure 16. In interpreting this figure, it must be remembered that the pool was equipped with a 2-hp floating aerator unit and the ditch, with a 5-hp cage rotor unit. There is no question that the aerator in the ditch was more powerful than required; therefore, little information on power requirements for aeration in the ditch was obtained. Dissolved-oxygen levels in the pool approached zero for several days in a row on two occasions, however, indicating full utilization of the aerator capacity. The $BOD_5$ removal during these periods might be used to estimate aeration requirements. If one assumes the floating

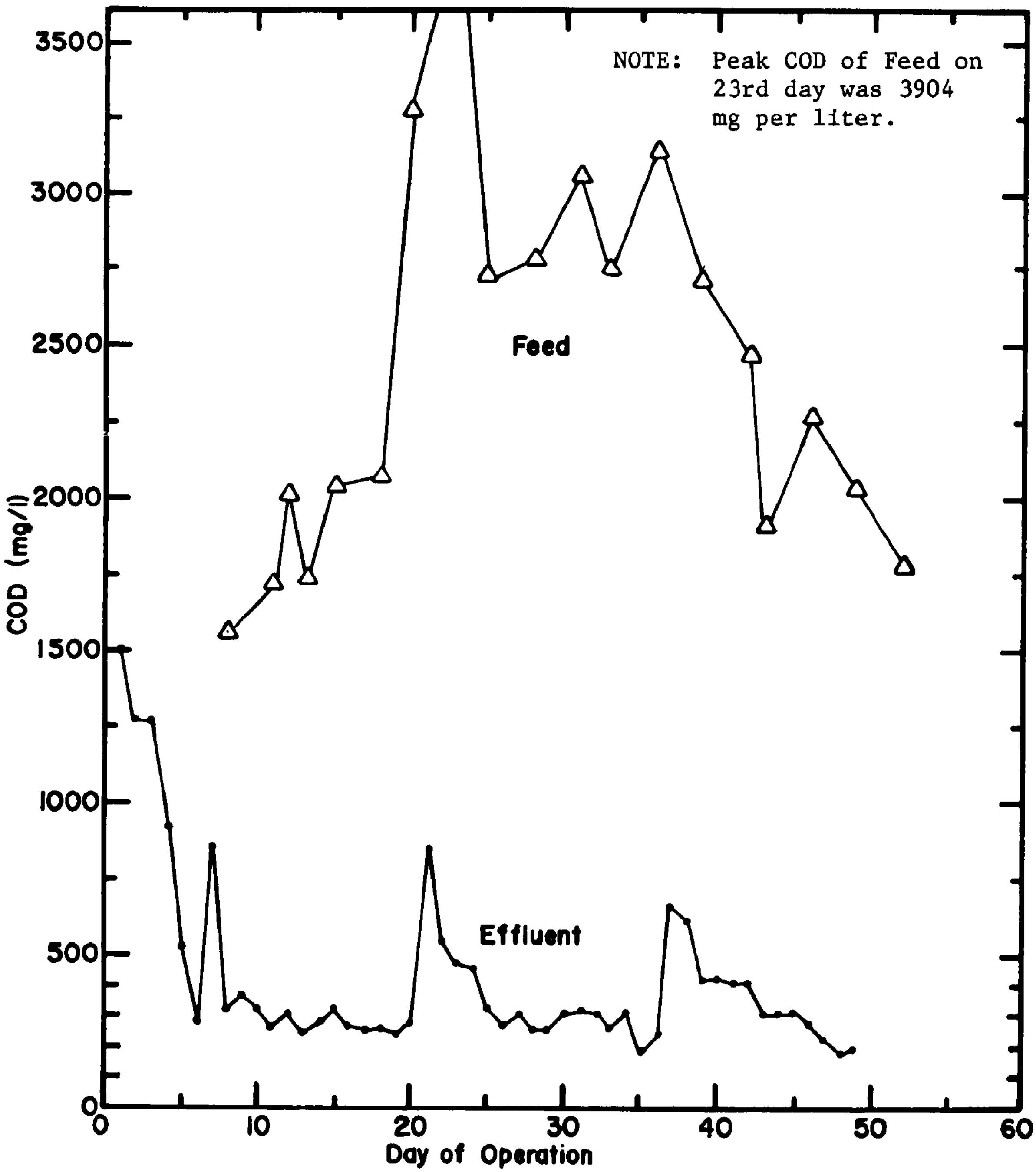



Figure 11. COD of Feed and Effluent Streams of the Ditch During Operation on Corn Canning Wastes

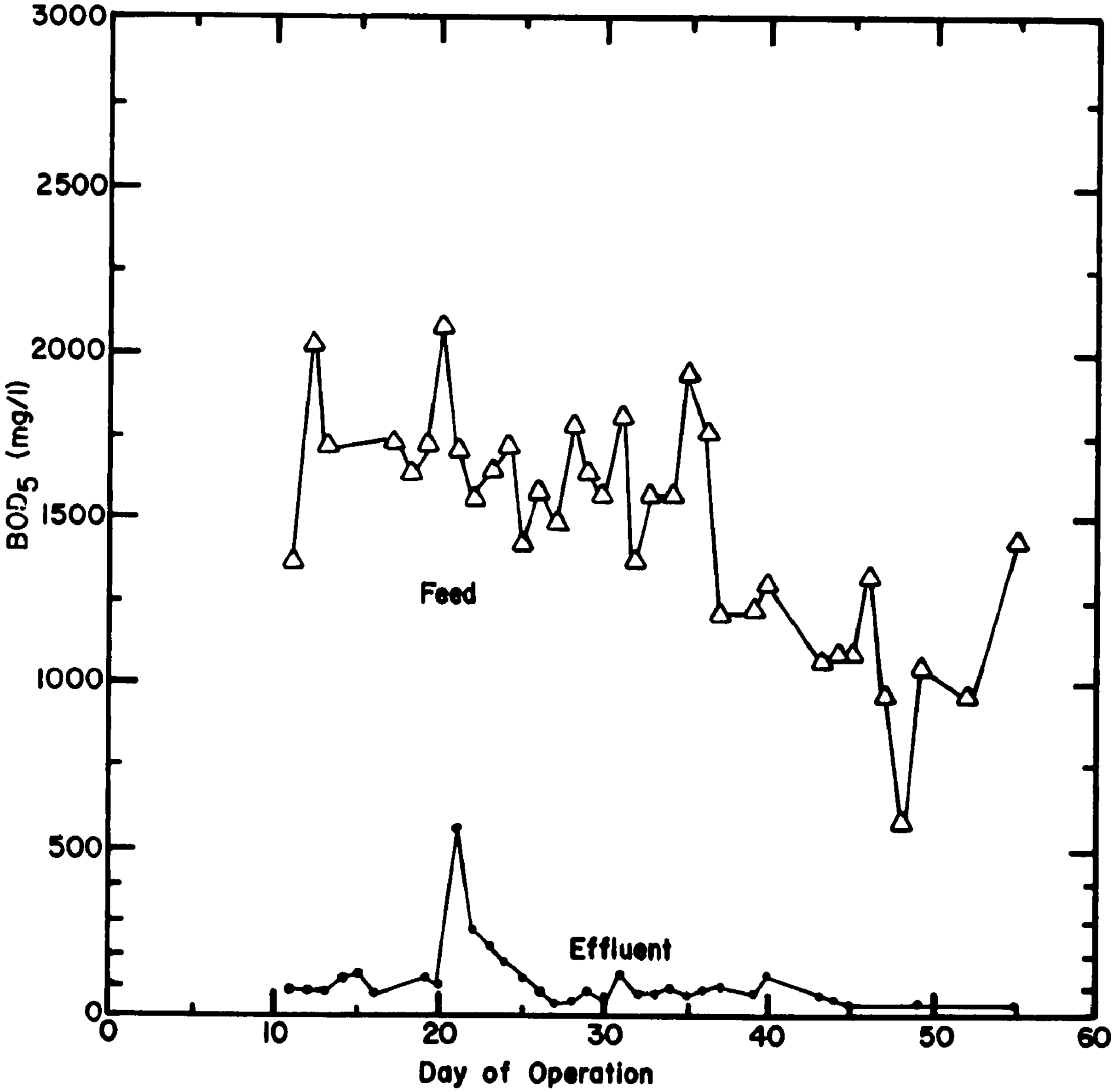



Figure 12. $BOD_5$ of Feed and Effluent Streams of the Ditch During Operation on Corn Canning Wastes

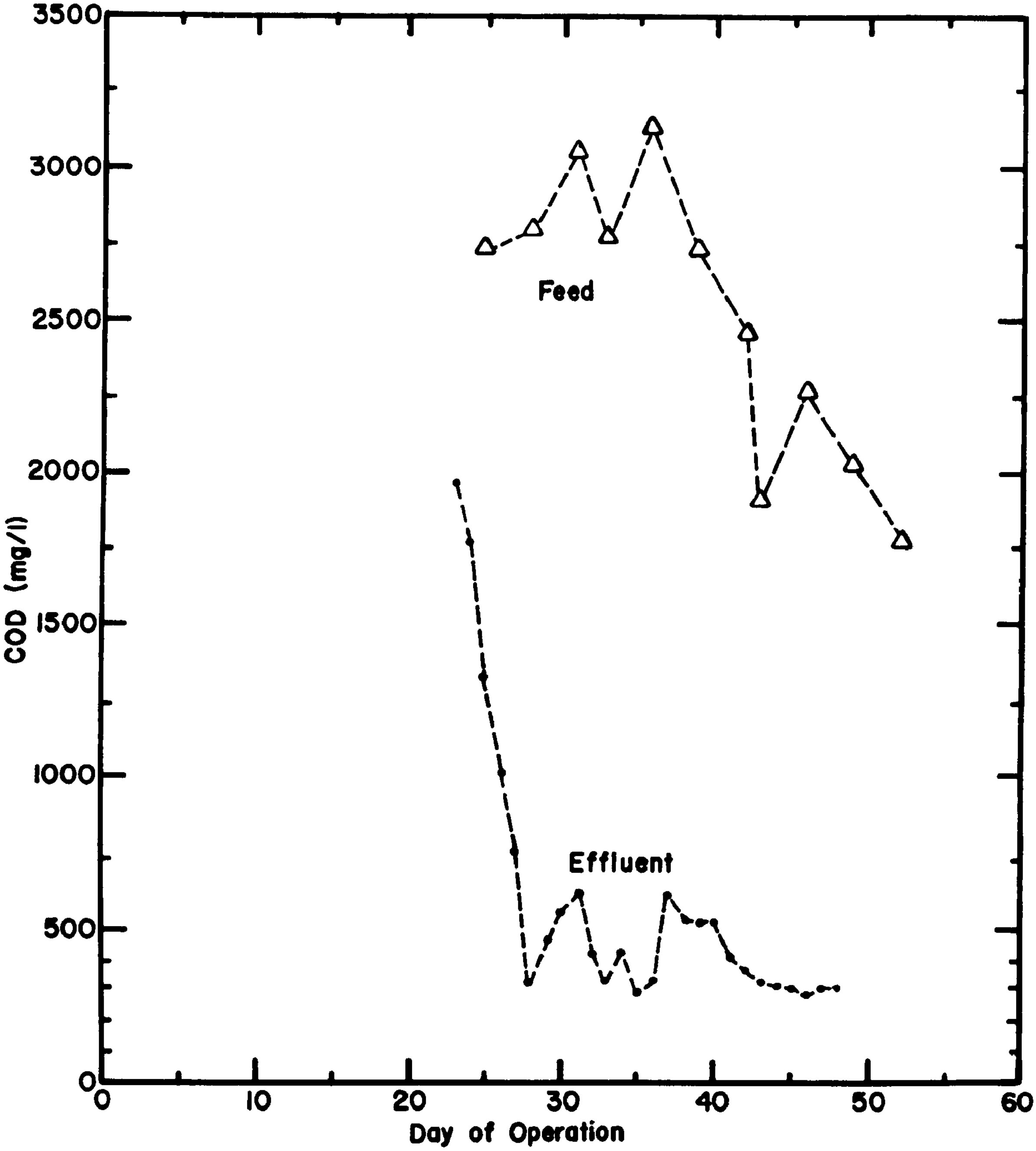



Figure 13. COD of Feed and Effluent Streams of Pool During Operation on Corn Canning Wastes

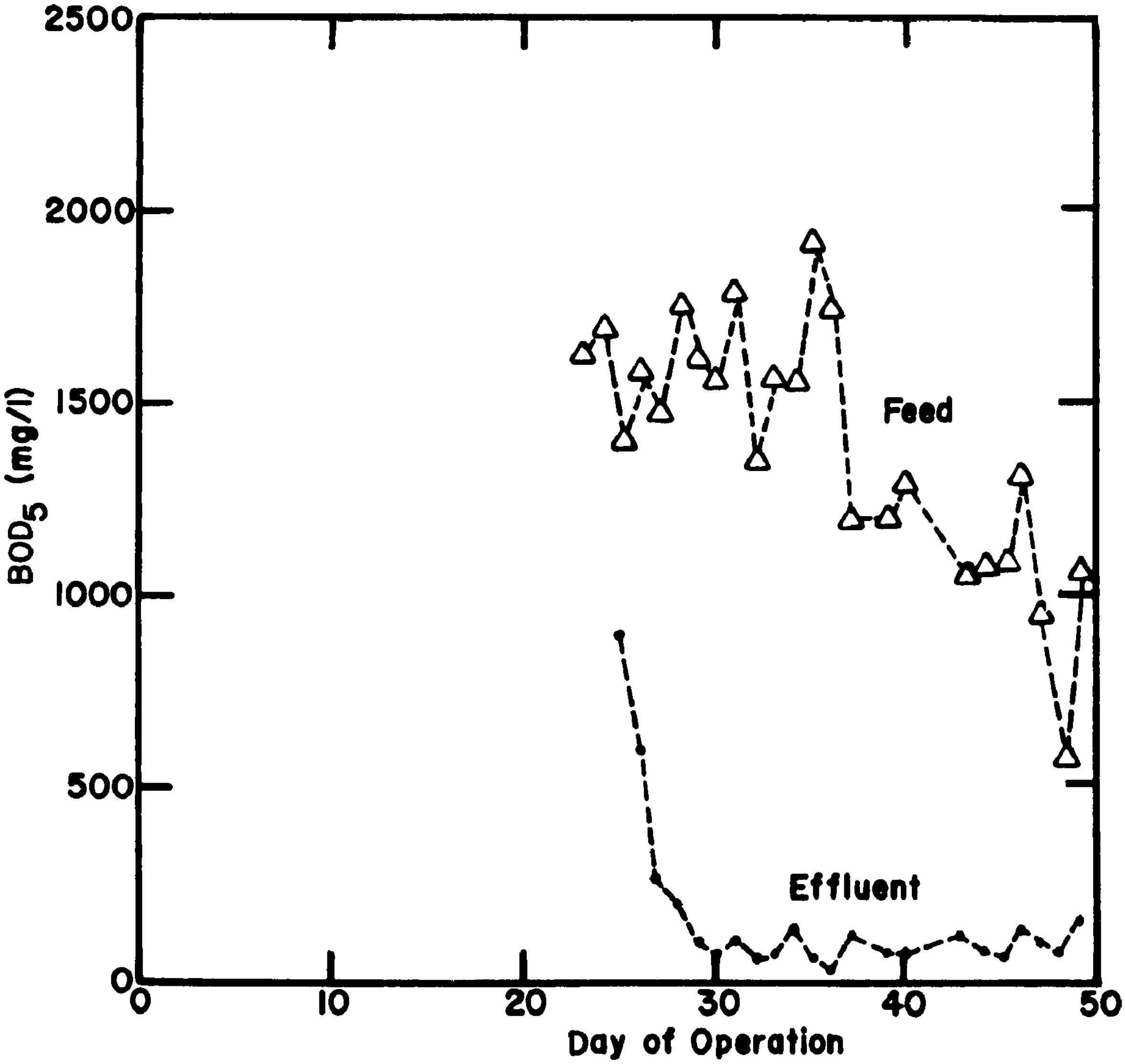



Figure 14. $BOD_5$ of Feed and Effluent Streams of Pool During Operation on Corn Canning Wastes

aerator can transfer two pounds of $O_2$ per hp-hour, the 2-hp unit will transfer 96 pounds in one day. From Days 26 to 31 (a period when the DO was near zero), 75 pounds of $BOD_5$ were being removed per day; on Days 40 to 44, when the DO was measured at 1.0 to 1.8 mg per liter, the unit was handling 85 pounds of $BOD_5$ a day. Using these periods as a basis for calculation, one arrives at an estimate of 1.2 pounds of dissolved oxygen per pound of $BOD_5$ removed. During the first of the two periods, the detention time was greater than 40 hours; during the second, the time was about 30 hours. Both detention times were higher than for best operation, and performance was probably considerably below

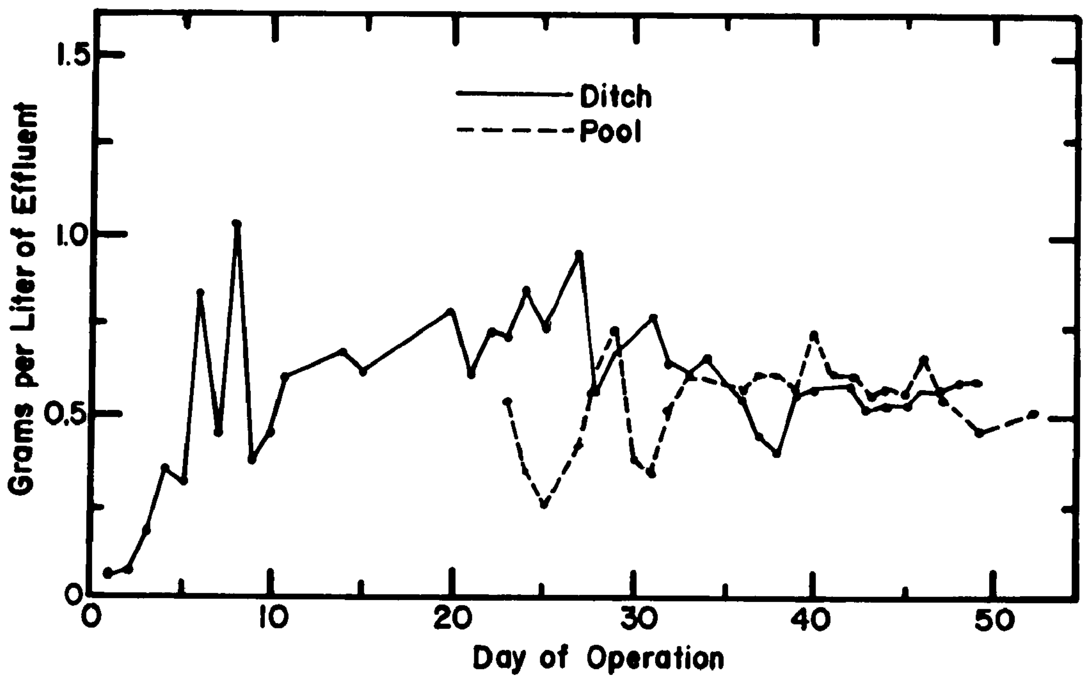



Figure 15. Dry Weight of Solids Recovered from Effluent Streams by Filtration During Operation on Corn Canning Wastes

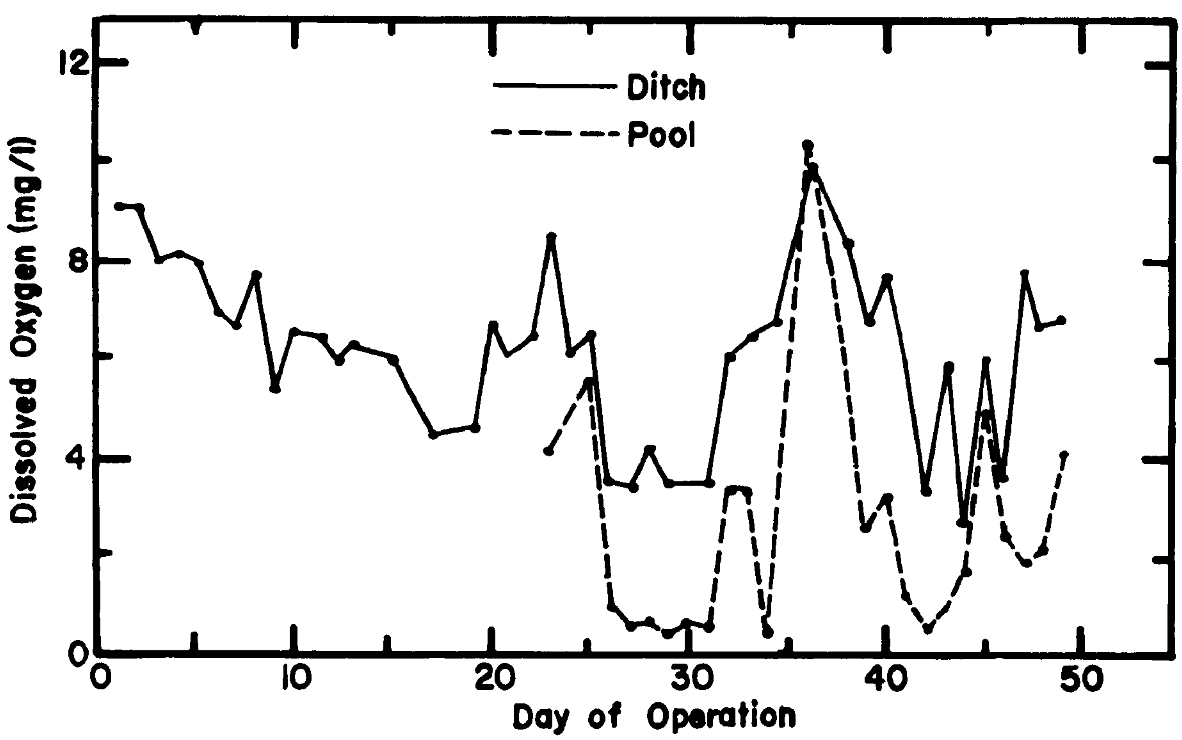



Figure 16. Dissolved Oxygen Concentration Each Day at 2 p.m. During Operation on Corn Canning Wastes

optimum. A further question is raised when the performance from Days 35 to 38 is considered. Then the unit was handling about 120 pounds of $BOD_5$ a day with DO levels averaging 8.0. During this period, based on the same oxygen transfer assumption, the oxygen use must have been less than 0.8 pounds of dissolved oxygen per pound of $BOD_5$ removed. During this period the temperature dropped to a low of about 5°C (see Figure 4), which would permit greater oxygen transfer, but would not account for the lower oxygen requirement. Reference of Figure 14 shows that $BOD_5$ levels in the effluent were satisfactorily low during this interval.

Probably a better approach to estimation of oxygen use was to measure the rate of change in DO in samples removed from the ditch. These measurements were made in a flask that allowed no air space above its contents, and stirring was provided with a magnetic stirrer. The flask was fed fresh feed from a buret at a rate that would give the same retention time in the flask as in the ditch. The assumption was that the oxygen use in the flask sample continued at a rate that allowed removal of 95 pounds of $BOD_5$ per day -- the rate of removal being accomplished in the ditch at the time of these measurements. Oxygen use was 3 mg per liter per minute in several measurements. For a ditch volume of 11,000 gallons, the oxygen consumed then would have been 65 pounds per day, or 0.7 pound per pound of $BOD_5$ removed.

## Use of Nitrogen and Phosphate

Levels of phosphate and ammonium ion in the effluent and feed for the ditch are given in Figures 17 and 18, respectively. Levels of phosphate in the effluent were lower than in the feed in spite of phosphate additions to the fermentation. During one interval, between Days 20 and 23, phosphate levels were below 0.1 mg per liter. Ammonium nitrogen levels were also too low to measure at intervals during the operations (Days 12-14 and Day 48). Actually, the amounts of nitrogen and phosphorus added were greater than required, on the basis of previous experience; almost one-third more was required to give 50-percent protein. The additions had been calculated on the expectation of higher $BOD_5$ to COD ratios than were actually observed. From this, larger mycelium yields were expected than were obtained.

## Microbial Pattern

Samples of the cultures from the ditch and pool were examined microscopically at regular intervals. Some aspects of culture behavior were evident on macroscopic observation. Among these were clump size. The mycelial clumps were never as large as those obtained in laboratory cultures. They were large enough to be readily visible; some were as

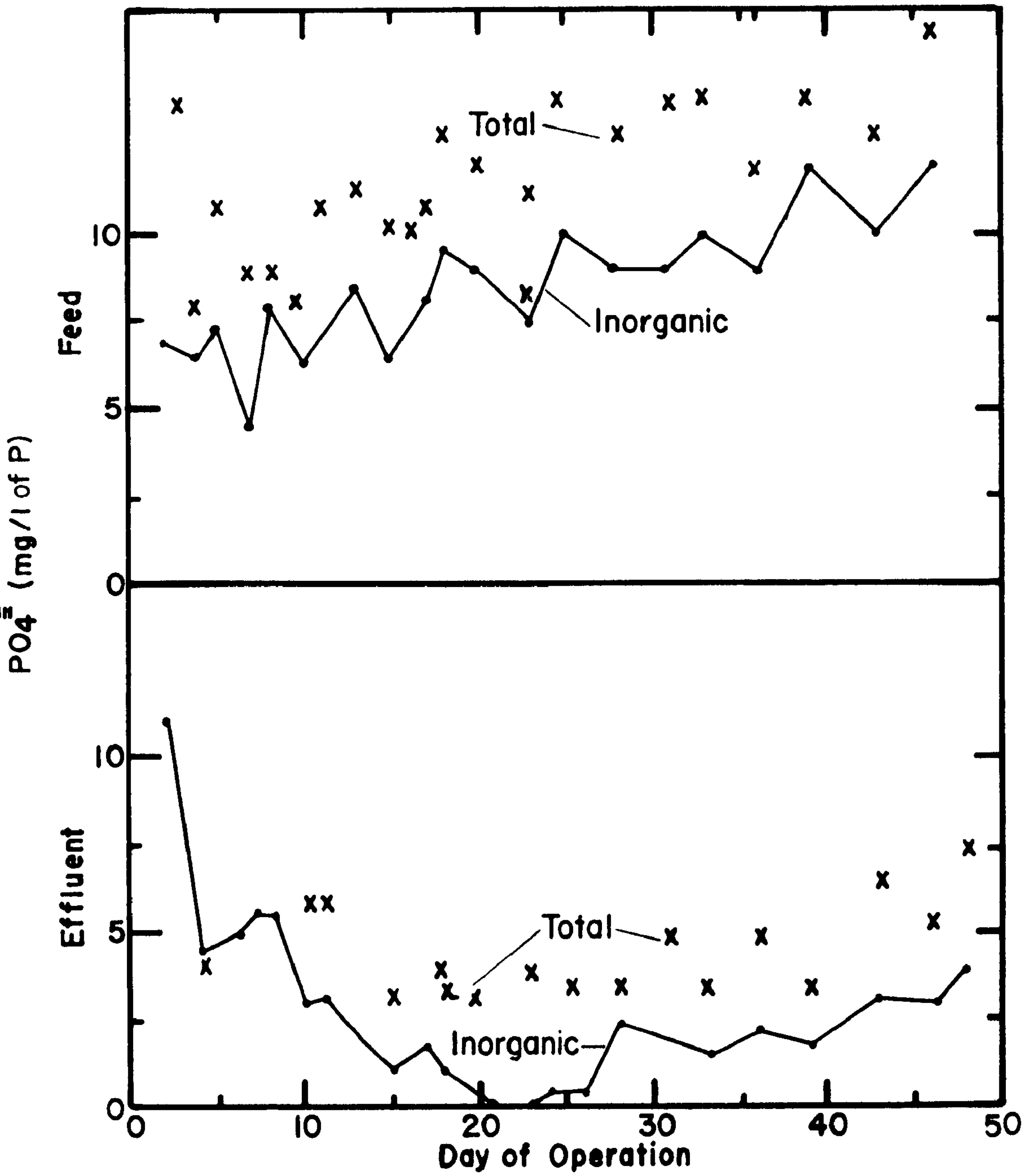



Figure 17. Concentration of Phosphates in Feed and Effluent of Ditch

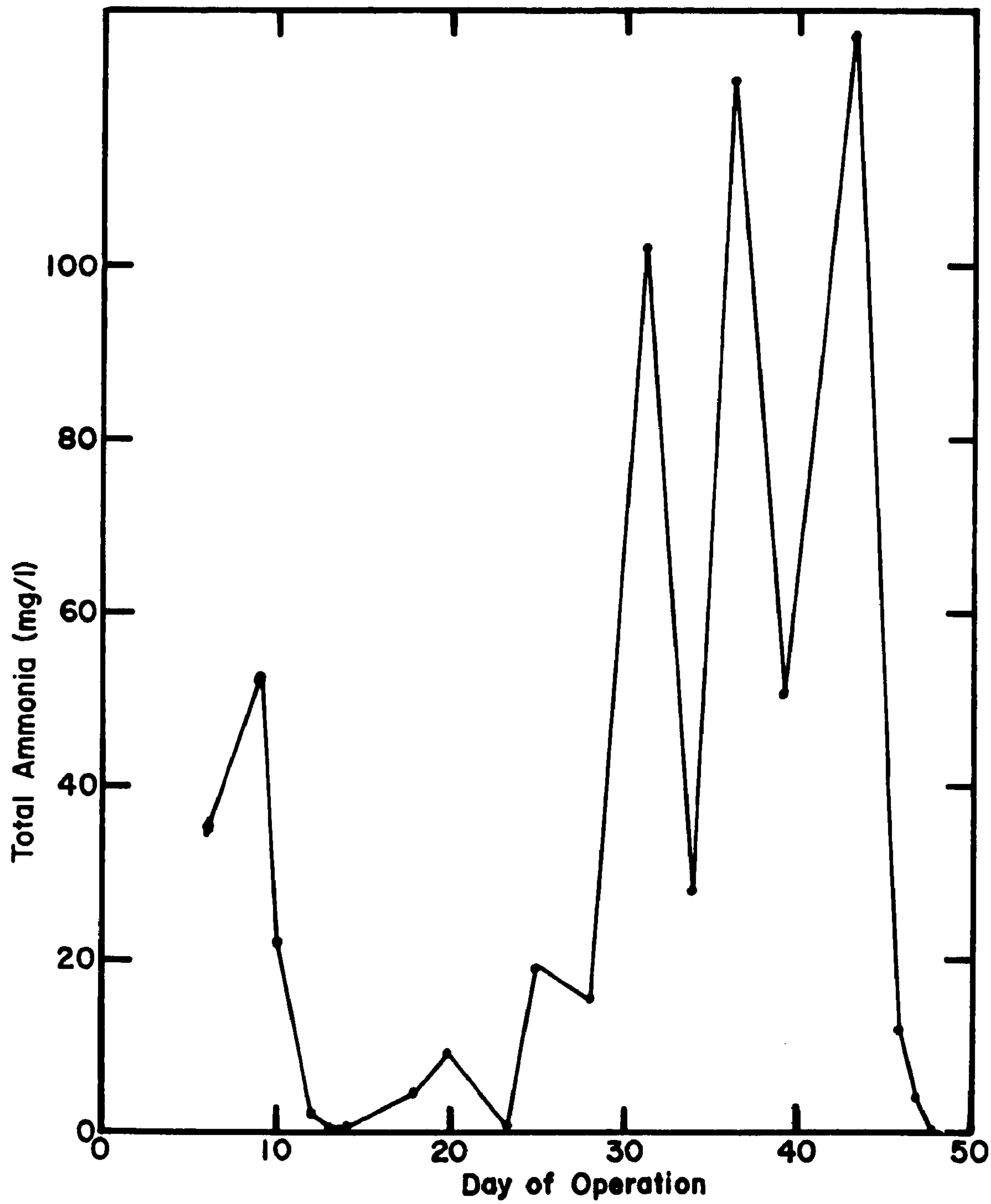



Figure 18. Ammonium Ion Concentration of Effluent from Ditch During Operation on Corn Canning Wastes

large as several millimeters in diameter. The difference from laboratory experience in clump size may have been a function of the greater mechanical violence of the aerator systems or may have been caused by other factors.

Microscopic examination showed the presence of few yeasts or bacteria at all times during the tests. Another fungus, believed to be a *Geotricum*, did begin to appear in the ditch a few days after inoculation, and by mid-season comprised 50 to 70 percent of the mycelial mass. It became less prominent in late season, and by the time of discontinuance of operations comprised not more than 20 percent of the mycelial mass. An occasional clump of this organism was seen in the pool culture, but it never became prominent. Some of what was apparently *Geotricum* was present in laboratory fermentations of corn wastes conducted in the earlier *Fungi Imperfecti* project.

There was evidence that the mycelial clumps were smaller at the lower temperatures encountered in the pool and ditch during part of the project.

## Recovery of Mycelium

Several techniques were investigated for recovery of effluent mycelium. The mycelium was too fine for efficient recovery by simple screening; a process which had been successful in laboratory studies. Neither was vacuum filtration promising. It, too, had worked satisfactorily on laboratory cultures. It proved possible on vacuum filtration of laboratory cultures to build up mycelial filter cakes 1/8- to 1/4-inch thick before filtration rates slowed to any marked degree. Using pilot-plant mycelial material, however, filtration rates were reduced to 0.1 gallon per minute per square foot of 1/2-inch fungal cake thickness by the time four gallons per square foot had been filtered.

Considerable investigation was made on the use of a Sweco vibratory filter for mycelium recovery. Results are shown in Table 3. These results are considered the poorest that might be expected, since they were obtained late in the season when the mycelium was especially fine because of cold weather. The mycelium concentrate from the No. 120 Sweco screen contained 2.5-percent solids. It was filtered readily on a vacuum filter to produce a cake 0.5- to 1-inch thick and of 20-percent solids.

The vacuum filter cake formed from fungal material collected on the Sweco unit could itself be used as a filter to clean up the effluent from the Sweco. A 0.5-inch fungal cake accommodated 20 gallons of Sweco effluent per square foot of surface before slowing to a filtration rate of 0.2 gallon per minute per square foot.

Table 3. Performance of Sweco Vibratory Filter on Corn Waste Effluents

| Screen Mesh | Gallons Flow per sq ft per min | Percentage Mycelium Recovery | COD Effluent | $BOD_5$ Effluent |
|---|---|---|---|---|
| 94 | 8 | -- | 1352 | -- |
| 105 | 6 | -- | 928 | -- |
| 120 | 6 | 52 | 664 | 142 |
| 165 | 2 | 65 | 332 | 74 |

Another promising method of cleaning up the filtrate from the Sweco was by the use of a sand bed. It was found possible to filter 20 bed-volumes of Sweco 120 filtrate at flow rates of from 2 to 6 gallons per square foot per minute by using an 8-inch depth of 60 to 80 mesh sand covered with a 12-inch depth of 16-20 mesh sand and with head depths of less than 24 inches. The filtrate was reduced from an initial turbidity of "80" on a Klett scale to a turbidity of "4.5". The latter turbidity corresponds to a value of 50 by the Jackson candle turbidimeter. The mycelium contained in the sand bed could be recovered by back washing with one volume of water.

Settling was investigated as a means of recovering the mycelium, but did not look promising. A clear supernate was obtained, but the settling rate was frequently as slow as one inch per hour.

Centrifuging gave rapid clearing at forces above 600 xg.

It was also possible to filter, through Whatman No. 4 paper, with reasonable flow rates and freedom from clogging by first bubbling air through the effluent to cause foaming. Finer materials concentrated in the foam and could be skimmed off. Filtration could then be conducted with much less tendency to clog.

## Drying

Drying tests were limited to laboratory trials. It was possible to achieve drying in a laboratory oven at temperatures up to 110°, to yield a product of light brown color and little taste. Surface-hardening was a definite problem with material from the pilot plant and drying layers of greater than 1/8-inch thickness would seem impractical unless some precautions, such as humidity control, were taken.

## Other Corn Waste Studies

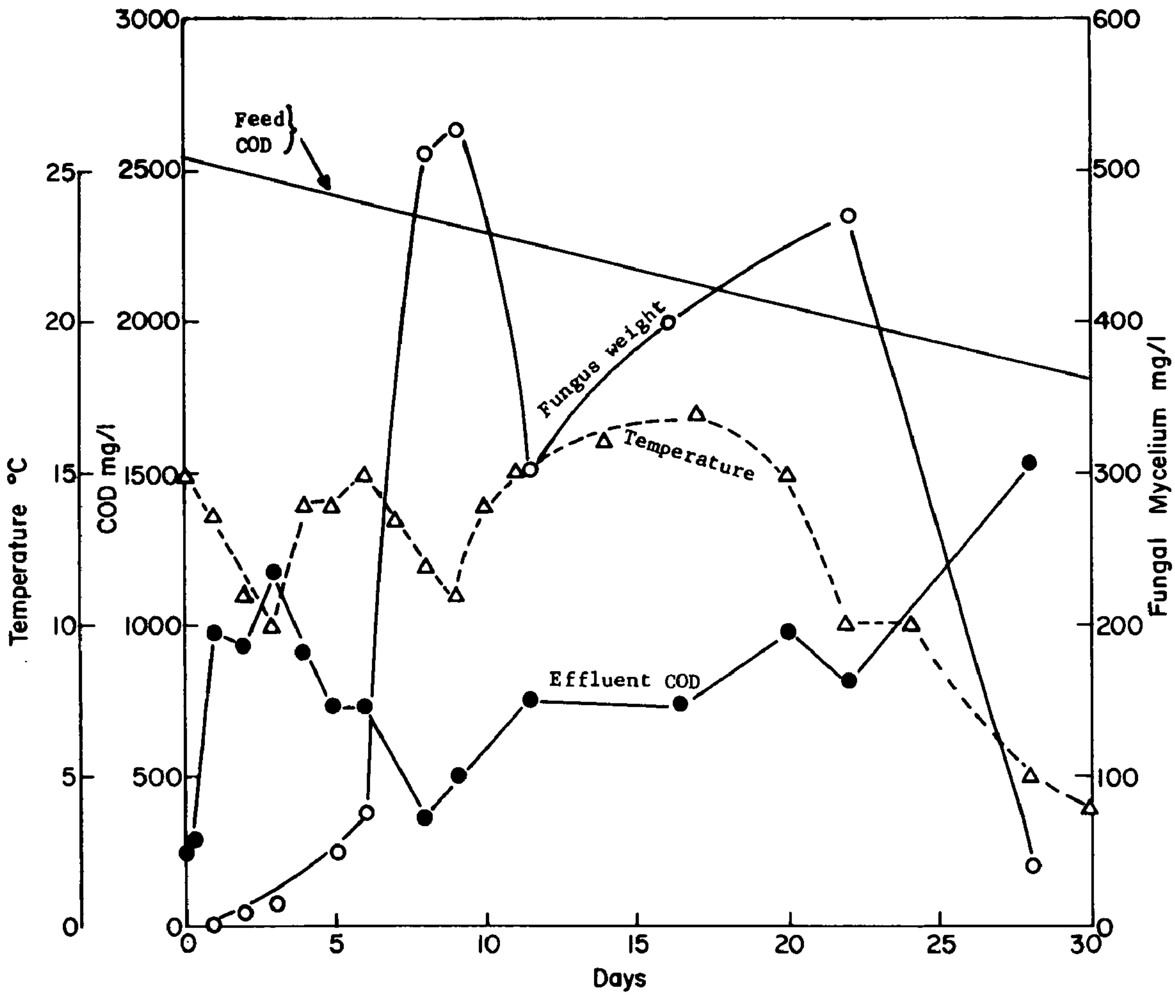
### First Season Pilot-Plant Operation

During the 1969 season, the aerated pool was operated for eight days during the corn canning season and then for an additional 22 days using accumulated corn canning wastes from the lagoon. The pool temperature did not rise above 17°C during the entire operating cycle and was below 10°C for the last seven days of operation. The data obtained are summarized in Figure 19. The COD reduction was considerably less than obtained in the 1970 season; it was in the neighborhood of 70 percent. The culture maintained itself well with few yeasts, bacteria, and protozoa being present.

### Study of Lagooned Wastes

The inadequate COD removal observed in the first season of operation may have been caused by low operating temperatures or the use of lagooned waste. There was no question from gross observations that changes were occurring in the lagoon so that material drawn from the lagoon was no longer equivalent to fresh corn wastes. To compare digestion of fresh corn waste and corn waste drawn from the lagoon, parallel continuous fermentations were set up in the laboratory and operated for 30 days. The corn and lagoon wastewater feeds were transported to the laboratory in five-gallon polyethylene containers and frozen until used in this experiment. Each culture system was inoculated with mycelium taken from the pool (1969 season). Each was maintained at about 24°C, at pH 3.4, and fed to give a retention time of 30 hours. The COD of the fresh corn was 4320 mg per liter; the effluent COD was 160 to 200 mg per liter, and the mycelium yield about 1500 mg per liter. The COD of the lagoon waste was 2288 mg per liter; the effluent COD was about 400 for the first 15 days, and then dropped to about 150, and remained there. The mycelium yield was 1000 mg per liter. It was concluded that there were no significant differences in performance between fresh and lagooned corn wastes that were discernible in this experiment. These results are shown in Figures 20 and 21. The arrows in these figures refer to breakdowns in the feeding equipment which produced both fungal starvation and washout before repairs were made.

In the 1970 season, the question arose as to whether the finer mycelium and the appearance of another fungal species in the ditch culture might be a function of use of lagooned feed, rather than feed directly from the plant operations. To help answer this question, laboratory shake flask experiments were conducted using fresh plant waste and lagooned wastes as media, and using either inoculum from the ditch or from laboratory *T. viride* culture. Other variations were the use of different ratios of ammonium sulfate and sodium phosphate. Only trivial growth




*Feed COD is from the corn canning receiving lagoon and dropped off linearly during the 30 days of this study.

Figure 19. Performance of Aerated Pool in Continuous Treatment of Corn Waste by *T. viride*

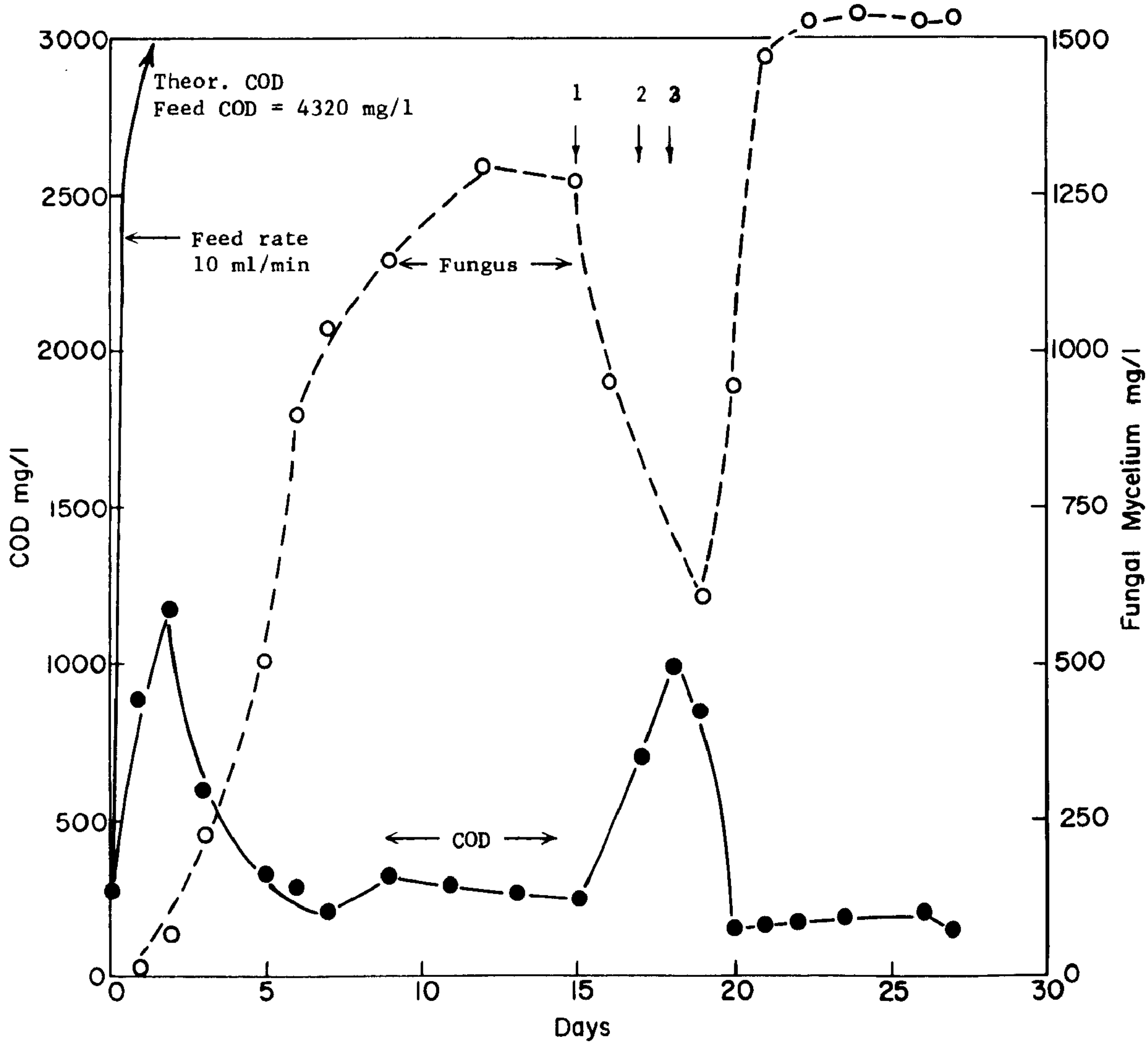



Figure 20. Continuous Laboratory Digestion by *T. viride* of Corn Wastes Drawn Directly from Plant Effluent

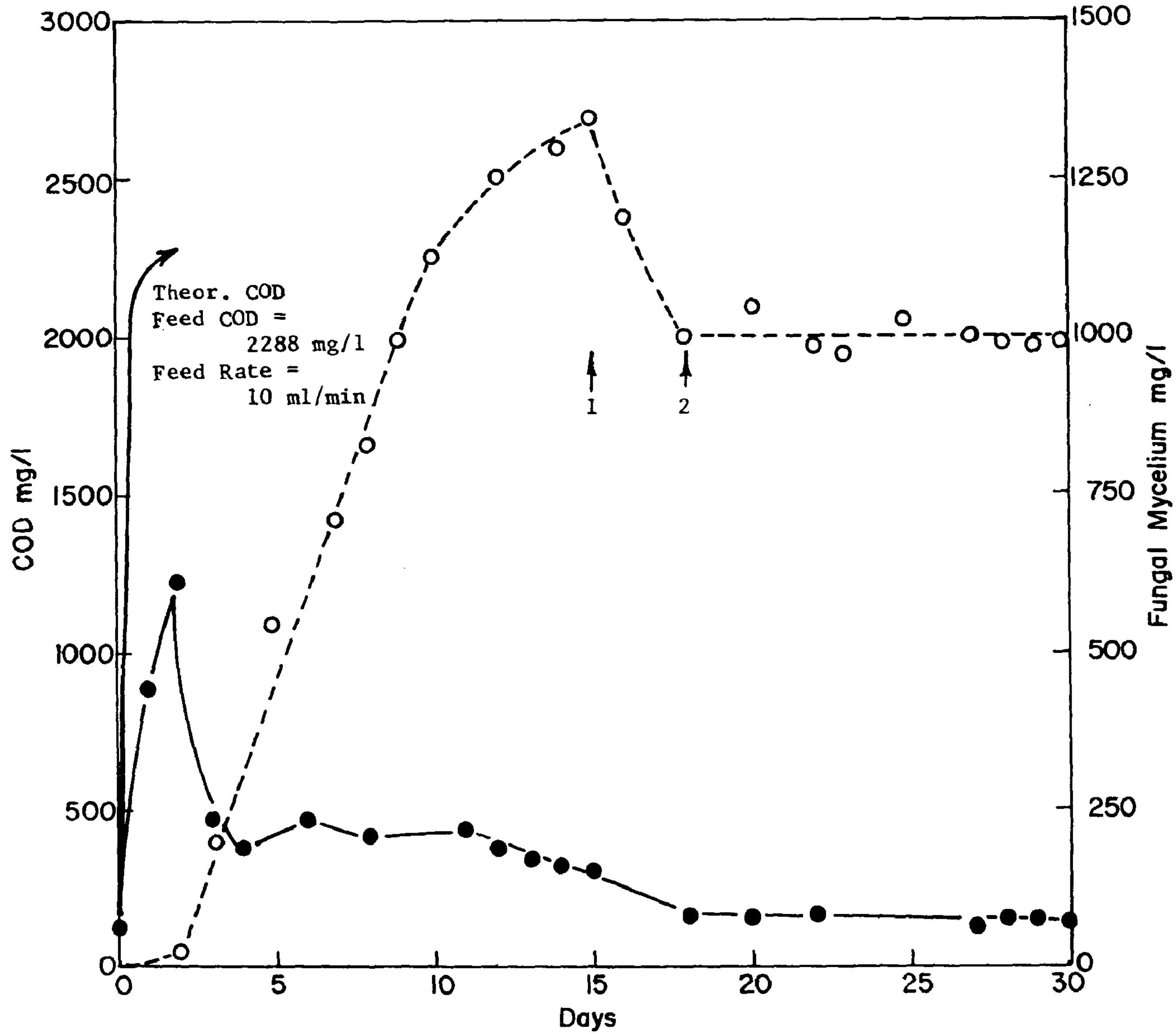



Figure 21. Continuous Laboratory Digestion by *T. viride* of Corn Wastes Drawn from the Receiving Lagoon

was obtained in any instance using waste from the lagoon. Ten times as much growth was obtained using fresh corn canning wastes, regardless of the source of inoculum. The lack of growth on lagooned wastes using inoculum from the ditch was inconsistent with the fact that successful removal of $BOD_5$ and mycelium production was regularly being achieved in the ditch itself on these same lagooned wastes. Subsequent to this experiment, the point of withdrawal of feed from the lagoon was moved as close as possible to the point of entry of the plant discharge. This caused a slight increase in mycelium floc size, but nothing impressive.

## Temperature Effects

Laboratory experiments were undertaken to determine whether low temperatures were the probable cause of poor COD removal during the 1969 season. The approach was to set up two parallel fermentations, one operated at room temperature (21 to 24°C) and the other in the cold room (12°C). Feed rates were varied and mycelium was recycled in the cold room fermentation in an attempt to increase effectiveness of COD removal. Results are indicated in Figure 22. The feed to both the room temperature and the cold room fermentations had a COD of 1735 mg per liter. The initial feed rate was 10 milliliters per minute, which is equivalent to a retention time of 30 hours. At the arrow marked with a "1" on the graph, the feed rate of the cold room fermentation was reduced to 7.5 milliliters per minute. At the point marked by arrow 2, recycling of the mycelium was instituted. The recycling returned nearly all of the mycelium to the fermentation. It is seen that from that point on, the COD gradually dropped to a level of 200 mg per liter. Probably some lysis of mycelium occurred since the final level of mycelium in the fermentation was only moderately higher than expected with this level of COD removal, even without recycling of mycelium. The COD level eventually matched that attained at room temperature.

Recycling of mycelium to keep the standing concentration high was necessary to obtain reasonable COD removal at 12°C.

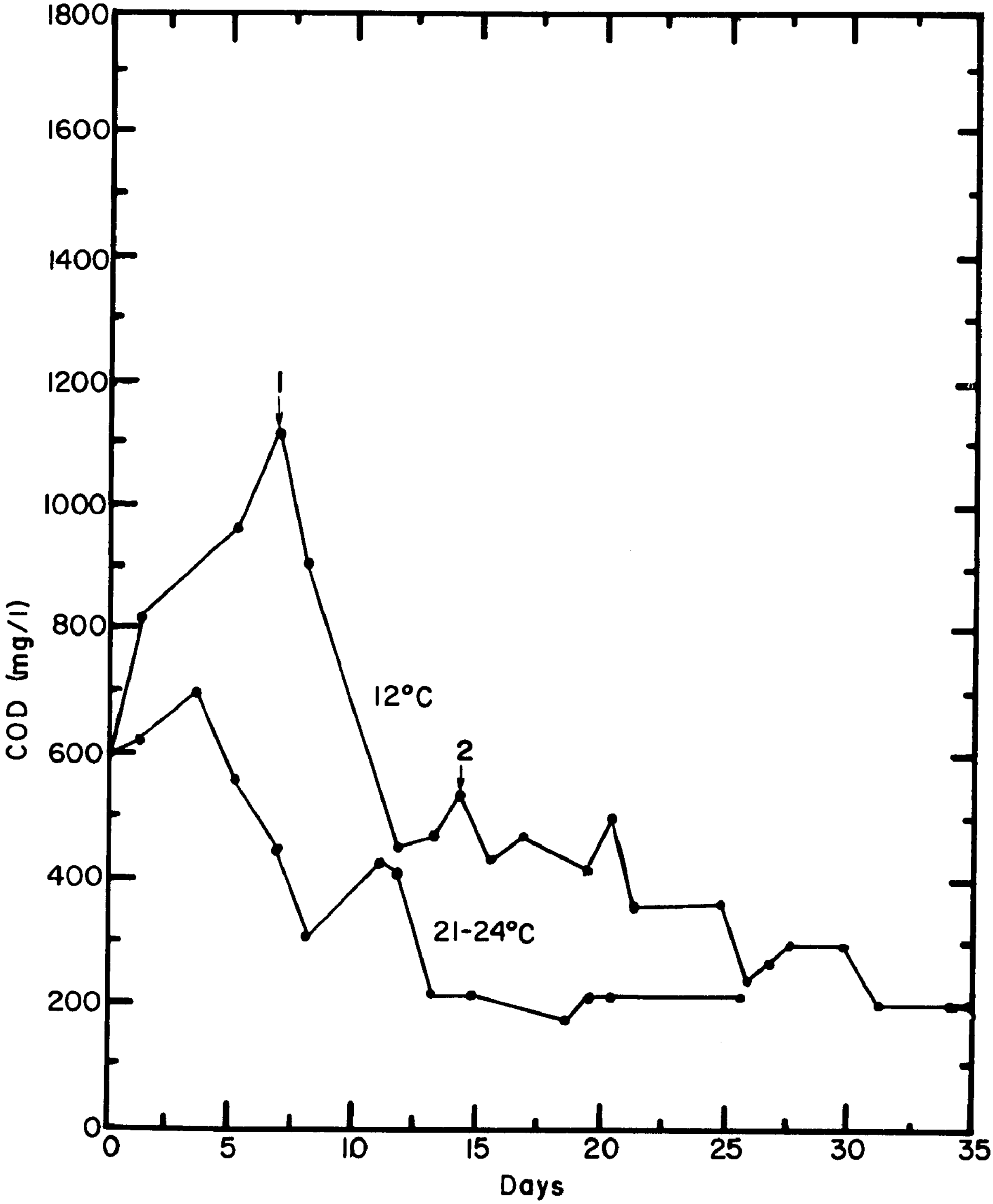



Figure 22. Performance of Laboratory Treatment of Lagooned Wastes at Two Temperatures

Operating Conditions

The pattern of operating conditions used in treating pea wastes is shown in Figures 23 through 31. In interpreting these figures, the period from the 1st through the 35th day includes the pertinent experience with pea wastes; after the 35th day, silage juice was added in amounts that contributed the greater part of the $BOD_5$ load.

The retention times used were initially 45 hours, and were stepped down to 18 hours by the end of the period of treatment of pea wastes. The pattern of regulation of retention times is shown in Figure 23. Addition

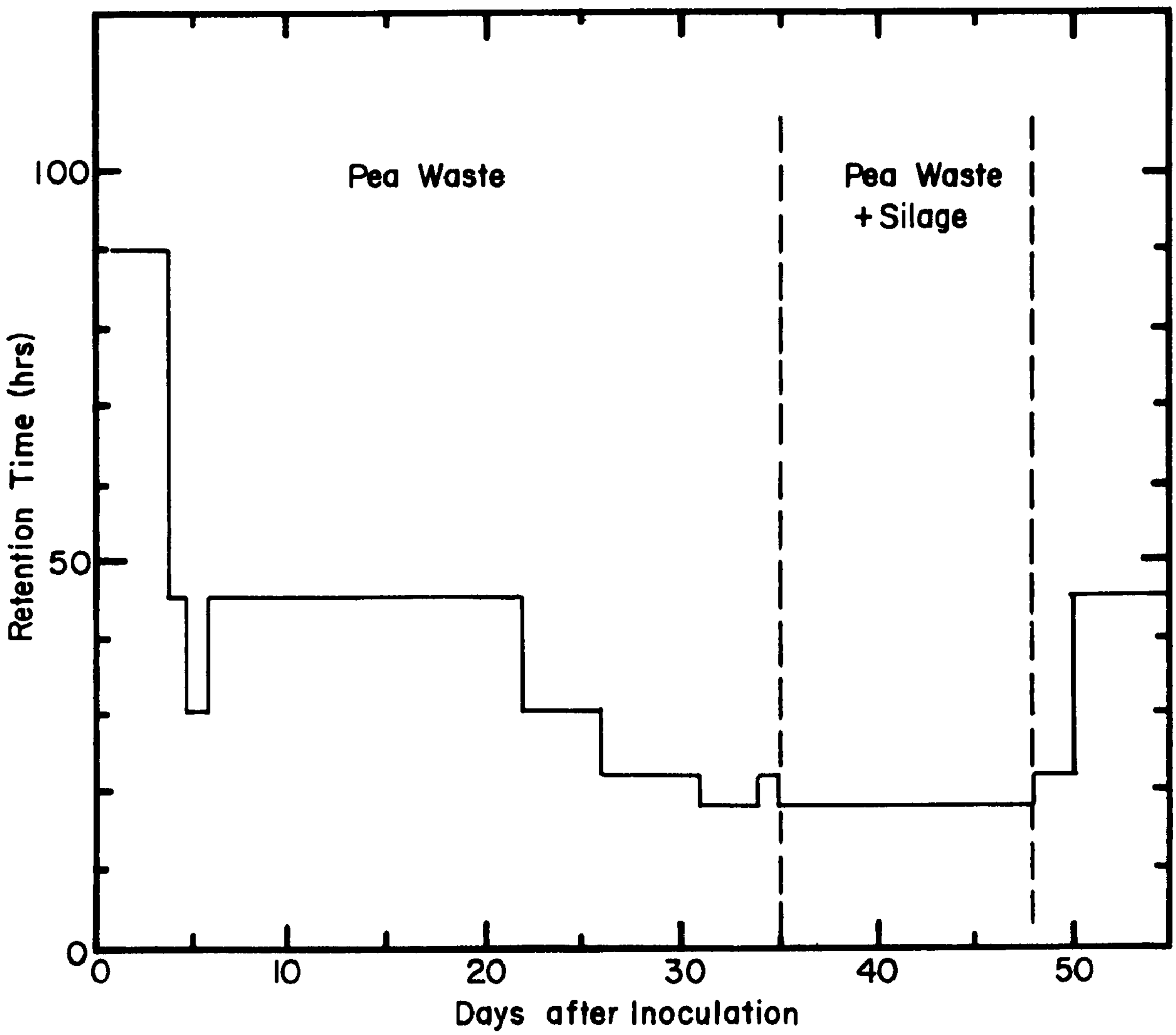



Figure 23. Feed Identity and Retention Time in Pool

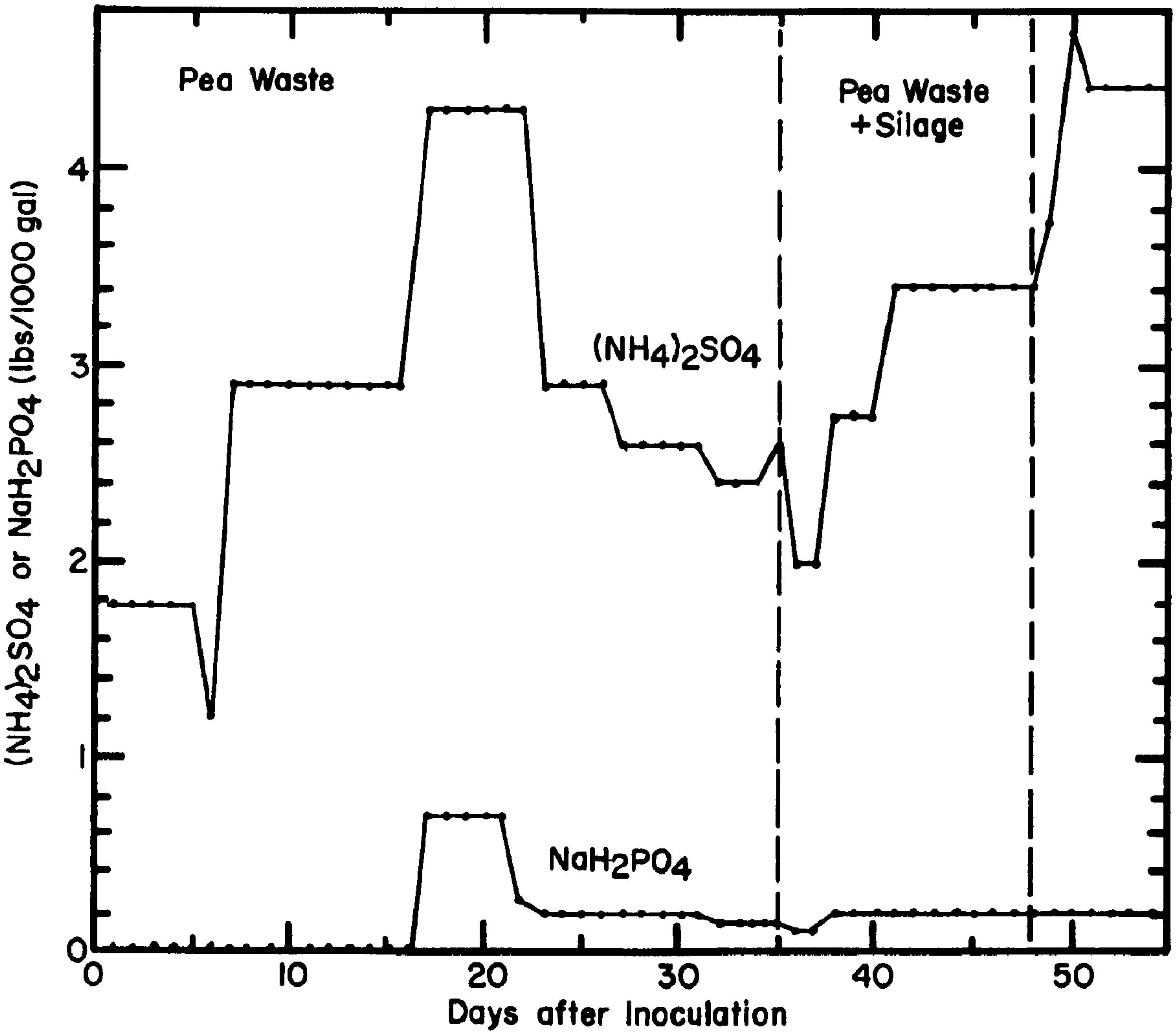



Figure 24. $(NH_4)_2SO_4$ and $NaH_2PO_4$ Additions to Pool in Pounds per 1000 Gallons of Feed

of ammonium sulfate and sodium dihydrogen phosphate is shown in Figure 24. Addition of phosphate was not begun until the 16th day. The amount of sulfuric acid required to maintain a pH of about 3.5 is shown in Figure 25. The amount required was greater than for corn wastes; it averaged 6.5 pounds per 1000 gallons of feed. The temperature pattern is shown in Figure 26. The temperature dipped to 16°C on two days, but was generally above 18°C, and on one day, reached 30°C.

The total load of $BOD_5$ and COD fed to the pool per day is shown in Figure 27. The general pattern was one of increasing loads as the season progressed, with the initial $BOD_5$ loads being in the neighborhood of 30 pounds per day and loads later in the season being about 50 pounds per day. COD loading increased from initial levels of about 80 pounds per day to levels, later in the season, of about 120 pounds per day.

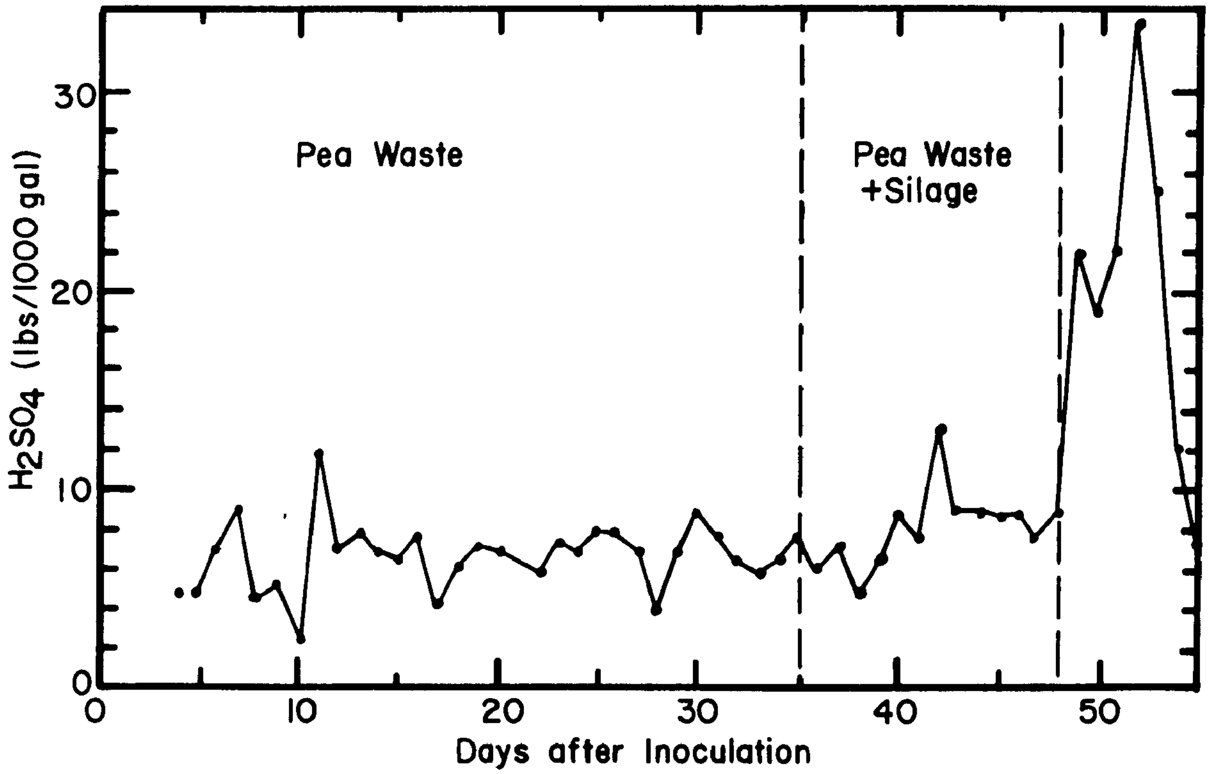



Figure 25. Sulfuric Acid Additions Required to Maintain pH at About 3.7

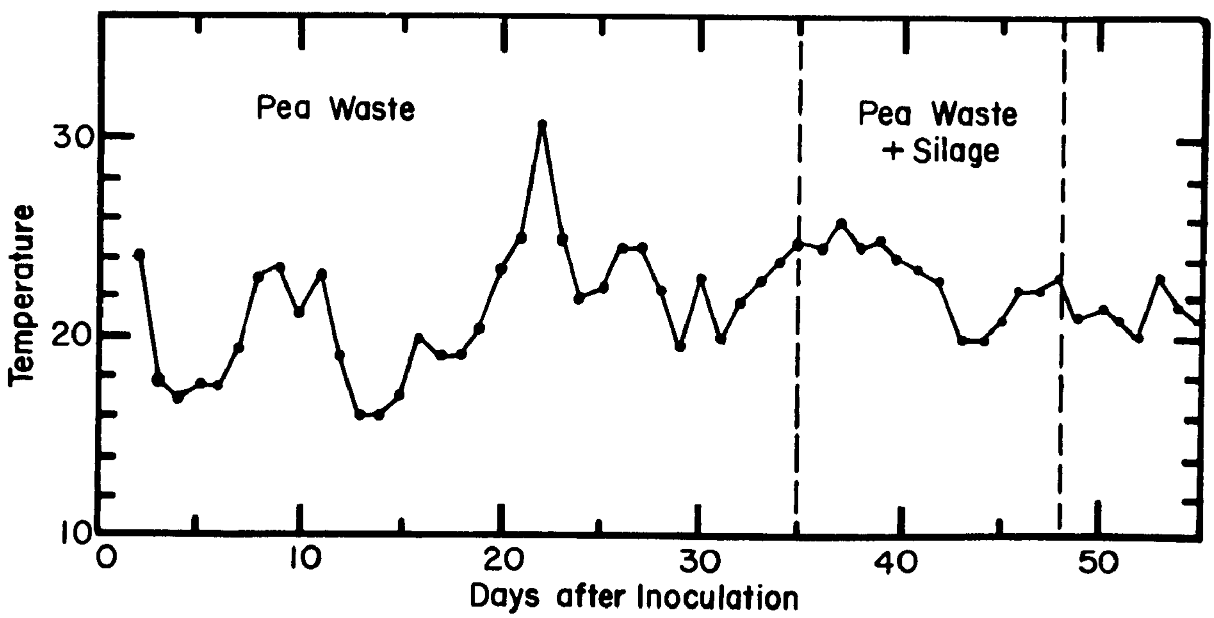



Figure 26. Temperature of Pool Contents at 11 a.m. Each Day

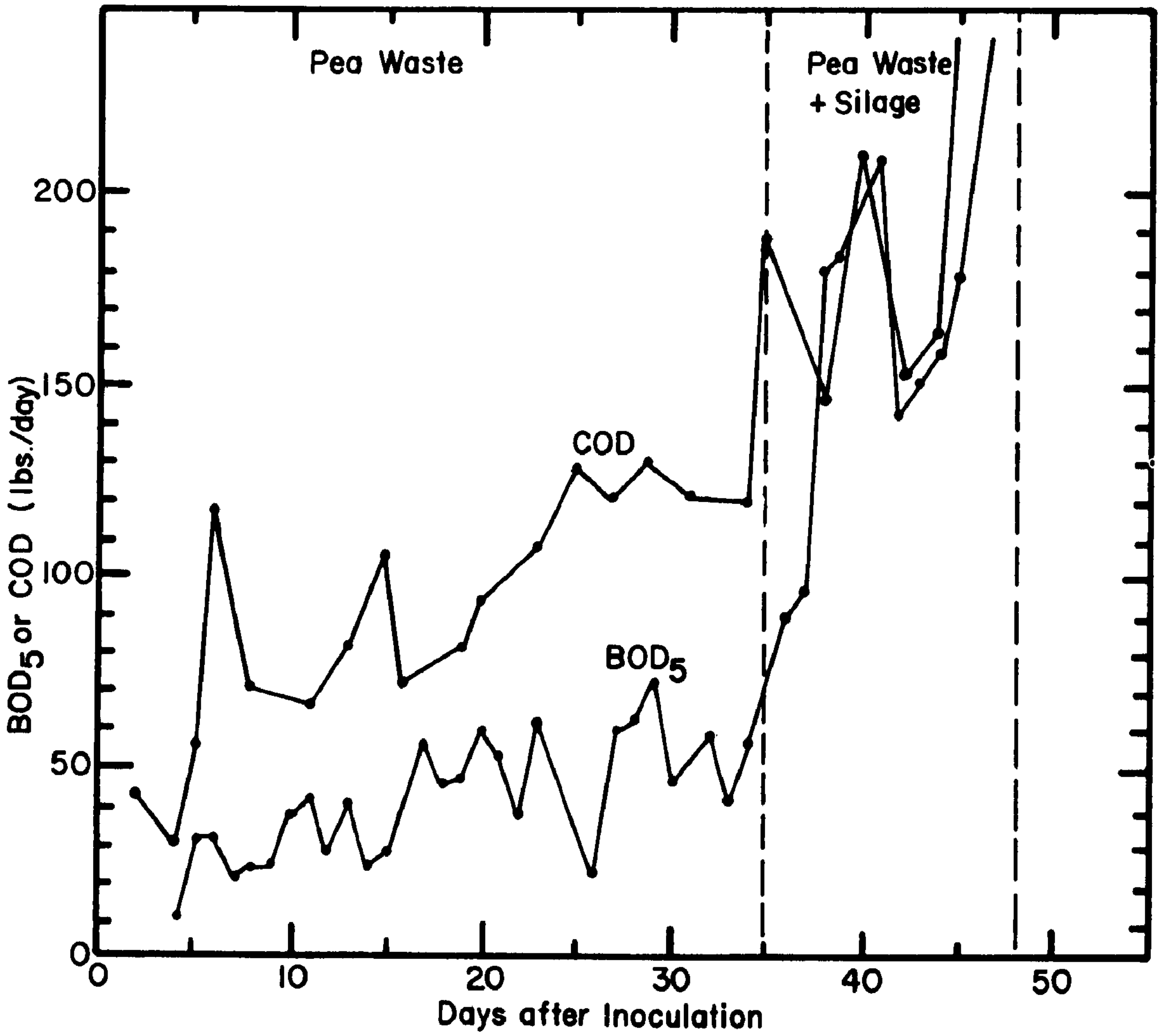



Figure 27. Total Loading of Pool in Pounds $BOD_5$ or COD per Day

Removal of Organic Matter

COD levels in the feed and effluent are shown in Figure 28, and corresponding $BOD_5$ levels in Figure 29. COD levels have been reduced from values in the neighborhood of 1600 to values in the neighborhood of 300. In eight days, the values were as low as 150 mg per liter. Most of the peaks and valleys in the effluent COD curve are unexplained, but the increase on Day 15 corresponds to a change in the floral balance with the appearance of a much greater proportion of a thin-stranded fungus.

The effluent $BOD_5$ pattern shows a discontinuity at Day 22. Before Day 22, it vacillated about 20 mg per liter and was consistently below

45. $BOD_5$ removal was above 95 percent during the latter period of operation.

A more detailed analysis of feed and waste characteristics obtained from frozen composite samples, which included equal volumes from 20 samples over the course of the operating season, is shown in Table 4. The ash content of the wastes was very high. Most of this ash was sodium chloride used in the plant to separate the peas on a density basis.

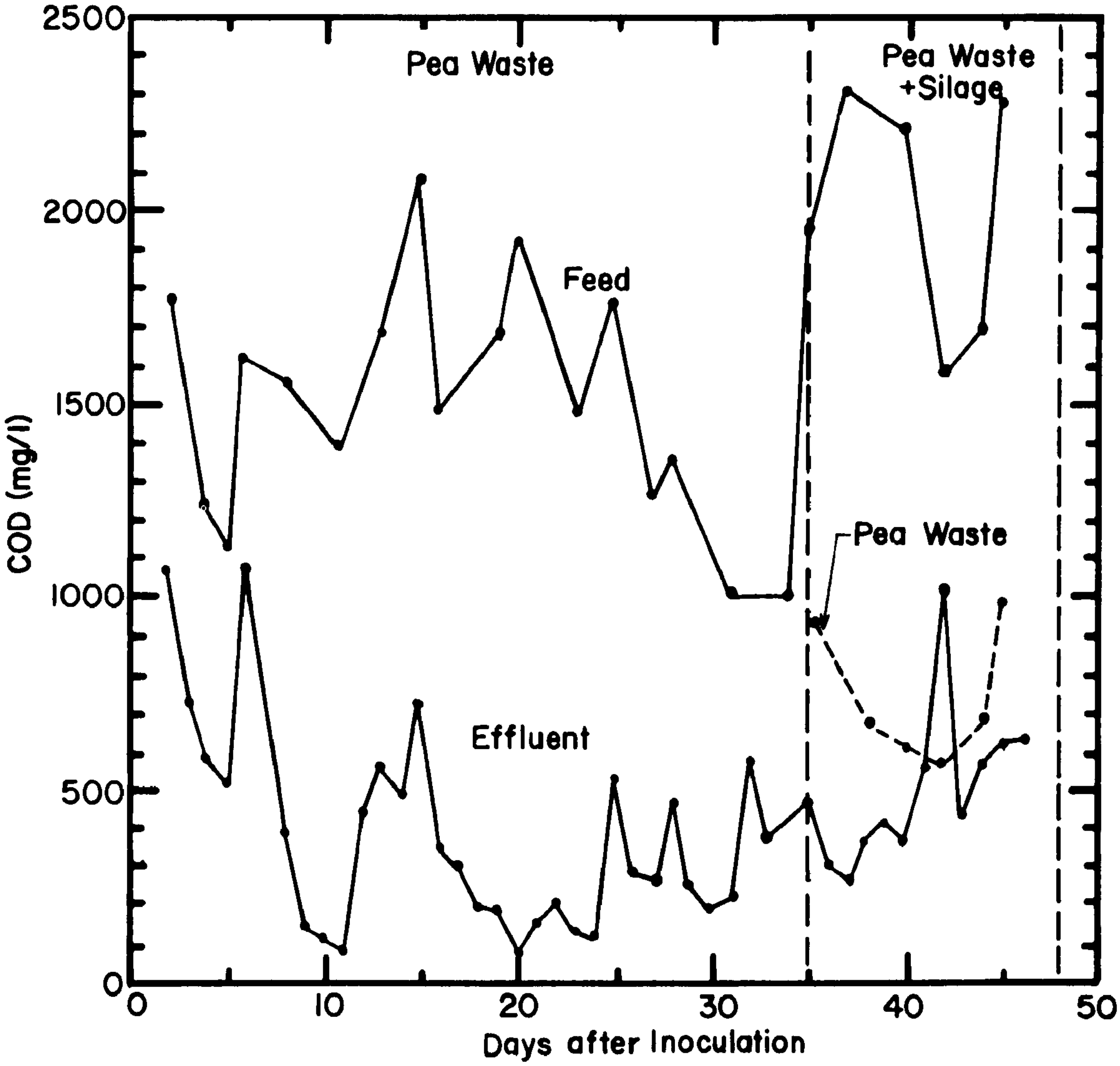



Figure 28. COD of Feed and Effluent Streams

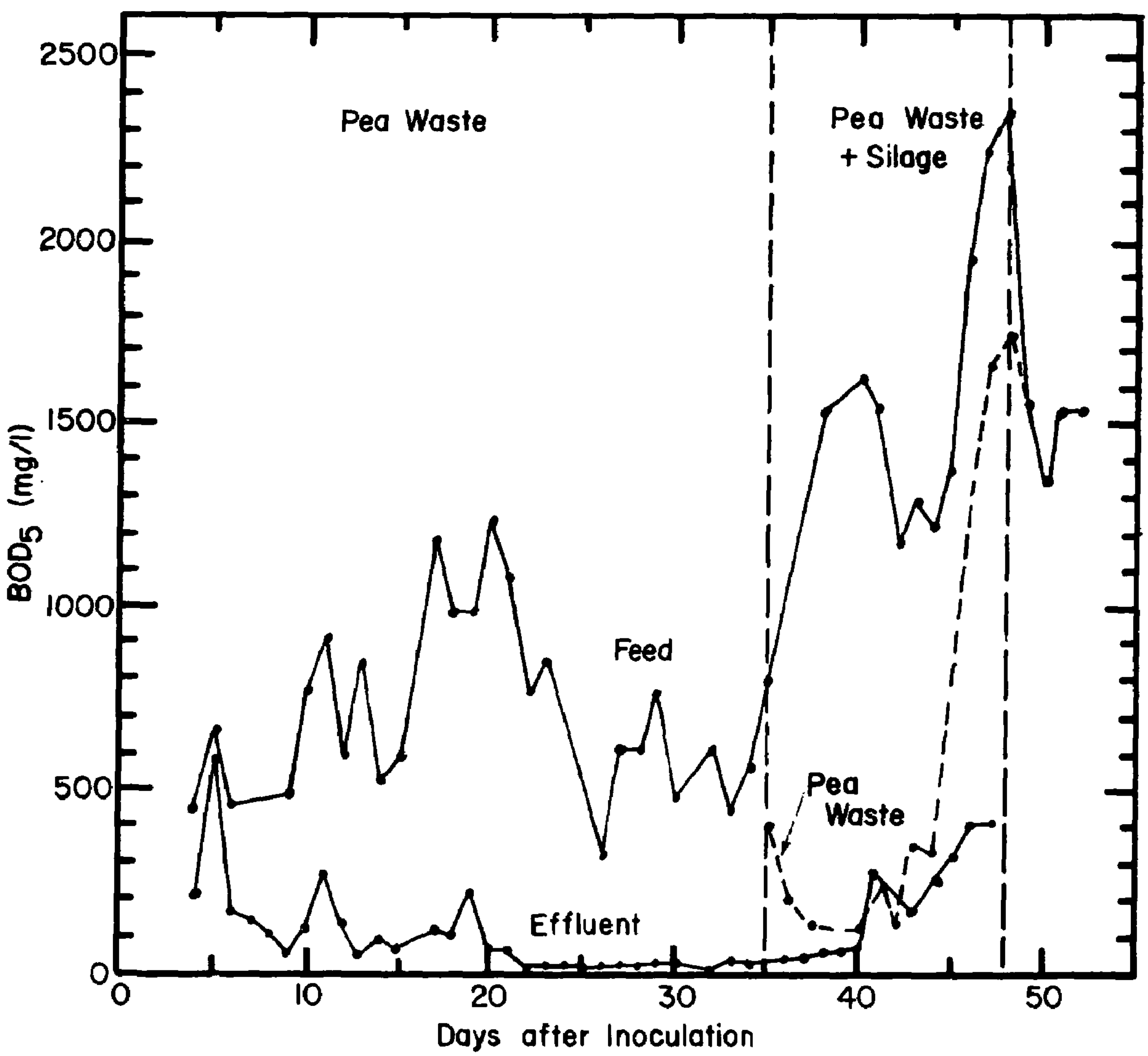



Figure 29. $BOD_5$ of Feed and Effluent Streams

Table 4. Analysis of Feed and Effluent Pea Wastes

| Test | Milligrams per Liter: Feed | Milligrams per Liter: Clarified Effluent |
|---|---|---|
| COD | 1650 | 324 |
| $BOD_5$ | 772 | 61 |
| TOC | 962 | 126 |
| Suspended solids | 264 | 1* |
| Total solids | 6818 | 6585 |
| Volatile solids | 917 | 121 |
| Mycelium (dry wt) | 0 | 420 |
| Ash | 5898 | 5874 |
| Ammonia as N | 45 | 5 |
| Phosphate as P | 13 | 10 |

*"Suspended solids" in this instance refers to suspended materials not removed by filtration, but which could be collected by centrifugation.

The ratio of $BOD_5$ to COD in the feed averaged about 0.5. The ratio in the effluent averaged about 0.2, and during the latter part of the season, was in the neighborhood of 0.1.

## Mycelium Recovery

The yield of mycelium is shown in Figure 30. The yield is not a consistent fraction of the $BOD_5$ removed. Between one and 15 days after start-up, the recovered mycelium had a dry weight equivalent to about one-third the $BOD_5$ removed. Between 15 and 20 days it increased to about 50 percent, and by the end of the pea season it was about 60 percent of the $BOD_5$ removed.

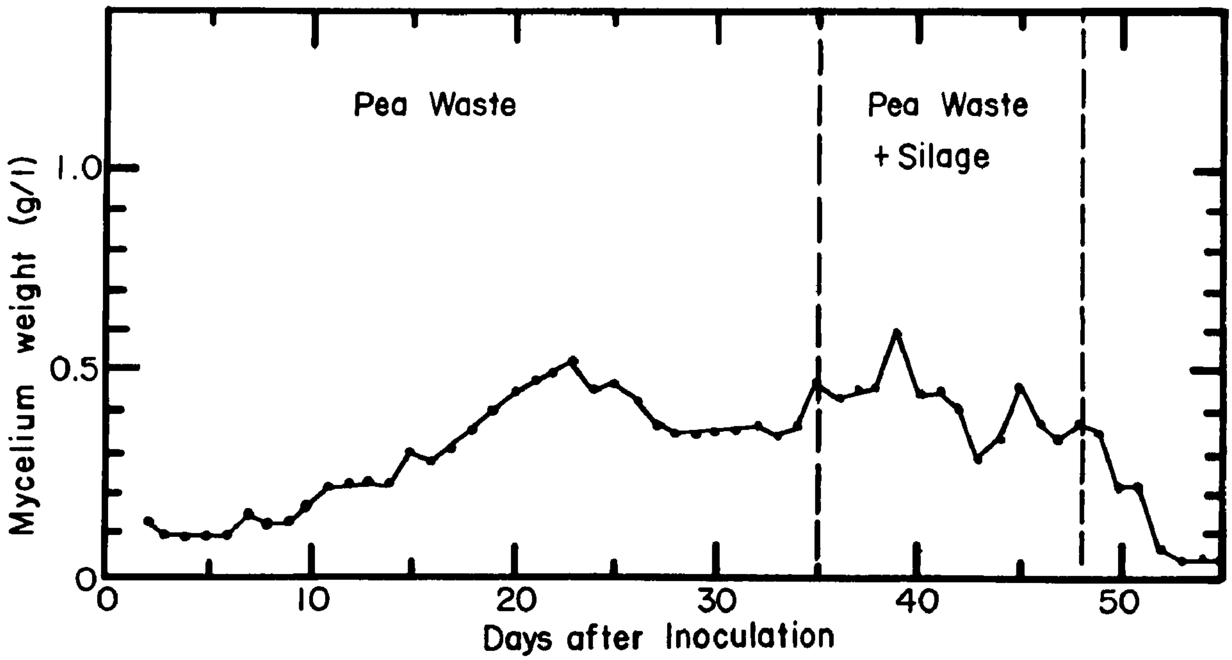



Figure 30. Dry Weight in Grams per Liter of Solids Filtered from Effluent Stream

## Oxygen Consumption

Dissolved oxygen levels are represented in Figure 31. According to the manufacturer, the aeration unit used provided aeration at the level expected of a 1.5-hp floating aerator. It kept up with the oxygen requirements of the system at all times during the treatment of pea canning wastes. The lowest DO values were 2.0, and generally the values were above 3.0 milligrams per liter in both pea and corn fermentations.

## Microbial Pattern

The microbial mass in the pea waste treatment was always dominated by fungi, with bacteria and protozoa being present only in small numbers. On about the eleventh day there was a shift in fungal type from *Trichoderma viride*, which had been used as an inoculum, to another fungus, possibly of the *Fusarium* genus. *T. viride* continued to be evident but in decreasing amounts until, at the end of the season, it formed probably not more than 10 percent of the mycelial mass. The *Fusarium*-like organism produced much finer floc than did *T. viride* and so could not be recovered on coarse filters. It could, however, be recovered on filter paper (Whatman No. 4).

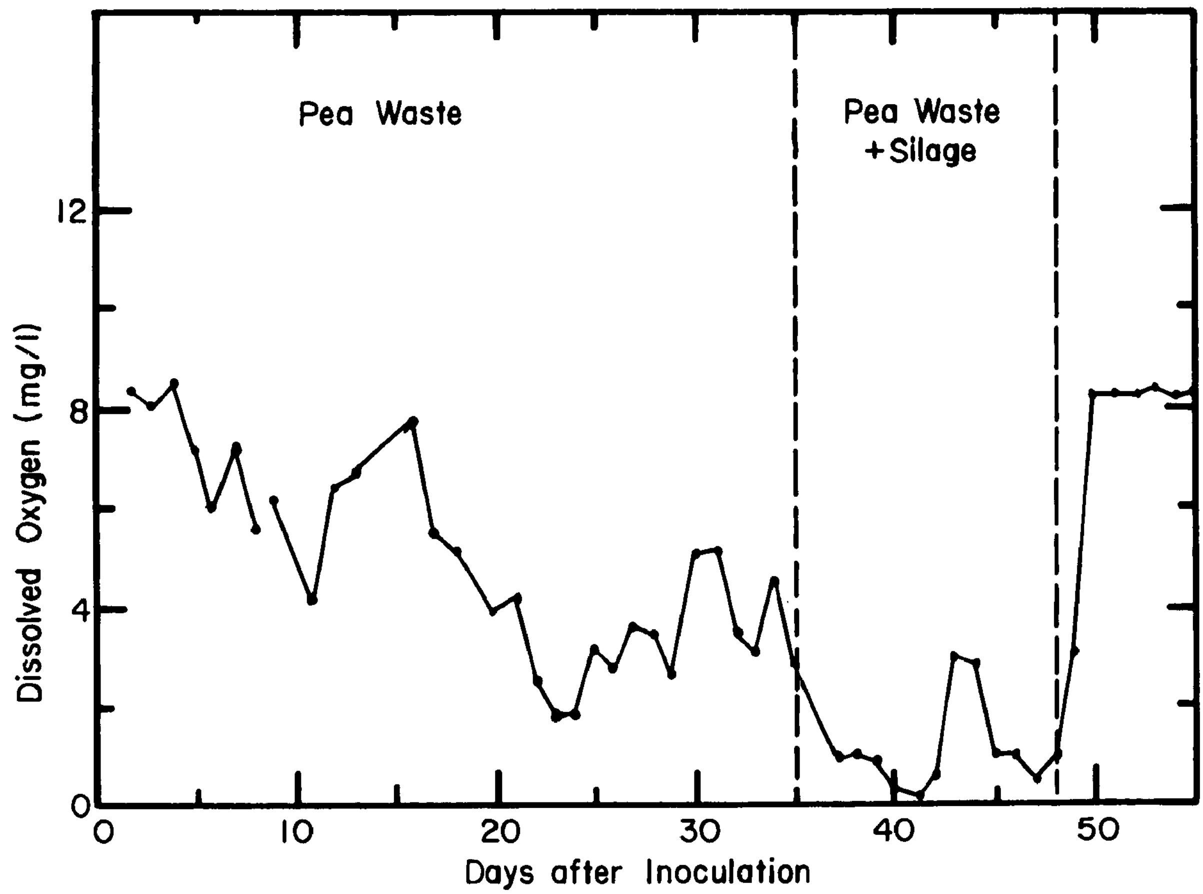



Figure 31. Dissolved Oxygen Concentration in Pool at 11 a.m. Each Day

A laboratory study was undertaken to determine whether the changes that occurred in the lagoon from which the feed to the pilot plant was drawn were of prime importance in affecting the microbial balance in the aerated pool. It was found in shake-flask studies that *T. viride* grew well on fresh plant waste and poorly on wastes drawn from the receiving lagoon. Using a mixture of the *Fusarium*-like fungus and *T. viride* as inoculum, the *Fusarium*-like organism dominated when wastes from the receiving lagoon were used as substrate. Additions of ammonium sulfate; ammonium sulfate, sodium dihydrogen phosphate, magnesium sulfate, calcium chloride, ferrous sulfate, manganous sulfate, zinc sulfate, and cobalt chloride; starch; dextrose; or peptone did not change the dominance of the *Fusarium*-like organism when the wastes from the receiving lagoon were used. Also, the closer to the point of plant discharge that lagoon samples were taken, the better they supported *T. viride* growth.

## Corn Silage Wastes

In the corn processing operation at Glencoe, the husks and cobs are accumulated in a large pile which undergoes anaerobic fermentation. An aqueous solution called "silage juice" is released and stored in a lagoon. The solution has an extremely high $BOD_5$ level and presents a difficult disposal problem. Near the end of the pea canning season, the $BOD_5$ of the pea canning waste from the lagoon dropped to a low level and presented an opportunity to test the effectiveness of the *Fungi Imperfecti* system on the silage wastes. The silage juice from the previous season was run into the pilot plant with the pea waste at this time. The operating variables and performances are represented as extensions of the corresponding data on pea canning wastes in Figures 23 through 31. Figures 28 and 29 show the proportion of the total load from pea canning wastes and the proportion from silage during the period when silage juice was being added to the fermentation. The amount of COD or $BOD_5$ from silage juice is the difference between the dotted lines which show the levels from the pea waste and the solid lines which represent total levels fed to the fermentation.

The levels of COD in the silage juice were 40,300 mg per liter and the $BOD_5$ level was 38,000 mg per liter. In calculating the COD and $BOD_5$ levels being added to the pool, account was taken of the volume of pea wastes that were being added coincidentally and which acted as diluents.

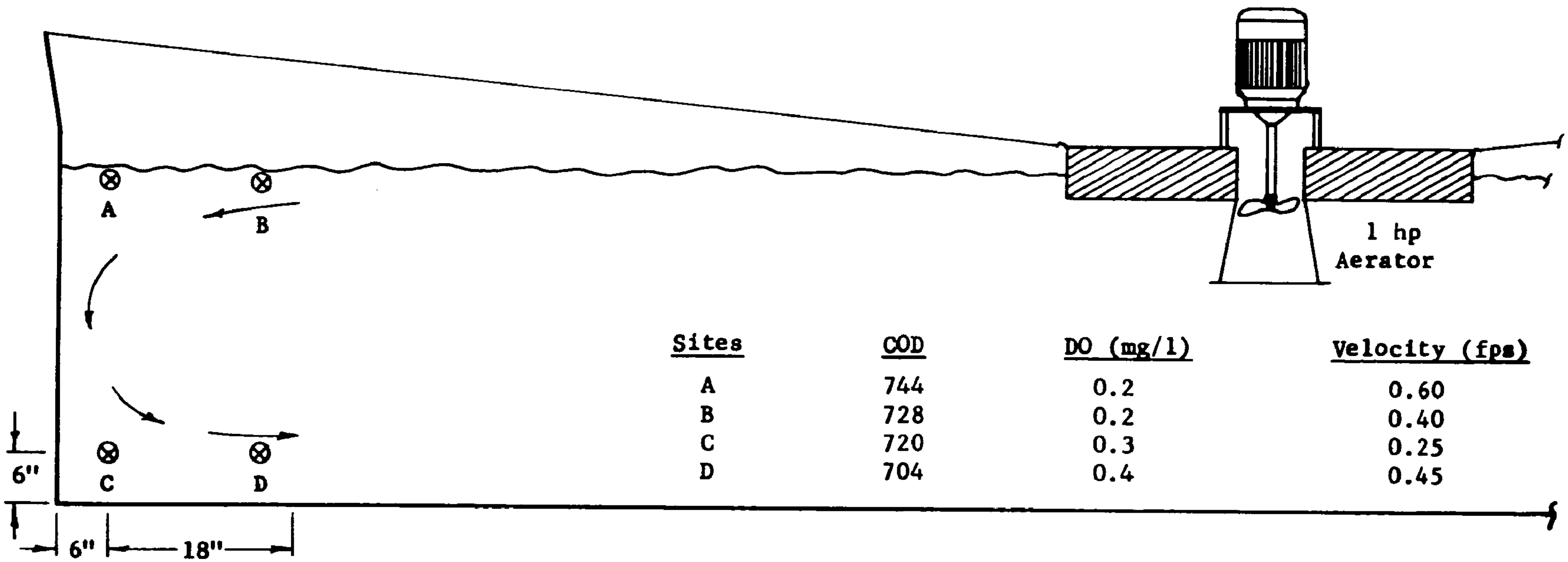
The retention time during treatment of silage juice was 18 hours (Figure 23). The temperature was above 20°C on all days (Figure 26). Sulfuric acid requirements were slightly higher than on pea wastes alone. They averaged 8.1 pounds per 1000 gallons of wastes treated (Figure 25). Ammonium sulfate and sodium phosphate additions were made (Figure 25) assuming the levels in the silage juice to be low. Later analysis showed nitrogen levels to be high enough (4.04 percent of the total solids) to support a mycelium of 50-percent protein, assuming 50 percent of the solids are recovered as mycelium.

COD removal (Figure 28) was about 83 percent; $BOD_5$ removal (Figure 29) was about 95 percent during the first five days of silage addition. This later decreased to 80 percent. The decrease in performance was associated with a decrease in DO levels to near zero. Calculating oxygen use at the times of low DO, and assuming that the 1.5-hp unit provides three pounds of dissolved oxygen per hour, one arrives at an estimated oxygen use of 72 pounds per day. About 136 pounds of $BOD_5$ were being removed per day. The calculated requirement is therefore 0.5 pound of dissolved oxygen per pound of $BOD_5$ removed. The mycelium yield appeared to be low, equivalent to only 25 to 30 percent of the $BOD_5$ removed. The biomass continued to be dominated by the *Fusarium*-like organism that dominated the pea waste fermentation.

## Mechanical Performance

There was some concern in designing the systems that there might be dead spots where the flow rate was too low to keep the mycelium in suspension and where oxygen levels would be much lower than the average for the system. Sampling of the pool at a time when DO levels were below one mg per liter gave the pattern shown in Figure 32. The level of total solids represented by the COD on the unfiltered samples, showed uniform suspension at the sampling points. The DO values differed, but only over a twofold range. Flow velocities differed by 2.3 fold between extremes among the points examined. These examinations were made with a 1-hp aerator. With a 2-hp aerator, the circulation was obviously adequate. The values recorded in Figure 32 are averages of three samples taken at each sampling site.

The circulation pattern in the ditch was even better than in the pool. With the oversized aerator used, the flow velocity was three feet per second. There was a tendency for the mycelium to concentrate in the foam on both units. Advantage could be taken of this tendency in harvesting mycelium.




| Sites | COD | DO (mg/l) | Velocity (fps) |
|---|---|---|---|
| A | 744 | 0.2 | 0.60 |
| B | 728 | 0.2 | 0.40 |
| C | 720 | 0.3 | 0.25 |
| D | 704 | 0.4 | 0.45 |

Figure 32. Flow Velocities, Dissolved Oxygen and COD Values at Selected Sampling Points in the Aerated Pool. (Sampling points are indicated as ⊗ .)

# SECTION VI

# DISCUSSION

## General Effectiveness

### Organic Compound Removal

The general effectiveness of the *Fungi Imperfecti* digestions on the three wastes to which it was applied in the pilot-plant studies is summarized in Table 5. The figures used in preparing the Table are neither the best nor the worst that could have been chosen from performance data, nor are they general averages; rather they represent averages from periods of stabilized favorable performance. $BOD_5$ removal was good and COD removal fair, in the cases of both corn canning wastes and pea canning wastes. In neither instance was removal as good as that obtained in laboratory fermentations where $BOD_5$ removal ran above 99 percent and COD removal about 96. The reason for the poorer performance is probably in the finer mycelium produced in the pilot-plant operations. Samples for analysis were prepared by filtration of a relatively small volume of effluent through Whatman No. 4 filter paper. Because the mycelium was fine, this procedure did not produce an entirely clear effluent. In the laboratory, a much larger mycelium was produced which was more easily retained on the filter. An indication of the validity of this reasoning is seen in data cited in Table 6 in which a composite effluent was completely clarified by centrifugation. The COD was reduced from 305 to 215 and the $BOD_5$ from 59 to 41. These levels in the effluents would correspond to 92-percent reduction of COD and 97.5-percent

Table 5. General Efficiency of *Fungi Imperfecti* Process

| | Corn Canning Wastes | Pea Canning Wastes | Silage Wastes |
|---|---|---|---|
| Percent $BOD_5$ removal | 96 | 95 | 80 |
| Percent COD removal | 88 | 81 | 83 |
| Percent TOC removal | 93 | 87 | 85 |
| Mycelium produced per unit $BOD_5$ removed | 0.5 | 0.6 | 0.3 |
| $H_2SO_4$ use -- lb/1000 gallons | 4.0 | 6.5 | 8.1 |
| Retention time -- hours | 22 | 18 | 18 |

Table 6. Characteristics of Composite Samples of Corn Waste Feed and Effluent Collected in Mid-Season**

| | Milligrams per Liter | | |
|---|---|---|---|
| | Feed | Effluent | Clarified Effluent |
| COD | 2536 | 305 | 215 |
| $BOD_5$ | 1580 | 59 | 41 |
| Suspended solids | 210 | 101* | 0 |
| Total solids | 2520 | 2237 | 2136 |
| Volatile solids | 1490 | 521 | 432 |
| Mycelium (dry wt) | 0 | 646 | 0 |
| Ash | 1070 | 1058 | 998 |
| TOC | 1608 | 104 | 81 |
| Ammonia, as N | 49 | 23 | 0.2 |
| $PO_4^{\equiv}$ | 9 | 0.1 | 0.05 |

*"Suspended solids" in this instance refers to suspended materials not removed by filtration, but which could be collected by centrifugation.

**Composites are from the same 20 days in each instance.

reduction of $BOD_5$. It is believed that similar improvements in removal of $BOD_5$ and COD could be effected in the case of pea canning wastes, but it is not certain that they could be achieved in the case of silage waste. The conversions of $BOD_5$ to mycelium in the case of corn and pea canning wastes are not greatly different from those obtained in laboratory digestions.[1] They are slightly lower in the pilot plant, but this may represent loss of fine mycelium. It would be of interest to determine if the mycelial yield could be improved by shortening the fermentation time, to reduce losses by endogenous respiration, and by decreasing the amount of nitrogen added to the treatment system. Higher levels of nitrogen generally promote more oxidation of carbon sources.[6] On the other hand, reducing added nitrogen to the point of reducing the protein content of the mycelium would defeat one of the objectives of the use of *Fungi Imperfecti*. This objective is that of using the fungus as a high protein animal feed. Analysis of a sample of fungus obtained from the corn waste digestion showed a nitrogen content of 8.63 percent. This corresponds to 54-percent protein if one multiplies by the conventional conversion factor of 6.25. There is, of course, no assurance that all of the material recovered by filtration is mycelium; some could represent undigested suspended solids present in the original feed. The level of suspended solids in the feed was, however, low. It averaged only 210 milligrams per liter in the corn canning waste and 50 milligrams per liter in the pea wastes.

## Nitrogen and Phosphate Removal

Nitrogen and phosphate removal is of particular interest because it is highly desirable, from the standpoint of water quality, that the levels in the effluent be very low. In the 1970 season of operation, more ammonium sulfate and sodium phosphate were inadvertently added than required either by calculation or by previous experience. Even so, the levels of phosphate were uniformly lower in the effluent than in the influent, and at several periods were essentially zero. Nitrogen levels were likewise essentially zero at some periods of operation. These low levels had no apparent effect on $BOD_5$ or COD removal. These observations, coupled with observations in the laboratory, make it appear highly likely that the process can be operated with almost no leakage of inorganic nitrogen or phosphorus into the effluent stream. The levels of organic nitrogen and phosphorus will be largely a function of the amount of mycelium that escapes into the effluent stream.

## Acid Usage

Acid usage was disappointingly high, and on the basis of requirement per pound of $BOD_5$ processed, was almost three times as high as in laboratory experience with corn processing waste. This may only reflect a higher level of hardness in the water and a lower $BOD_5$ concentration; *i.e.*, more water has to be acidified per unit of $BOD_5$ handled. Another important factor bearing on acid use is the effect of anaerobic changes that take place in the lagoon. Direct titration of fresh wastes and of lagoon wastes showed that almost twice as much acid was required to titrate the material drawn from the lagoon as was required to titrate the fresh plant wastes. The acid actually required in the treatment was about two-thirds that required to titrate lagoon wastes; thus giving evidence of some acid production by the digestion itself. It is quite evident that a variety of changes occur quickly in the lagoon. These are evidenced both by the effect of the lagoon materials on *Trichoderma viride* growth and by changes in smell and color.

Closely related to the question of acid use is the question of the amount of base that may be required to return the effluent stream to neutrality. Titration of the effluent streams from treatment of corn processing wastes and pea processing wastes showed return to neutrality could be achieved by use of 0.0041 equivalents of base per 1000 gallons. Comparing on the equivalency basis, only about five percent as much base is required to return the solution to neutrality as was required of acid to effect the acidification.

## Retention Times

Retention times were approached conservatively in attempts to achieve good $BOD_5$ and COD removal. After long enough operating times at one retention time for the treatment to become stabilized, further decreases in retention time were made. In no instance did decreases in retention time increase $BOD_5$ levels in the effluent. It, therefore, seems likely that retention times were never a limiting factor in performance, and that much shorter times might have been used successfully than were tried. It would be of great interest to determine the effect of retention time on growth habit of the fungi and upon mycelial yield per unit of $BOD_5$ removed.

## Oxygen Requirements

Knowledge of oxygen requirements is critical to estimates of the economy of the process. Estimates achieved during the present study leave more uncertainty than is desirable. Estimates of oxygen requirements made during the operation on corn wastes were 1.2, less than 0.8, and 0.7 pounds of oxygen per pound of $BOD_5$ removed. These values differ markedly from the value of 0.14 pound of oxygen per pound of $BOD_5$ removed estimated during the laboratory phase of *Fungi Imperfecti* studies.[1] Some of the measurements were by similar techniques and no errors in calculation could be found. Perhaps it was not valid to assume that readings of oxygen consumption at a selected point in time were representative of the average oxygen consumption rate over a 24-hour period. In any case, it seems certain that the estimate of 0.14 pound of oxygen per pound of $BOD_5$ removed is an impossibly low figure. Removal of one pound of $BOD_5$ yielded not more than 0.6 pound of mycelium. The missing 0.4 pound must have been completely oxidized. It is reasonable to assume that the $BOD_5$ was not originally at a higher stage of oxidation than carbohydrates and that it was oxidized to carbon dioxide and water. This would require 0.4 pound of oxygen on stoichiometric considerations alone. Allowing only for this portion of oxygen consumption would require the use of 0.4 pound of oxygen per pound of $BOD_5$ removed. Extrapolating from this base, a figure of 0.7 pound of dissolved oxygen used per pound of $BOD_5$ removed would seem the most favorable estimate that one can presently make. No estimates of oxygen use on pea canning wastes can be made. Estimates on silage wastes were 0.5 pound of DO used per pound of $BOD_5$ removed. It would be of considerable interest to alter such variables as retention time and nitrogen addition in the hope that they would increase mycelium yield. This should decrease oxygen requirements, if more carbon is transferred to cell mass.

## Temperature Effects

Low temperatures definitely limit the effectiveness of the process. During the first season, temperatures below 12°C had considerable adverse effect. During the 1970 season, temperatures down to 10°C were successfully accommodated. Successful operation at still lower temperatures could probably be achieved if part of the effluent mycelium were recycled. It is also possible that on prolonged operation at low temperatures, selection would take place for substrains that grow rapidly at low temperatures. With depression of growth rate by low temperatures, a finer mycelium was produced. In some instances, it may be possible to use waste heat from processing operations to maintain the temperature of the treatment facility in the winter months.

## Microbial Stability

The microbial system remained fungal in type at all times and it is thought that acidification was adequate to give dominance to a fungal type flora. This generalization was derived from common experience with the effect of acidity on flora in sewage treatment[7] as well as from our own experience with *Fungi Imperfecti*. There were, however, shifts in the type of flora that were dominant. Laboratory experience led us to believe that a *Fusarium* type of fungus would predominate on pea wastes, and such indeed proved to be the case even though inoculation was with *Trichoderma viride*. *Trichoderma viride* remained dominant during the short 1969 season operation on corn waste. It also remained dominant in the aerated pool during the 1970 season, but became secondary to *Geotricum* in the ditch during midseason operations. One reason for the submergence of *T. viride* to *Geotricum* may well have been the effect of the lagoon waste. In laboratory shake-flask studies, lagooned wastes proved to be unfavorable to *Trichoderma viride* growth. One argument against this theory is that moving the point of intake from the lagoon nearer to the point of plant effluent discharge had no immediate effect on the microbial balances in the ditch. The percentage of *Trichoderma viride* did however gradually increase until it was once again predominant late in the season. Another factor of importance in determing which fungus predominated in the 1970-season operation may have been excesses of nitrogen and phosphate. A tentative generalization can be made that acidification favors fungal growth, but that the fungus which will predominate will depend on the composition of the waste.

## Harvesting

The finer mycelium encountered in the pilot plant, compared with the mycelium seen in the laboratory, made harvesting a more critical problem than anticipated. The best combination explored seemed to be that of using a gross technique such as the Sweco filter to remove as much of the mycelium as possible, and then use of a sand filter to remove the finer mycelium that passed through the filter. Material recovered by backwashing the sand filter could probably be further concentrated by recycling it through the Sweco filter. The concentrate from the Sweco filter could readily be concentrated to a 20-percent solids content by vacuum filtration. Ideally, one should vary operating conditions to attain the coarse, flocculant mycelium observed in the laboratory fermentations. Work should be done to determine the role that violent agitation plays in producing a finer mycelium. There was also evidence that higher temperatures favored a coarser mycelium. Retention time may play a role and this should also be investigated. There was evidence, at least in shake-flask experience, that the use of lagooned waste promoted finer mycelium as well as promoting selection of species that inherently produced finer mycelium.

## Inoculation

The inoculation techniques used generally worked well and *Trichoderma viride* initially established itself in all cases even though it was, on occasion, displaced by other *Fungi Imperfecti*. The only failures occurred when pH control failed immediately after inoculation. The time required for the fungus to begin vigorous removal of $BOD_5$ after inoculation was generally longer than desirable. Four to six days were required. This parallels several laboratory experiences. It may be that some substrain selection is required in the continuous culture before it really begins performing vigorously. If this is true, then substrain selection made during inoculum buildup should shorten the initial lag in waste digestion start-up.

The expedient of producing inoculum in a culture rich in nutrient to obtain a high concentration of mycelium has been successful. Preserving mycelium in the cold, in a frozen stage, or after dehydration allowed regeneration of the culture, but only after some difficulty; the yeast contained in the mycelium in relatively low numbers multiplied much more quickly than the fungus and dominated the cultures for the first few days.

## Mechanical Performance

In planning the experimental program, it was hoped that comparisons could be made between the floating aerator and the ditch-cage aerator system for use with *Fungi Imperfecti*. For several reasons which included discrepancy in size of the aerator units, differences in floral balance in the two systems, and a loss of effective pH control in the pool at a critical time in the season, comparisons of the two systems was difficult. Both worked satisfactorily. Slightly better performance was obtained in the ditch, but it is not certain that this was caused by the mechanical factors associated with this configuration. The slightly higher temperature that prevailed in the ditch is considered a slight advantage.

Because of the use of acid conditions, evidences of corrosion were watched for. The cage aerator was coated with an acid-resistant paint and no evidences of corrosion were observed. The shaft of the floating aerator unit did show corrosion. Two unusual factors probably contributed to this. One was because of a loose connection in the pH control equipment, the pH of the pool unit dropped to well below 2 for several days. The other was that 316 stainless steel was used for the bulk of the unit and 304 stainless steel for the propeller shaft. This would tend to promote corrosion of the shaft.

Other equipment generally performed satisfactorily. A loose connection in one of the pH controller units caused disasters on two occasions, but this cannot be considered characteristic of the equipment. It was necessary to clean the pH electrodes frequently to obtain reliable performance. Otherwise they became covered with fungal growth which slowed their responses.

## Comparisons with an Extended Aeration Process

Another experimental program was run independently by the Green Giant Company in parallel with the *Fungi Imperfecti* studies. It is described below.

An aerated lagoon for treatment of cannery wastewater was constructed at the Green Giant Company, Glencoe, Minnesota plant during the summer of 1969. In relation to the total wastewater load, the lagoon is of pilot scale and was built to provide an actual field evaluation with extended operation, as applied to vegetable canning factory waste. The experience reported here covers only a partial season.

### Description of the Facilities

The aerated lagoon consists of a triangular-shaped earthen pond having a liquid capacity of 1.35 million gallons. The water surface is approximately 200 feet along each leg of the triangle. The liquid depth is 15 feet. The earthen sides slope up from the bottom a distance of 13 feet vertically and 26 feet horizontally (2:1 slope). The sides continue to slope upward from that point a distance of 2.5 feet vertically and 15 feet horizontally (6:1 slope). From the 15.5-foot level to the top of the berm at 18 feet, the slope returns to the 2:1 ratio. Thus,the earth slopes on the inside of the ponds are at 2:1 with a 15-foot wide berm at the water line which has a flatter, 6:1 slope.

The lagoon is aerated by one 75-hp platform mounted "Lightnin" aerator, Model LAR-150, manufactured by Mixing Equipment Company, Rochester, N.Y. The unit consists of a 75-hp horizontal-shaft electric motor connected by a flexible coupling to a right-angle speed reducer. The speed reducer unit has a 5-inch vertical steel shaft extending from the platform to the water surface. At the end of the shaft is an impeller consisting of four blades of flat one-inch steel plate. The diameter of the impeller is 9ft, 6 inches. The shaft and impeller rotate at 37.9 rpm. The impeller is positioned at the water surface with the top of the blades just barely covered when in a static position. Except for the four steel blades and the cast steel hub, there is nothing submerged in the water. The aerator is suspended over the lagoon by a structural steel platform supported by three reinforced concrete columns with concrete footings. The lagoon bottom directly beneath the impeller is covered with a 6-inch thick concrete slab extending around the column footings, to protect against the possibility of erosion caused by the action of the impeller. There is a structural steel footbridge from the lagoon bank out to the support platform.

Wastewater is fed into the lagoon through an orifice tank. This consists of a steel tank with a bolt-on plate with circular orifice. There is an overflow weir at the top of the tank with any excess feedwater sent back to the source; thus providing an orifice under constant head. The rate of discharge into the lagoon is controlled by providing an orifice of given diameter. The formula for orifice discharge used is:

$$Q = 11.94\ d^2\sqrt{H}$$

where $Q$ = discharge in gpm
$d$ = orifice diameter in inches
$H$ = head on orifice in feet

The formula assumes a coefficient of discharge of 0.6. There has been considerable investigation of the hydraulics of orifice discharge at the size and head range involved, and this formula is considered accurate to within one percent or less. It is, thus, the most accurately measured variable involved in the project. The orifice tank is provided in duplicate to control the simultaneous discharge of two separate wastewaters into the lagoon, if such were a desired part of the experiments. In addition to an influent feed pump, a second pump is provided for recirculation of treated water back into the lagoon.

The discharge of wastewater out of the lagoon is controlled by a 51-inch-diameter steel weir plate overflowing into a catch basin. The catch basin discharges through a culvert to the adjacent lagoon No. 1B. Figure 33 provides a schematic view of the facilities.

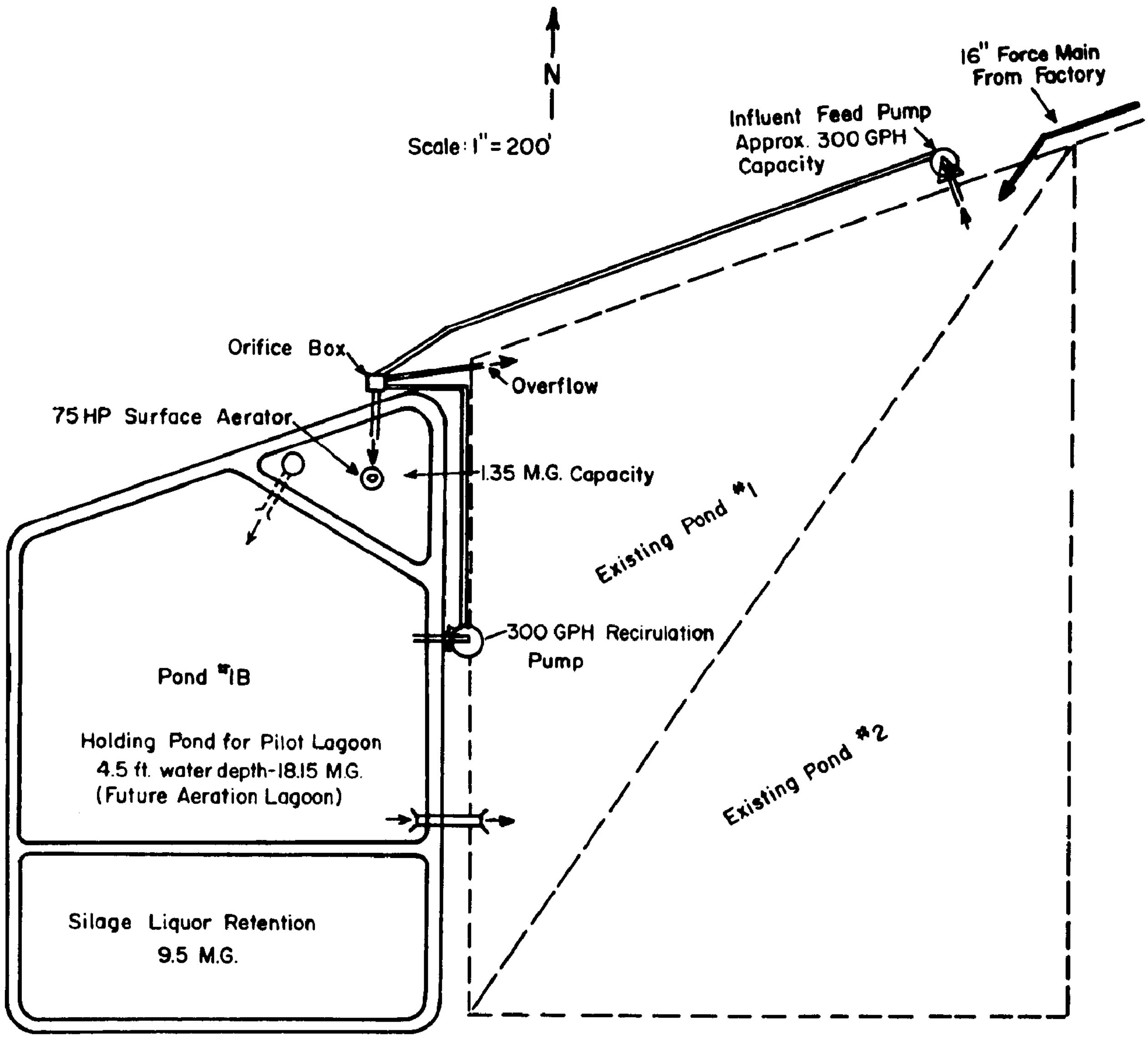



Figure 33. Pilot Lagoon for Extended Aeration at Glencoe, Minnesota

## Evaluation of Performance

Even though the aerator did not begin operating until September 6, it was possible to obtain quite a bit of information. The waste feed supply was taken from the original Pond No. 1 of the seven staged ponds, and thus the system continued to operate even after the end of pea and corn pack. There was no observable difference in the biological process whether the waste was treated almost immediately fresh from the factory, or if it had been retained in Pond No. 1 for a long period of time. The system is evaluated as to the following features:

Mechanical Reliability of Aeration Equipment. The aerator functioned continuously from September 6 to November 14, with no problem or difficulty. The machine operates unattended although someone visits the site once a day. No maintenance or attention was required except for change of gear lube at the end of the break-in period.

Cold Weather Operation. The equipment can be operated in cold weather provided incoming waste furnishes a heat source, or until the ambient temperature and the mixing aerating action turns the entire pond to ice. However, splashing of water onto the structure must be controlled to prevent ice formation on the platform. This pilot installation was found to be deficient because water is splashed against the face of the supporting columns at such an angle that some water is thrown up onto the platform. It is believed that this can be partially corrected by adding a baffle or deflector at each column. The unit was shut down November 15 when the temperature dropped to 12°F.

Lining of Earth Lagoon. Because the $BOD_5$ concentration of corn wastewater is quite high (about ten times as high as domestic sewage), the oxygen requirements are also high. This requires a high energy input into the lagoon. The pilot installation has 55.6 hp per million gallons of lagoon capacity. This hp-volume ratio approaches the level required in activated sludge plants where aeration is performed in concrete tanks. It was the opinion of most of the persons consulted who had experience with aerated ponds that a concrete or bituminous lining would be required in the earth lagoon to control erosion of the banks. The lagoon was constructed without a lining, relying on the 6:1 "broken back" berm section at the water line to control erosion. This has been completely successful to date with only very slight erosion at the waterline. This is a significant finding since a lining would involve great expense.

Biological Efficiency of the Process. The biological efficiency of the process (*i.e.*, whether corn waste would actually respond to treatment in this type of system), was evaluated in the following ways:

A. The efficiency of the process is calculated by the formula:

$$E = \frac{230\ kt}{1 + 2.3\ kt}$$

where: E = percent $BOD_5$ removed

t = lagoon detention time in days

k = reaction coefficient

During operation, the actual efficiency of the process is determined by sampling and $BOD_5$ analysis of the influent and effluent from the system. From the data obtained it has been calculated that the reaction coefficient at 20°C is $k_{20}$ = 0.86. Thus, at 20°C and a 6-day detention time, $BOD_5$ reductions of 92 percent are obtainable. This corresponded in practice to treatment of 44 pounds of $BOD_5$ per hp per day. It should be pointed out that the $BOD_5$ tests performed were on the settled effluent from the system. In practice it is expected that the settled solids on the bottom of the first pond following aeration will decompose and cause some subsequent rise in the $BOD_5$ levels. This is not reflected by the test data.

The limits of performance of the *Fungi Imperfecti* system, although not adequately probed, are given for comparison. During one period of several days (Days 22 to 35, Figure 24) in the pool, treatment of 50 pounds of $BOD_5$ per hp per day with 95-percent removal of $BOD_5$ was observed. Temperatures during this period varied from 16°C to 8°C.

B. In addition to detention time, the efficiency is affected by temperature. The reaction rate coefficient was found to vary with temperature according to the van't Hoff - Arrhenius equation:

$$k_t = k_{20}\,\theta^{t-20} \quad \text{(where } \theta = 1.035\text{)}$$

θ, the temperature correction factor, is 1.072 in batch systems. This does not fit the data from continuous systems. By trial and error we found that θ = 1.035 best fit these data.

A continuous record of water temperature and air temperature was obtained by using a soil-air thermograph. From the data obtained, it was possible to compare the observed efficiencies with the theoretical calculated efficiencies as temperature and feed rate varied. Some of the results are shown in Figures 34, 35, and 36.

C. Another variable which affects the reaction coefficient, *k*, is the availability of nutrient for the microorganisms to grow and multiply. From September 16 to October 14, one pound of nitrogen was added to the system for each 30 pounds of $BOD_5$ applied, and one pound of phosphorus was added for each 150 pounds of $BOD_5$ applied. For a short period, from September 23 to October 1, the $BOD_5$ application was increased without changing the nutrient addition. On October 14, the nutrient addition was

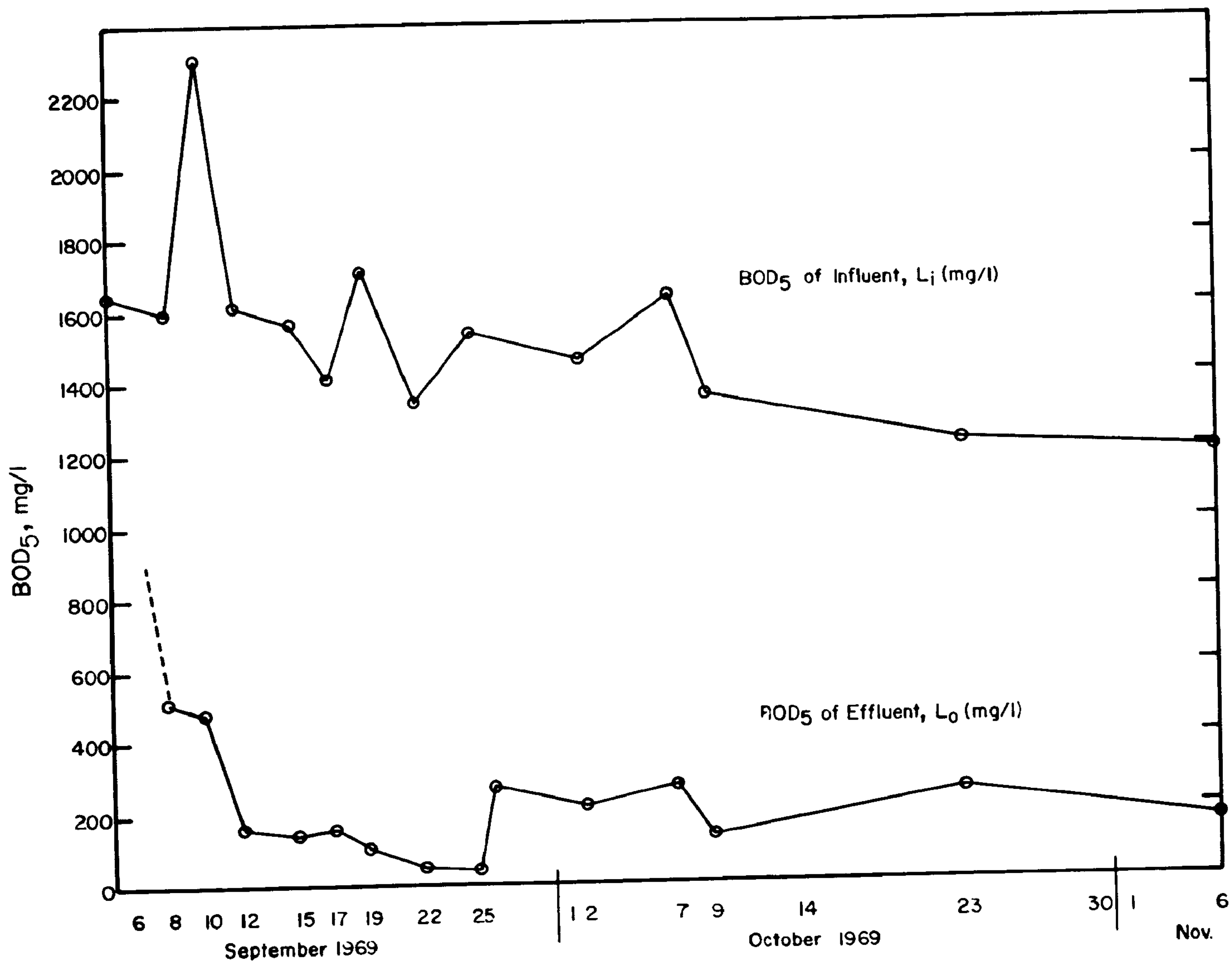



Figure 34. $BOD_5$ Sample Results for Pond

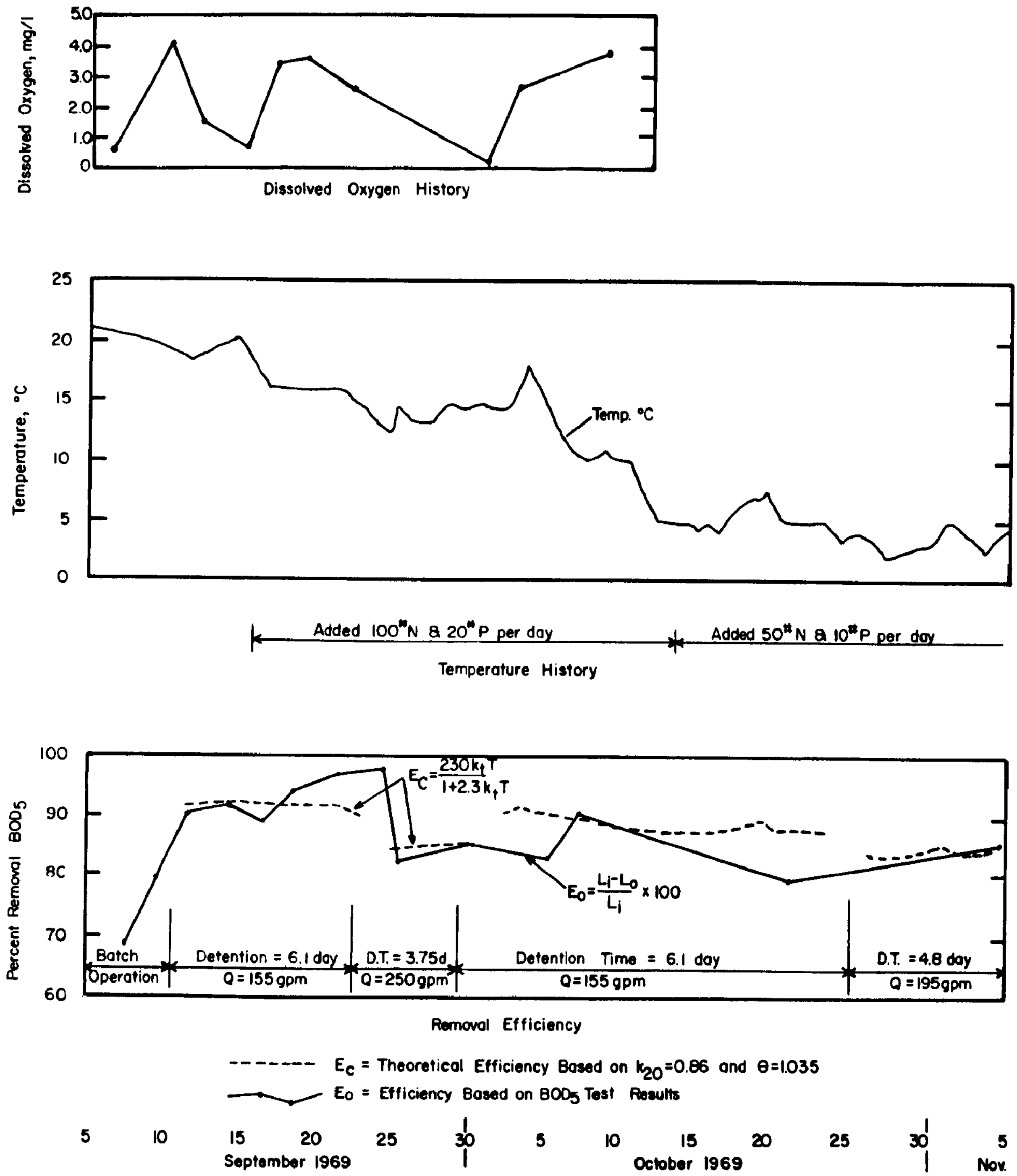
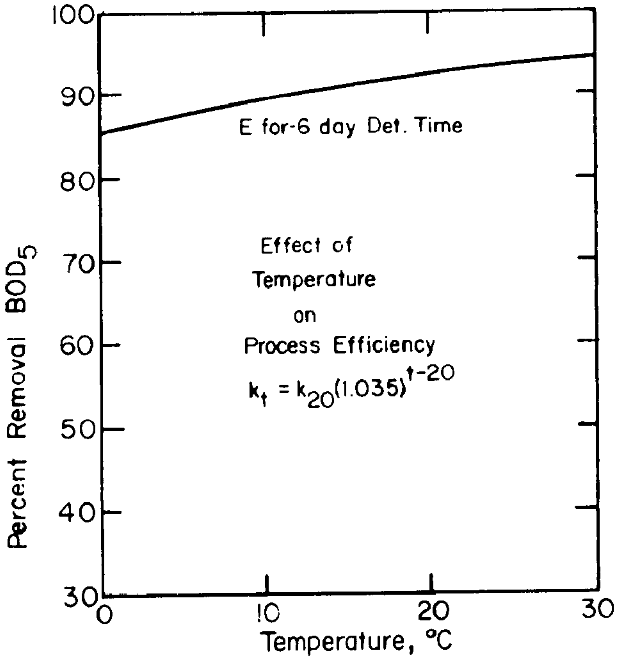



Figure 35. Dissolved Oxygen, Temperature, and Removal Efficiency in Pond




$k_t = k_{20}(1.035)^{t-20}$

| t, °C | $k_t$ |
|---|---|
| 1 | 0.45 |
| 2 | 0.46 |
| 3 | 0.48 |
| 4 | 0.50 |
| 5 | 0.52 |
| 6 | 0.53 |
| 7 | 0.55 |
| 8 | 0.57 |
| 9 | 0.59 |
| 10 | 0.61 |
| 11 | 0.63 |
| 12 | 0.65 |
| 13 | 0.67 |
| 14 | 0.70 |
| 15 | 0.72 |
| 16 | 0.75 |
| 17 | 0.78 |
| 18 | 0.80 |
| 19 | 0.83 |
| 20 | 0.86 |
| 21 | 0.89 |
| 22 | 0.92 |
| 23 | 0.95 |
| 24 | 0.99 |
| 25 | 1.02 |

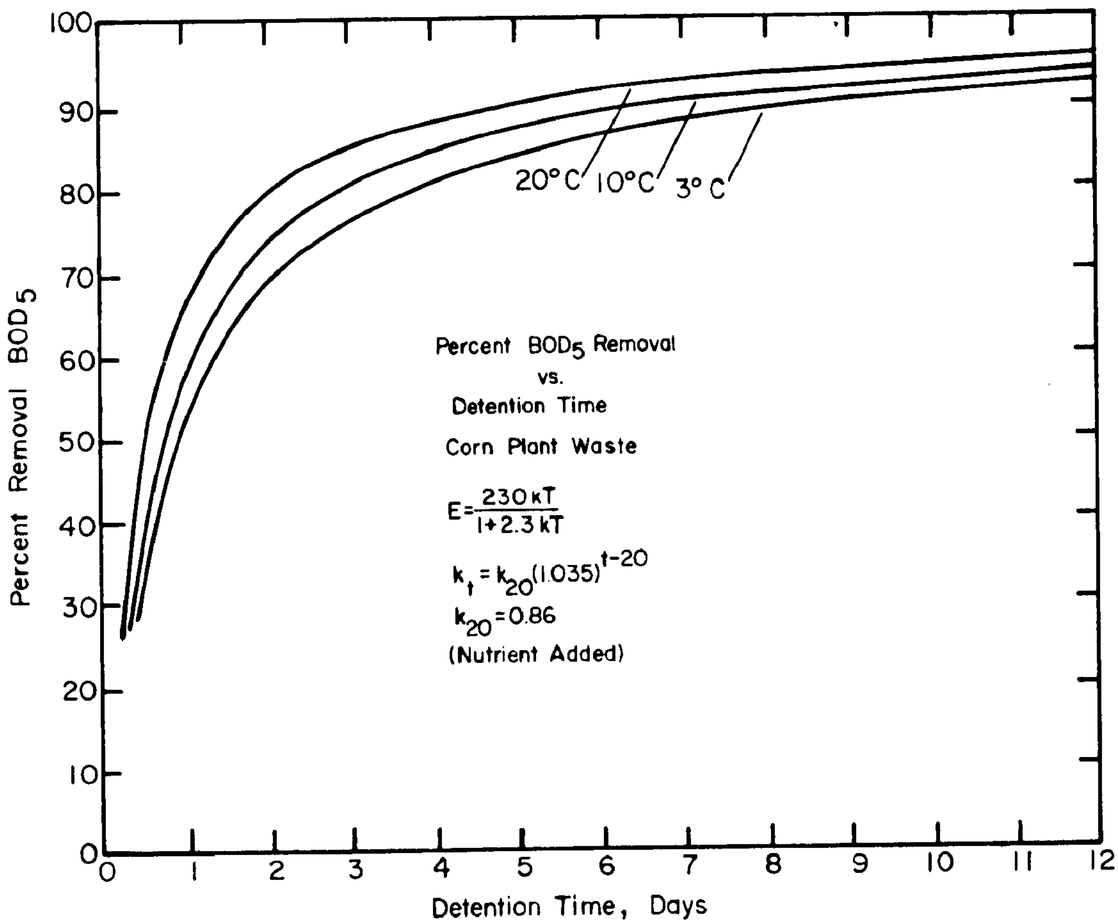



Figure 36. Effect of Temperature and Detention Time on Removal Efficiency in Pond

cut in half. The effects of these changes in nutrient level are not evident from the data available. More study will be required to determine the minimum required amount of nutrient.

Aeration Capability of Mechanical Equipment. The biological reaction coefficient determines the detention time and thus, the pond volume, assuming a given level of performance is required. Since the difference in cost of earthwork in building a lagoon of 20 mg versus one of 15 mg is not large, some variation in the reaction coefficient does not have a major effect on capital costs. The major part of the capital costs result from the installation of mechanical aeration equipment. Therefore, it is important to know the capability of each aerator to handle $BOD_5$ loading under the conditions anticipated.

Based on the guaranteed capacity of the aerator to supply 5856 pounds of oxygen per day to tap water under standard operating conditions (3.2 hp per hr), the calculated capacity under lagoon conditions was estimated at 3860 pounds per day. Therefore, the project was set up to apply 4000 pounds of $BOD_5$ per day to the aeration lagoon in the initial runs. As it turned out, the $BOD_5$ concentrations in the raw waste were less than anticipated, and the actual application was about 3000 pounds per day. This feed rate did not tax the capacity of the aerator to determine its maximum capability. On September 24, the feed rate to the system was increased to apply 4800 pounds $BOD_5$ per day. After seven days at this loading, the dissolved oxygen level in the system was down near zero. The lagoon and effluent samples from the lagoon were odorous, whereas no odor had been observed before. The settling characteristics of the effluent solids were lost. It appeared that the aeration equipment was overloaded, and the load was reduced to its previous level. After a couple of days the system recovered.

With a system of six-day detention time, a delay is required to determine the effect of changes in loading. There is an additional delay for the $BOD_5$ test. When corn and pea pack ended the frequency of sampling was cut back to once a week or less because of the loss of seasonal help in the Food Science Laboratory. With the observations of other variables providing effective data, there was a reluctance to change too many variables at once. As a result, we have not yet determined the exact $BOD_5$ removal capabilities of the 75-hp aerator. Based on an interpolation of the data thus far, it seems safe to assume that 3300 pounds of $BOD_5$ per day can be removed by the pilot plant without depleting the oxygen. To accommodate the entire waste stream from the Glencoe plant, approximately ten 75-hp aerators would be required.

Electrical Power Consumption. The electric utility bill for the period of September 15 to October 15, was $667. About 90 percent of the power was consumed by the 75-hp aerator. Thus, it appears to cost $20.00 per day for electrical energy to operate the aerator. If the aerator is kept loaded at an overall efficiency of 90 percent, the $BOD_5$ removal would average 3000 pounds per day. The electrical energy cost would be $0.0067 per pound of $BOD_5$ removed.

The total $BOD_5$ load at the Glencoe Plant is estimated as follows:

| | | |
|---|---|---|
| Pea waste | - 60 mg at 1,200 mg/l = | 600,000 lb $BOD_5$ |
| Corn Waste | -120 mg at 1,600 mg/l = | 1,600,000 lb $BOD_5$ |
| Silage juice | - 5 mg at 60,000 mg/l = | 2,500,000 lb $BOD_5$ |
| | Total | 4,700,000 lb $BOD_5$ |

For 90-percent $BOD_5$ removal in the aeration system the total annual electrical energy cost is estimated as follows:

4,7000,000 lb x 0.9 x \$0.0067 = \$28,200

For peas, this amounts to about \$0.0024 per case. However for corn, including the silage liquor, this calculates out to about \$0.0068 per case.

On the basis of increased cost per case as estimated above, all other operating costs (maintenance, etc.) are negligible.

## SECTION VII

## ECONOMIC ESTIMATES

Estimated costs of operation of the *Fungi Imperfecti* system are higher than in laboratory studies[1] for three reasons. One reason is the higher sulfuric acid demand; another is revision of estimates of oxygen requirements; and the third is the greater difficulty in filtering material produced in the pilot plant. The higher sulfuric acid requirements are a function of the use of harder water and of a more dilute plant-waste stream. Amortization costs and interest costs would be reduced by fourfold per unit of product or per unit of $BOD_5$ if the equipment were used the year around instead of for three months.

Cost estimates per pound of product and per pound of $BOD_5$ treated are given in Table 7. In making the estimates, it has been assumed that

Table 7. Cost Estimates on Corn Processing

| | Cents per pound product | Cents Per pound $BOD_5$ |
|---|---|---|
| $H_2SO_4$ | 0.86 | 0.43 |
| $(HN_4)_2SO_4$ | 0.84 | 0.42 |
| $NaH_2PO_4$ | 0.20 | 0.10 |
| Aeration | | |
| Power | 0.78 | 0.39 |
| Investment | 2.32 | 1.16 |
| Labor | 1.67 | 0.83 |
| Filtration | | |
| Sweco | 0.18 | 0.09 |
| Sand bed | 0.92 | 0.46 |
| Vacuum filter | 0.66 | 0.33 |
| Drying | | |
| Heat | 0.35 | 0.18 |
| Investment | 0.92 | 0.46 |
| Total | 9.70 | 4.85 |
| Credit for dry solids | -3.50 | -1.75 |
| Net Cost | 6.20 | 3.10 |

the $BOD_5$ concentration in 1.0 mgd of feed is 1600 milligrams per liter. In calculating sulfuric acid cost, it has been assumed that sulfuric acid will cost 1.7 cents per pound. Also, it appears that it will be necessary to use 3 pounds per 1000 gallons of feed if fresh feed is used, rather than the 4 pounds that were necessary when waste from the lagoon was treated. In calculating ammonium sulfate costs, a cost of 2 cents per pound has been assumed for the ammonium sulfate and a requirement of 2.5 pounds per 1000 gallons of feed has been assumed. This is less than the 3.5 pounds used during the bulk of the operation in 1970, but is adequate to give a mycelium with a protein content of 50 percent and is in line with previous experience on requirements. In calculating the sodium phosphate costs, it has been assumed that sodium dihydrogen phosphate will be available at 11 cents per pound and that 0.11 pound per 1000 gallons of feed will be adequate. This again is less than used in the 1970 operation, but was adequate in previous experience and should assure a near zero phosphate level in the final effluent. In calculating aeration costs, it has been assumed that 0.7 pound of dissolved oxygen will be required for each pound of $BOD_5$ removed, that 1 hp delivers 2 pounds of dissolved oxygen, and that electricity will be available at 1.5 cents per kilowatt-hour. In calculating investment costs, it has been assumed that $500 per horsepower will pay for both aeration equipment and auxiliary equipment, including the lagoon; that interest costs will be 7 percent; that the investment would be amortized over 10 years; and that the unit will be operable for 90 days of the year. In calculating labor costs, it has been assumed that one man can take care of the unit and that $100 a day will be adequate to cover this item.

In calculating filtration costs it has been assumed that a combination of a Sweco unit, a sand bed, and vacuum-filter would be required. For the Sweco unit it has been assumed that a 40-square-foot unit would be required. Such a unit would cost about $7000. A sand bed to handle one million gallons a day has been assumed to cost $35,000. A vacuum filter to dewater 6000 lb of solids per day has been assumed to cost $25,000. A drum drier to handle 6000 lb a day will probably cost about $35,000. The power cost for drying from 80 percent to 10 percent moisture has been estimated at 0.35 cents per lb of dry product, on the basis of heat at a total cost of 45 cents per million Btu, as follows:

> Drying from 80 percent to 10 percent moisture requires evaporation of 3.89 lb water per lb dry product. It is assumed that the overall drying efficiency is such that 2000 Btu is needed to evaporate 1 lb of water. Therefore, the cost per lb of dry product is:

$$3.89 \text{ lb } H_2O \times 2000 \frac{\text{Btu}}{\text{lb } H_2O} \times \frac{0.45}{10^6 \text{ Btu}} = 0.0035$$

These costs are tabulated in Table 7. Sale of the product might be expected to return 3.5 cents per pound by analogy with the selling price of soy meal, comparable in protein content and quality.

Among the factors that could lower operating costs per pound of $BOD_5$ in a significant degree are higher $BOD_5$ concentrations, longer operating seasons, softer water, wastes containing adequate nitrogen and phosphorus, and a mycelium that filters as readily as did the laboratory materials.

Operating on a year-round basis would reduce investment costs to one-fourth those listed, reducing the total cost to about 3.0 cents per pound of $BOD_5$. Production of a readily filterable material, as was accomplished in the laboratory, would eliminate the need for the sand filter, to give a cost (on a year-round basis) of about 2.9 cents per lb of $BOD_5$. The credit of 3.5 cents per lb of product, or 1.75 cents on a pound of $BOD_5$ basis, would reduce the net cost to about 1.1 cents per lb of $BOD_5$ treated. Further economies would be possible if oxygen requirements, or costs, and chemical use could be lowered. A major reduction would occur if drying could be avoided; *e.g.*, by direct feeding of the wet mycelium. On a year-round basis, a savings of about 0.30 cents would result, reducing the cost per lb of $BOD_5$ to about 0.8 cent.

## SECTION VIII

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## SECTION IX

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## SECTION X

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**6 Title**

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Nash, Harold A.
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**27 Abstract**

The use of the imperfect fungus, *Trichoderma viride*, to treat corn and pea wastes has been tested in continuous fermentation at the 10,000-gallon scale. Both a pool unit and an oxidation ditch were tested. The pH was 3.7, and ammonium ion and phosphate were added. The average residence time was 20 hours. An aerated lagoon was also operated to compare with the two fungal systems.

In the fungal systems, about 96 percent removal of $BOD_5$, 88 percent removal of COD, and 93 percent removal of TOC was achieved on corn canning wastes. Performance on pea canning wastes was somewhat less. Essentially zero levels of ammonia nitrogen and inorganic phosphate could be attained in the effluent stream.

Fungal yields, on a dry-weight basis, were about 50 percent of the $BOD_5$ of the feed, and the protein content of the dry mycelium was about 50 percent.

Costs are estimated at 4.9 cents per pound of $BOD_5$. Sale of mycelium as feed could decrease this to 3.1 cents. Operation on a year-around basis with sale of the mycelium would decrease costs to about 1.1 cents per pound of $BOD_5$. Direct feeding of the mycelium without drying could further reduce the net cost to about 0.8 cent per pound of $BOD_5$.

| Abstractor | Institution |
|---|---|
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