A STUDY OF POSSIBLE TOXIC EFFECTS OF CHILI-PROCESSING WASTE WATER ON ACTIVATED SLUDGE PROCESS

by

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ABSTRACT

An investigation of the possible effects of chili-processing waste water on microbial populations instrumental in biological waste treatment was conducted. Batch reactors were used to conduct experiments which compared the treatability of chili-processing waste waters to the treatability of municipal sewage. Experiments were also conducted to determine the effect of acclimation of biological solids on treatability. Using low initial solids concentrations in some experiments, values of constants in Monod kinetics were determined for the chili-processing waste waters.

It was concluded that chili-processing waste waters are amenable to biological treatment and exhibit no gross toxic effects on the biological solids. However, the soluble chemical oxygen demand (COD) is removed at rates slower than the rate at which the soluble COD in municipal sewage is removed. Also, the chili-processing waste waters have a higher level of refractory COD than does the municipal sewage. It was demonstrated that the difference in rates of removal of soluble COD from chili-processing wastes and from municipal sewage was due to acclimation of biological solids to a particular substrate.

Monod-predicted rate constants differed significantly from experimentally-determined ones. This was concluded to result from an inability to precisely and accurately determine viable initial organism concentration from suspended solids measurements.

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INTRODUCTION

New Mexico is a water-limited state, with much of its water supply being used for agriculture. One of the important agricultural industries in New Mexico is that of the cultivation of chili with 8,700 acres currently being used for that purpose. There is no reason not to expect continued expansion of this industry.

Chili processing creates substantial amounts of waste water. During the chili processing season, a great deal of domestic and restaurant chili preparation also takes place, adding substantially to the officially recorded amounts of chili waste water effluent.

In New Mexico, the chili food-processing industries produce an effluent which may commonly be treated by the municipal sewage treatment plant with mixtures of varying dilutions with sewage. The characteristics of this waste water differ from the characteristics of domestic sewage. In addition, the processing of chili is a seasonal one, involving essentially two different effluents: those resulting from the processing of red chili and those resulting from the processing of green chili. This situation makes possible the problem of shock loadings, which result from the introduction of a waste to a biological treatment system which is not acclimated to the particular waste.

PURPOSE

The purpose of this study was to determine if waste water effluent from a chili-processing industry exerted any toxic effect on microbial populations such as those cultivated in activated sludge. The effect of such effluent on activated sludge was desired to be determined as the city of Las Cruces sewage treatment plant is an activated sludge process.

It was also desired to determine the effect of contacting the chili-processing effluent with an acclimated microbial population as opposed to an unacclimated one. In addition, some kinetics of microbial growth using chili-processing waste as substrate were determined in order to be compared to the kinetics of growth in municipal sewage.

LITERATURE REVIEW

Chili-Processing Waste Waters

The effluent used in these experiments was obtained from Cal-Compack, a chili-processing industry located in Las Cruces which does discharge its waste waters to the municipal sewage treatment plant.

The processing of green chili involves soaking the fruits in a 15% lye solution before they are roasted. Chlorine is used only to clean the equipment and is then rinsed off with water. Green chili is processed from mid-July to mid-September, and involves approximately 20% more volume of water than the processing of red chili.

Soil is removed from the red chili in a water bath containing a food grade, F. D. A.-approved detergent and approximately 50 ppm chlorine (1). The fruits are then washed and defective pods are sorted out. The peppers are sliced, dried, ground to a fine powder, and then stored in barrels. Processing of red chili occurs from mid-September to mid-December.

The solids of the waste water are separated by screening. The size of screen utilized at Cal-Compack in Las Cruces is 20 mesh per square inch.

Very little information is available about the composition and concentration of the liquid waste. Employees of the Las Cruces Sewage Treatment plant have monitored the effluent of Cal-Compack on selected occasions. Their data are summarized in Tables 1 and 2.

Composition of Chili

Watt and Merrill (2) described the composition of mature red chili including seeds to be 74.3% water, 3.7% protein, 2.3% fat, 18.1% carbohydrate, and 1.6% ash with traces of calcium, phosphorus, iron, sodium, potassium, thiamine, riboflavin, niacin, and ascorbic acid. Information procured from Cal-Compack (1) states the composition will vary dependent on soil and climatic conditions, and describes mature red chili as generally 13% protein, 18% fiber, 8% ash, 12% fat, 37% carbohydrates and 12% moisture. The difference in values probably reflects the fact that the second description refers to the processed fruit. Chili also contains tocopherols, pungent principles, and flavonoid compounds.

The ability of chili to reduce rancidity in meat has been demonstrated (3), although it is unknown whether this reduction is due to a suppression of biological activity. None of the components listed above as constituents of chili are regarded as toxic. It might be possible, however, for some combination of these substances to have antimicrobial properties.

Awasthi and Singh (4) isolated and identified two substances from extractions of chili fruits: palmatic acid and capsicum oleo-

Table 1. Characteristics of Green Chili-Processing Effluent of Cal-Compack as Monitored by Las Cruces Waste Water Treatment Plant Personnel

Date	Susp. Sol. (mg/1)	Sett. Sol. (mg/1)	pH	B.O.D. (mg/1)	C.O.D. (mg/1)
8-27-75	195	26	10.5	292	598
8-29-75	206	55	12.0	--	411
9-19-75	198	19	11.2	484	825
9-23-75	201	13	11.2	320	817
8-25-76	86	10.5	10.7	--	620
8-26-76	66	18	11.9	--	641
8-31-76	124	11	9.5	--	478
9-1-76	83	7.5	10.5	406	541
9-2-76	163	16	11.8	675	--

Table 2. Characteristics of Red Chili-Processing Effluent of Cal-Compack as Monitored by Las Cruces Waste Water Treatment Plant Personnel

Date	Susp. Sol. (mg/1)	Sett. Sol. (mg/1)	pH	C.O.D. (mg/1)
10-24-74	358	27	--	662
10-29-74 (9:30AM)	138	4.0	--	146
10-29-74 (4:15PM)	03	--	--	115
10-30-74 (11:30AM)	72	--	--	212
10-30-74 (3:05PM)	40	--	--	123
10-31-74 (3:20PM)	90	--	--	356
11-4-74	181	--	--	362
11-7-74 (10:10AM)	32	0.6	--	185
11-7-74 (2:45PM)	72	5.5	--	229
11-19-74	454	--	--	703
12-24-74	678	--	6.8	--
1-9-75	59	--	6.9	--
1-15-75	--	6.0	7.4	--
10-3-75	50	1.1	7.6	846
10-15-75	92	1.1	7.8	442
11-3-75	121	2.0	7.2	569
12-2-75	524	4.5	6.7	1640
12-10-75	429	7.0	7.1	2145

resin. Capsicum oleoresin is insoluble in water and poisonous when undiluted (5). Its medicinal uses (as a commercial product) consist of internal ingestion as a local GI stimulant, and external application as a counter-irritant salve (6).

Activated Sludge Process

The principle of activated sludge is that of contacting a waste water with aerobic microorganisms capable of oxidizing organic matter readily. Aerobic conditions are maintained by mechanical surface aeration, by diffused air, or by a combination of the two. The treated waste is passed into a settling tank, where the solids resulting from microbial growth (sludge) are separated from the effluent. Part of the sludge is recycled to the activated sludge tank as "seed" to reinoculate new sewage with the floc-forming microorganisms.

Although algae, bacteria, fungi and protozoa may all be present in an activated sludge system, bacteria become dominant as primary feeders on the organic waste (7), and are the organisms of primary importance. Several factors affect the growth of bacteria and at least one will always be limiting. The most important parameters affecting microbial growth in waste water treatment are temperature, pH, availability of nutrients, oxygen supply, presence of toxins, and type of substrate (8).

Shock loads occur in an activated sludge system when there is a drastic change in the characteristics of the waste water. The predominant species in an activated sludge at any specific point in time is dependent upon the type and concentration of the waste water. A sudden change in waste water composition can result in a situation in which the predominant species cannot readily degrade the major substrate constituent of the new waste water. Shock loadings can cause the complete failure of an activated sludge process.

Investigations of Toxic Effects on Activated Sludge Processes

There is a great deal of current interest in determining whether certain waste waters exhibit toxic effects on activated sludge processes (and other types of biological waste treatment). There are many substances which may cause an unfavorable environment for the growth of microorganisms. Adverse effects may vary from low levels of metabolic inhibition to actual cell death.

Many toxic substances are not present in significant concentrations in municipal wastes. Toxicity becomes evident at a critical ratio of the toxic ion or substance to biomass and therefore there is no generally applicable toxic ion concentration (9).

However, considerable concentrations of toxic substances frequently occur in industrial wastes and may reach municipal sewage treatment plants from this source. Therefore, reduction in efficiency of biological treatment may often be caused by toxic or antibacterial properties of the waste being treated. A knowledge of these materials, their chemistry, their mechanisms of inhibition, and their inhibitory concentrations for the system in question is needed to evaluate their potential effect. Only when the processes by which a waste water may adversely effect the operational efficiency of a biological system are fully understood can measures be taken to deal intelligently with the problem.

The term "toxic" is a relative one, and is often used interchangeably in sanitary engineering with the terms "antibacterial" and "inhibitory." The concentration at which a material becomes toxic may vary from a fraction of a milligram per liter to several thousand milligrams per liter. At low concentrations, stimulation of biological activity is often observed. But as the concentration is increased above this stimulating level, biological activity decreases. This is the point at which inhibition occurs or "toxic effects" are noted, depending upon the choice of terminology. Finally, at some high concentration of the substance, the biological activity of the system approaches zero.

Batch reactors are often used in toxicity studies relating to activated sludge systems. A batch reactor is characterized by the fact that flow is neither entering nor leaving on a continuous basis.

Parameters denoting the efficiency of activated sludge can be interpreted using indications of degree of flocculation, settling velocity of the sludge, compactibility of the settled sludge, efficiency of BOD or COD reduction, and the removal of phosphates (10).

In some studies, toxic effects can be equated to a maximum reduction in total substrate conversion or in oxygen utilization. It should be noted, however, that there can be exceptions to this general rule, at least as far as oxygen utilization is concerned. In systems where toxic effects are exerted through the mechanism of uncoupling oxidative phosphorylation, an increase rather than a decrease in oxygen uptake activity will be noted (11). Therefore, the most dependable parameter in toxicity studies appears to be efficiency of BOD or COD reduction.

Previous research on the effects of chili waste on an activated sludge process (12) utilized a bench scale model of a completely mixed activated sludge system. It was concluded the introduction of chili waste produced a slight decline in efficiency, but after an acclimitization period the system could treat the waste with efficiencies comparable to those of sewage treatment. Chili waste was found to be readily degradable and exhibited no adverse effects on a completely mixed activated sludge process.

However, the chili waste used in this study was not an actual industrial processing waste, but was manufactured by blending whole, dry red chili in water and straining out the solids. This investigation was undertaken because of a desire to use actual industrial waste water and to consider green chili waste water in addition to red.

Kinetics of Microbial Growth

Most biological waste treatment systems operate in stages of microbiological growth where the maximum growth rate cannot be realized because there is not an unlimited amount of substrate available for metabolism and cell synthesis (8). The concentration of substrate has become limiting or critical, and the maximum theoretical rate of growth therefore cannot occur. Substrate removal after critical substrate level has been reached is described by first or second order kinetics. Experimental work has shown that second order rate constants are almost always less variable than first order ones, as pertains to measurement of data (13).

Monod kinetics describes bacterial growth, oxygen utilization, and substrate utilization before critical substrate level has been reached, and it has been shown that this kinetic model can be applied to heterogeneous cultures in well defined substrates (14).

Monod kinetics yield two reaction constants, k_m and K, which are maximum theoretical growth rate and substrate saturation coefficient, respectively. Substrate saturation coefficient defines the concentration of substrate at which microbial growth rate is one half the theoretical maximum growth rate of k_m.

Manipulation of Monod kinetic expressions can be used to obtain predictions of first order and second order reaction rates (14). It has been determined that these predictions are

$$k_1 = \frac{k_m}{K} C_{cr}$$

where k_1 is the first order reaction rate and C_{cr} is the limiting substrate concentration. The second order reaction rate (k_2) is defined as

$$k_2 = \frac{k_m}{K} \qquad (15).$$

Another common term in kinetic description of microbial growth is Y, representing yield factor. This term is defined as the amount of biological solids produced per unit of organic material used. Yield factors, like k_m and K, can be expected to vary, depending largely on the species of microorganisms present and upon the substrate. Generally, acceptable values of Y will lie between 0.4 and 0.6 (40-60%) (16).

EXPERIMENTAL PROCEDURE

Collection and Storage of Waste Water

Samples of green chili-processing waste water and samples of red chili-processing waste water were collected on two different dates as grab samples from the manhole behind Cal-Compack.

The samples were collected and stored in plastic containers which had been washed prior to collection. The samples were then stored until use in freezer lockers. To verify that freezing did not change the characteristics of the waste, COD values of both the soluble and total effluent and suspended solids were determined according to methods described in Standard Methods (17).

Municipal sewage was collected from the Las Cruces Treatment Plant on the same day in which it was used for experiments, so no storage was required. Cal-Compack was processing during the experimental period, so the municipal sewage collected doubtlessly contained some chili-processing effluent. However, the chili-processing wastes were substantially diluted so that comparisons between the municipal sewage and the undiluted chili-processing waste waters were possible.

Maintenance and Acclimation of Biological Solids

The biological solids used in this investigation were grown from a seed obtained from the Las Cruces municipal waste water treatment plant. The cultures were maintained in plexiglass containers of 3-liter volume which were completely mixed and aerated through the use of diffused air. The units were fed at 24 hour intervals by discontinuing the aeration, allowing 30 minutes of settling, removing approximately one liter of the supernatant, and then adding approximately one liter of fresh substrate after which aeration was again continued. The plexiglass containers were contained in an environmental chamber, in which the temperature was maintained at 30°C.

Three cultures were used in this study. One was continuously fed municipal sewage. The other two were fed undiluted red chili-processing effluent and undiluted green chili processing effluent, respectively. These two stock cultures were acclimated to the processing waste for a minimum of 8 days and a maximum of 15 days before being used in any experiments.

On days experiments were being run, a volumetric portion of the stock culture was withdrawn to be used in the experiments before the unit was fed.

Chili Waste Water vs. Sewage Experiments

Plexiglass cylinders with a six-inch diameter and 11-inch depth were used as batch reactors. Aeration and mixing was provided by two Brookfield Counter-Rotating Mixers rotating at 500 rpm. The mixing thus obtained created almost no vortex or splattering.

The mixers and plexiglass cylinders were held in wooden stands as shown in Figure 1, which served the purpose of keeping the mixers and plexiglass containers in fixed positions. The stands were constructed so that the shaft of the mixer was above the geometric center of the base of the plexiglass container. The mixer head was then adjusted so that the propellors were three inches above the bottom of each container. These measures were taken in order to eliminate, as much as possible, differences between reactors. The entire units, reactor, mixer, and stand, were contained in an environmental chamber which maintained a constant temperature of $30^{o}C$.

For each experiment, three liters of municipal sewage at room temperature was placed in one reactor. Chili-processing effluent at room temperature was then placed in the second reactor, and tap water was added to achieve a total volume of three liters. Dilutions were made by a rough color comparison so the initial concentration of the waste water would be approximately the same as that of the municipal sewage. Diluting green chili-processing effluent 1:2 and the red chili-processing effluent 1:3 produced

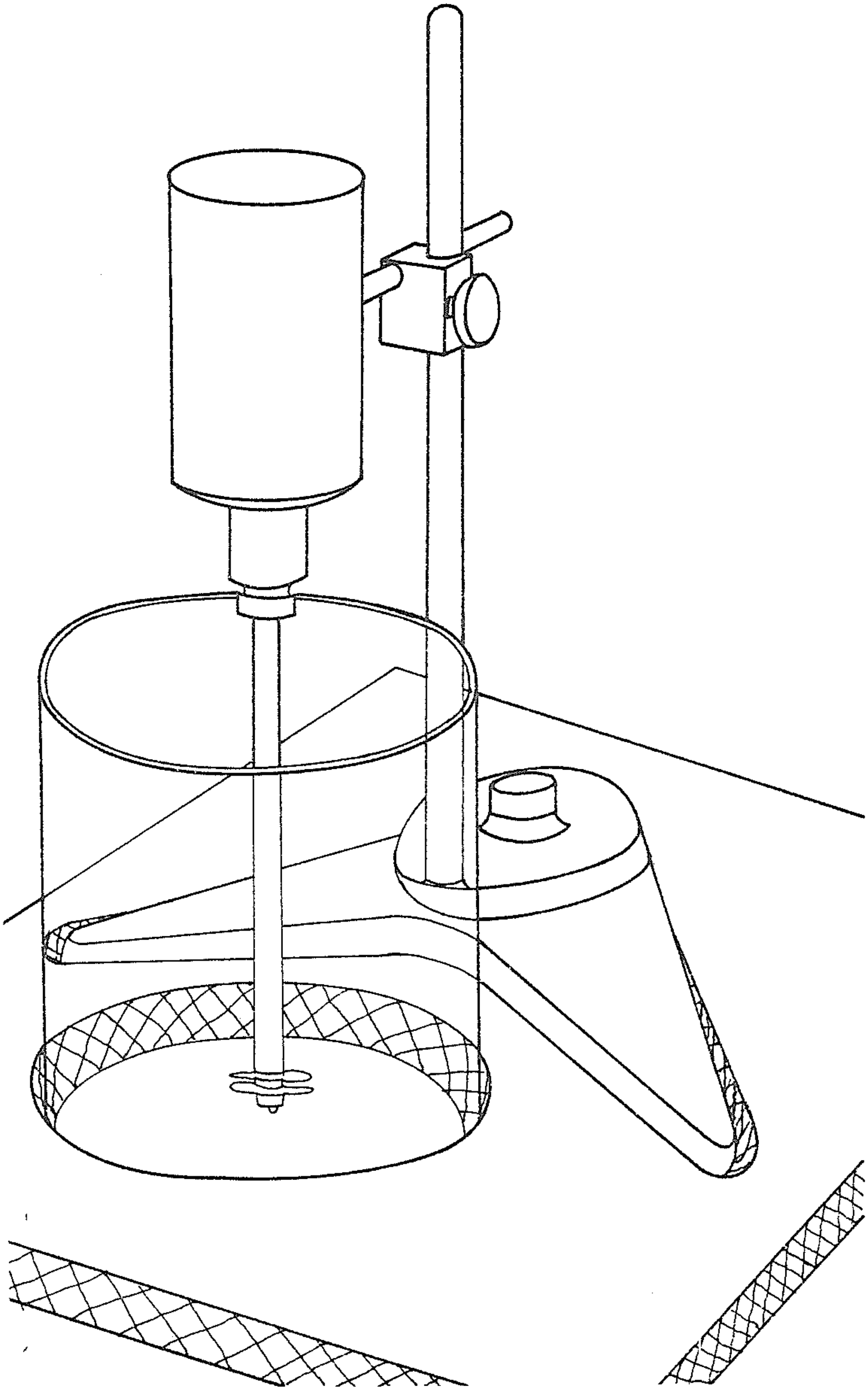

Figure 1. Experimental Apparatus: Reactor, Mixer, and Stand

satisfactory initial COD values comparable to those of the sewage.

At zero time, equal volumetric amounts of the biological solids which were fed only municipal sewage were introduced into each reactor. Total COD, soluble COD, and suspended solids were determined. Total COD and soluble COD were determined according to methods outlined in _Standard Methods_ (17). Total COD and soluble COD were determined by the dichromate reflex method and samples diluted to a volume of 20 ml were used. Suspended solids measurements were determined using Gelman 47 mm glass fiber filters of predetermined weight which were dried in an oven after volumes of 5 or 10 ml were filtered through them. All suspended solids determinations were run in triplicate.

Samples were analyzed for soluble and total COD at 1 hr., 2 hr., 4 hr., and 6 hr. Another sample was analyzed as a check for total maximum COD removal at 17 hours, and suspended solids were determined. The contents of each reactor were discarded at the end of each run.

Acclimated vs. Nonacclimated Biological Solids Experiments

To determine the effect of acclimatization of biological solids upon the metabolism of chili-processing effluent, the reactors and mixers previously described were used. The substrate used was undiluted red or green chili-processing waste water, which had been allowed to come to room temperature.

At zero time, an equal volumetric amount of biological solids was introduced into each reactor. The source of one "seed" was the culture which had been fed only municipal sewage, and the source of the other seed was a stock culture which had been acclimated to the particular waste water being used as substrate.

The experiment was then run and monitored in a method identical to the one described for the waste water vs. sewage experiments.

Low Initial Solids Experiments

Batch studies were run with low initial solids concentrations to obtain the kinetic constants described by the Monod equation. The same experimental procedure as described previously was used.

The substrate consisted of undiluted red or green chili waste at room temperature. At zero time, a 10 ml volume of biological solids which had been acclimated to the waste water being used as substrate was introduced into the reactor. Total COD, soluble COD, and suspended solids were determined. Total COD and soluble COD were determined at one-hour intervals for 0-14 hours. At the last sample time of 14 hours, final suspended solids in the reactor was also determined, and the contents of the reactor were discarded.

Analysis of Data

Yield Coefficient and Percent COD Oxidized

The yield coefficient of the data was obtained by determining the ratio of soluble COD removed to the net increase in solids. The percent COD oxidized was obtained by determining the ratio of the difference between initial total COD and final total COD to the amount of soluble COD removed.

The experimental COD values obtained at 6 hours were in all cases equal to or only slightly higher than the COD values obtained at the 17-hour end point. However, since the final suspended solids measurement obtained was determined at the 17-hour sample time, the corresponding 17-hour COD readings were used to determine the yield factor and percent COD oxidized. In the cases where this did not result in values identical to ones determined with the 6-hour COD data, it resulted in yield factors slightly lower than and percent COD oxidized slightly higher than those obtained using the 6-hour COD data.

First Order Kinetics

The kinetics of substrate removal were analyzed using a least squares straight line fitting APL program. In first order kinetics

$$\frac{dc}{dt} = -k_1 C$$

where k_1 is the first order growth rate constant and C is substrate concentration. Then

$$\frac{-dc}{C} = k_1 dt \ .$$

$$-\ln C\Big]_{C_o}^{C} = k_1 \ (t-t_o) \ .$$

As $t_o \rightarrow$ 0 then

$$\ln C - \ln C_o = -k_1 t$$

$$\ln C = \ln C_o - k_1 t \ .$$

In the straight line solution of the least squares fitting program

$$y = a + bx$$

$$a = \ln C_o \text{ and } b = -k_1 .$$

Second Order Kinetics

In second order kinetics, if k_2 is the second order growth rate constant and C is the concentration of substrate, then

$$\frac{dc}{dt} = -k_2 C^2$$

$$\frac{-dc}{C^2} = k_2 dt$$

$$C^{-1}\Big]_{C_o}^{C} = k_2(t - t_o)$$

As $t_o \rightarrow$ 0 then

$$C^{-1} - C_o^{-1} = k_2 t$$

$$\frac{1}{C} - \frac{1}{C_o} = k_2 t$$

$$\frac{1}{C} = \frac{1}{C_o} + k_2 t.$$

In the straight line solution of the least squares fitting program if

$$y = a + bx$$

then

$$a = \frac{1}{C_o} \quad \text{and } b = k_2.$$

Monod Kinetics

The Monod expression for the concentration of the substrate C at any time t can be described by the following equation where C_o denotes initial substrate concentration (mg/l), t denotes time, S_o is initial organism concentration, and y is the yield coefficient (14).

$$\ln C - \ln \left[\left[S_o + y \; (C_o - C) \right] \frac{C_o}{S_o} \right]$$

$$= \frac{(S_o + y \; C_o)}{y \; K} \times \ln \left[\frac{S_o + y \; (C_o - C)}{S_o} \right] - \frac{k_m t}{y \; K} \; (S_o + y \; C_o).$$

The terms K and k_m are the substrate saturation constant and the maximum growth rate constant, respectively. The equation may be rewritten as

$$\frac{\ln C - \ln \left[S_o + y(C_o - C) \; \frac{C_o}{S_o} \right]}{\left[\frac{S_o + y \; C_o}{y} \right] (t)}$$

$$= \frac{1}{Kt} \ln \frac{S_o + y\ (C_o - C)}{S_o} - \frac{k_m}{K}\ .$$

Now, let

$$R = \frac{\ln C - \ln \left[S_o + y\ (C_o + C)\ \frac{C_o}{S_o} \right]}{\left[\frac{S_o + y\ C_o}{y} \right] (t)}$$

and let $$Z = \frac{1}{t} \ln \left[\frac{C_o + y\ (C_o - C)}{S_o} \right]\ .$$

Substituting the last two equations into the previously given Monod equation will yield

$$R = \frac{-k_m}{K} + \frac{1}{K} z.$$

In the straight line solution of the least squares fitting program if

$$y = a + bx$$

then $$a = \frac{-k_m}{K} \quad \text{and } b = \frac{1}{K}\ .$$

The Monod equation is extremely sensitive to the value of S_o, which is approximated by the initial suspended solids concentration but is actually the initial organism concentration. Therefore, in analysis of the experimental data, both the actual measured suspended solids concentration and an optimized S_o value, which gave the best correlation coefficient, were used so that results of both could be compared.

Determination of Monod-Predicted First Order and Second Order Growth Rate Constants

According to some research, K and k_m, which are respectively the substrate saturation coefficient and the maximum specific growth rate constant, are the constants for a given substrate (18). If this is so, then it should be possible to use these values to obtain first and second order growth rate constants. The growth-limiting substrate concentration (C_{cr}) is defined as (14)

$$C_{cr} = K\,(K + C_o + \frac{S_o}{y})^{\frac{1}{2}} - K$$

and S_{cr}, the organism concentration at which the substrate is growth limiting is defined as

$$S_{cr} = S_o + y\,(C_o - C_{cr}).$$

The first order growth rate constant is defined as

$$k_1 = \frac{S_{cr}}{y} \quad \frac{k_m}{K + C_{cr}} \; .$$

The second order growth rate constant is defined as

$$k_2 = \frac{k_m}{K} \; .$$

RESULTS AND DISCUSSION

General

This section presents tabulated and graphical summaries of the results of this investigation, along with a discussion of the results.

As can be verified easily from the tabulated data presented in the Appendix, initial values of COD of both the green and the red chili-processing waste water did not vary significantly from the values determined upon the day of collection. Therefore it was concluded that freezing of the waste water until the date of use did not significantly change the characteristics of the waste water.

The results for both red and green chili experiments are summarized in Table 3. Yield factor, percent COD oxidized, first order and second order rate constants as determined from described computer analysis are tabulated, along with the correlation coefficients for the analysis. Table 4 lists the results for the same experiments, giving the rate order coefficients and correlation coefficients for analysis of the total COD reduction curves.

Figures 2-5 are graphical representations of all the chili waste water experiments vs. municipal sewage experiments. Figures 6-9 are graphical depictions of all the acclimated vs. nonacclimated seed experiments. Figures 10-17 are graphical depictions of the reduction of total COD in all experiments.

Table 3. Kinetic Results of Soluble COD Reduction Curves

Date	Type	Yield Factor	% COD Oxidized	k_1 $(hr)^{-1}$	Correlation	k_2 $(hr)^{-1}(mg/l)^{-1}$	Correlation
Green chili waste water vs. sewage							
Oct. 16	chili	0.44	46	0.111	0.967	6.64×10^{-4}	0.955
Oct. 16	sewage	0.40	48	0.115	0.917	8.31×10^{-4}	0.890
Oct. 21	chili	0.46	45	0.082	0.882	5.19×10^{-4}	0.912
Oct. 21	sewage	0.61	45	0.099	0.870	6.54×10^{-4}	0.907
Oct. 31	chili	0.50	79	0.099	0.882	4.42×10^{-4}	0.861
Oct. 31	sewage	0.49	45	0.200	0.988	1.15×10^{-3}	0.975
Nov. 7	chili	0.54	42	0.132	0.938	8.80×10^{-4}	0.907
Nov. 7	sewage	0.60	52	0.171	0.999	1.22×10^{-3}	0.994
Geometric means: k_1 chili = 0.104; k_1 sewage = 0.140; k_2 chili = 6.05×10^{-4}; k_2 sewage = 9.34×10^{-4}							
Green chili waste water acclimated vs. nonacclimated seed							
Oct. 24	acclimated	0.42	48	0.219	0.970	1.01×10^{-3}	0.999
Oct. 24	non	0.37	52	0.241	0.951	1.09×10^{-3}	0.906
Oct. 28	acclimated	0.51	49	0.244	0.981	1.27×10^{-3}	0.996
Oct. 28	non	0.47	43	0.193	0.961	8.74×10^{-4}	0.979
Geometric means: k_1 acclimated = 0.231; k_1 nonacclimated = 0.216; k_2 acclimated = 1.13×10^{-3}; k nonacclimated = 9.76×10^{-4}							

Table 3 (Continued)

Date	Type	Yield Factor	% COD Oxidized	k_1 $(hr)^{-1}$	Correlation	k_2 $(hr)^{-1}(mg/l)^{-1}$	Correlation
Red chili waste water vs. sewage							
Feb. 1	chili	0.58	40	0.153	0.950	8.57×10^{-4}	0.915
Feb. 1	sewage	0.54	64	0.305	0.996	2.42×10^{-3}	0.969
Feb. 4	chili	0.49	47	0.147	0.932	9.73×10^{-4}	0.898
Feb. 4	sewage	0.31	56	0.275	0.961	2.20×10^{-3}	0.896
Feb. 11	chili	0.58	44	0.180	0.919	1.06×10^{-3}	0.876
Feb. 11	sewage	0.44	47	0.354	0.970	3.94×10^{-3}	0.887
Geometric means: k_1 chili = 0.159; k_1 sewage = 0.309; k_2 chili = 9.60×10^{-4}; k_2 sewage = 2.75×10^{-3}							
Red chili waste water acclimated vs. nonacclimated seed							
Feb. 18	acclimated	0.40	45	0.345	0.993	1.14×10^{-3}	0.979
Feb. 18	non	0.39	31	0.237	0.951	5.47×10^{-4}	0.896
Feb. 27	acclimated	0.41	48	0.376	0.995	1.14×10^{-3}	0.948
Feb. 27	non	0.45	49	0.276	0.945	6.62×10^{-4}	0.947
Mar. 4	acclimated	0.41	45	0.516	0.998	3.18×10^{-3}	0.939
Mar. 4	non	0.46	42	0.365	0.980	1.29×10^{-3}	0.903
Geometric means: k_1 acclimated = 0.406; k_1 nonacclimated = 0.288; k_2 acclimated = 1.6×10^{-3}; k_2 nonacclimated = 1.05×10^{-3}							

Table 4. Kinetic Results of Total COD Reduction Curves

Date	Type	k $(hr)^{-1}$	Correlation	k $(hr)^{-1}(mg/l)^{-1}$	Correlation
Green chili waste water vs. municipal sewage					
Oct. 16	chili	8.64×10^{-3}	.922	8.85×10^{-6}	.923
Oct. 16	sewage	8.89×10^{-3}	.867	9.87×10^{-6}	.866
Oct. 21	chili	8.53×10^{-3}	.921	9.48×10^{-6}	.917
Oct. 21	sewage	7.79×10^{-3}	.913	7.40×10^{-6}	.911
Oct. 31	chili	2.68×10^{-2}	.759	4.36×10^{-5}	.771
Oct. 31	sewage	2.63×10^{-2}	.973	4.05×10^{-5}	.977
Nov. 7	chili	1.31×10^{-2}	.907	1.67×10^{-5}	.904
Nov. 7	sewage	7.80×10^{-3}	.889	7.13×10^{-6}	.914
Green chili waste water acclimated vs. non acclimated seed					
Oct. 24	acclimated	4.19×10^{-2}	.994	5.32×10^{-5}	.991
Oct. 24	non	3.59×10^{-2}	.973	4.57×10^{-5}	.970
Oct. 28	acclimated	3.25×10^{-2}	.946	4.51×10^{-5}	.939
Oct. 28	non	4.63×10^{-2}	.844	8.57×10^{-5}	.850
Red chili waste water vs. municipal sewage					
Feb. 1	chili	1.53×10^{-2}	.971	1.80×10^{-5}	.971
Feb. 1	sewage	3.01×10^{-2}	.998	3.38×10^{-5}	.997
Feb. 4	chili	1.42×10^{-2}	.966	1.66×10^{-5}	.967
Feb. 4	sewage	3.82×10^{-2}	.949	4.55×10^{-5}	.949
Feb. 11	chili	2.00×10^{-2}	.963	2.33×10^{-5}	.963
Feb. 11	sewage	2.09×10^{-2}	.963	2.33×10^{-5}	.964
Red chili waste water acclimated vs. non acclimated seed					
Feb. 18	acclimated	2.42×10^{-2}	.966	1.45×10^{-5}	.962
Feb. 18	non	2.06×10^{-2}	.997	1.18×10^{-5}	.997
Feb. 27	acclimated	2.66×10^{-2}	.985	1.53×10^{-5}	.982
Feb. 27	non	3.22×10^{-2}	.927	1.88×10^{-5}	.919
Mar. 4	acclimated	2.88×10^{-2}	.992	1.62×10^{-5}	.991
Mar. 4	non	3.39×10^{-2}	.958	1.99×10^{-5}	.950

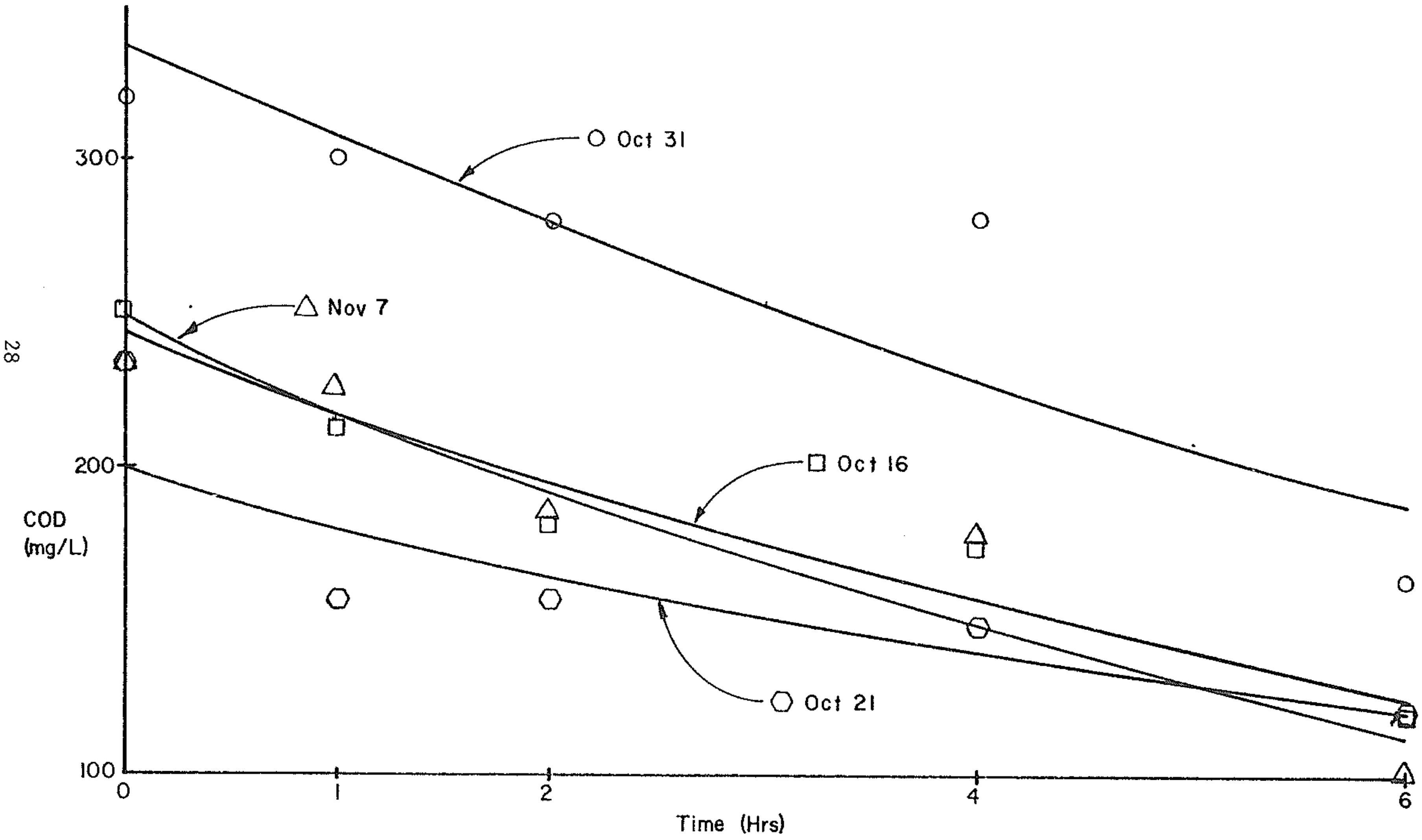

Figure 2. Soluble Green Chili Waste Water COD vs. Time

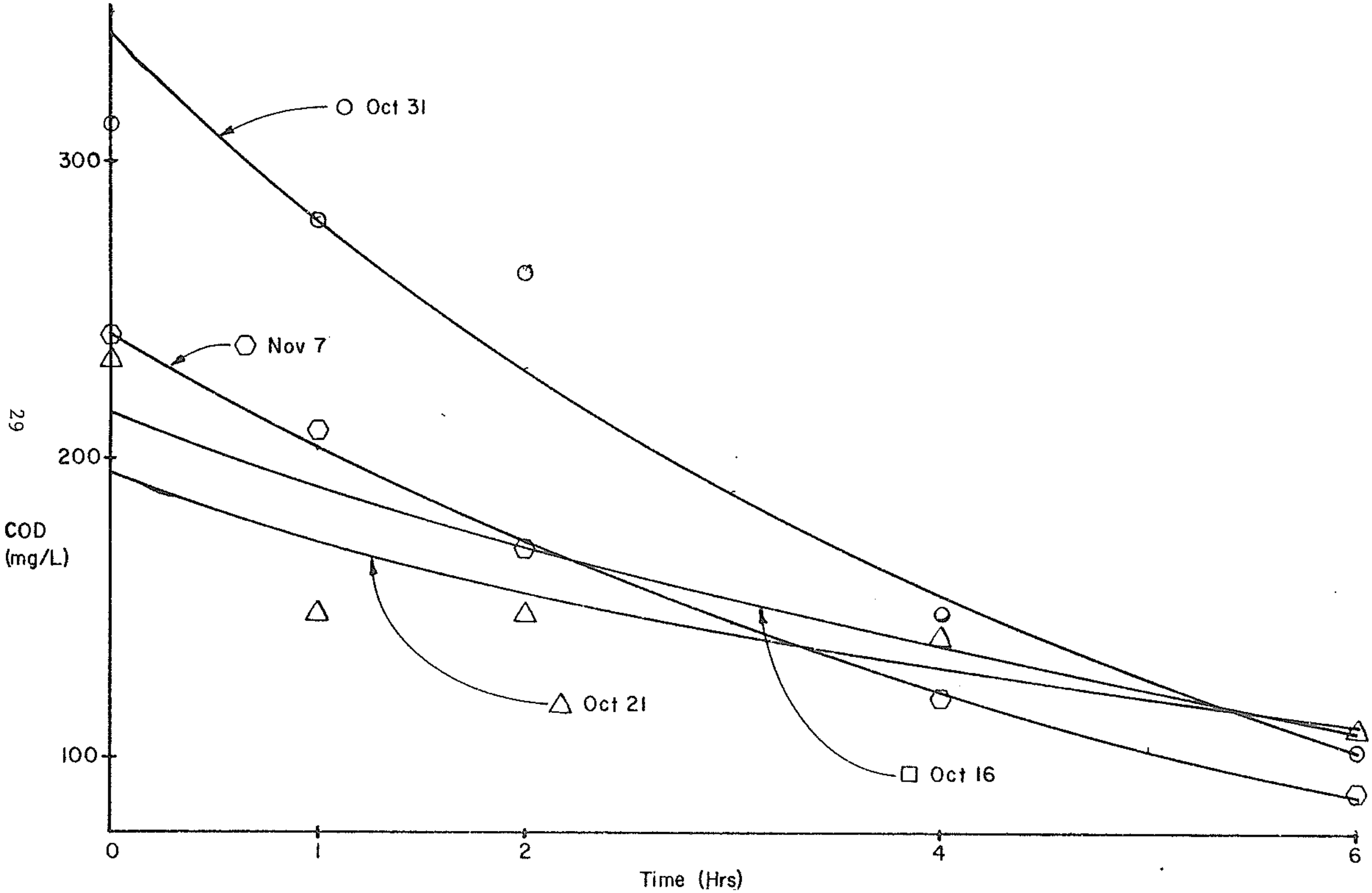

Figure 3. Soluble Municipal Sewage COD vs. Time

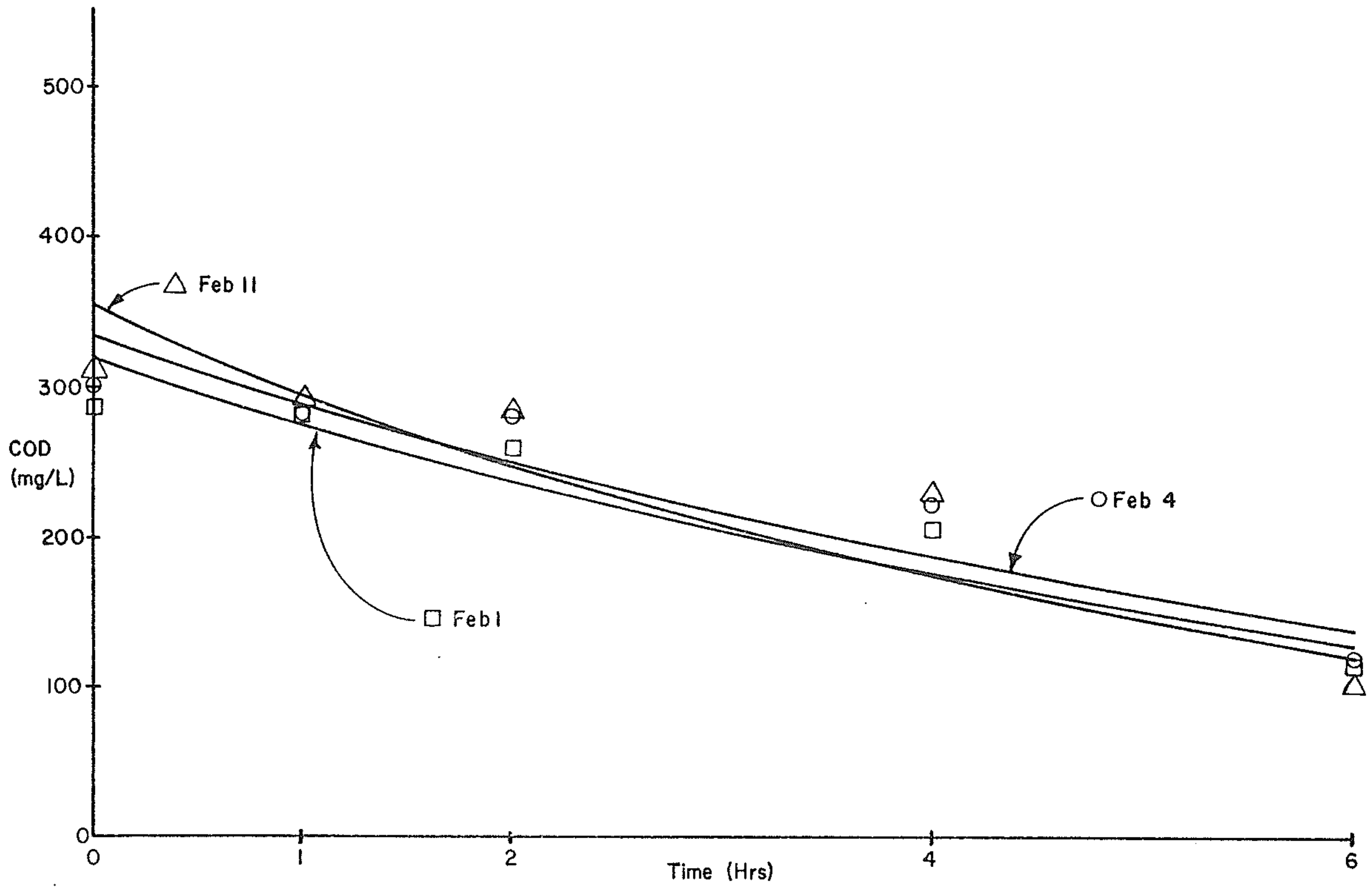

Figure 4. Soluble Red Chili Waste Water COD vs. Time

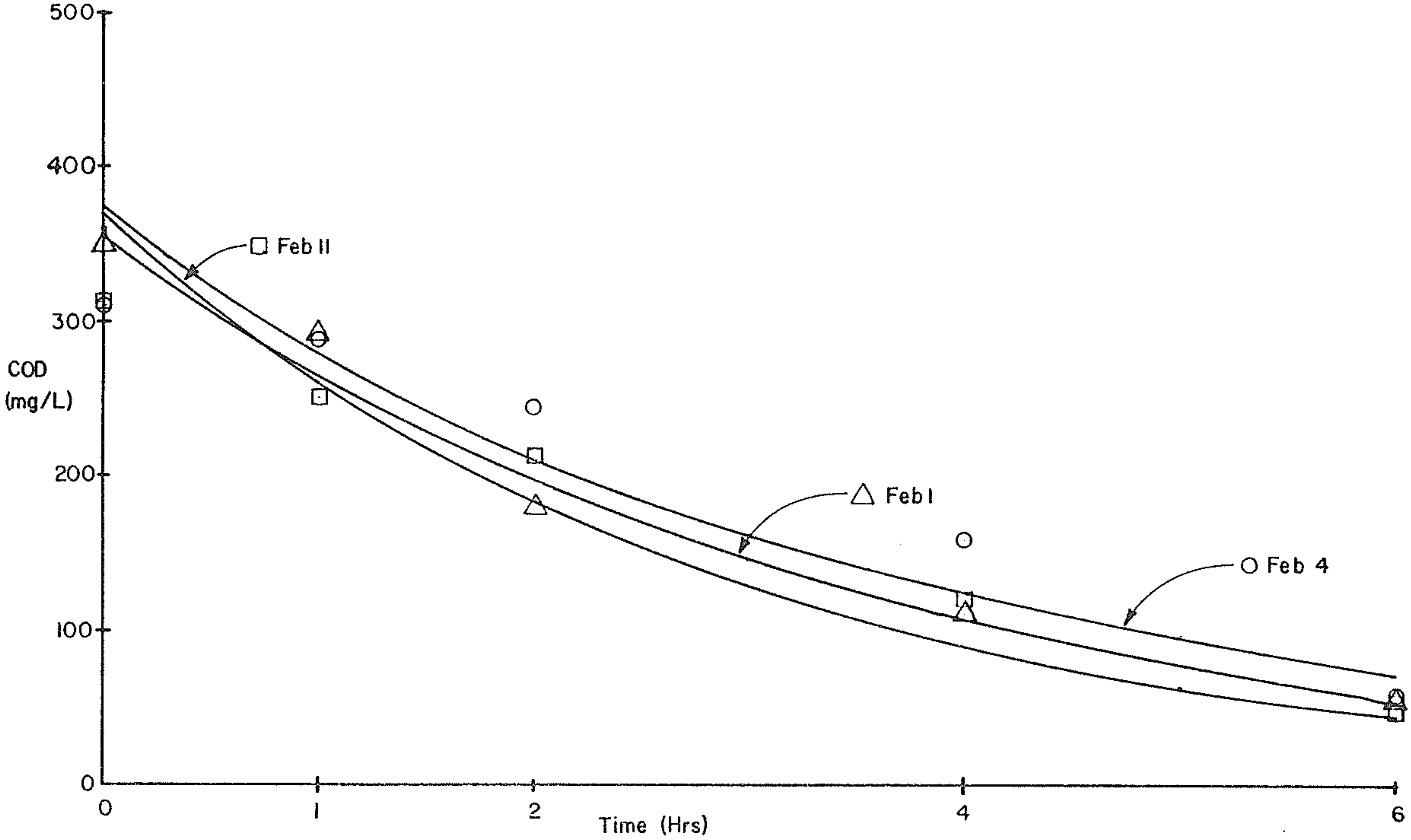

Figure 5. Soluble Municipal Sewage COD vs. Time.

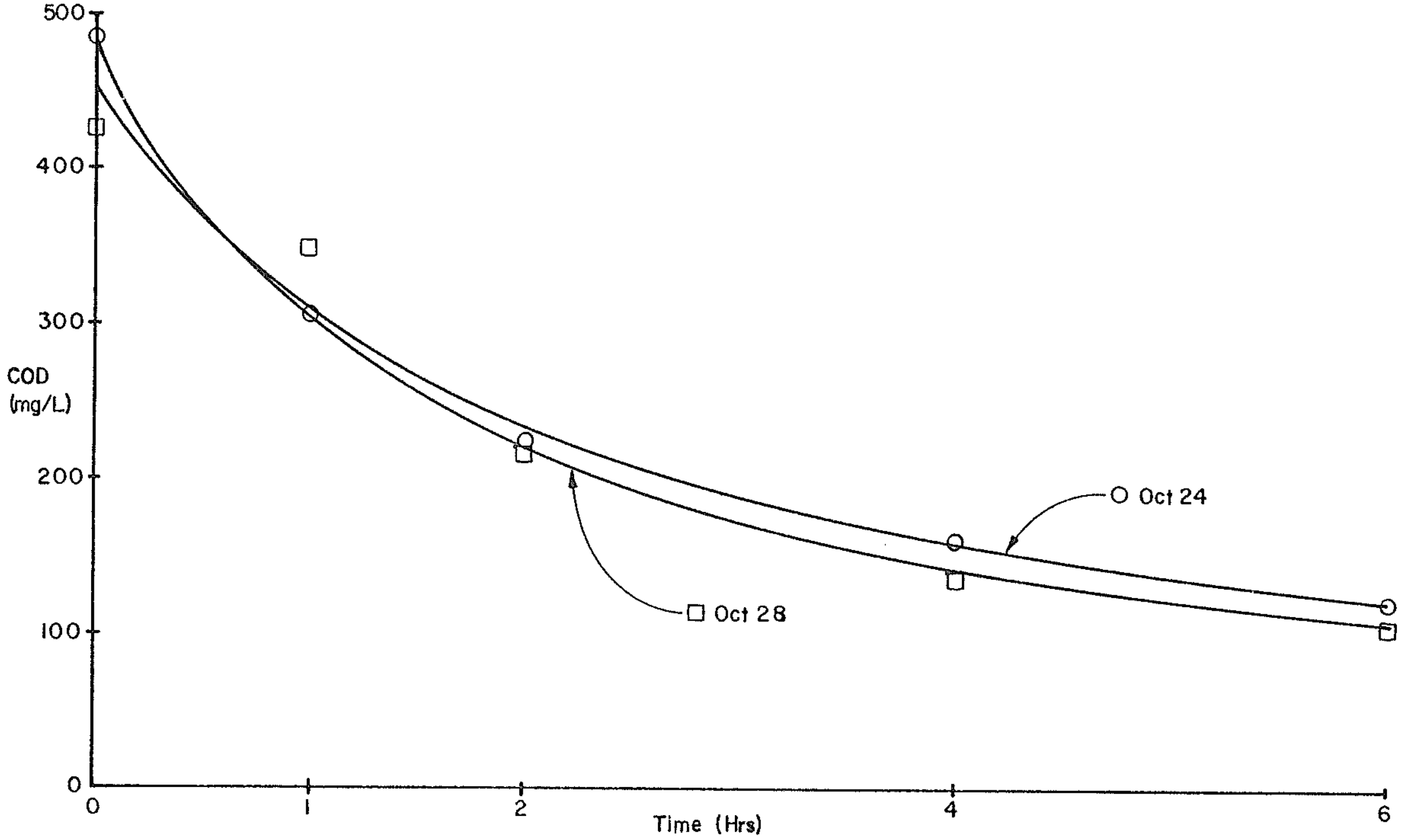

Figure 6. Acclimated Seed: Soluble Green Chili Waste Water COD vs. Time.

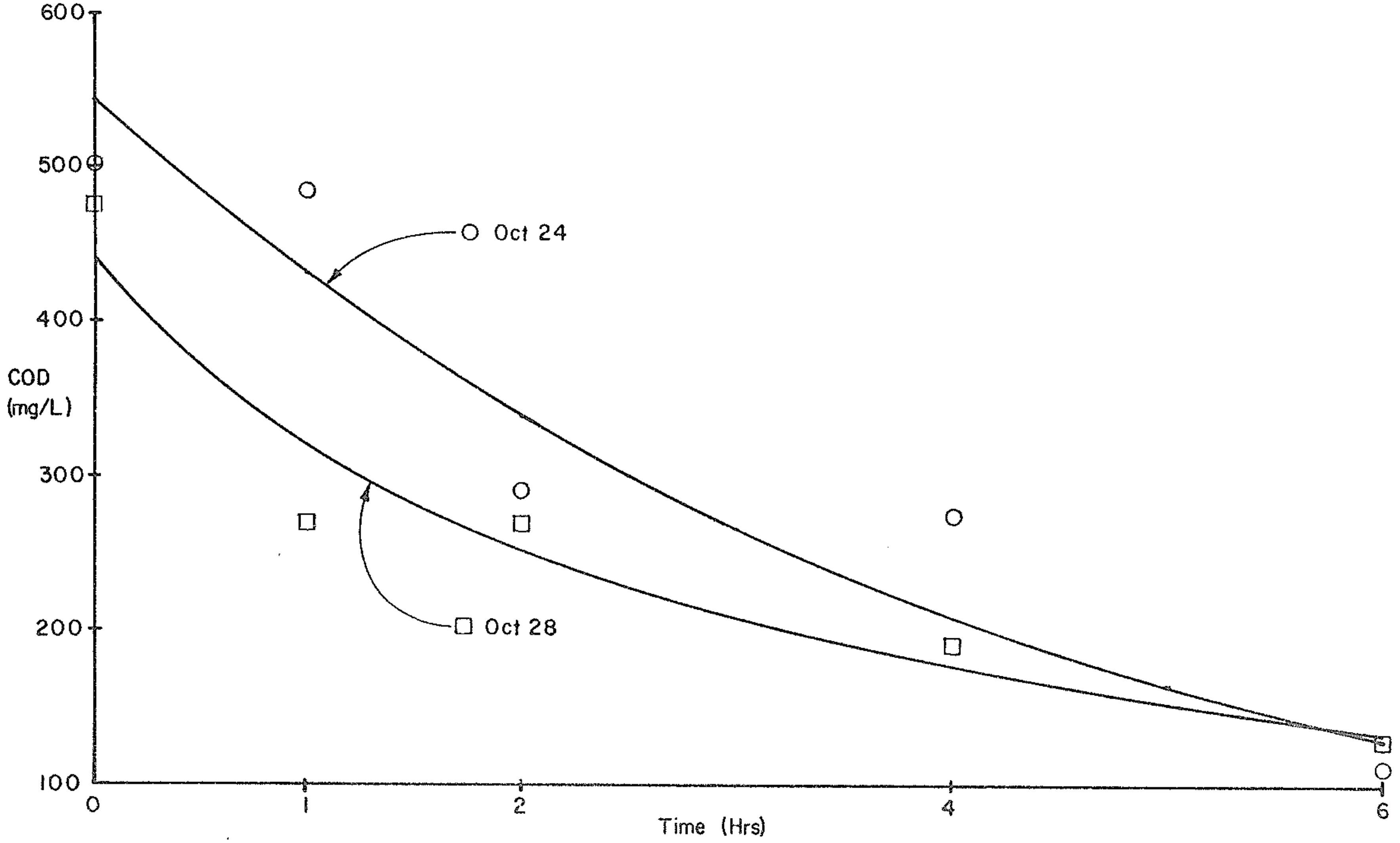

Figure 7. Nonacclimated Seed: Soluble Green Chili Waste Water COD vs. Time.

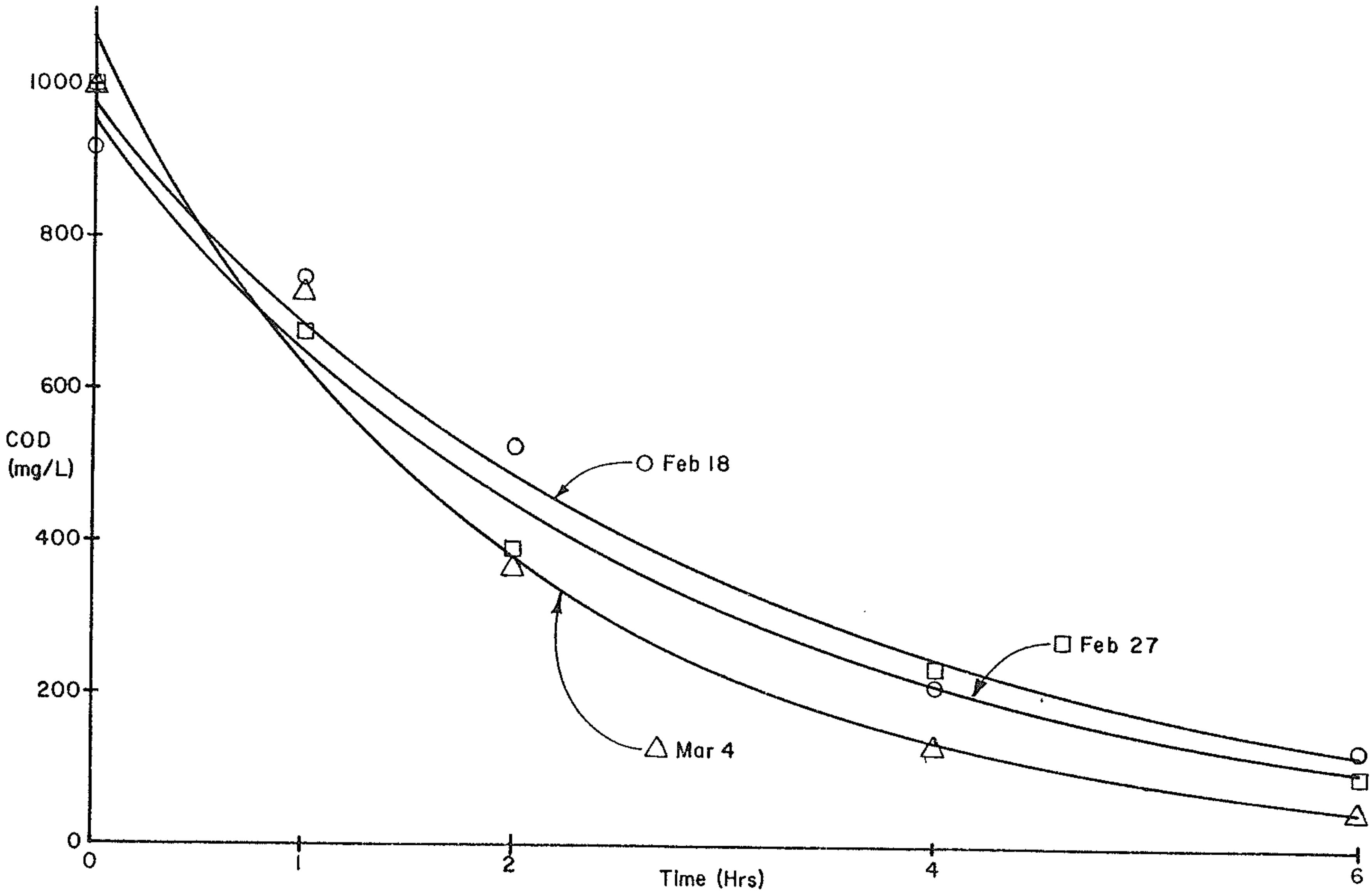

Figure 8. Acclimated Seed: Soluble Red Chili Waste Water COD vs. Time

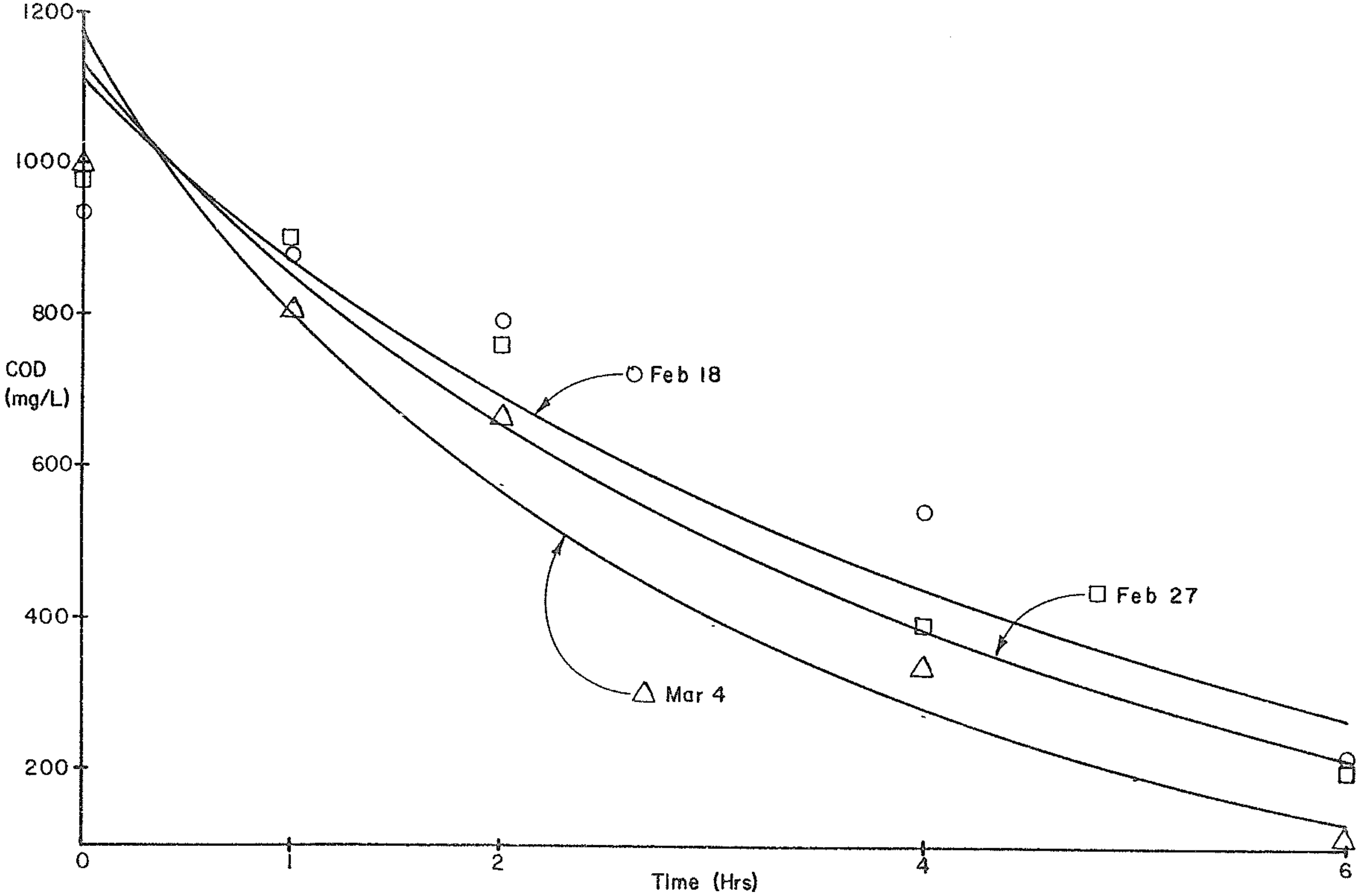

Figure 9. Nonacclimated Seed: Soluble Red Chili Waste Water COD vs. Time.

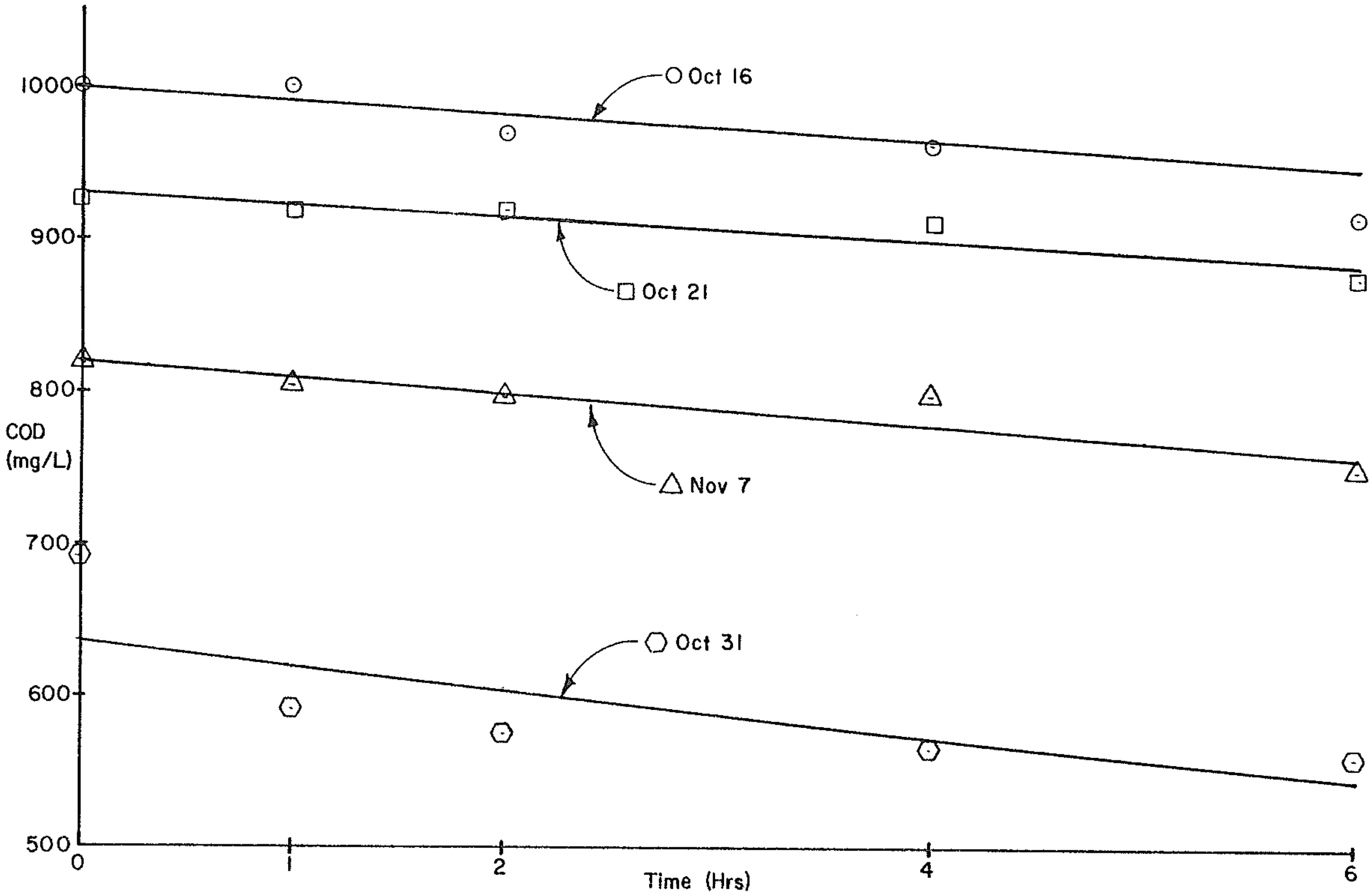

Figure 10. Total Green Chili Waste Water Total COD vs. Time

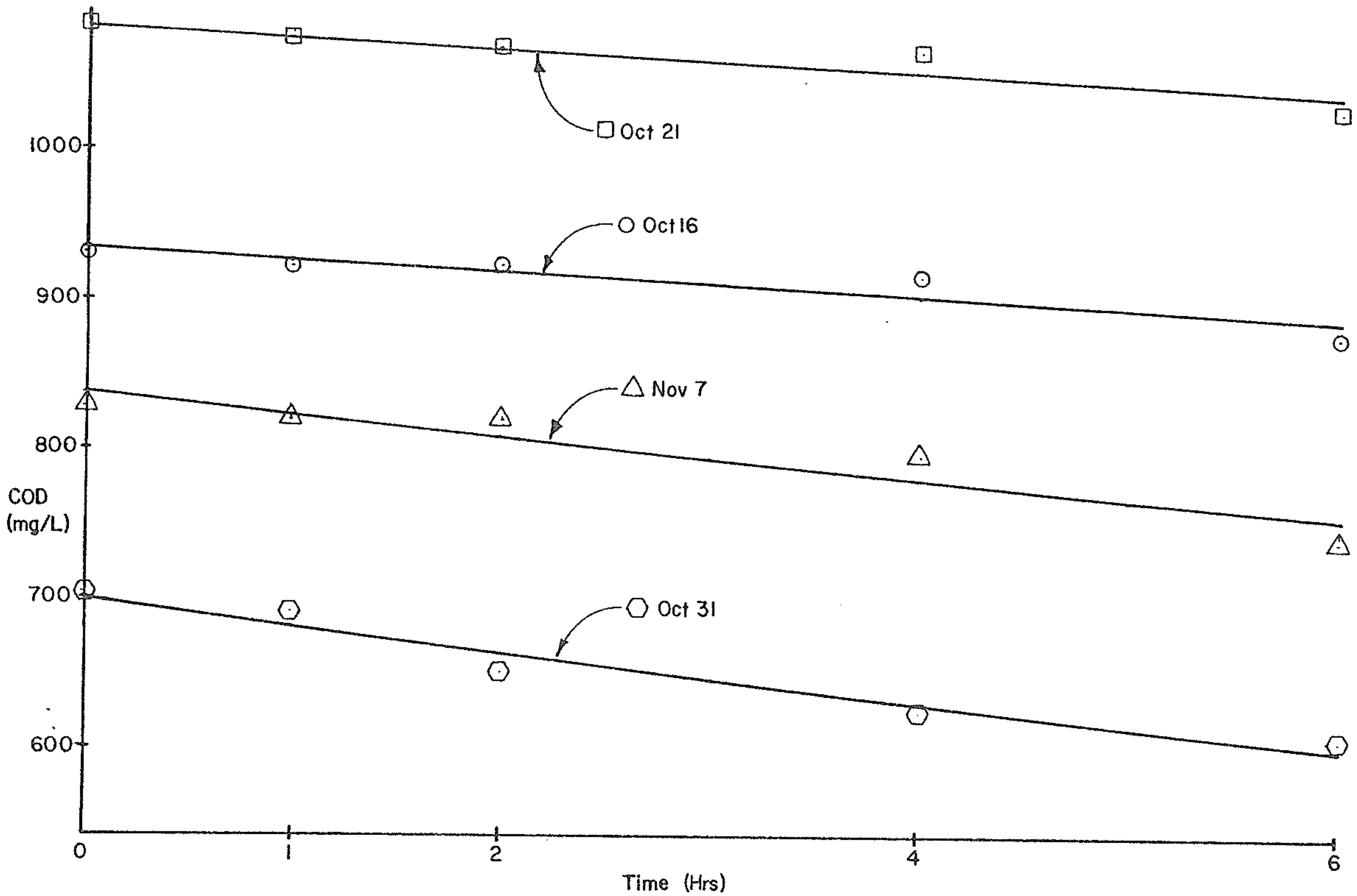

Figure 11. Total Municipal Sewage COD vs. Time

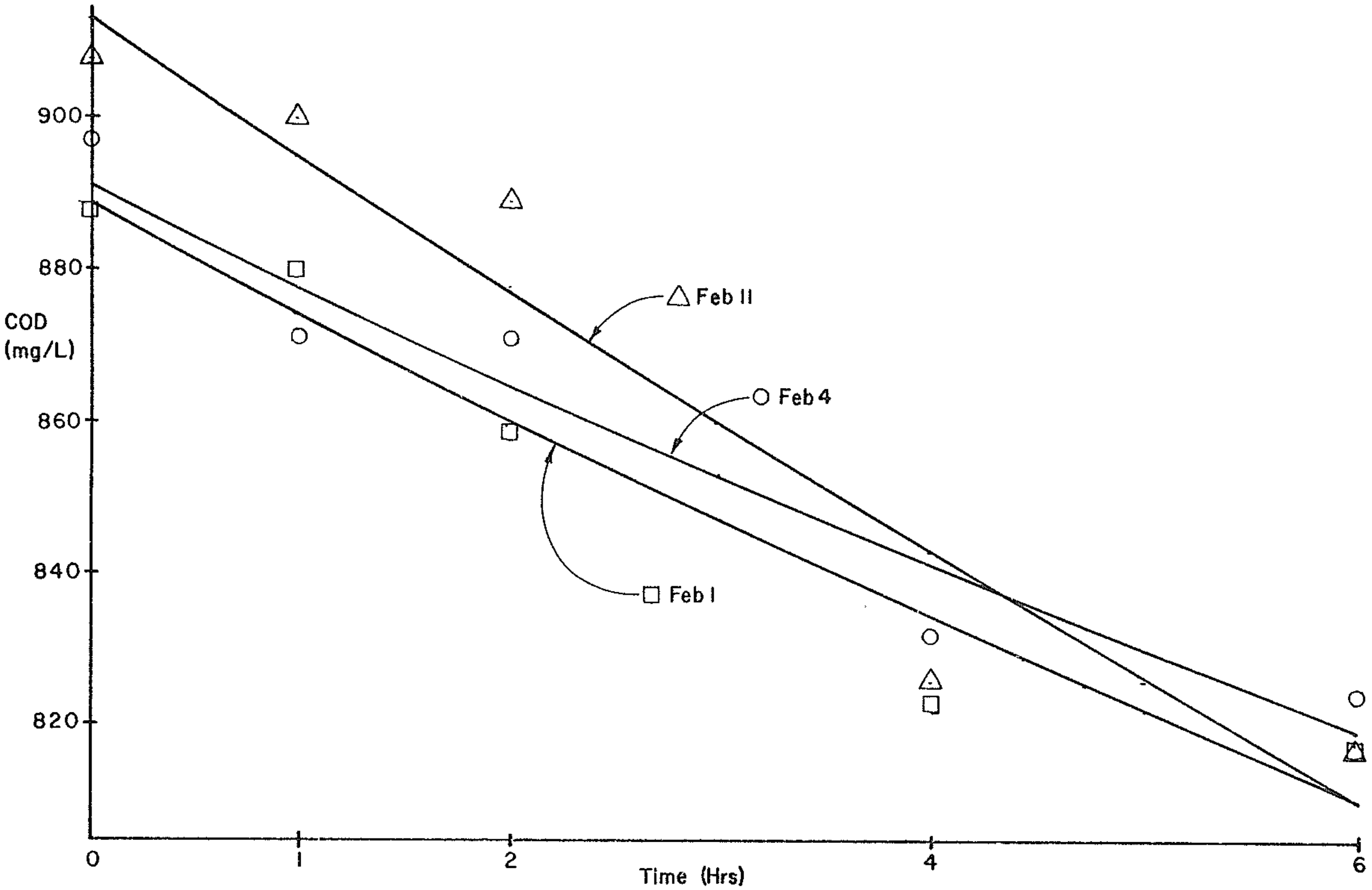

Figure 12. Total Red Chili Waste Water COD vs. Time

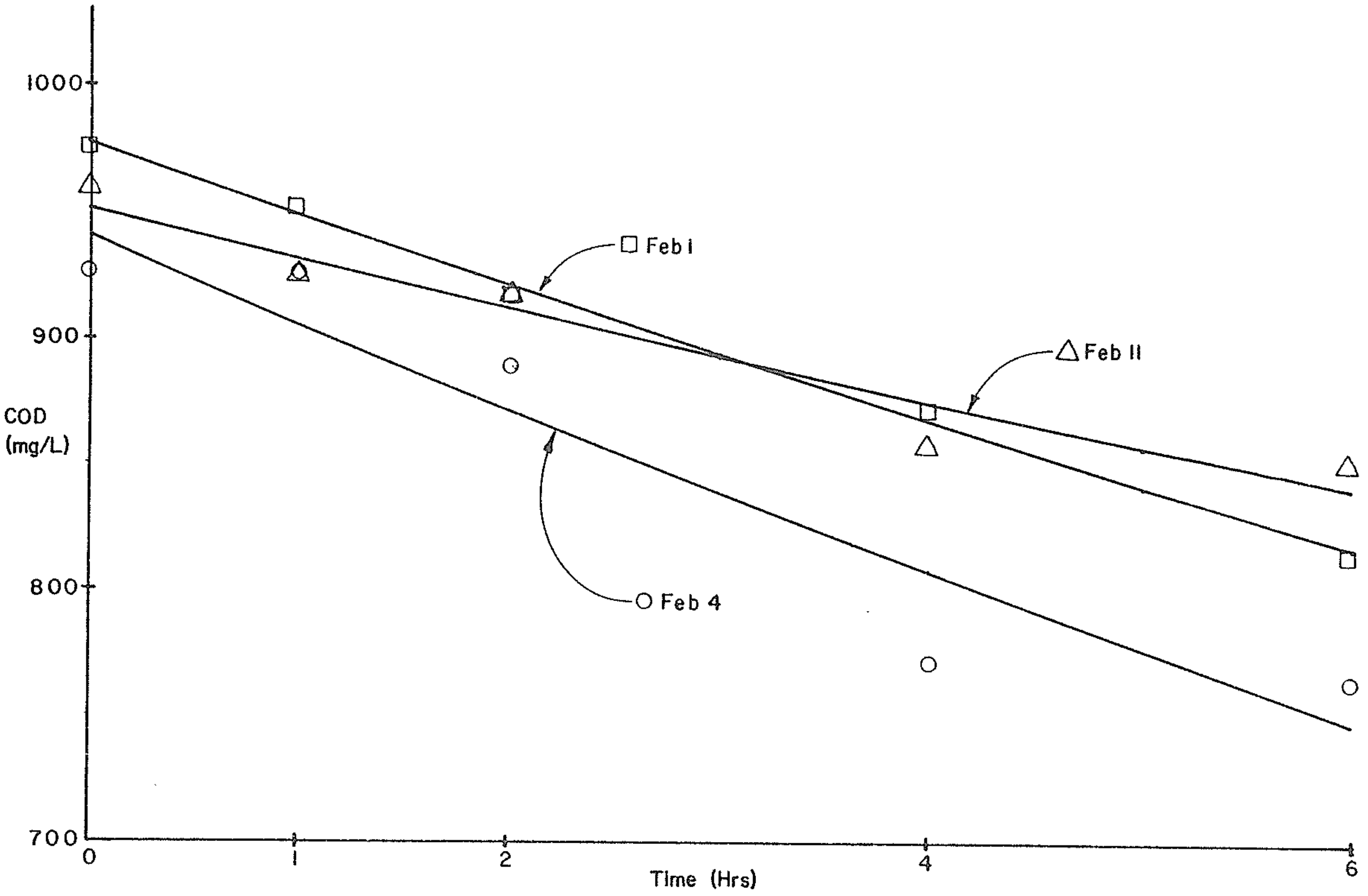

Figure 13. Total Municipal Sewage COD vs. Time

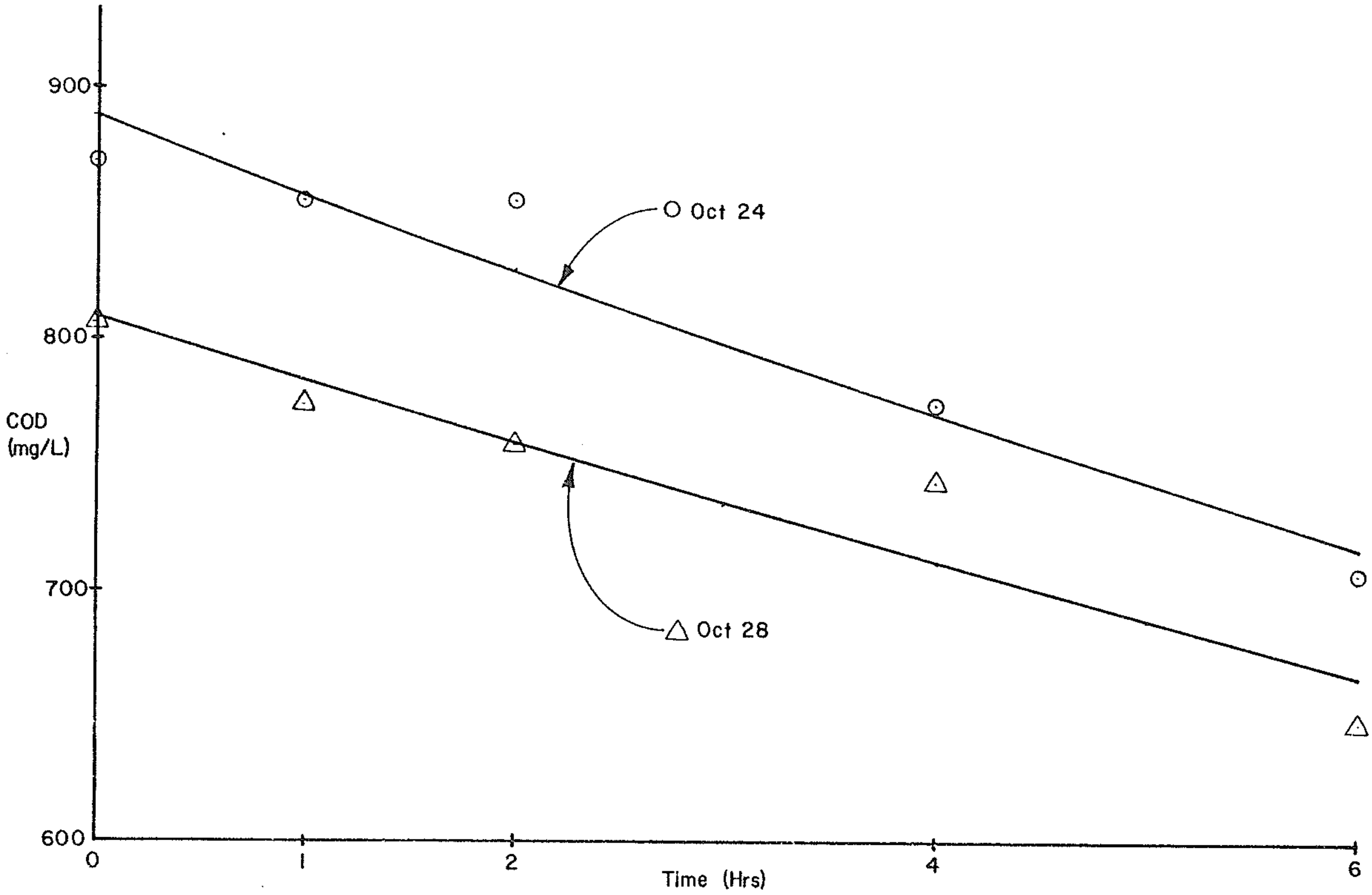

Figure 14. Acclimated Seed--Total Green Chili Waste Water COD vs. Time

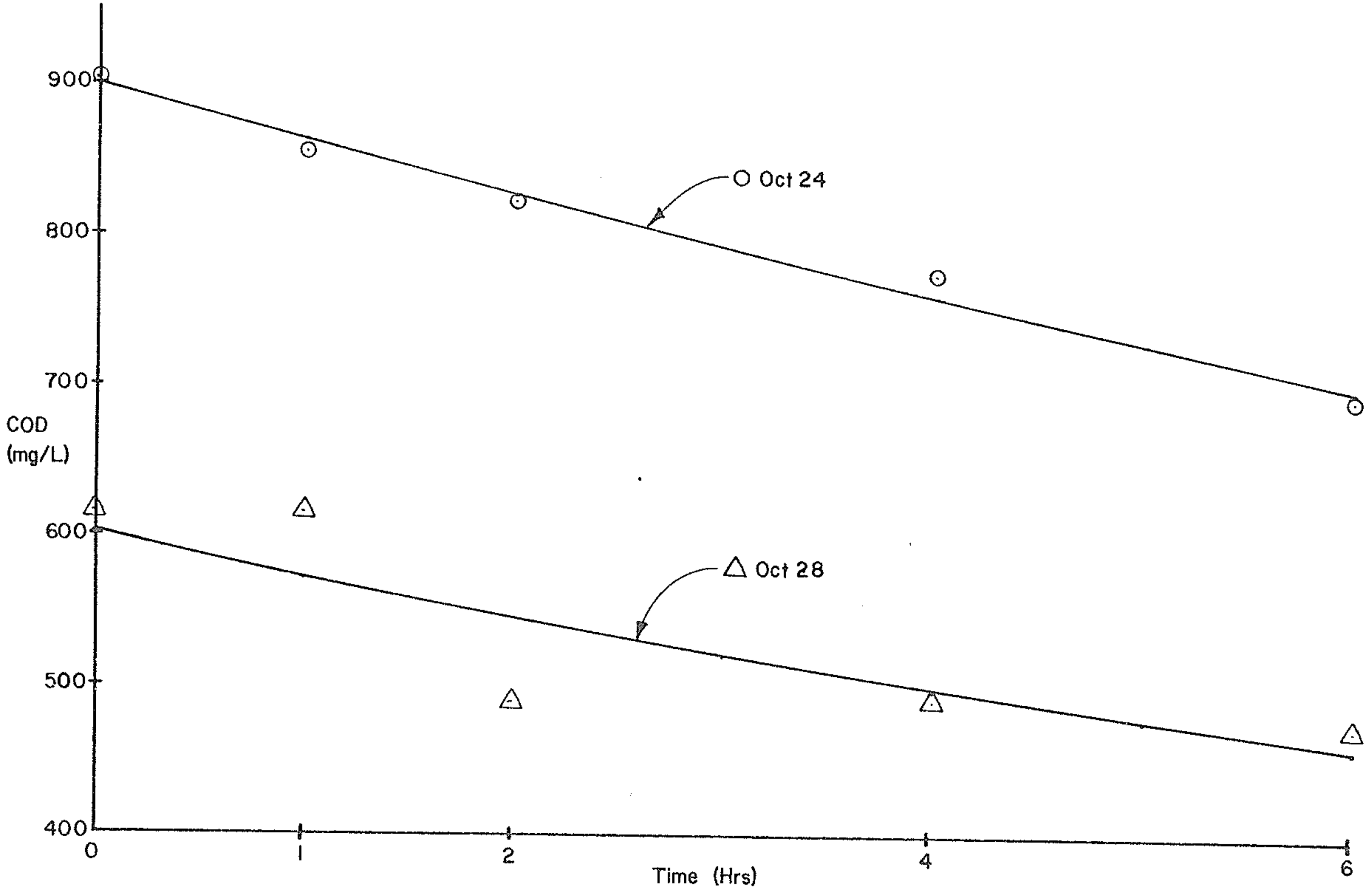

Figure 15. Nonacclimated Seed--Total Green Chili Waste Water COD vs. Time

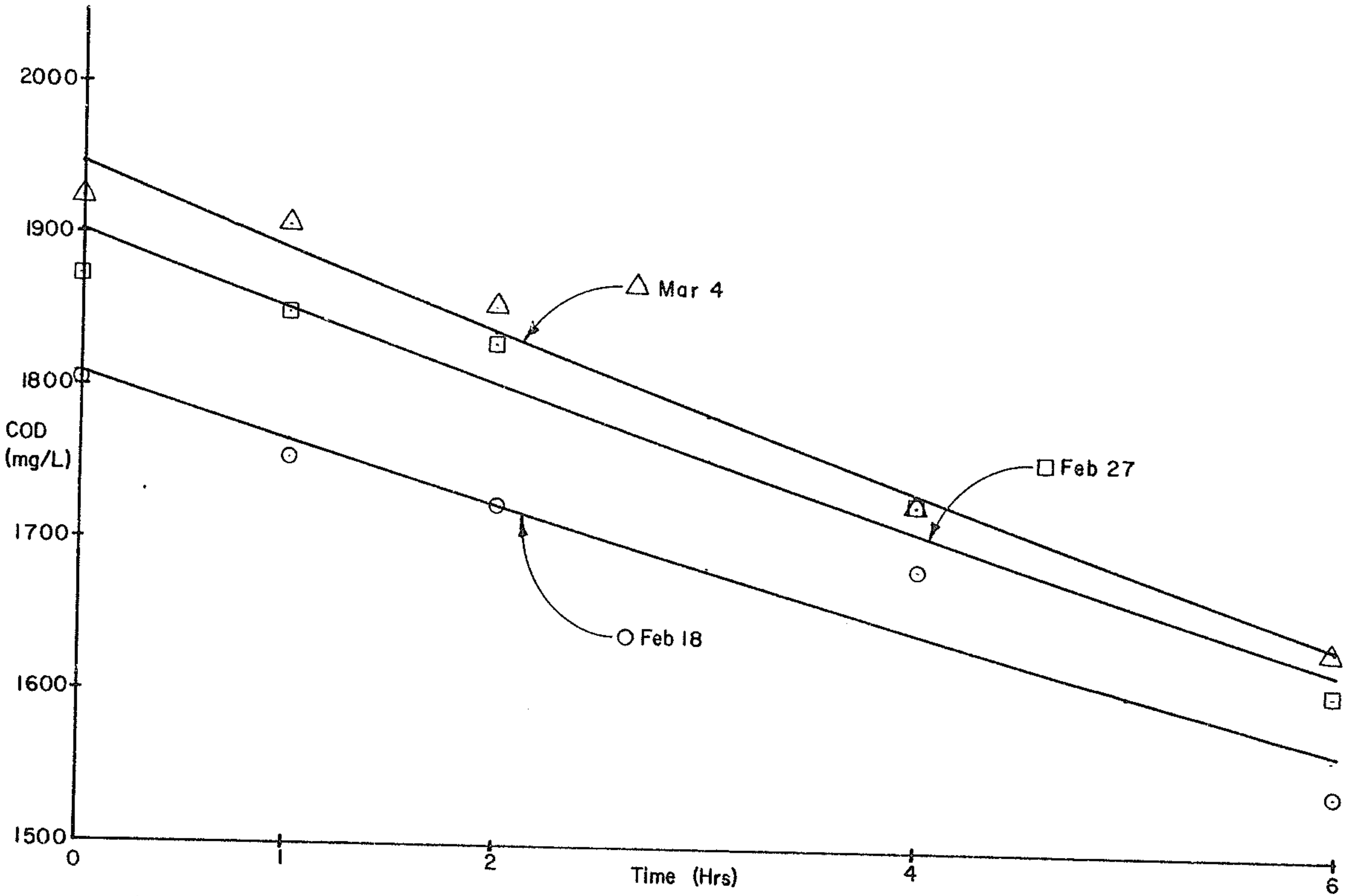

Figure 16. Acclimated Seed: Total Red Chili Waste Water COD vs. Time

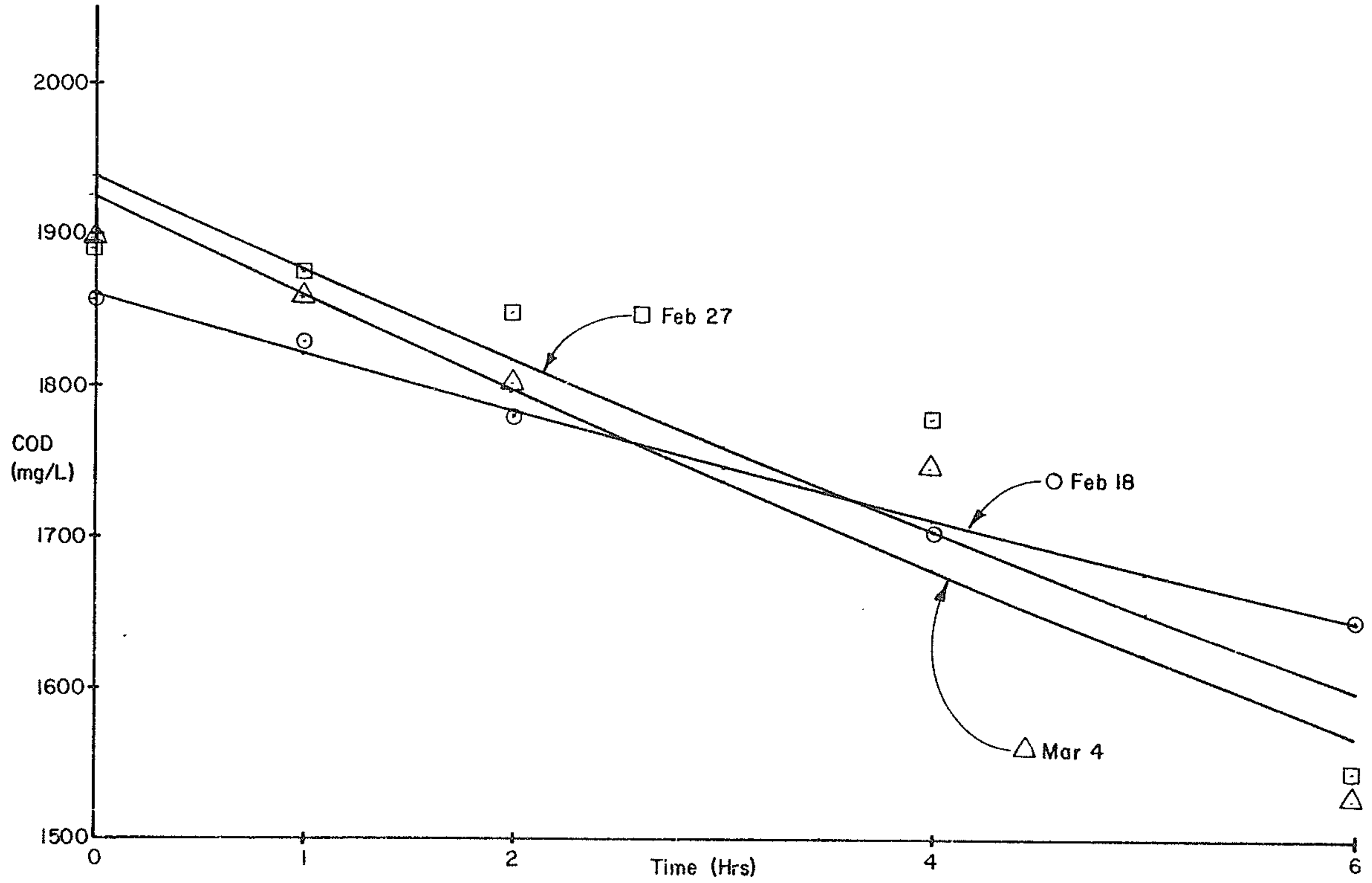

Figure 17. Nonacclimated Seed: Total Red Chili Waste Water COD vs. Time

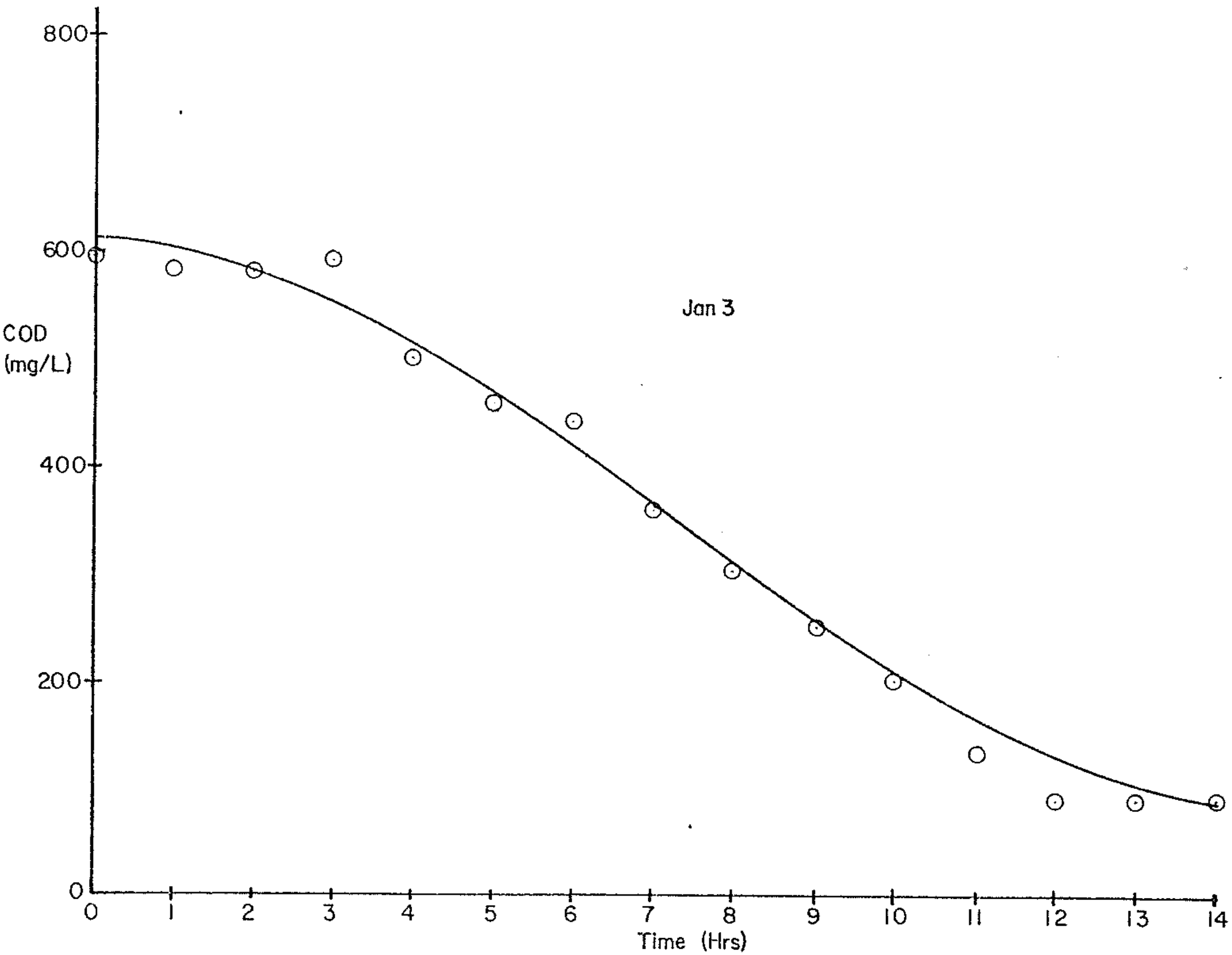

Figure 18. Soluble COD vs. Time of Green Chili Waste Water (1)

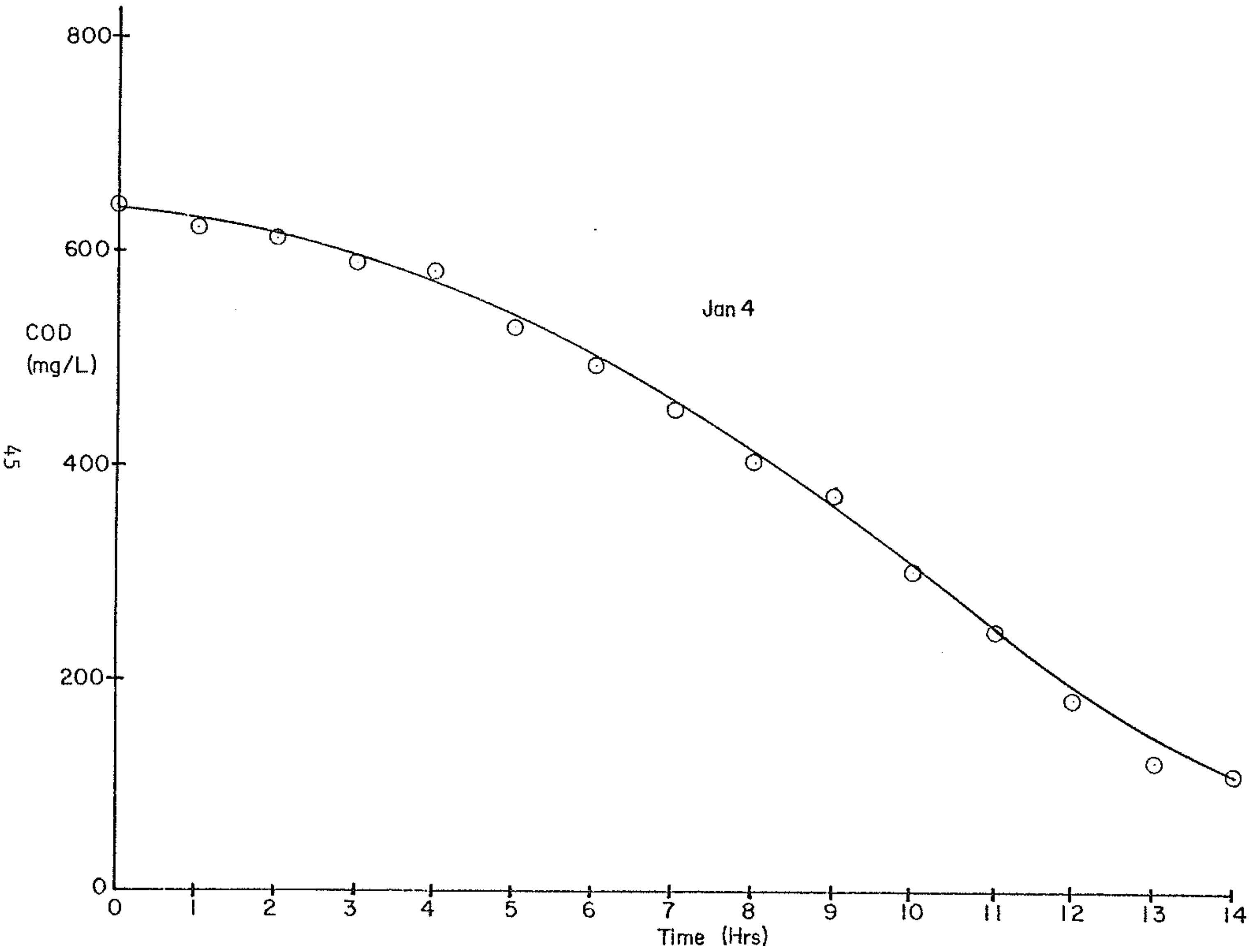

Figure 19. Soluble COD vs. Time of Green Chili Waste Water (2)

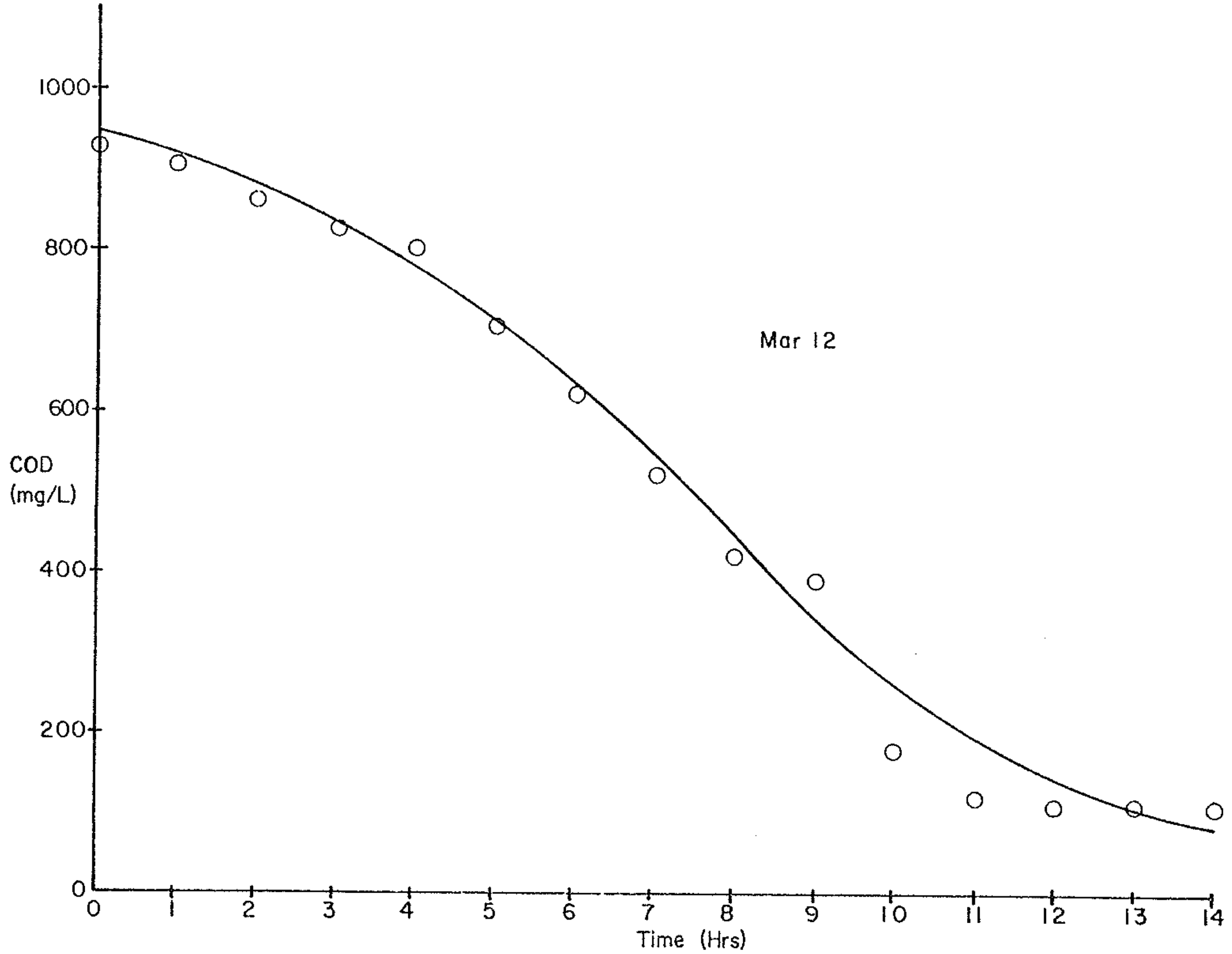

Figure 20. Soluble COD vs. Time of Red Chili Waste Water (1)

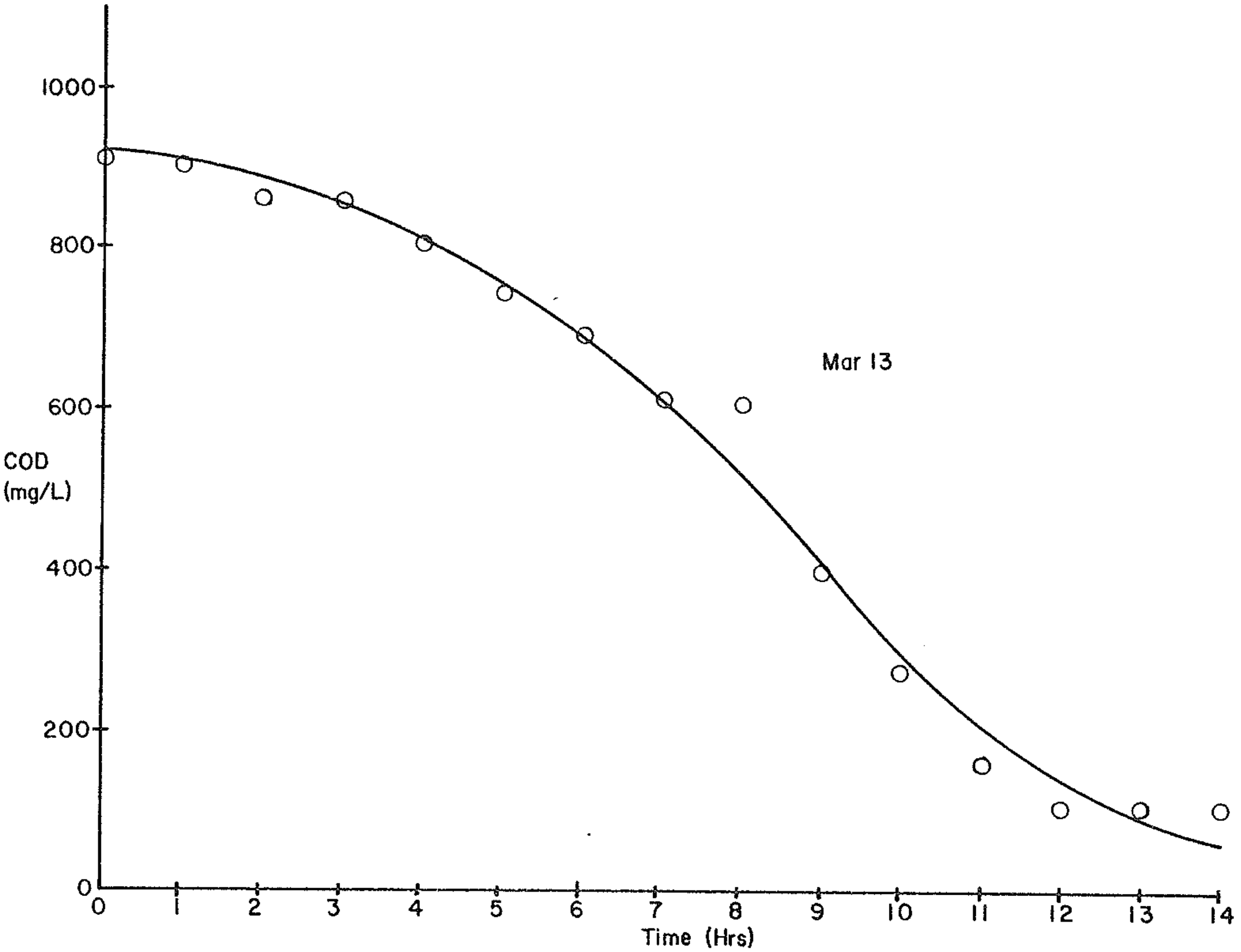

Figure 21. Soluble COD vs. Time of Red Chili Waste Water (2)

Figures 18 and 19 are graphical representations of the low initial biological solids experiments using green chili waste water as substrate. Figures 20 and 21 are graphical representations of the low initial solids experiments using red chili waste water as substrate.

Table 5 gives the results of computer analysis of the low initial biological solids experiments. Table 6 presents a comparison of the experimentally determined rate constants with the Monod predicted ones.

Chili Waste Water vs. Sewage Results

Municipal sewage was metabolized at rates generally faster than the rates at which either of the waste waters were metabolized, as can be seen graphically from the COD reduction curves and also from the magnitude of the k values determined by computer analysis.

Comparison of the magnitude of k values is summarized in Table 3. Geometric means yield a first order k value for the metabolism of red chili waste water of 0.159 as compared to 0.309 for the metabolism of sewage. Second order k values are 9.60×10^{-4} and 2.75×10^{-3}, respectively. The difference in magnitude of corresponding k values in the green chili waste water experiments is not as great, with first order k value for the metabolism of green chili waste being 0.104 as compared to a value of 0.140 for sewage. Second order k values for this system are 6.05×10^{-4} and 9.34×10^{-4},

Table 5. Results of Low Initial Biological Solids Experiments

Date	S_o mg/1	k_{max} hr^{-1}	k mg/1	Correlation
Green Chili Waste Water				
Actual Solids				
January 3	78	0.130	19.5	0.919
January 4	72	0.130	15.9	0.966
Optimized Solids				
January 3	40	0.190	23.9	0.928
January 4	75	0.128	15.7	0.967
Red Chili Waste Water				
Actual Solids				
March 12	84	0.168	28.4	0.9744
March 13	69	0.164	31.0	0.9420
Optimized Solids				
March 12	90	0.164	28.1	0.9750
March 13	45	0.20	35.0	0.9520

Table 6. Comparison of Experimentally Determined k Values with Monod-Predicted k Values

Date	Type	C_{cr}	S_{cr}	k_1 monod	k_1 exp	$\frac{k_1 \text{ monod}}{k_1 \text{ exp}}$	k_2 monod	k_2 exp	$\frac{k_2 \text{ monod}}{k_2 \text{ exp}}$
Green chili waste water vs. sewage									
Oct. 16	chili	160	612	1.29	0.111	11.62	8×10^{-3}	6.64×10^{-4}	12.05
Oct. 21	chili	150	561	1.21	0.082	14.76	8×10^{-3}	5.19×10^{-4}	15.41
Oct. 31	chili	114	379	0.92	0.099	9.29	8×10^{-3}	4.42×10^{-4}	18.10
Nov. 7	chili	130	525	1.05	0.132	7.95	8×10^{-3}	8.80 s 10^{-4}	9.10
Green chili waste water acclimated vs. non acclimated seed									
Oct. 24	acclimated	165	727	1.33	0.219	6.07	8×10^{-3}	1.01×10^{-3}	7.92
Oct. 24	non	165	707	1.33	0.241	5.52	8×10^{-3}	1.09×10^{-3}	7.34
Oct. 28	acclimated	130	444	1.05	0.244	4.30	8×10^{-3}	1.27×10^{-3}	6.30
Oct. 28	non	136	505	1.10	0.193	5.70	8×10^{-3}	8.74×10^{-4}	9.15
Red chili waste water vs. sewage									
Feb. 1	chili	173	542	0.980	0.153	6.41	5.6×10^{-3}	8.57×10^{-4}	6.53
Feb. 4	chili	135	434	0.765	0.147	5.20	5.6×10^{-3}	9.73×10^{-4}	5.75
Feb. 11	chili	156	564	0.884	0.180	4.91	5.6×10^{-3}	1.06×10^{-3}	5.28
Red chili waste water acclimated vs. nonacclimated seed									
Feb. 18	acclimated	254	968	1.44	0.345	4.17	5.6×10^{-3}	1.14×10^{-3}	4.91
Feb. 18	non	259	1092	1.47	0.237	6.20	5.6×10^{-3}	5.47×10^{-4}	10.24
Feb. 27	acclimated	260	987	1.47	0.376	3.91	5.6×10^{-3}	1.14×10^{-3}	4.91
Feb. 27	non	255	1092	1.45	0.276	5.25	5.6×10^{-3}	6.62×10^{-4}	8.46
Mar. 4	acclimated	260	1029	1.47	0.516	2.85	5.6×10^{-3}	3.18×10^{-3}	1.76
Mar. 4	non	252	1090	1.43	0.365	3.92	5.6×10^{-3}	1.29×10^{-3}	4.34

respectively. It can be concluded that with both the chili waste waters and with both first order and second order kinetic models used to analyze the data, the chili waste water is metabolized more slowly than the municipal sewage.

It would appear quite possible that the lower reaction rates in the waste waters could be due to an acclimatization process, during which the bacterial populations adapt themselves to metabolism of a new substrate. This conclusion is supported by examination of the soluble COD reduction curves. It can be observed in both cases that the municipal sewage metabolism curves depict rapid removal in the early time periods, with removal then becoming one with a rate of increasing decrease. This is characteristic of a system where the microbial population is already acclimated to the substrate that it is metabolizing.

In comparison, the soluble COD removal curves of the waste waters do not exhibit an early rapid rate of removal, but appear to reflect a system in which the removal is more constant over the entire time period.

Again, this trend is more clearly evident in the red chili waste water vs. municipal sewage, which would be consistent with the observation that there is a larger difference in the k values of red chili waste water and municipal sewage than the ones of green chili waste water and municipal sewage.

If these differences are indeed due to initial suppression of microbial activity, then it might be concluded that the waste waters do indeed exhibit an antimicrobial effect on the biological solids. However, the effects do not seem significant enough to warrant the term "toxic" as discussed in the theory section, for gross bacteriocidal or inhibitory effects are not noted. Rather, all systems seem amenable to biological treatment and oxidation of their constituents, although the soluble COD of municipal sewage does appear to be reduced at a rate faster than the reduction rate in the waste waters, at least in the early parts of the experiment. No significant differences in yield factors or percent COD oxidized are noted in either of the two comparisons.

The COD of both waste waters and the municipal sewage samples generally appear to be reduced to characteristic levels, which, however, differ among the three. Many studies report toxic effects in terms of % COD removed. In this investigation such a parameter would lead to misleading results.

It should be noted that the average level of treatability of municipal sewage in this investigation was a COD of 76 while the same value was 121 and 100 for green chili-processing waste water and red chili-processing waste water, respectively. Therefore it appears that the waste waters contain a higher level of COD which is resistant to biological treatment than that contained in the municipal sewage, at least as pertains to a 17-hour time period. Whether this material would be amenable to biological treatment in time periods afforded by such systems as anaerobic digestors and aerobic digestors is unknown.

While it cannot be stated that the waste waters in question do not exhibit toxic effects upon individual microbes, the effect noted in these experiments is not one of great inhibition or metabolic repression. Since toxicity becomes evident at a critical ratio of toxic ion to biomass, a food-limited mass culture reactor such as the one in this investigation holds a significant capacity for resisting toxic substances (9). Therefore, these experiments may well represent a system where any antimicrobial effects can be masked and then compensated for by adaptation of the microbial population.

Acclimated vs. Nonacclimated Seed

The effects of adaptation predicted in the previous discussion become evident upon examination of the results of the acclimated vs. nonacclimated biological solids experiments. Again, conclusions can be drawn from examination of the magnitude of k values and the graphical depiction of the soluble COD removal curves.

The effect appears significant in both green chili-processing waste water and red chili-processing waste water. Using green chili waste water as substrate, the geometric mean of first order and second order k values are 0.231 and 1.13×10^{-3}, respectively, in the experiments where acclimated seed was used. The corresponding k values are 0.216 and 9.7×10^{-4}, respectively, where a nonacclimated seed was used. Using red chili waste water as substrate, the geometric mean of first order and second order k values are 0.406 and 1.60×10^{-3}, respectively, in the experiments where acclimated seed was used. The corresponding k values are 0.288 and 1.05×10^{-3}, respectively, for the experiments where the seed was not acclimated. This is a significant difference, and corresponds to the observation of lower k values for metabolism of red chili waste water as compared to those for municipal sewage.

These experiments demonstrate a definite acclimation effect. Since the characteristics exhibited in the waste water vs. municipal sewage were shown to be ones that predicted such an effect, it can be concluded that lower removal rates for the waste water than for the municipal sewage can be attributed to a lag period in which the microbial population is adapting itself to metabolism of the new substrate, rather than to any inhibitory effect of the substrate itself, which remains constant with time. As can be observed from both the data and the corresponding curves, once acclimation has been achieved, total soluble COD reduction of the waste water substrates is comparable to levels of reduction achieved by the acclimated biological solids.

Practical Applications

The data summarized in Table 3 can be used to make some practical predictions about the effect of chili-processing effluent on activated sludge treatment facilities. These predictions can be made using the geometric mean values of k values (as first order kinetics yield a general best fit of the data) and the arithmetic mean of the initial COD value of the substrate in question.

Assuming a six-hour detention time, these results predict that a red chili waste water would be reduced from an initial COD of 259 to a final value of 138, while municipal sewage collected during the same time period with an initial COD of 252 would be reduced to a final level of 108. Green chili waste water of an initial COD of 298 would be reduced to a final level of 114, while municipal sewage collected during the same time period with an initial COD of 323 would be reduced to a final COD value of 50.

The difference between the treatability of municipal sewage and green chili waste water appears to be negligible when viewed in this way. The difference in treatability of red chili waste water and municipal sewage appears to be a more significant one.

However, the acclimitization experiments demonstrate that lower rates of substrate reduction of the chili waste waters are due to unacclimated biological solids, a situation which can rapidly be corrected in a system as dynamically changing as the population which comprises activated sludge. Therefore, if there are any initial effects on an activated sludge treatment plant caused by the introduction of chili-processing wastes, the situation can be expected to become improved with time.

It is highly unlikely that any effects exerted will even be noticeable in reality. It should be remembered that this investigation deals with an extreme situation. It is doubtful that chili-processing waste waters will ever comprise a full half or third of the entire volume to be treated, as was the situation in this investigation.

Kinetics of Total COD Reduction Curves

Very little published work includes kinetics of total COD curves. Total COD measurements are commonly used in research as a necessary parameter of mass balance rather than a tool to base kinetic predictions on.

It is easy to hypothesize the reason for this absence of kinetic analysis of total COD reduction curves after examination of tabulated results and graphical representations. Very few conclusions can be drawn from these results, aside from the observation that first order and second order k values usually correspond within their grouping to values described by one order of magnitude.

There are several reasons for the lack of meaningful trends depicted by the total COD reduction curves. The first is the validity of the data itself. It can be noted that generally the correlation coefficients for the k values listed are not as high as those recorded for the k values for the soluble COD reduction curves. This is to be expected, as the sample being analyzed is obviously not as homogeneous as the soluble samples, and therefore more susceptible to inherent precision errors.

Complicating this situation is the fact that the substrate in question was not only a solution, but contained suspended solids, most of which were probably not biological solids and therefore could exhibit unlimited variability in their corresponding COD value. This all contributes to creating a situation where there is not as much assurance of comparable samples as in a soluble sample system.

Aside from the problems of obtaining precise data, it should be considered that environmental conditions do not affect the total COD reduction curve in exactly the same way that they affect a soluble one. The total COD curve is not as immediately sensitive to substrate concentration as the soluble COD reduction curve.

Also, the total COD reduction curve is affected by several conditions that do not apply to the soluble COD reduction curve. First, the total COD curve may remain linear at the initial value for the early period of the test, while the soluble curve exhibits its period of greatest rate of substrate reduction. This can be due to a period in which the substrate is being adsorbed to the microbial cells and therefore removed from the system, but during which a significant amount of metabolism and cellular growth is not yet occurring.

At the end of aerobic digestion, the soluble COD reduction curve may level out while there is an increase in the slope of the curve for total COD reduction. This is due to the system entering endogenous respiration, where metabolism of other bacteria results in an increase in the percent of soluble COD being oxidized without a corresponding increase in synthesis of cellular material. In any case, the total COD reduction curves are not as precisely defined or as kinetically predictable as the soluble COD reduction curves.

In this investigation, the total COD reduction curves appeared comparable in all experiments, with little difference noted from one experiment to another.

Comparison of Experimental k Values With Monod-Predicted k Values

Table 5 summarized the Monod constants determined for the low initial biological solids experiments. It should be noted in reference to the previous discussion that the total COD reduction curves when analyzed as previously discussed for fit to Monod-predicted curves yielded correlation coefficients of generally 0.90, which is significantly lower than the correlation coefficients tabulated in Table 3 for the soluble COD reduction curves.

As was discussed in the experimental methods section, the initial solids value was optimized. The optimization in initial biological solids resulted in very little difference in the k_m and K values thereby obtained, but it should be noted for later discussion that the S_o values themselves were thereby appreciably changed.

Some research (17) has concluded there may be an initial lag period in the experiment, and that the deletion of this portion of the data results in a better definition of the curve by Monod kinetics. This was applicable in this investigation, as deleting the data of the first one or two hours did not result in a better curve fit.

An average of the values obtained from the two optimized curves were used in both cases to determine the average k_m and K values for each substrate system. These were then used to calculate the Monod-predicted k values, and also the predicted critical substrate level and critical solids level of the previously discussed experiment. The results are tabulated in Table 6.

The Monod-predicted values for both first order and second order kinetic models were greater than the experimentally determined values by approximately one order of magnitude. Also, as can be readily concluded from the listed critical substrate and critical solids level, use of the constants k_m and K predict the experimental system is in Monod kinetics above critical substrate level for the majority of the test period. As is shown by computer analysis of the experimental systems, in reality this is not so, with the systems in fact being substrate-limited, and exhibiting first order and second order kinetic removal of substrate.

However, by understanding these two contradictory models of removal of substrate, it is easily understood why the Monod-predicted constants of rate of removal are greater than those determined experimentally. Figure 22 depicts the theoretical removal of the same

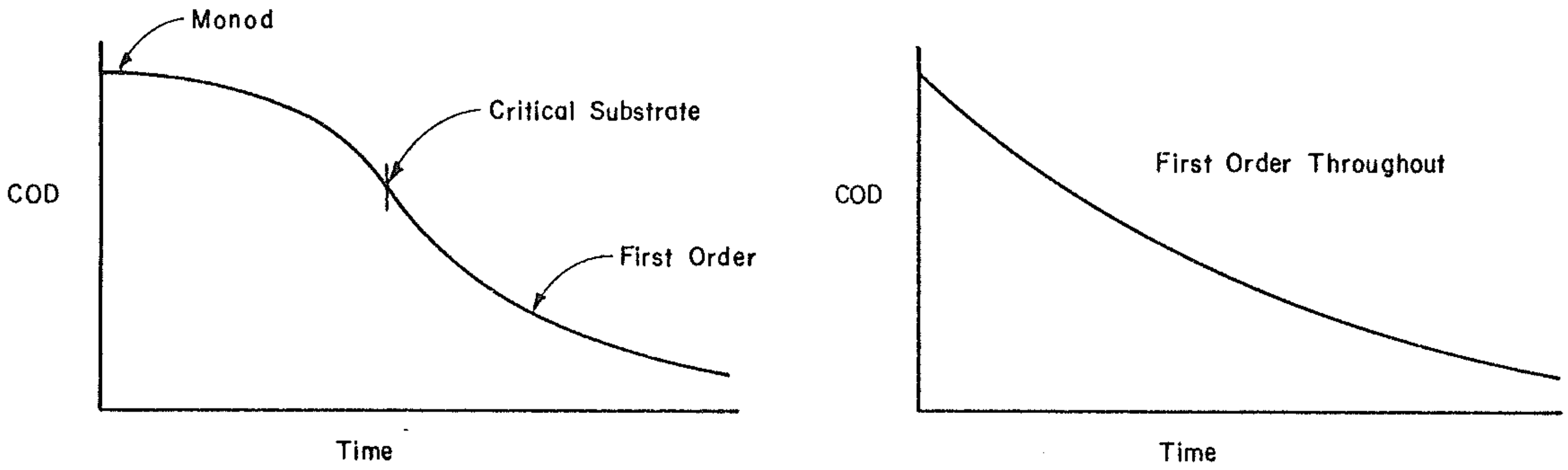

Figure 22. Comparison of First Order Substrate Reduction with Substrate Reduction Above Critical Substrate Level

amount of identical substrate. However, one system is assumed to be in first order while the other exhibits the Monod curve characteristic of systems in which the substrate concentration has not yet become a limiting factor. It is easily determined that one would generally predict greater k values for the first order portion of the Monod curve than for the curve which is first order throughout the entire period.

Some researchers doubt the validity of overall kinetic values as constants as having basic significance. Such workers describe kinetic terms as being significantly functions of other parameters which are as important as substrate. Busch (9) suggests that the variation in response with reaction environment is one of the major weaknesses in use of overall kinetics instead of a more fundamental analysis.

It should be noted that by the very description of k values as reaction rate constants one defines a term which describes the effect of everything except concentration of substrate. It functions as holding these extraneous variables constant for a given reaction. Therefore it is unwise to expect values of k not to vary from experimental system to experimental system, and in dealing with heterogeneous populations of microorganisms some significant variation can seldom be avoided.

If one assumes, however, that these extraneous variables do not affect the reaction in an amount of significance when compared to the nature of the substrate, the concentration of the substrate, and the amount of viable organisms initially present, then Monod-kinetics should indeed yield useful predictions of k values.

The problem would appear to be one of accurately defining these variables. As can be seen from Table 5, there was sometimes considerable difference in the actual value of suspended solids experimentally measured and the optimized initial biological solids value. Simply the discrepancy in the terms "suspended solids" and "biological solids" would seem to pinpoint where the problem might lie in applying Monod kinetics.

If one were able to measure with great accuracy the fraction of viable organisms in the suspended solids measurement, then experimental results might indeed correspond more closely to those predicted by the model. This difference in measurement would also affect the computed yield coefficient for a given experiment.

As discussed earlier, the Monod equation is extremely sensitive to initial organism concentration. The solids level used in the majority of experiments of this investigation were substantially higher than those used in the low initial biological solids experiments. Obviously, as the measurement is magnified so is the inherent error in the measurement.

CONCLUSIONS

1. Soluble substrate removal of red and green chili-processing waste waters occurs at a rate lower than that of removal of soluble COD of municipal sewage. The chili-processing waste waters contain a higher level of refractory COD than does the municipal sewage.

2. The lower rate of soluble substrate removal in the chili-processing waste waters is due to acclimation of the biological solids to a particular substrate. Lower rates are not observed when the chili-processing waste water is treated with acclimated biological solids.

3. Monod-predicted rate constants differ significantly from experimentally determined ones. This is thought to be due to an inability to precisely and accurately determine viable initial organism concentration from suspended solids measurements.

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APPENDIX

EXPERIMENTAL DATA

Table 7. Collection Data

Green Chili Waste Water Collected September 2 at Approximately 4:00 pm	
Total COD	423 mg/liter
Soluble COD	410 mg/liter
Suspended Solids	26 mg/liter
Red Chili Waste Water Collected December 9 at Approximately 4:00 pm	
Total COD	976 mg/liter
Soluble COD	410 mg/liter
Suspended Solids	26 mg/liter

Table 8. Green Chili Waste Water vs. Sewage Data

Hour	Soluble Waste Water COD	Soluble Sewage COD	Total Waste Water COD	Total Sewage COD	Initial Solids (mg/1)	Final Solids (mg/1)
			October 16			
0	250	212	1000	930	Waste water	
1	212	181	1000	922	578	635
2	181	173	969	922	Sewage	
4	173	166	961	915	653	700
6	119	96	953	874		
			October 21			
0	233	233	926	1082	Waste water	
1	156	148	918	1074	539	591
2	156	148	918	1066	Sewage	
4	148	140	910	1066	681	757
6	120	109	875	1026		
			October 31			
0	320	321	691	703	Waste water	
1	300	280	592	691	270	348
2	280	262	576	650	Sewage	
4	280	148	567	623	393	501
6	163	102	562	604		
			November 7			
0	233	241	819	827	Waste water	
1	225	209	803	819	461	533
2	185	169	797	819	Sewage	
4	177	120	797	795	567	659
6	100	88	747	739		

Table 9. Green Chili Waste Water Acclimated vs. Non-acclimated Biological Solids Data

Hour	Soluble Acclimated COD	Soluble non-acclimated COD	Total Acclimated COD	Total non-acclimated COD	Initial Solids (mg/1)	Final Solids (mg/1)
			October 24			
0	484	501	903	891	Acclimated	
1	306	484	855	855	592	743
2	226	290	822	855	Nonacclimated	
4	161	274	774	774	532	712
6	121	111	693	707		
			October 28			
0	426	474	806	616	Acclimated	
1	348	269	774	616	283	447
2	216	269	758	490	Nonacclimated	
4	137	190	743	490	361	525
6	104	128	648	474		

Table 10. Red Chili Waste Water vs. Sewage Data

Hour	Soluble Waste Water COD	Soluble Sewage COD	Total Waste Water COD	Total Sewage COD	Initial Solids (mg/l)	Final Solids (mg/l)
			February 1			
0	286	348	888	976		
1	280	288	880	952	Waste Water	
2	257	178	859	917	473	558
4	202	109	823	872	Sewage	
6	113	57	817	814	576	665
			February 4			
0	300	310	897	926		
1	280	286	871	926	Waste Water	
2	278	241	871	889	319	424
4	220	157	832	771	Sewage	
6	119	58	824	764	489	624
			February 11			
0	309	313	908	959		
1	289	250	900	925	Waste Water	
2	278	210	889	917	448	570
4	223	119	826	856	Sewage	
6	99	35	817	850	501	626

Table 11. Red Chili Waste Water Acclimated vs. Nonacclimated Biological Solids Data

Hour	Soluble Acclimated COD	Soluble non-acclimated COD	Total Acclimated COD	Total non-acclimated COD	Initial Solids (mg/l)	Final Solids (mg/l)
			February 18			
0	920	936	1806	1856		
1	745	879	1756	1829	Acclimated	
2	523	790	1726	1779	680	743
4	211	540	1687	1703	Nonacclimated	
6	131	220	1542	1647	647	886
			February 27			
0	1001	976	1886	1890		
1	673	901	1852	1875	Acclimated	
2	391	760	1832	1848	701	1075
4	236	391	1729	1779	Nonacclimated	
6	98	200	1608	1544	697	1042
			March 4			
0	994	996	1926	1897		
1	725	801	1908	1858	Acclimated	
2	361	663	1856	1802	700	1084
4	130	332	1728	1746	Nonacclimated	
6	49	109	1637	1528	668	1074

Table 12. Low Initial Biological Solids in Green Chili Waste Water Data

	January 3			January 4	
Hours	Soluble COD	Total COD	Hours	Soluble COD	Total COD
0	595	672	0	642	710
1	582	672	1	621	700
2	580	665	2	610	700
3	541	660	3	588	683
4	500	650	4	580	669
5	458	640	5	528	661
6	442	620	6	492	651
7	359	612	7	451	642
8	303	607	8	403	626
9	251	582	9	371	605
10	201	542	10	300	610
11	132	510	11	239	582
12	90	503	12	181	558
13	90	503	13	122	524
14	90	460	14	111	496
	Initial Solids mg/l	78		Initial Solids mg/l	72
	Final Solids mg/l	346		Final Solids mg/l	396

Table 13. Low Initial Biological Solids in Red Chili Waste Water Data

	March 12			March 13	
Hours	Soluble COD	Total COD	Hours	Soluble COD	Total COD
0	926	998	0	909	982
1	903	998	1	900	973
2	860	980	2	860	973
3	825	968	3	855	973
4	800	954	4	801	950
5	703	954	5	742	940
6	620	928	6	692	906
7	520	890	7	611	890
8	420	871	8	606	872
9	390	850	9	397	843
10	180	846	10	276	810
11	120	821	11	160	760
12	111	770	12	107	751
13	111	682	13	107	735
14	111	609	14	107	704
	Initial Solids mg/l	84		Initial Solids mg/l	69
	Final Solids mg/l	521		Final Solids mg/l	493