

EFFECTS OF CADMIUM ON
BATCH AEROBIC BIOLOGICAL TREATMENT

by

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I. INTRODUCTION

With more stringent effluent quality standards from wastewater treatment plants being contained in recently passed federal and state legislation, attention has been focused on the reduction or removal of inhibitory or potentially toxic substances. The presence of toxic substances in wastewaters can have detrimental effects on biological treatment processes, and of equal importance, the possibility of harmful effects to aquatic and terrestrial organisms downstream from the treatment plant discharges.

In recent years an increased interest has been shown in the presence of heavy metals in the environment and the possible resulting toxicity to aquatic and human life. Heavy metals are widely distributed in the earth's crust, and can be found in practically every living and inanimate substance in the world. Several of these metals have been found to be essential ingredients for life, e.g., iron, copper, zinc, and manganese, while others have no known beneficial role, e.g., mercury and lead. Presently the increased concern about the presence of heavy metals and their possible toxicity, results from their wide usage in major industries, as shown in Table I.

The hazard of heavy metal toxicity to human life can be seen in the cases of mercury poisoning in Minamata, Japan (2) and the cadmium caused itai-itai disease outbreaks in Japan (3). While lead poisoning may result in brain damage, inhalation of some insoluble chromium pigments may cause cancer (4).

Heavy metal toxicity to biological waste treatment processes is important to study since practically all municipal treatment plants and a large majority of industrial treatment plants utilize biological treatment systems and these systems may contain heavy metal discharges. Several general studies have been made on the effects of heavy metals in biological systems. McDermott et al. (5, 6, 7, 8) investigated the toxicity of chromium, copper, nickel, and zinc on the activated sludge process. Results of their studies show that at low concentrations of the metals the biochemical oxygen demand (BOD) removal efficiency of the biological reactors slightly decreased. While a large slug dose of a metal would immediately upset the activated sludge plant, the plant would recover with time. Adams, et al. (9) studied the same heavy metals and found that the effects on anaerobic digestion were not similar to the effects on the activated sludge process. The anaerobic digester performed in an "all or nothing" reaction to heavy metal concentrations in which case the digester functioned satisfactorily or ceased to function entirely. Barth (10) suggests that the susceptibility of anaerobic systems to metal toxicity is due to the small number of anaerobic species. Whereas an aerobic system, activated sludge for example, has very diverse types of organisms so that several species might be adversely affected without affecting the overall system.

The objective of this research was to evaluate the toxic effects of cadmium on aerobic batch cultures of microorganisms. By subjecting batch cultures to varying cadmium concentrations as shock

loaded units and several acclimated units the toxic effect was determined. Utilizing volatile solids production and substrate removal parameters determinations were made to ascertain the effects of cadmium on aerobic treatment.

A review of literature pertaining to the existence of cadmium in the environment, the chemistry of cadmium, and previous studies examining the toxicity of cadmium to wastewater treatment systems is presented in the next section. The materials and methods of this investigation follows and the results and discussion of the results of this study are then presented. A section examining the engineering applications of the results is presented followed by the conclusions of this study of the effects of cadmium on aerobic batch biological treatment.

II. LITERATURE REVIEW

A. Cadmium in Industry and the Environment

Cadmium, a heavy metal previously mentioned in the introduction, is found throughout the earth's crust. Approximate average concentrations of cadmium found in rocks are as follows: igneous rocks - 0.2 mg/kg, shales - 0.3 mg/kg, sandstones - 0.05 mg/kg, limestones - 0.035 mg/kg, and coal - 0.2 mg/kg (11). Estimates of the total cadmium quantity in the upper mile of the earth's continental crust are approximately 200×10^9 tons (11).

While cadmium occurs throughout the lithosphere it is not the primary resource of any mining operations. Cadmium is obtained as a by-product of refining primary product metals. Lead and zinc are examples of primary products which can not be extracted and refined without the concurrent production of cadmium.

Refinement of cadmium is accomplished in several steps. The initial stage consists of the ore being roasted so that sulphur gaseous products and cadmium will be distilled off. Cadmium is relatively volatile and therefore will distill off before the primary product metal (Boiling Point Cd-767°C, Zn-905°C, Pb-1620°C, Cu-2580°C). The distilled cadmium will be collected in the precipitated flume dust which is passed through the furnace several times to enrich the cadmium concentration. Enriched flue dust composition still contains a large part of the primary metal which is then taken into solution by oxidizing agents in sulphuric acid at high temperature. The leachate is then purified by different processes used for different

metals. The final refinement stage consists of a caustic soda bath to remove as much trace amount of zinc as possible, followed by either a vacuum distillation or an electrolysis process to produce marketable cadmium. Purity of marketable quality cadmium is 99.95 - 99.97 percent (11). Finally the cadmium is cast into plates, rods, or lenses to be used in industry.

The major cadmium consuming countries are in descending order: United States, West Germany, Great Britain, and Japan. Industries that use the greatest quantities of cadmium in these four nations are: electroplating (25 percent), pigments (23 percent), stabilizers for polyvinyl chloride (16 percent), and nickel-cadmium batteries (13 percent) (12). In the future the use of cadmium in solar energy collectors may account for 50 percent of cadmium consumption (12). Table II shows the breakdown of the United States 1968 industrial usages of cadmium.

In the electroplating industry cadmium is used for corrosion protection of steels, iron, copper, brass, and alloys on everything from aircraft to household appliances and hardware. The use of cadmium as a protective coat has several advantages: 1) it is deposited easily and uniformly on intricately shaped objects, 2) high ductility, thus plated parts can be stamped or formed, 3) good solderability and high electrical conductivity, and 4) good corrosion resistance to alkalis, saltwater, and tropical atmosphere.

Combined with various additives cadmium compounds can range in color from lemon yellow to a deep maroon. Thus cadmium is used

Table II. Estimated Annual Industrial Uses of Cadmium (11).

Use	U.S.A. (1968) Metric Tons
Electroplating	2,720
Pigments	1,270
Plastics (stabilizers)	910
Alloys	450
Batteries	180
Miscellaneous	510
Total (approx.)	6,040

as pigment for a variety of materials such as plastic, textiles, paints, enamels, and printing inks.

Stabilizers are added to plastics to increase the lifespan of the plastic because they tend to degrade due to exposure to the atmosphere, to sunlight, or high temperatures for prolonged periods. A mixture of cadmium, barium, and zinc salts is commonly used for stabilizers.

Nickel-cadmium batteries are rechargeable and have a very long life. The battery uses a cadmium anode, nickel oxide cathode and an electrolyte of caustic potash. These batteries are used in communications equipment, motor starters and some electric appliances.

Cadmium also occurs in other industrial materials. Included in these materials are: coal, fertilizers, rubber, tires, motor oils, fungicides, and nuclear reactor materials.

Cadmium emissions from the mines, metal smelteries, and industries all enter the environment via air, soil, or water sources to add to the problem of cadmium contamination. Table III shows the results of a study done on the sources of cadmium emissions.

The majority of the airborne cadmium will be deposited in soil or water but some will remain airborne and will be inhaled by man and animals. During the last several decades the National Air Sampling Network (NASN) has kept yearly determinations of cadmium in several areas. In 1969 the NASN found the annual averages of the twenty largest cities in the United States ranged from $0.006 \mu\text{g}/\text{m}^3$ (San Francisco) to $0.036 \mu\text{g}/\text{m}^3$ (St. Louis) (14). At twenty

Table III. Estimated Cadmium Emissions to the Environment U.S.A. (1968) (13).

Category	Air (metric tons)	Soil/Water (metric tons)	Total (metric tons)
Extraction, Refining Production	953	294 (?)	1,247
Industrial Conversions (total)	15	?	15
Consumption and Disposal (total)	186	909	1,095
Fossil Fuel Combustion	132-998		132-998
Cadmium in Fertilizers		23-227	23-227
Tires	5.2		5.2
Lubricating Oils	0.8	?	0.8
Totals	1,292-2,158	1,226-1,430	2,518-3,588

nine non-urban sampling sites the 1969 annual average was well below $0.003 \mu\text{g}/\text{m}^3$, which was the lowest measurable concentration for the method employed (14). Numerous studies have been done on the air quality surrounding a point source of emissions (14). The results show the cadmium concentration of the air around the emissions source was several hundred times greater than the cadmium concentration of air of non-contaminated areas.

The contamination of soil with cadmium may have a detrimental effect on vegetation. Kobayashi, et al. (14) found that rice and wheat would take up considerable amounts of cadmium from soil. The wheat grains accumulated more cadmium but at cadmium concentrations above $10 \mu\text{g}/\text{g}$ in the soil both wheat and rice suffered lesser yields. John, et al. (15) studied cadmium uptake in radishes and lettuce and found after a three week growing period a reduced yield from both crops. Williams and David (16) researched the cadmium uptake from soils when superphosphate fertilizer and cadmium chloride was added to the soil. The results were an uptake of 0.4 to 7.0 percent of available cadmium in the soil and an increase in the cadmium content of the crops.

The occurrence of cadmium in water may present problems of an increased cadmium content in the aquatic organisms, which may have detrimental effects on the aquatic environment or be passed on to man through consumption. The World Health Organization recommended that cadmium concentrations in drinking water should not exceed $5 \text{ ng}/\text{g}$. Durum, et al. (17) found in a 1970 survey of 720 water samples from throughout the United States 42 percent had cadmium concentrations

between 1 and 10 ng/g and 4 percent were in excess of 10 ng/g. The increased cadmium concentrations in water can be due to industrial discharges and the metal or plastic pipes in the distribution systems. Several studies (14, 19) have pointed out that while only trace concentrations of cadmium are found in water samples, large concentrations of cadmium will exist in the bottom sediments.

B. The Chemistry of Cadmium

In aqueous solutions cadmium usually will form soluble complexes with organic and inorganic ligands. In natural water and wastewater systems the formation of complexes with hydroxide, chloride and ammonia to a lesser extent, are of particular concern. As shown in Figure 1, the cadmium hydroxy complexes, Cd^{2+} , CdOH^+ , $\text{Cd}(\text{OH})_2$ (aq), and HCdO_2^- contribute increasingly to the solubility of cadmium in the pH range 7-12. Figure 2 shows that the cadmium complexation by chloride ions becomes a significant factor in solubility considerations when the system contains at least 10^{-3} M chloride. In Figure 3 the role of ammonia as a ligand appears rather slight due to the low concentration of ammonia in most natural waters and wastewaters.

Posselt and Weber (20) have formulated mathematical models describing the equilibrium solubility of cadmium in natural waters and wastewaters for a variety of possible conditions. The solubility of cadmium in most environmental situations is controlled by hydroxide or carbonate. The respective solubility product expressions are

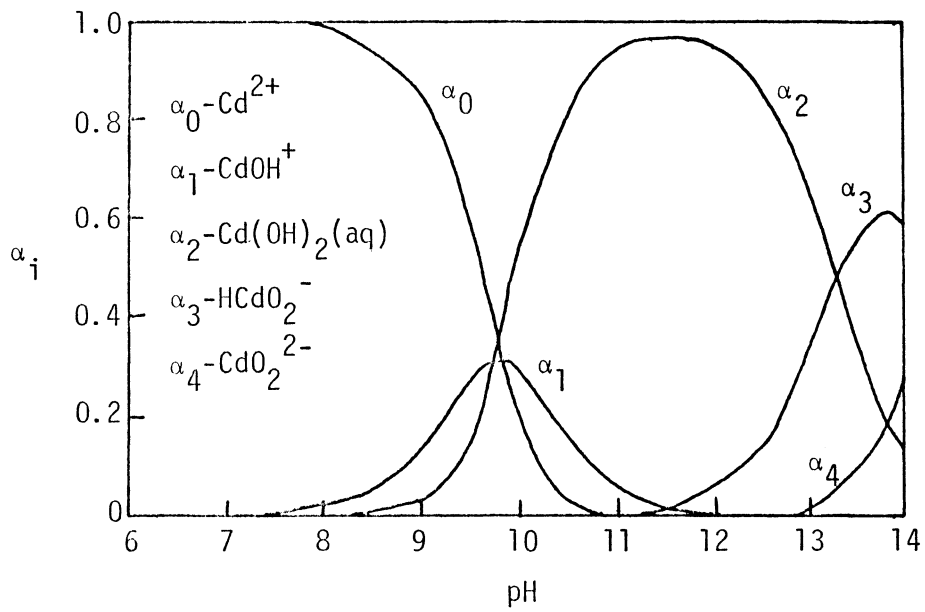


Figure 1. Distribution Diagram for Cadmium Hydroxide Complexes (20).

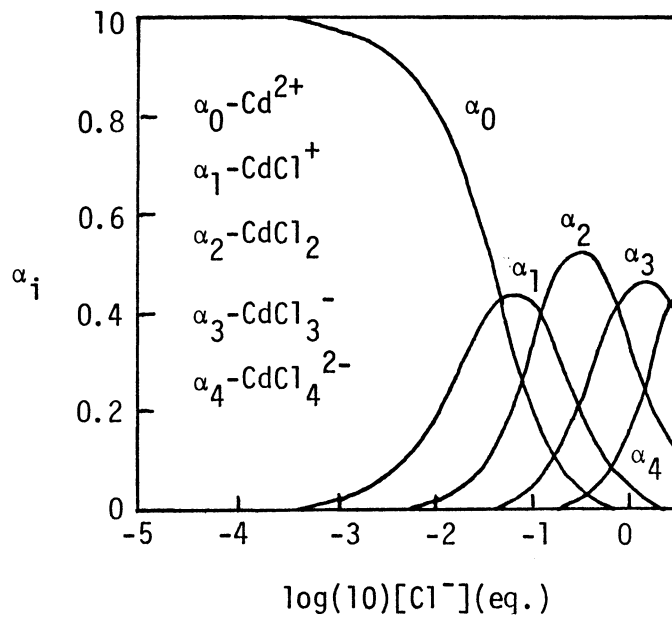


Figure 2. Distribution Diagram for Cadmium Chloride Complexes (20).

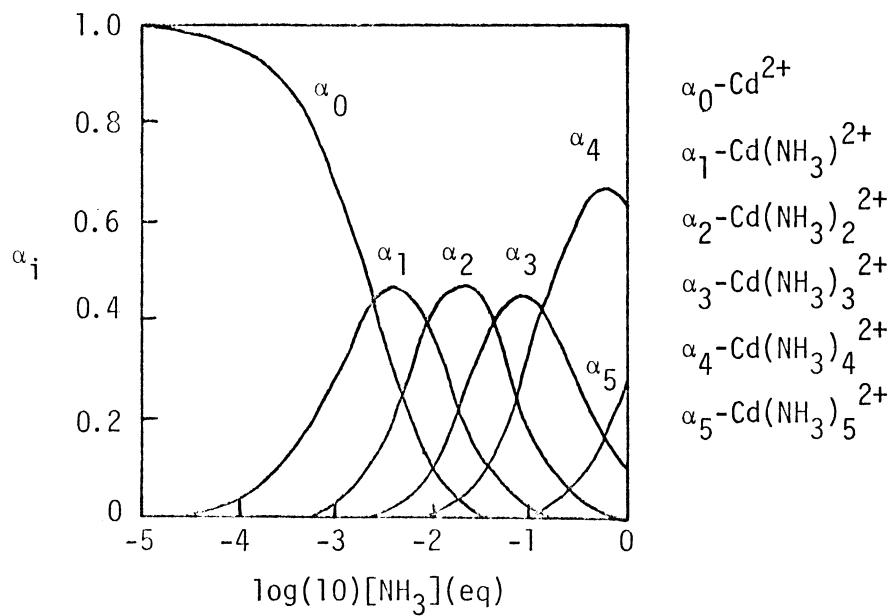


Figure 3. Distribution Diagram for Cadmium Amine Complexes (20).

$$K_{sp} = [\text{Cd}^{2+}] [\text{OH}^{-}]^2 = 2.2 \times 10^{-14} \quad [1]$$

$$K'_{sp} = [\text{Cd}^{2+}] [\text{CO}_3^{2-}] = 5.2 \times 10^{-12} \quad [2]$$

Solubility calculations based on these solubility products are valid only to about pH 8, beyond which the presence of hydroxy complexes becomes a factor. In a carbonate free system between pH 7-12, the mass balance for soluble cadmium in terms of formation constants is given by:

$$C = [\text{Cd}^{2+}] (1 + \beta_1[\text{OH}^{-}] + \beta_2[\text{OH}^{-}]^2 + \beta_3[\text{OH}^{-}]^3) \quad [3]$$

Substituting the solubility product, Equation [1], results in an expression for C which is independent of the cadmium concentration. This situation only holds true when the system remains saturated with solid cadmium hydroxide. Under this condition, C is equivalent to the solubility, S.

$$S = \frac{K_{sp}}{[\text{OH}^{-}]^2} (1 + \beta_1[\text{OH}^{-}] + \beta_2[\text{OH}^{-}]^2 + \beta_3[\text{OH}^{-}]^3) \quad [4]$$

In an aqueous system containing both hydroxide and carbonate, the controlling solubility product for the particular case will be determined by the ratio of the concentrations of the ions and their solubility products. Thermodynamically it is required that the relationship yielding the lower concentration of Cd^{2+} controls. Division of the two solubility products gives the ratio

$$R = \frac{[\text{OH}^{-}]^2}{[\text{CO}_3^{2-}]} = 0.00423 \quad [5]$$

If $R > 0.00423$ the hydroxide solubility product applies and if $R < 0.00423$, the carbonate solubility product is used to calculate the solubility. If R is equal to 0.00423 then either solubility product can be applied.

The "ion-ratio" method has also been employed as a rule for predicting the order of precipitation of solids in cases where two or more precipitation reactions are competing (22). Since this rule is based on the thermodynamic considerations in nonequilibrium conditions it could be overruled by kinetic factors. The equilibrium concentration of carbonate is obtained from the mass balance taken over all carbonic species

$$C_T = [\text{CO}_2] + [\text{HCO}_3^-] + [\text{CO}_3^{2-}] = [\text{CO}_3]_{\text{TOT}}, \quad [6]$$

and from the pertinent equilibria for carbonic acid and water at 25°C (20).

$$K_{a1} = \frac{[\text{H}^+][\text{HCO}_3^-]}{[\text{CO}_2]} = 4.4 \times 10^{-7} \quad [7]$$

$$K_{a2} = \frac{[\text{H}^+][\text{CO}_3^{2-}]}{[\text{HCO}_3^-]} = 5.6 \times 10^{-4} \quad [8]$$

$$K_w = [\text{H}^+][\text{OH}^-] = 1.0 \times 10^{-14} \quad [9]$$

Substituting into Equation [6], and rearrangement results in the desired term relating $[\text{CO}_3^{2-}]$, pH, and total analytic concentration of carbonic acid species:

$$[\text{CO}_3^{2-}] = \frac{C_T}{\frac{K_w^2}{[\text{OH}^-]^2 \cdot K_{a1} K_{a2}} + \frac{K_w}{K_{a2} [\text{OH}^-]} + 1} \quad [10]$$

If $R \leq 0.0043$ the concentration of soluble cadmium is calculated:

$$S = \frac{K_{sp}}{[\text{CO}_3^{2-}]} (1 + \beta_1 [\text{OH}^-] + \beta_2 [\text{OH}^-]^2 + \beta_3 [\text{OH}^-]^3) \quad [11]$$

in which $[\text{CO}_3^{2-}]$ is given by Equation [10].

In Figure 4 a plot of cadmium solubility versus pH for different total analytic concentrations of carbonic species is presented. Carbonate can be seen to have a great effect on the cadmium solubility, which suggests carbonate precipitation to remove cadmium could be a promising method.

In the range of chloride concentration $[\text{Cl}^-]_{eq} < 0.1 \text{ M}$ only CdCl^+ and $\text{CdCl}_2(\text{ag})$ need to be considered. In cadmium hydroxide saturated and carbonic species free systems the mass balance for soluble cadmium is:

$$S = \frac{K_{sp}}{[\text{OH}^-]^2} (1 + \beta_1 [\text{OH}^-] + \beta_2 [\text{OH}^-]^2 + \beta_3 [\text{OH}^-]^3) + \frac{K_{sp}}{[\text{OH}^-]^2} (21[\text{Cl}^-] + 166[\text{Cl}^-]^2) \quad [12]$$

The equilibrium concentration of chloride must be calculated from the mass balance for all chloride species:

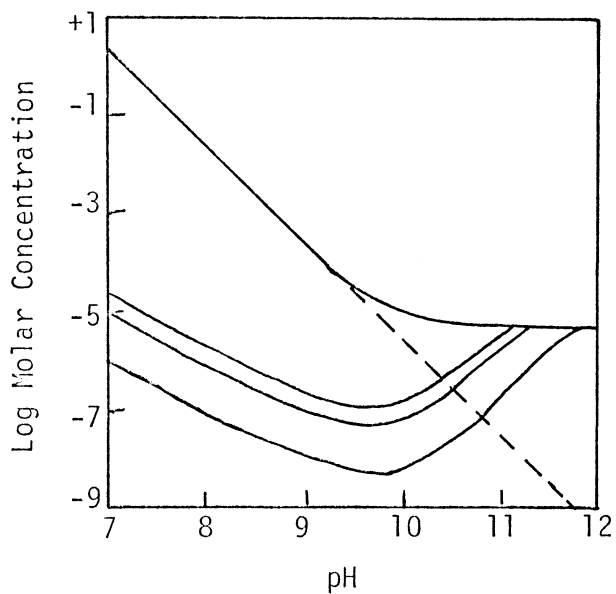


Figure 4. Solubility of cadmium as a function of pH at different concentrations of carbonic acid species. The dotted line represents the solubility corresponding to the solubility product of cadmium hydroxide. The solid lines from top to bottom correspond to $C_T = [\text{CO}_2] + [\text{H}_2\text{CO}_3] + [\text{HCO}_3^-] + [\text{CO}_3^{2-}] = 0,5 \times 10^{-4}, 10^{-3}, 10^{-2}, 10^{-2} \text{M (20)}$.

$$C_{Cl} = [Cl^-] + \frac{21K_{sp}[Cl^-]}{[OH^-]^2} + \frac{33K_{sp}[Cl^-]^2}{[OH^-]^2} \quad [13]$$

In systems that are governed by the presence of cadmium carbonate, Equations [12] and [13] become:

$$S = \frac{K_{sp}}{[CO_3^{2-}]} (1 + \beta_1[OH^-] + \beta_2[OH^-]^2 + \beta_3[OH^-]^3) + \frac{K_{sp}}{[CO_3^{2-}]} (21[Cl^-] + 166[Cl^-]^2) \quad [14]$$

$$C_{Cl} = [Cl^-] + \frac{21K_{sp}[Cl^-]}{[CO_3^{2-}]} + \frac{33K_{sp}[Cl^-]^2}{[CO_3^{2-}]} \quad [15]$$

Posselt and Weber (20) found at higher pH levels complexation by chloride can not compete with the hydroxide complexation and the influence of carbonate on solubility is independent of chloride concentration.

The mass balance equations for solubility in carbonate free solutions in the range pH 8-12 containing ammonia concentrations of 0 to 10^{-2} M are:

$$S = \frac{K_{sp}}{[OH^-]^2} [(1 + \beta_1[OH^-] + \beta_2[OH^-]^2) + (\beta'_1[NH_3] + \beta'_2[NH_3]^2 + \beta'_3[NH_3]^3)] \quad [16]$$

$$C_{\text{NH}_3} = [\text{NH}_3] \left(1 + \frac{K_b}{[\text{OH}^-]} + \frac{\beta'_1 K_{\text{sp}}}{[\text{OH}^-]^2} \right) + [\text{NH}_3]^2 \frac{2\beta'_2 K_{\text{sp}}}{[\text{OH}^-]^2} + [\text{NH}_3]^3 \frac{3\beta'_3 K_{\text{sp}}}{[\text{OH}^-]^2} \quad [17]$$

To calculate the solubility of a carbonate governed solution substitute $K_{\text{sp}}/[\text{CO}_3^{2-}]$ for $K_{\text{sp}}/[\text{OH}^-]^2$. Posselt and Weber determined that at lower pH levels ammonium ions formed while at $\text{pH} > 10.5$ the hydroxy complexes were a significant influence. Thus the effect of the total molar concentration of ammonia reached a maximum influence on cadmium solubility between $\text{pH} 8.5 - 10$.

Furthermore, Posselt and Weber believe, that complexation of cadmium by chloride and ammonia in natural fresh water is very insignificant due to the low occurrence of chloride and ammonia ions. But in a wastewater system the reactions may be of serious consequence in treatment of the wastewater.

The mathematical models presented were based on knowledge of relevant equilibria and their respective thermodynamic constants. Under the conditions assumed the models should accurately predict the solubility of cadmium at equilibrium in different cases. However there is some uncertainty to the actual performance of a system. In systems containing several ligands there exists the possibility of ligand-ligand interactions which complex the reactions. Phenomena such as phase transitions, aging, colloid formation, and differences in particle size have been found to obscure solubility measurements

subsequent to precipitation reactions (20). Another limiting factor in applications of thermodynamic solubility relationships is a slow attainment of equilibrium.

Posselt and Weber (20) researched the kinetics of cadmium precipitation in alkaline carbonate solutions as a function of pH, ionic strength, and concentration of cadmium, chloride, sulfate, and carbonate species. The initial rate of precipitation occurred rapidly with a second slow rate phase then occurring. Cadmium precipitation in a carbonate solution has several advantages over a noncarbonate system. The precipitation results in minimum solubility and occurs at faster overall rates. High carbonate to hydroxide ratios are optimum conditions for quantitative and rapid cadmium removal. These optimum conditions coincide with the pH range 9.3 - 10.0 which represents minimum cadmium solubility in carbonate governed systems. The initial precipitation rate decreased with increasing perchlorate ionic strength and sulfate concentration while the second rate was not affected. Chloride was found to exert no effect on the cadmium precipitation rates.

Gardiner (18) studied the complexation of cadmium with extracted humic acid and natural humic material in sewage effluent. The results show that equal concentrations of the two humic samples interacted with cadmium to similar extents and the humic complexes were substantially formed in 1 or 2 minutes. Since humic acid is a mixture and may have different complexing properties, the degree of complexation with a metal may not be anticipated.

Posselt and Weber (21) investigated cadmium corrosion and found several interesting results. In water of pH 8.3 - 10.55 the cadmium corrosion proceeded under cathodic control via reduction of oxygen. The reaction was limited by oxygen transfer to the corrosion sites over a range of experimental conditions.

Increased concentrations of hydroxide and carbonate species decreased the corrosion rate and precoating of the surface with carbonate or sodium metasilicate reduced the corrosion rate compared to surfaces that did not receive precoat treatment. A possibility of protective film formation would be responsible for the inhibition of the corrosion. Coupling of cadmium and different metals resulted in high corrosion of cadmium when coupled with copper which would be dynamically expected and a measurable rate in spite of cathodic protection by zinc.

Posselt and Weber suggest the following practices to minimize or prevent corrosion of cadmium contained in galvanized zinc:

- 1) Pretreatment of piping systems with solutions of carbonate or sodium metasilicate followed by low level feed of these compounds.
- 2) Manipulation and control of chemical factors (pH, alkalinity, hardness) so that the solubility of calcium carbonate is exceeded in order to facilitate interior coating of the pipes with calcium carbonate.
- 3) Elimination of coupling with more noble metals, e.g., copper, brass.

C. Effects of Cadmium in Wastewater Treatment

The importance of studying the toxic effects of cadmium on biological treatment is due to the strong possibility of cadmium presence in wastewater and because most treatment systems utilize some form of biological treatment.

Reid, et al., (23) studied the effects of heavy metals on a rotating drum apparatus with an attached sewage slime. At low concentrations of cadmium no adverse effects were noted, which was explained by the possible existence of some bacteria which are not susceptible to heavy metals.

Neufeld and Hermann (24) found it was possible to maintain a culture of organisms in an activated sludge unit at concentrations of cadmium greater than previously thought possible. Also determined in this study was that the affinity for cadmium by the sludge was not as great as mercury's affinity but greater than zinc's affinity for sludge. Neufeld and Hermann observed the initial inhibition of cadmium on activated sludge as a mechanism by which cadmium competes with the substrate until a saturation point is reached, at which time cadmium does not compete with the substrate but interferes in the metabolic chain.

Neufeld (25) investigated the metal induced deflocculation of activated sludge and observed severe deflocculation at cadmium concentrations of 20 mg/l or greater. Sludge deflocculation was defined as the formation of highly stable pinpoint floc, which can result in biomass loss over the weirs of a secondary clarifier and subsequent failure of the unit.

Utilizing a full scale treatment plant, Oliver and Cosgrove (26) studied the occurrence of heavy metals in a wastewater and the efficiency of activated sludge to remove the heavy metals. The occurrence of metals in the wastewater came in shock loads which would severely inhibit the plant operations resulting in inferior effluents of high turbidity. The activated sludge removed approximately 80 percent of the cadmium that entered the plant.

The performance of anaerobic digesters is also influenced by the presence of heavy metals. Mosey and Hughes (27) determined that anaerobic digestion started to fail at cadmium concentrations of 180 mg/l and could be reestablished with the removal of incoming cadmium. Mosey (28) observed that shock loads of cadmium had a rapid inhibitive reaction on anaerobic digesters which did not significantly increase with time. Thus the toxic effects of shock loads on digestion are more harmful than a gradual accumulation of cadmium to an equivalent concentration.

III. MATERIALS AND METHODS

With the legislative passages of more stringent effluent quality standards the detrimental effects and removal of toxic heavy metals present in industrial and municipal treatment plants needs to be investigated. The occurrence of heavy metals in wastewaters has become prevalent with the increased usages of heavy metals in industry.

This study focused primarily on the effects of shock and acclimated doses of cadmium on activated sludge with respect to substrate removal and solids production as a function of time. The chemical oxygen demand (COD), total suspended solids (TSS), and mixed liquor volatile suspended solids (MLVSS) were the parameters monitored in the study.

A. Laboratory Apparatus

This research was conducted by operating a large batch unit as a reserve and three smaller batch units for shock dosed and acclimated dosed tests. The test units were fed equal quantities of feed solution with varied cadmium dosages. A large glass container with a total volume of approximately 8 liters was used for the maintenance of 6 liters of mixed liquor as the reserve unit. Smaller glass containers with a total capacity of 4 liters were utilized for the test units.

Air was introduced into the units by aeration diffuser stones suspended in the units which also served to completely mix the solution and keep the mixed liquor solids in suspension. The air

passed through water traps to collect any contaminants and to provide moisture to counteract any possible evaporation out of the unit.

B. Feed Solution

The chemical composition of the wastewater used in this investigation is listed in Table IV. The feed solution contained an average chemical oxygen demand (COD) of approximately 650 milligrams per liter (mg/l), which gave an initial food to microorganism ratio (F/M) of approximately 0.80 days^{-1} for the control unit. Other required nutrients were provided as listed in Table IV.

A potassium phosphate buffer solution was used to control the pH of the units. The stock buffer solution had a pH of approximately 7.5 which maintained the pH in the reactors at 7.1 ± 0.5 .

A predetermined quantity, one fifth of the volume, of mixed liquor was wasted daily from the units, the one-fifth wasting was done to represent a 5 day mean cell residence time in the units. Appropriate quantities of nutrient and mineral solutions, and cadmium concentrations were then fed to the units with tap water being added to reach the initial volume.

One liter of the wasted mixed liquor from the reserve reactor was placed in the test unit and aerated preceding the test. After wasting one-fifth of the volume, the test reactor was fed including a known cadmium concentration to study the shock loading response. Several test reactors received daily dosages of a known cadmium

Table IV. Composition of Wastewater.

	Stock Concentration per liter (gram)***	Quantity Used per liter (ml)	Final Concentration per liter (mg/l)
Bacto-peptone (Nutrient Broth)	64.50	7.50	483.75
MgSO ₄ ·7H ₂ O	10.00	5.00	50.00
MnSO ₄ ·H ₂ O	1.00	5.00	5.00
FeCl ₃ ·6H ₂ O	0.05	5.00	0.25
CaCl ₂	0.75	5.00	3.75
KH ₂ PO ₄	52.75 **	15.00	791.25
K ₂ HPO ₄	107.00 **	15.00	1605.00
(NH ₄) ₂ SO ₄	100.00	2.50	250.00
CdCl ₂	20.30	*	*

*Dependent on experimental cadmium dose.

**Phosphate buffer solution.

***Stock concentrations made with distilled water.

concentration with the feed solution, to allow acclimation of the organisms to the cadmium concentration. After an acclimation period of 14 days the reactor was sampled for solids production and substrate utilization. The cadmium concentrations added to a test unit for shock loading data were : 10, 50, 100, 250, 500, 1000, 1250, and 1500 mg/l, respectively. The acclimated cadmium dosages were 50, 250, and 500 mg/l, respectively, and a control unit void of any cadmium admission was also tested.

C. Initial Start-Up

Activated sludge for seeding the reserve unit was obtained from the waste effluent of two operating continuous flow bench scale reactors in the laboratory. Batch type feeding was instigated immediately on a daily basis to the reserve unit. The reserve unit was acclimated to the wastewater to be used for 4 weeks to establish a solids concentration of approximately 810 mg/l and at this time experimentation began.

D. Analytical Techniques

Parameters for this investigation were monitored immediately after the introduction of cadmium in the feed of shock loaded units and after the feeding on the 14th day of the acclimation period for acclimated units. Samples of the mixed liquor were collected at 0, 1/2, 1, 2, 3, 4, 5, 6, 7 and 8 hours, respectively with 25.0 milliliters being filtered for solids determination and 20.0 milliliters of the filtrate being utilized in the COD determinations.

COD determinations were made in accordance with Standard Methods (29).

Determination of total suspended and volatile solids were performed in accordance with Standard Methods. A 5.5 cm Nalgene Buchner funnel and a 5.5 cm Reeve Angle 934AH glass fiber filter were used to perform all solids analyses. A Mettler Instrument Corporation Model H10 balance was used for all weight determinations.

A Fisher Accumet Model 230 pH/ion meter was used for pH determinations of the reactors. Accuracy of the readings was insured by intermittent standardization of the meter at a pH value of 7.0.

E. Methods of Data Analysis

Effects of the cadmium concentrations were determined by analysis of the growth-yield coefficients, substrate utilization efficiencies, and volatile solids to total solids ratio of the units. The data was presented in graphical form.

The growth-yield coefficient, Y , is defined as mass of micro-organisms per mass of substrate utilized, and can be calculated according to equation [18].

$$Y = \frac{\Delta MLVSS}{\Delta COD} \quad [18]$$

where:

Y = yield coefficient, mass/mass

$\Delta MLVSS$ = increase in MLVSS per time, mg/l/time, and

ΔCOD = decrease in COD per time, mg/l/time.

The Δ MLVSS and Δ COD were calculated from the 6 hour point after time zero since the substrate removal and solids produced leveled out at that time in most cases.

The substrate utilization efficiency was calculated with the expression,

$$E_s = \frac{100(S_0 - S_1)}{S_0} \quad [19]$$

where:

E_s = efficiency of substrate utilization, as a percentage

S_0 = initial substrate concentration, mg/l, and

S_1 = final substrate concentration, mg/l.

The volatile solids to total solids ratio was calculated with the expression,

$$VT_r = 100 \frac{(MLVSS)_f}{(TSS)_f} \quad [20]$$

where:

VT_r = volatile solids to total solids ratio, as a percentage,

$(MLVSS)_f$ = final MLVSS, mg/l, and

$(TSS)_f$ = final TSS, mg/l.

The final solids figures used were the 8 hour volatile and total solids calculations of the test units.

IV. RESULTS AND DISCUSSION

Batch fed activated sludge units were operated for approximately 8 weeks under closely controlled conditions. A mean cell residence time of 5 days was simulated by wasting one-fifth of the volume preceding each daily feeding, then refilling the unit to the desired volume with the feed solution and tap water. Samples of the mixed liquor from the test units were used for the COD, TSS, and MLVSS calculations from initial feeding to 8 hours after the feeding. Raw data for the 12 experimental units are recorded in tabular form in Appendix A. The remainder of this chapter will be a presentation and discussion of the results of this study.

A. Results

The solids production and substrate utilization for the experimental units subjected to cadmium concentrations of 0, 10, 50, 100, 250, 500, 1000, 1250, and 1500 mg/l, respectively, are graphically presented in Figure 5 through Figure 13. The yield coefficients, COD removal efficiencies, and volatile solids to total solids ratios of the different experimental units are listed in Table V. The yield coefficients, COD removal efficiencies, and volatile solids to total solids ratios versus cadmium concentrations are depicted graphically in Figures 14, 15, and 16. The Δ MLVSS and Δ COD utilized in calculating the yield coefficients, were determined by calculating the difference between the 6 hour data point and the initial data point from the graphs.

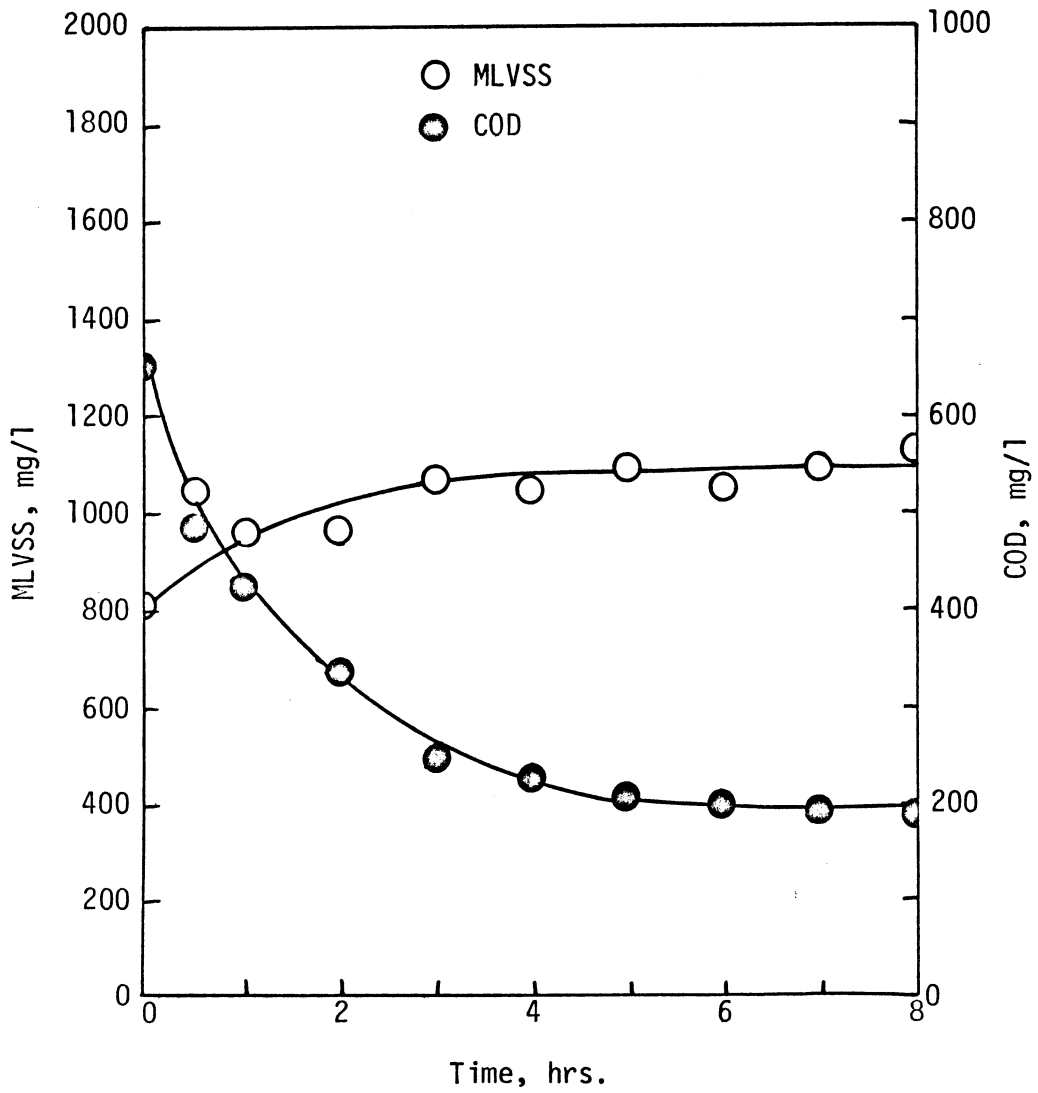


Figure 5. Microbial Growth and Substrate Utilization in Batch Control Unit

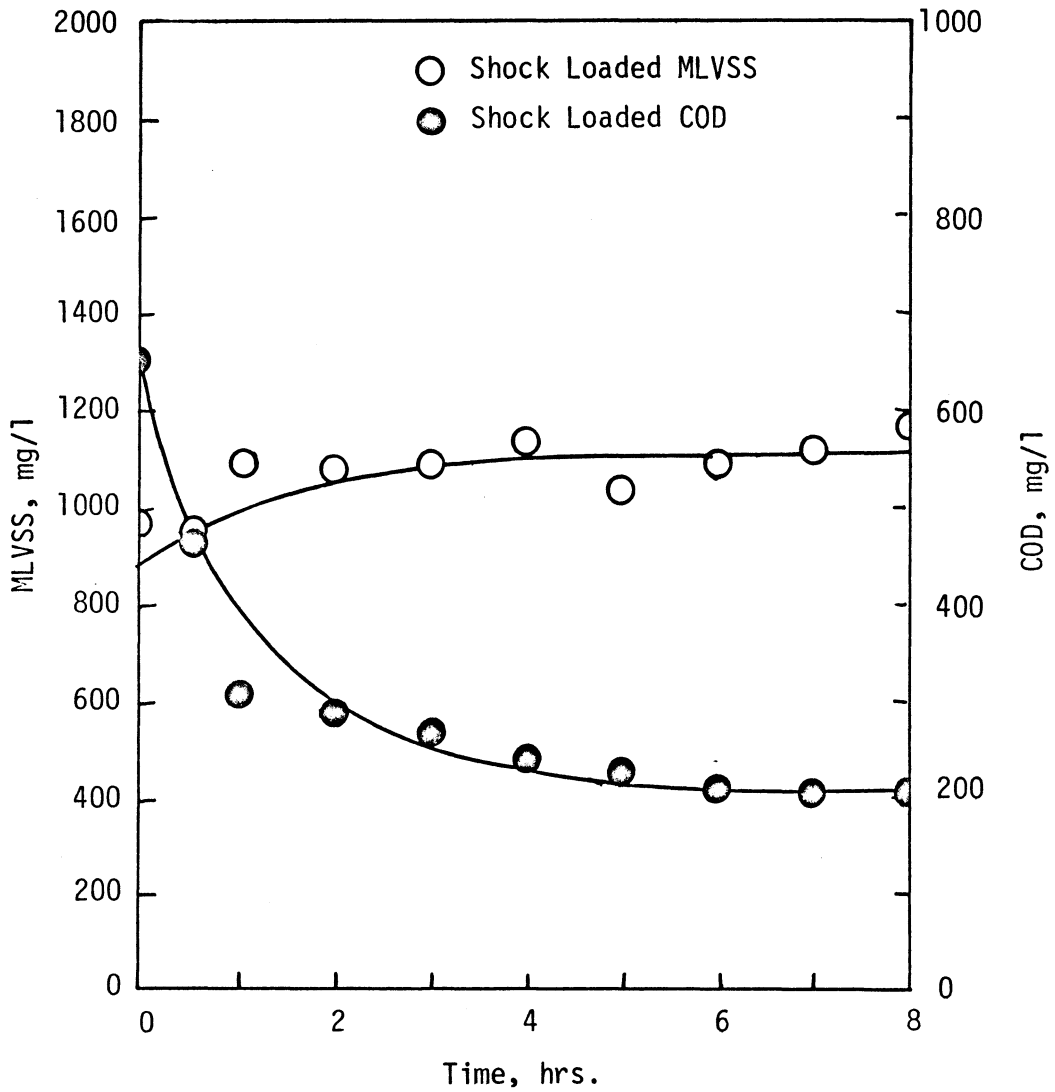


Figure 6. Effect of 10 mg/l of Cadmium on Microbial Growth and Substrate Utilization in Shock Loaded Batch Units.

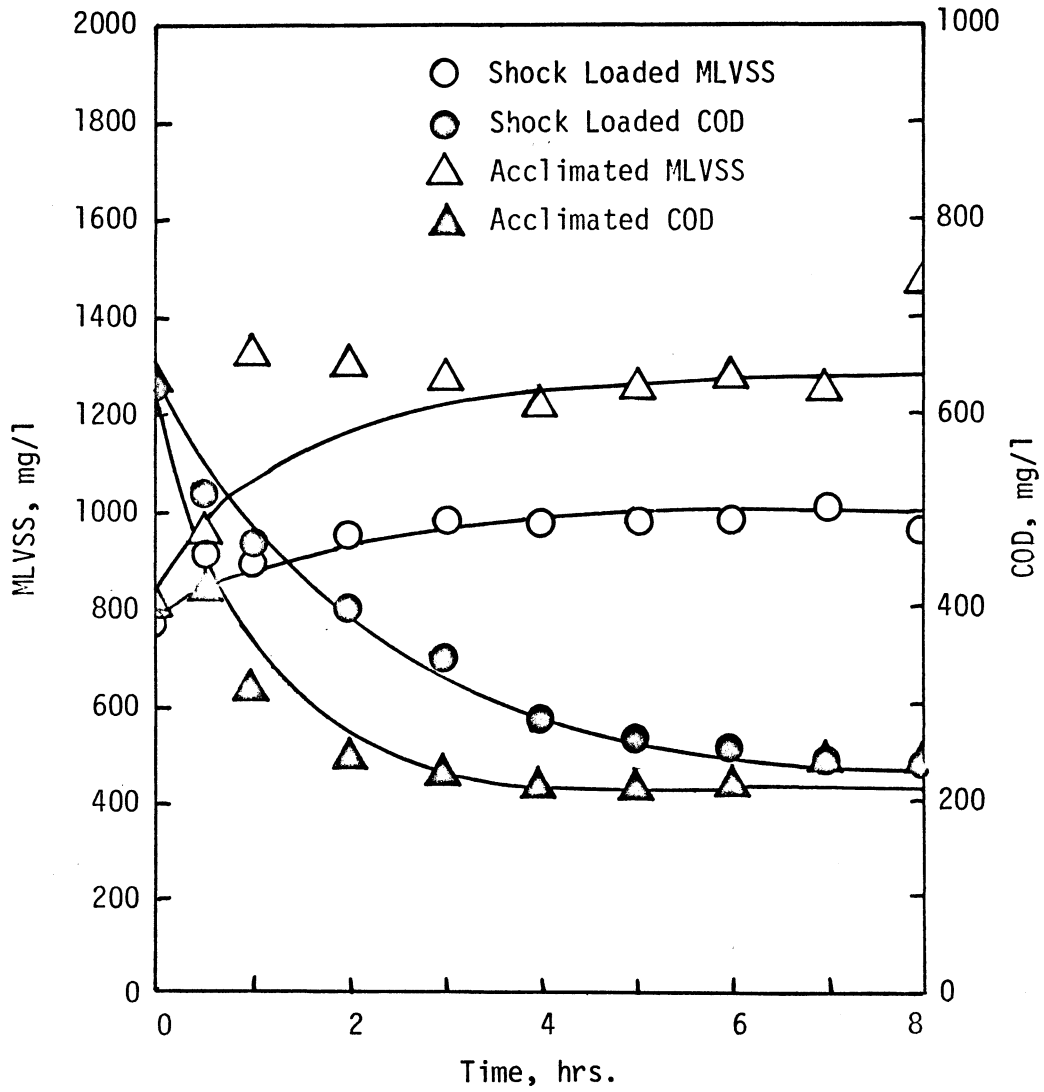


Figure 7. Effect of 50 mg/l of Cadmium on Microbial Growth and Substrate Utilization in Acclimated and Shock Loaded Batch Units.

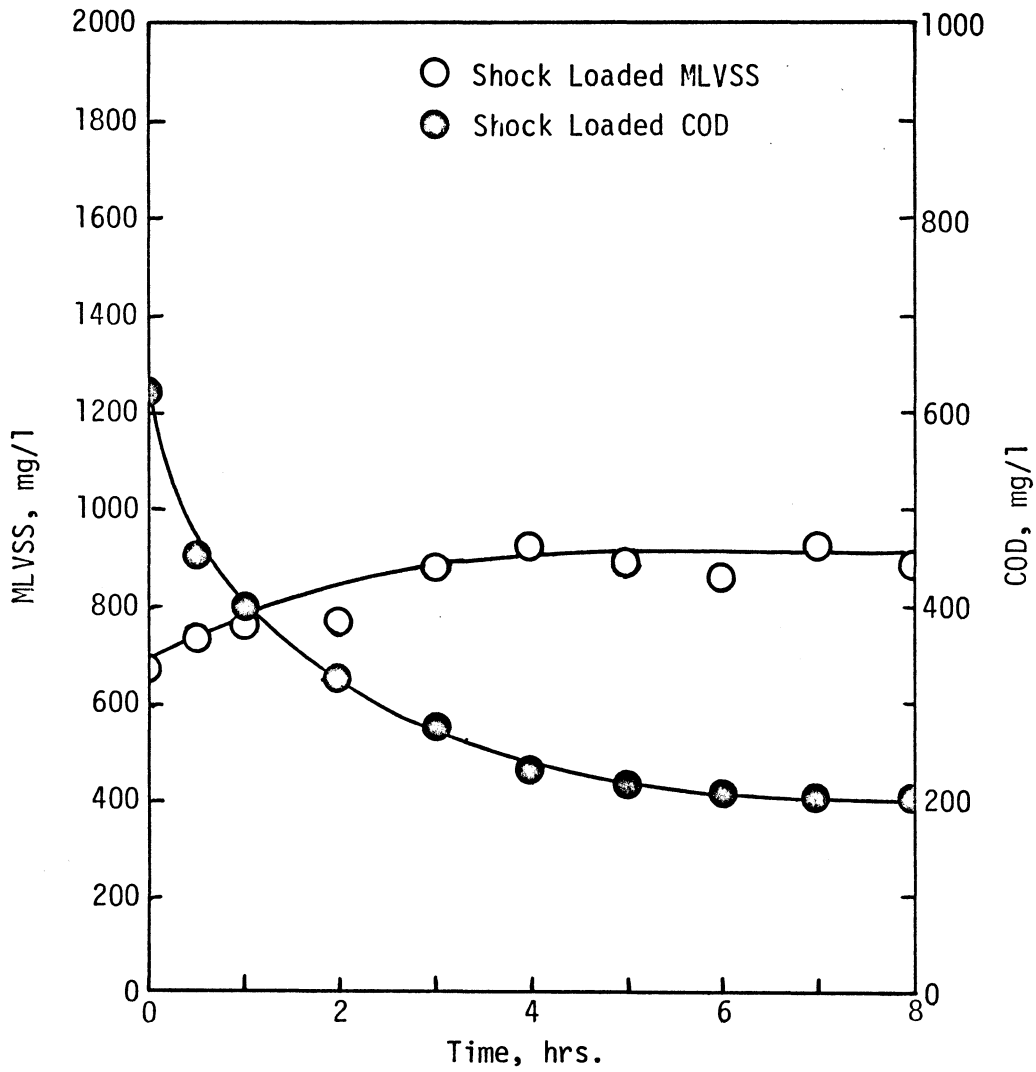


Figure 8. Effect of 100 mg/l of Cadmium on Microbial Growth and Substrate Utilization in Shock Loaded Batch Units.

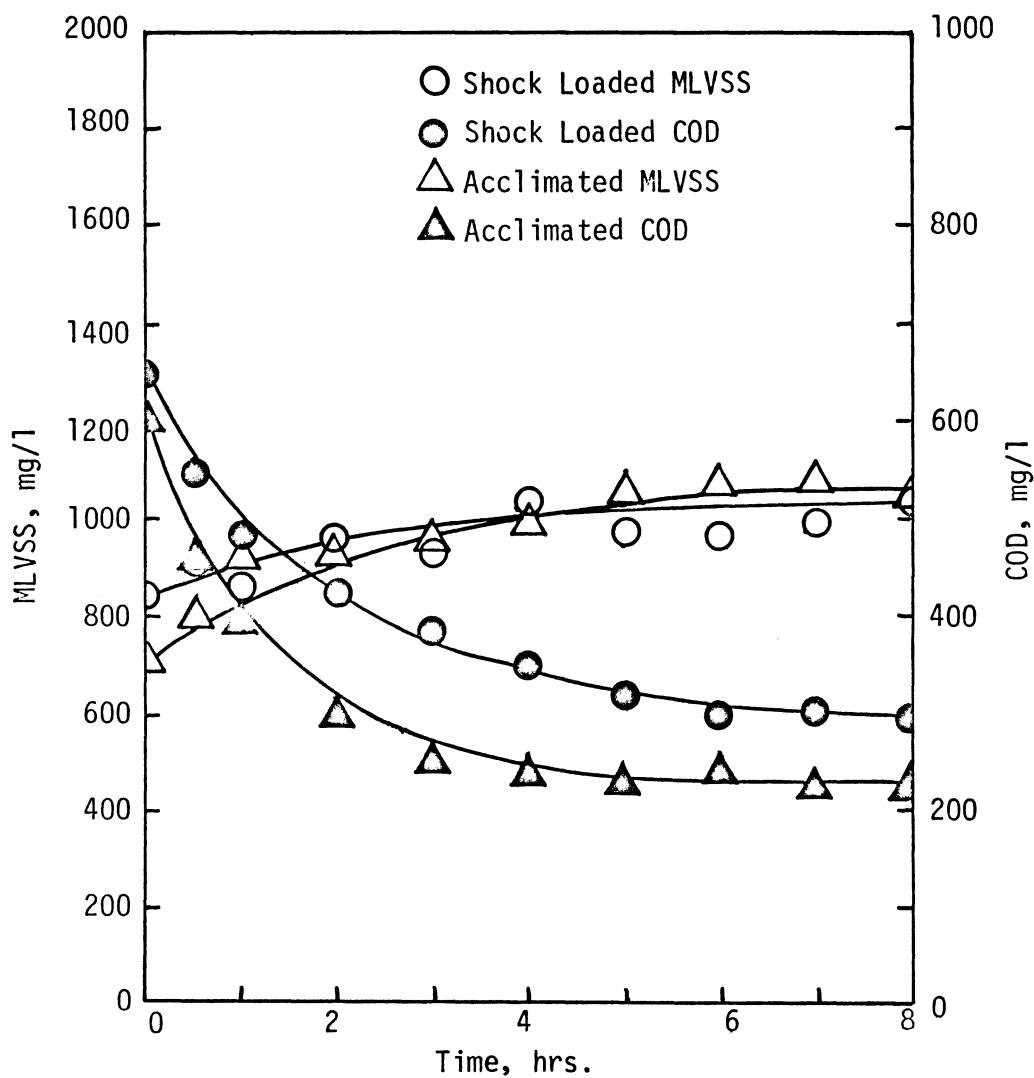


Figure 9. Effect of 250 mg/l of Cadmium on Microbial Growth and Substrate Utilization in Acclimated and Shock Loaded Batch Units.

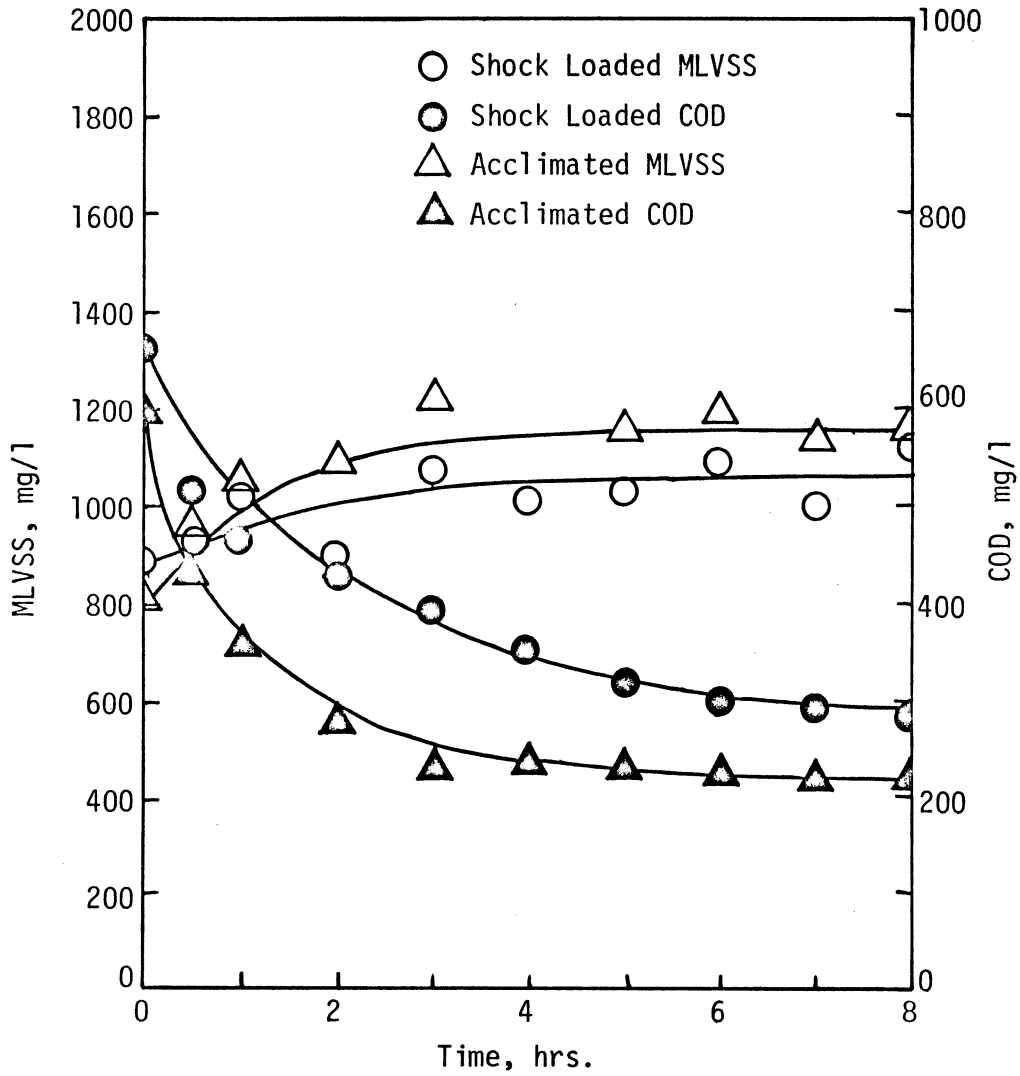


Figure 10. Effect of 500 mg/l of Cadmium on Microbial Growth and Substrate Utilization in Acclimated and Shock Loaded Batch Units.

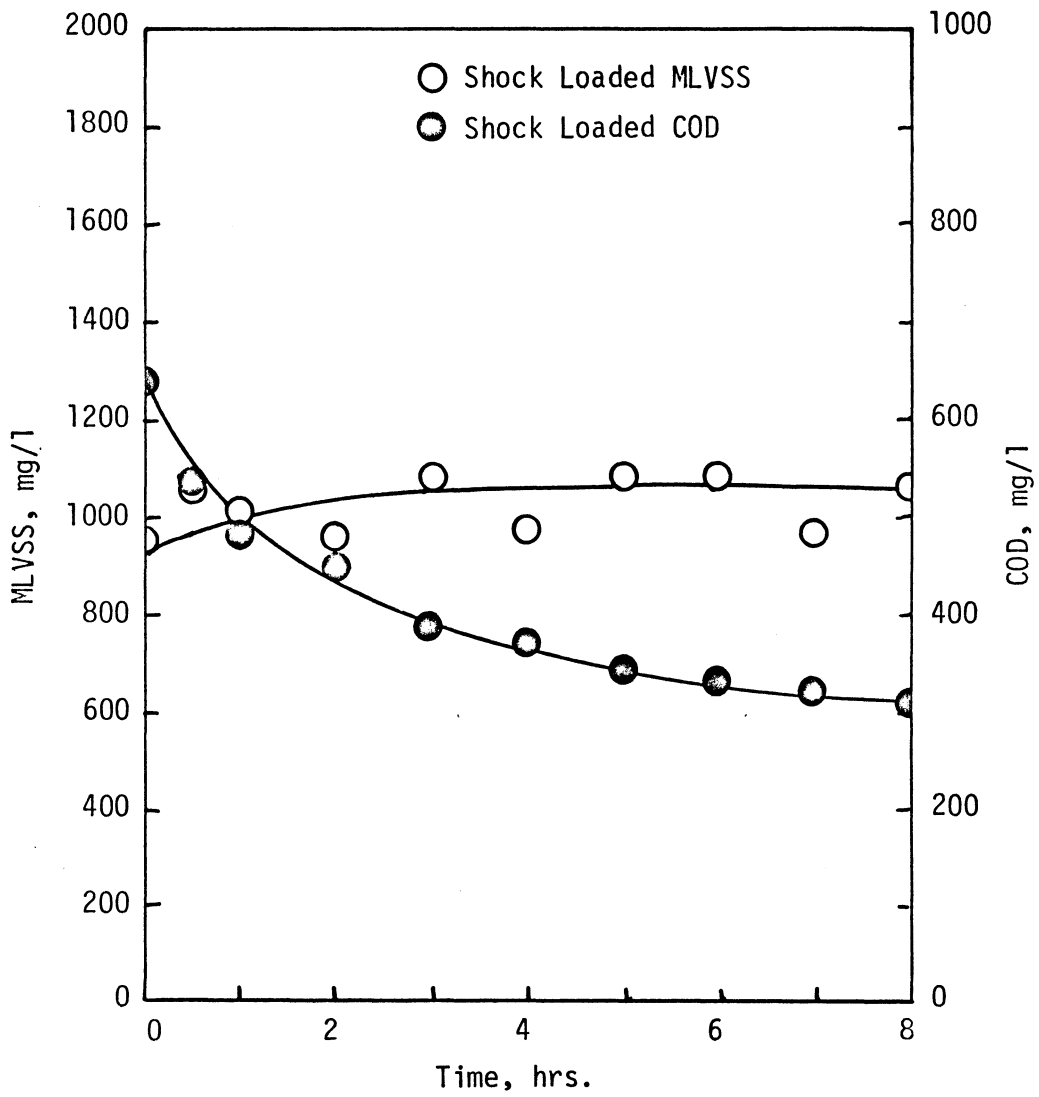


Figure 11. Effect of 1000 mg/l of Cadmium on Microbial Growth and Substrate Utilization in Shock Loaded Batch Units.

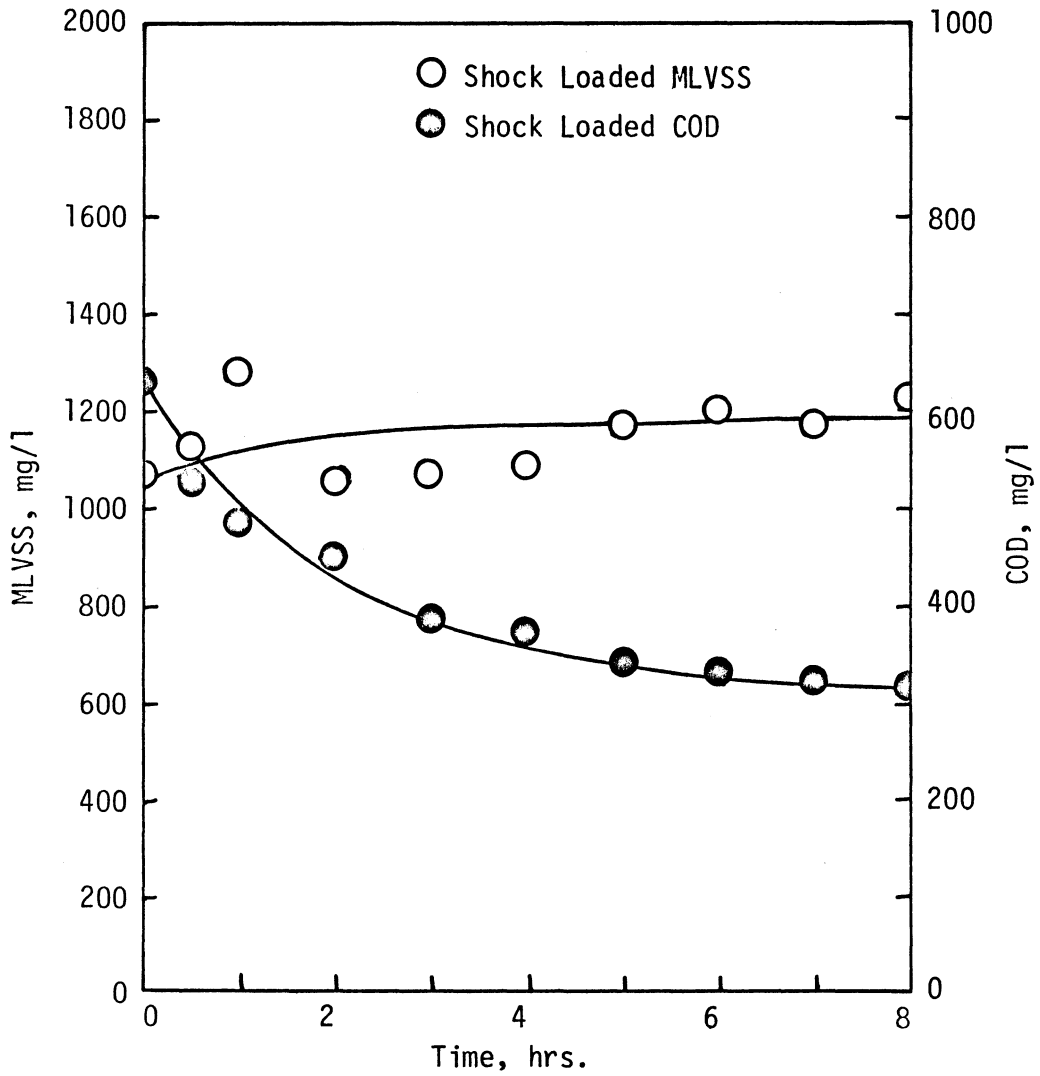


Figure 12: Effect of 1250 mg/l of Cadmium on Microbial Growth and Substrate Utilization in Shock Loaded Batch Units.

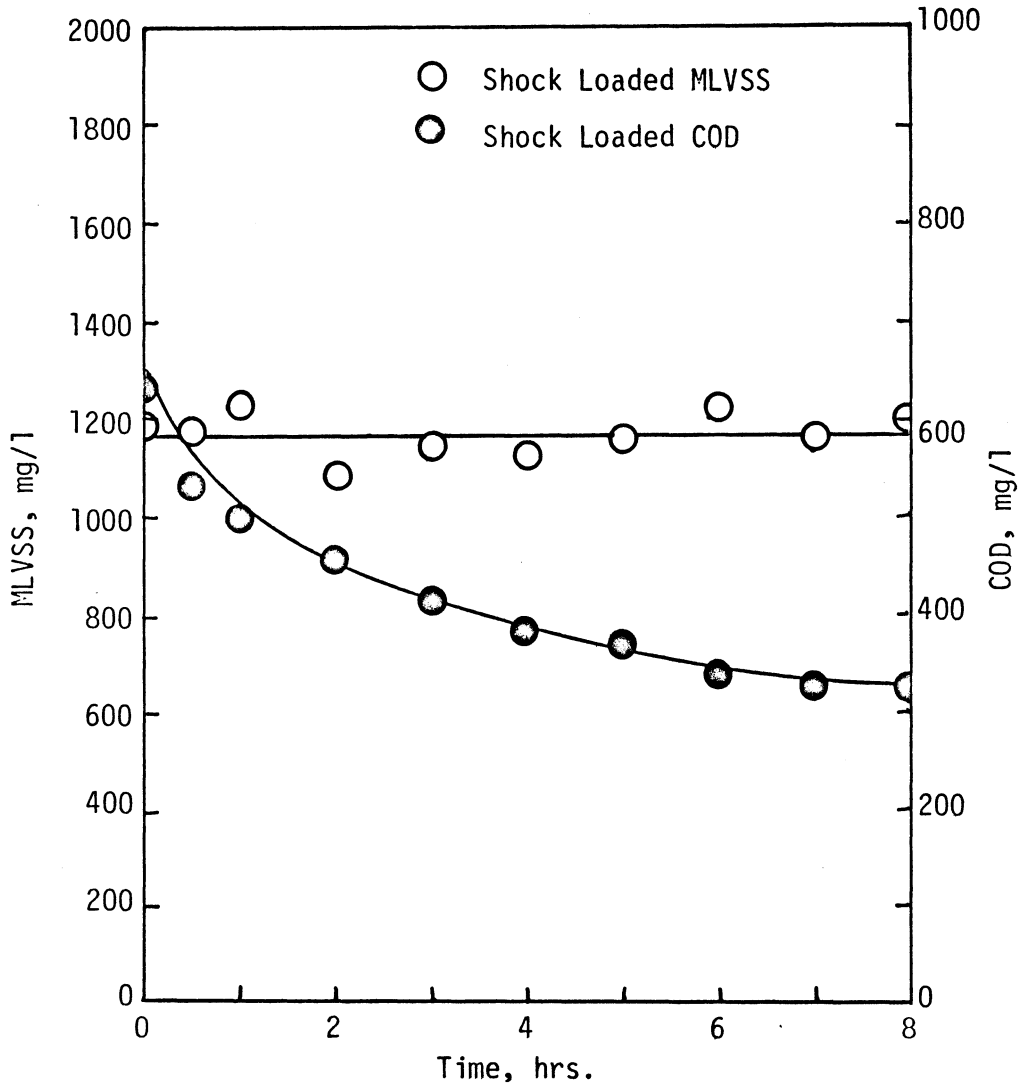


Figure 13. Effect of 1500 mg/l of Cadmium on Microbial Growth and Substrate Utilization in Shock Loaded Batch Units.

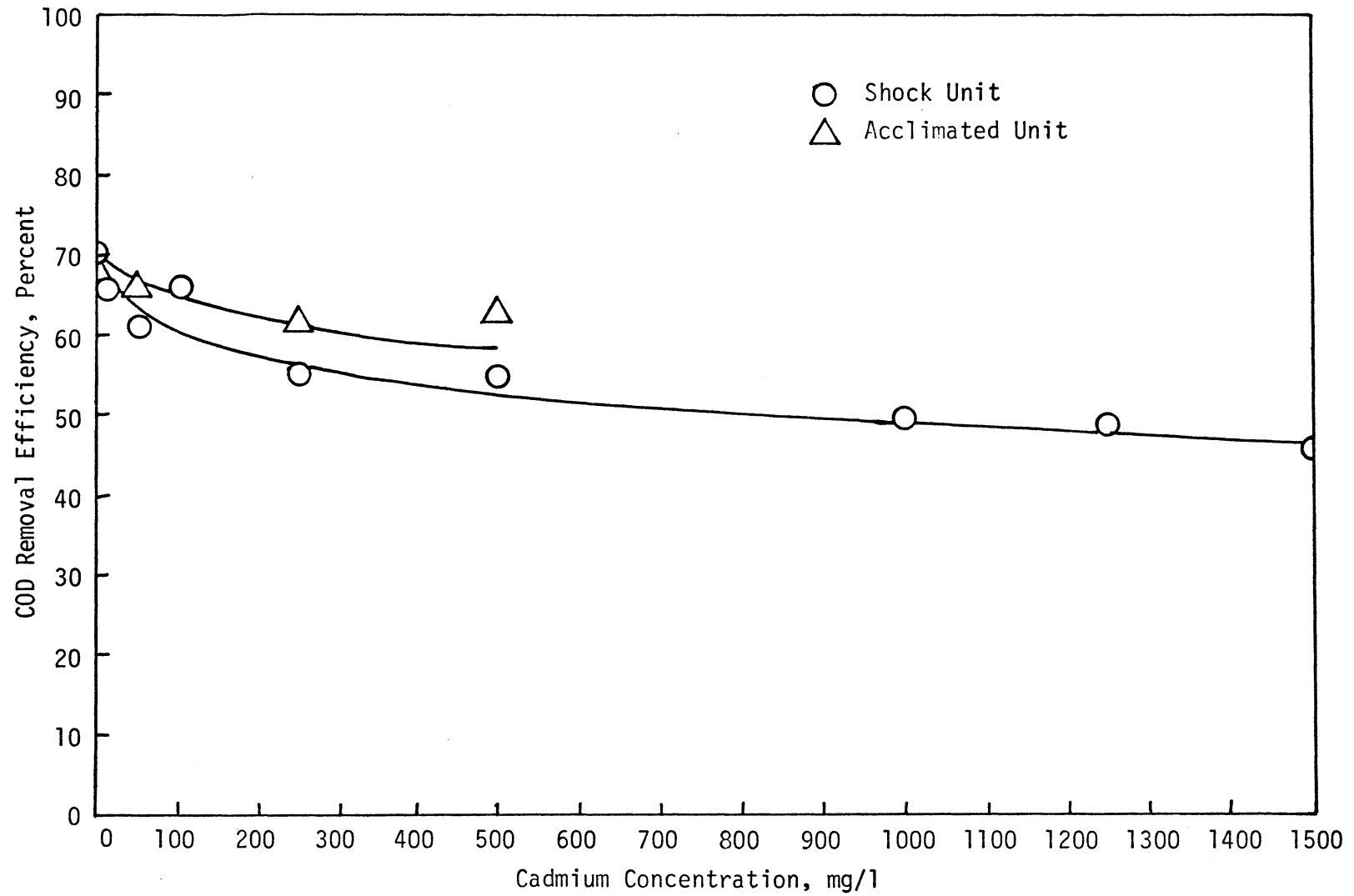


Figure 14. COD Removal Efficiency versus Cadmium Concentration.

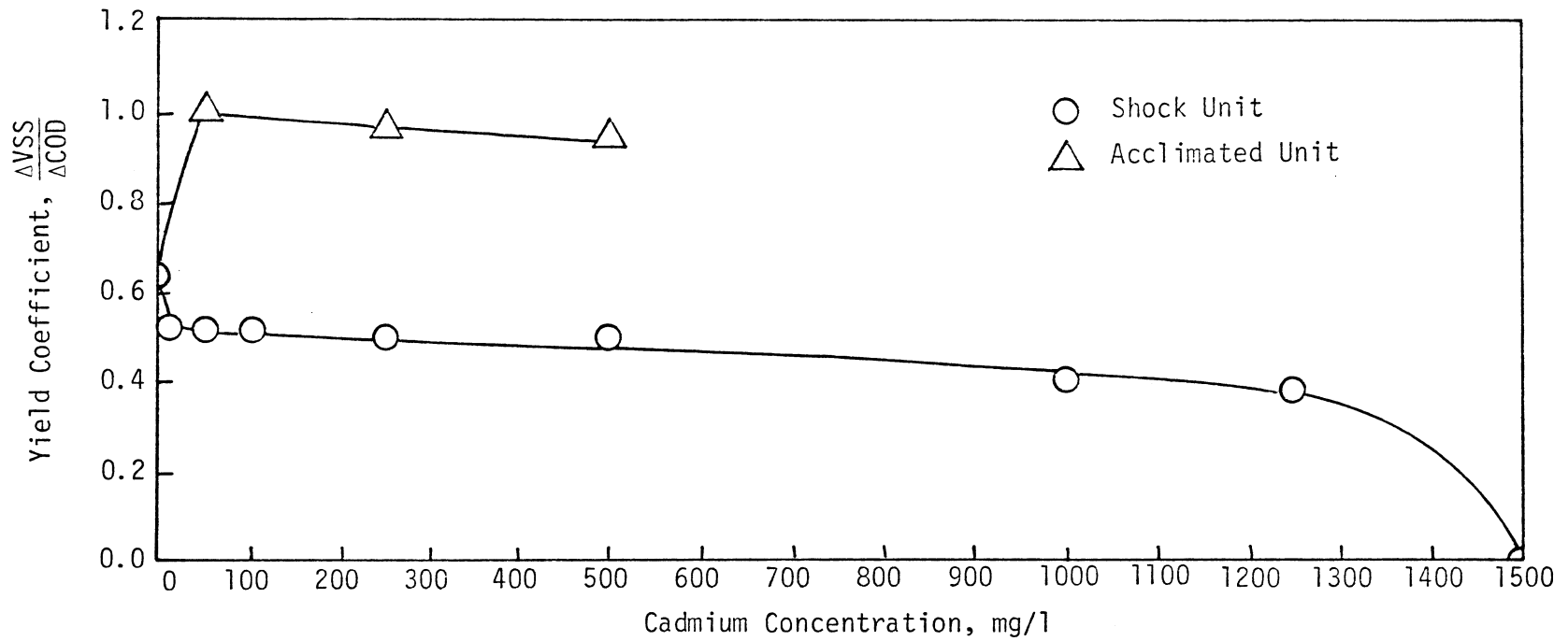


Figure 15. Yield Coefficient versus Cadmium Concentration.

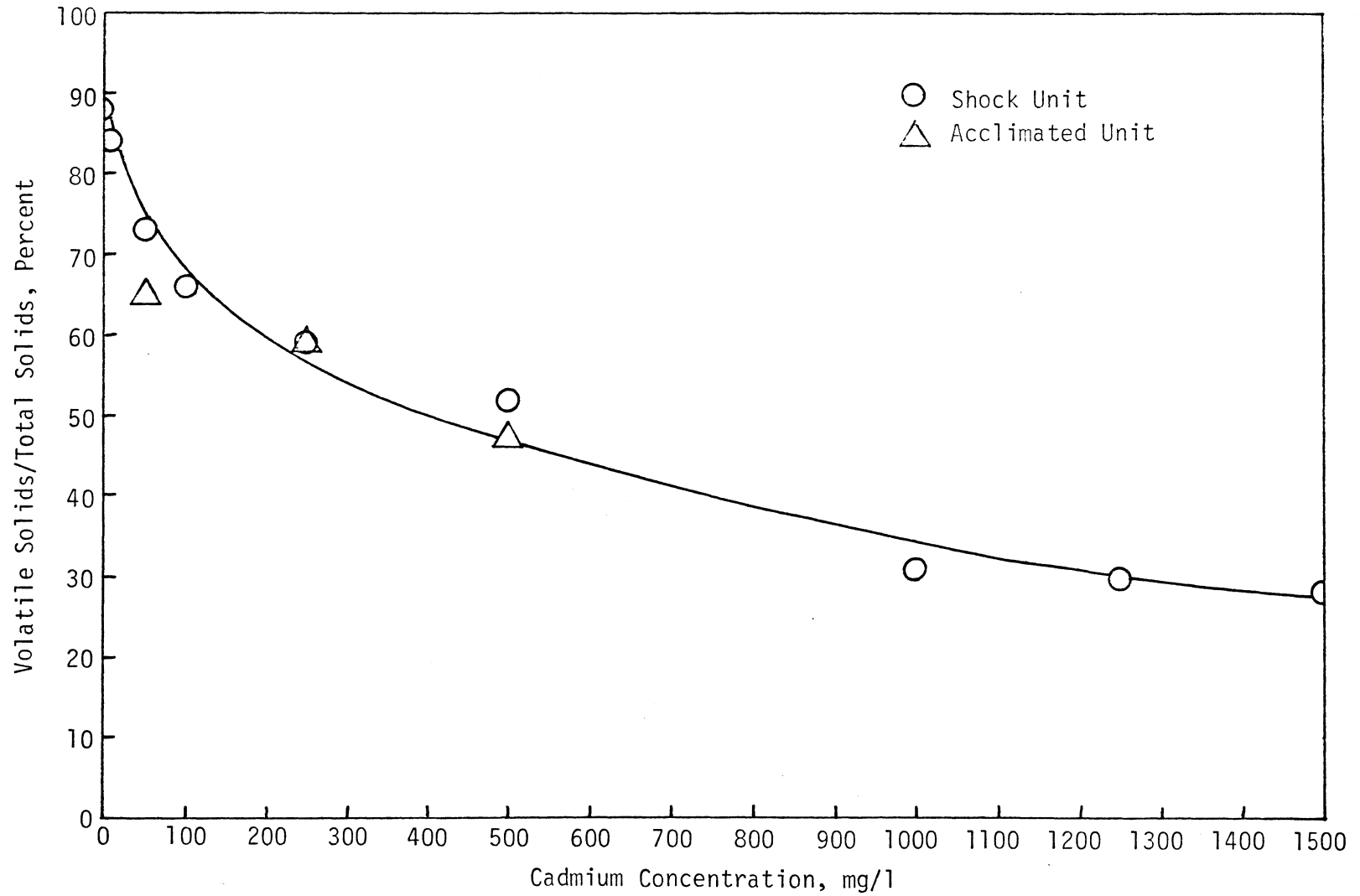


Figure 16. Volatile Solids to Total Solids Ratio versus Cadmium Concentration.

Table V. Effects of Different Cadmium Concentrations on Volatile Solids Production and COD Removal

Cd Concentration mg/l	Δ MLVSS mg/l	Δ COD mg/l	Yield Δ VSS/ Δ COD	COD Removal Efficiency (%)	$\frac{\text{Final VSS}}{\text{Final TSS}}$ (%)
<u>Shock Loaded</u>					
0	290	455	.637	70.0	88
10	225	430	.523	66.2	84
50	200	385	.520	61.1	73
100	210	410	.512	66.1	66
250	180	360	.500	55.4	59
500	180	360	.500	54.5	52
1000	130	320	.406	50.0	31
1250	120	310	.387	49.2	30
1500	0	290	.000	46.0	28
<u>Acclimated</u>					
50	425	425	1.000	66.4	65
250	360	370	.973	61.2	59
500	360	380	.947	63.3	47

B. Discussion

By inspecting the solids production and substrate utilization results of the experimental batch feed units, the toxic effects of cadmium concentrations on acclimated and shock loaded units are evident. The differences of the shock loaded units and acclimated units, and the general trends of the toxic effects are discussed in this section.

1. 10 mg/l of cadmium - by examining the results of the shock loaded unit and the control unit several interesting factors are evident. The difference of the yield coefficients, 0.637 for the control unit and 0.523 for the 10 mg/l of cadmium shock loaded unit can be attributed to the effect of the cadmium on the microorganisms. Upon introduction of cadmium as a shock load into the unit the organisms that were very susceptible to the cadmium caused stress may have been immediately affected. Thus the stressed organisms may not have functioned properly, resulting in decreased sludge production, hence a decreased Δ MLVSS in the shock loaded unit. This decreased Δ MLVSS of the shock loaded unit resulted in a lesser yield coefficient than in the control unit.

While the shock load of 10 mg/l of cadmium had a marked effect on the solids production, the COD removal efficiency of the unit was only reduced by approximately 4 percent from the COD removal efficiency of the control unit. Thus it can be concluded that a shock load of 10 mg/l or less of cadmium does not greatly affect the substrate removal efficiency.

entering the setting, the crawler would begin at the front, left corner and shear trees as it proceeded to the front, right corner, dropping trees to the right side of the machine in the process. Once at the right side of the setting, the operator would then back up in his previous tracks until he had passed several trees, at which time he would go forward, shear them, and back up again. Thus, by traveling in a reverse gear and shearing in a forward gear, the operator would work his way to the left side of the setting again, having cut two strips of trees (one going across, one coming back) without having to turn around and drop trees into the standing timber. After cutting out a deck area, the operator would then proceed around the setting in a counter-clockwise fashion, felling trees to the 'outside'. The minimum diameter cut with the crawler shears was about 15 cm (6 in). Stems smaller than this would be lost in the brush or too expensive to handle on an individual basis with the grapple skidder used for bunching. These smaller stems usually presented no major problem to run over with the crawler, a practice followed to avoid hampering the skidding operation.

Stems too large to be cut with shears are felled by hand, following the major portion of the skidding operation. When the skidding is almost complete, the sawyer will begin cutting on one side of the setting while the skidders work the other side, maintaining at least two tree lengths

the cadmium concentration are eliminated, leaving the predominate cadmium resistant microorganisms which achieve greater solids production per substrate utilized, thus resulting in a greater yield coefficient.

A comparison of the COD removal efficiencies of the acclimated unit and shock loaded unit show an interesting fact. While the removal efficiency of the 50 mg/l of cadmium shock loaded unit decreased from the efficiency of the 10 mg/l of cadmium shock loaded unit, the removal efficiency of the 50 mg/l of cadmium acclimated unit equaled the COD removal efficiency of the 10 mg/l of cadmium shock loaded unit. Therefore, the conclusion that an acclimated unit receiving 50 mg/l of cadmium will perform comparable to a 10 mg/l of cadmium shock loaded unit may be drawn. In Figure 7 the acclimated unit's ability to remove the substrate faster than the shock loaded unit may be noted. This fact may be attributed to the presence of cadmium tolerant organisms in the acclimated unit, so that all the organisms present in the unit immediately begin removing the substrate. Whereas in the shock loaded unit organisms totally or partially susceptible to cadmium were being affected by the cadmium, thus decreasing the utilization of substrate, resulting in a slower substrate removal rate.

Despite the increased volatile solids production of the acclimated unit, the volatile solids to total solids ratios of the acclimated and shock loaded units are approximately equal, Figure 16. A possible reason for the resulting ratio in the acclimated unit

may be the daily addition of cadmium, an inorganic solid that increases the total solids in the unit.

3. 100 mg/l of cadmium - Several factors are observed after studying the results of the shock loaded unit subjected to 100 mg/l of cadmium.

The yield coefficient of the unit is less than the yield coefficient of the 50 mg/l of cadmium shock loaded unit. This decrease is in accord with the trend of decreasing yield coefficients as shock loaded cadmium concentrations increase, (Figure 15). This decreasing trend of yield coefficients may be attributed to the reduction of solids production per substrate utilized in the test units. As the shock load cadmium concentration increases the number of organisms completely inhibited increases which will reduce the resulting solids production. The organisms that are partially inhibited by the cadmium may utilize more of the substrate for maintenance purposes preceding solids production per substrate utilized.

The general trend of decreasing volatile solids per total solids ratios as shock loaded cadmium concentrations increases continues in the 100 mg/l of cadmium unit. As the shock dosages increase, the volatile solids decrease due to the cadmium caused inhibition, and the total solids increase due to the addition of cadmium, an inorganic solid, resulting in an overall decrease of the ratio.

4. 250 mg/l and 500 mg/l of cadmium - Cadmium concentrations of 250 mg/l and 500 mg/l were tested in both acclimated and shock loaded units.

Comparing the yield coefficients of 250 mg/l and 500 mg/l of cadmium acclimated and shock loaded units several previously recognized trends are observed. As shown in Figure 15, the acclimated units have greater yield coefficients than the shock loaded units at 250 mg/l and 500 mg/l of cadmium. Another trend noticed in both types of test units was the decreasing of the yield coefficients as the cadmium concentration increases.

The greater yield coefficients of the acclimated units compared to the shock loaded units may be attributed to the predominance of cadmium resistant organisms as explained in the discussion of the 50 mg/l of cadmium results. The decreasing yield coefficients of the increasing cadmium acclimated units may be attributed to the reduction of solids production per substrate utilized in the acclimated units. This reduction of solids production may be due to the increasing number of organisms inhibited by cadmium in the units as the cadmium concentration increases. Another possible cause of lower solids production is due to the noticeable precipitation of cadmium. The precipitate may adsorb to the biological floc which can inhibit the organisms.

The yield coefficients of the 250 mg/l and 500 mg/l of cadmium shock loaded units followed the previously observed trend mentioned in the discussion of the 100 mg/l of cadmium results. The decrease in the yield coefficients of the 250 mg/l and 500 mg/l of cadmium

shock loaded units can be attributed to the reduction of solids production as previously examined.

COD removal efficiencies of the acclimated units for 250 mg/l and 500 mg/l of cadmium were greater than the COD removal efficiencies of the shock loaded units, as shown in Figure 14. In acclimated units the organisms present are the predominate cadmium tolerant organisms which can utilize the substrate at that cadmium concentration. In the shock loaded units the toxic effects of the cadmium upon the susceptible organisms results in the inhibition of the unit's ability to utilize the substrate, thus lesser COD removal efficiencies.

The ability of the acclimated units to utilize the substrate at a faster rate than the corresponding shock loaded units can be seen in Figures 9 and 10. As explained in the discussion of the 50 mg/l of cadmium results, the presence of cadmium resistant organisms in the acclimated units may be responsible for the faster substrate utilization.

In Figure 16 the volatile solids per total solids ratios for the acclimated and shock loaded units can be seen to be approximately equivalent. The low ratios of the acclimated units may be caused by the increasing total solids due to daily addition of cadmium, an inorganic solid.

5. 1000 mg/l and 1250 mg/l of cadmium - In the shock loaded units subjected to 1000 mg/l and 1250 mg/l of cadmium all the previously observed and discussed trends continued. The yield

coefficients, COD removal efficiencies, and volatile solids per total solids ratios all decreased as the cadmium concentration increased, (Figures 14, 15, and 16).

6. 1500 mg/l of cadmium - While the COD removal efficiency and volatile solids per total solids ratio of the 1500 mg/l of cadmium shock loaded unit followed the previously observed trends, (Figures 14 and 16), the yield coefficient results was unexpected. As seen in Figure 13, the shock loaded unit did not produce any noticeable solids, hence a yield coefficient of 0.00 resulted. The complete lack of solids production may signify that at a cadmium concentration of 1500 mg/l all the substrate was utilized for the maintenance of the organisms and none for growth.

V. ENGINEERING APPLICATIONS

Presence of heavy metals in a biological treatment system becomes an important consideration in the performance of the system as observed in this investigation of the effects of cadmium on biological treatment. While several studies (5, 6, 7, 8, 26, 31, 32) have shown the existence of heavy metal removal in biological treatment, the overall operating efficiency of the treatment system has to be considered, especially to meet the increasingly strict effluent quality standards.

Reduction or removal of the heavy metal from the waste stream preceding a biological treatment system may be accomplished by several techniques. Dilution of the waste below the "toxic threshold" of the pollutant, chemical precipitation, electrodeposition, cementation, evaporation, solvent extraction, reverse osmosis, ion exchange, and activated carbon adsorption are methods that are utilized. Since each metal behaves differently a thorough study of the metal's chemistry must be performed for each waste treatment problem.

Chemical precipitation is the most employed treatment method. Almost complete precipitation as the metal hydroxides can be achieved using lime, soda ash or sodium sulfide for cadmium additions. Pretreatment prior to precipitation may be employed to remove or separate any complexing agents. Also flow separation may enhance the overall treatment by allowing individual metal waste streams to receive the best treatment for the individual metal waste. Posselt

and Weber (33) examining the sorptive uptake of cadmium on the hydrous oxides of Al^{3+} , Fe^{3+} , and Mn^{4+} concluded that the use of Mn^{4+} and Fe^{3+} hydrous oxides was a feasible approach to remove cadmium.

Cementation, which consists of contacting a metal bearing solution with the correct metal powder or scrap, usually iron, will precipitate certain selected metals as metallic "sponge". This method is particularly useful where metal recovery is desirable.

Another method employed to recover the metal waste is solvent extraction involving extracting a particular metal from solution by contacting the solution with an organic reagent. Evaporation which is a distillation process and electrodeposition which uses insoluble anodes, are also used for metal recovery.

Ion exchange results in a concentrated regenerant brine from the exchange resin which must be treated. Wastewaters are passed through the ion exchange resulting in cleansed water which permits the water to be reused thus saving on water consumption.

Reverse osmosis utilizes a semipermeable membrane to separate the solution into a concentrated and a dilute solution. The dissolution and fouling of the membrane are problems that can occur in a reverse osmosis unit.

Activated carbon has been very effective in achieving removals of trace metals. Using an activated carbon unit following other types of physical-chemical treatment processes would effectively remove the heavy metal prior to discharge (31).

Knowledge of how a heavy metal may effect a biological treatment system is helpful since most wastewater treatment plants utilize biological treatment processes and the increasing presence of heavy metal discharges. From the analysis of this investigation a conclusion may be drawn as to the operation of a treatment plant receiving cadmium concentrations in the wastewater. A treatment plant having a F/M ratio of 0.73 - 0.80 days⁻¹ will operate sufficiently when subjected to a shock load of 10 mg/l of cadmium or an acclimated unit continuously receiving 50 mg/l of cadmium. Further studies of biological treatment systems contaminated with heavy metals should examine methods to improve metal removals and improve efficiencies of the biological system.

VI. CONCLUSIONS

The existence of cadmium in a biological treatment unit has a definite detrimental effect upon the microorganisms. This observation was established by the operation of batch fed shock loaded and acclimated biological units subjected to various cadmium concentrations. From an analysis of the data the following conclusions were made:

1. At cadmium concentrations of 10 mg/l in a shock loaded unit and 50 mg/l in an acclimated unit the COD removal efficiencies were only reduced by approximately 4 percent from the COD removal efficiency of the control unit.

2. Acclimated units subjected to small concentrations of cadmium may result in a maximum yield coefficient. This stimulatory response may be attributed to the predominance of cadmium resistant organisms.

3. A shock loaded unit subjected to a cadmium concentration of 1500 mg/l will possibly utilize all the substrate for maintenance of the organisms and none of the substrate for growth. Hence greater cadmium concentrations may result in solids destruction.

4. Yield coefficients in both acclimated and shock loaded units decrease as the cadmium concentrations increase, due to the increasing inhibition of solids production.

5. The toxic effects of cadmium are more detrimental upon shock loaded units than acclimated units at a given cadmium concentration.

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APPENDIX A

Raw Data for the Twelve Batch Fed Units

Table A-I

Cadmium = 0 mg/l (control unit)

Hour	TSS mg/l	MLVSS mg/l	COD mg/l
0	872	808	650
1/2	1132	1052	484
1	1056	964	424
2	1048	964	336
3	1188	1069	248
4	1168	1048	236
5	1220	1092	204
6	1168	1056	200
7	1216	1096	192
8	1296	1136	188

Table A-II

Cadmium = 10 mg/l (shock loaded unit)

Hour	TSS mg/l	MLVSS mg/l	COD mg/l
0	1132	960	648
1/2	1100	952	468
1	1292	1096	308
2	1212	1084	288
3	1252	1096	268
4	1284	1140	240
5	1204	1040	224
6	1292	1096	208
7	1320	1116	204
8	1388	1172	204

Table A-III

Cadmium = 50 mg/l (shock loaded unit)

Hour	TSS mg/l	MLVSS mg/l	COD mg/l
0	1060	776	628
1/2	1168	904	516
1	1172	892	464
2	1240	948	400
3	1292	980	348
4	1272	964	288
5	1288	968	264
6	1264	980	256
7	1304	1008	244
8	1320	960	240

Table A-IV
Cadmium = 50 mg/l (acclimated unit)

Hour	TSS mg/l	MLVSS mg/l	COD mg/l
0	1020	800	636
1/2	1328	960	416
1	2308	1336	320
2	2024	1308	244
3	2008	1272	224
4	1916	1212	220
5	2052	1248	216
6	1904	1276	220
7	2060	1256	240
8	2268	1472	232

Table A-V

Cadmium = 100 mg/l (shock loaded unit)

Hour	TSS mg/l	MLVSS mg/l	COD mg/l
0	1012	676	620
1/2	1116	736	456
1	1124	752	396
2	1160	772	324
3	1316	884	276
4	1408	932	236
5	1360	896	216
6	1284	860	212
7	1440	928	204
8	1336	884	204

Table A-VI

Cadmium = 250 mg/l (shock loaded unit)

Hour	TSS mg/l	MLVSS mg/l	COD mg/l
0	1684	840	664
1/2	1604	916	548
1	1512	856	484
2	1656	960	424
3	1724	1028	384
4	1644	928	348
5	1704	972	320
6	1660	972	300
7	1668	992	304
8	1704	1012	296

Table A-VII
Cadmium = 250 mg/l (acclimated unit)

Hour	TSS mg/l	MLVSS mg/l	COD mg/l
0	1400	704	600
1/2	1468	792	460
1	1708	912	392
2	1780	936	296
3	1744	944	252
4	1764	984	236
5	1780	1060	228
6	1824	1068	248
7	1808	1076	228
8	1784	1060	228

Table A-VIII
Cadmium 500 mg/l (shock loaded unit)

Hour	TSS mg/l	MLVSS mg/l	COD mg/l
0	1744	876	660
1/2	2000	924	516
1	1944	1020	468
2	1932	892	424
3	2124	1072	392
4	2000	1004	352
5	2064	1028	320
6	2052	1088	300
7	2036	1000	288
8	2136	1120	280

Table A-IX

Cadmium = 500 mg/l (acclimated unit)

Hour	TSS mg/l	MLVSS mg/l	COD mg/l
0	1868	900	592
1/2	2704	968	432
1	2300	1060	356
2	2336	1084	272
3	2572	1208	232
4	3252	1516	236
5	2424	1152	236
6	2624	1192	228
7	2436	1124	224
8	2400	1132	224

Table A-X

Cadmium = 1000mg/l (shock loaded unit)

Hours	TSS mg/l	MLVSS mg/l	COD mg/l
0	3200	952	640
1/2	3448	1056	536
1	3072	1004	488
2	3016	960	424
3	3268	1084	380
4	3032	976	348
5	3344	1092	336
6	3352	1084	316
7	3160	964	308
8	3368	1056	300

Table A-XI

Cadmium = 1250 mg/l (shock loaded unit)

Hour	TSS mg/l	MLVSS mg/l	COD mg/l
0	3660	1068	630
1/2	3976	1128	526
1	4320	1296	482
2	3748	1060	450
3	3748	1076	387
4	3756	1092	371
5	3940	1180	344
6	4108	1212	332
7	3952	1180	324
8	4072	1232	316

Table A-XII

Cadmium = 1500 mg/l (shock loaded unit)

Hour	TSS mg/l	MLVSS mg/l	COD mg/l
0	4228	1184	628
1/2	4428	1168	530
1	4464	1236	498
2	4052	1084	458
3	4164	1152	419
4	4164	1136	387
5	4216	1160	360
6	4296	1228	340
7	4252	1172	328
8	4296	1204	328

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EFFECTS OF CADMIUM ON BATCH AEROBIC BIOLOGICAL TREATMENT

by

Peter Cranson Ryder Shelley

(ABSTRACT)

This investigation explored the effects of cadmium on batch fed shock loaded and acclimated activated sludge test units subjected to various cadmium concentrations.

Analysis of the substrate utilization and volatile solids production of the test units has shown an increasing detrimental effect coinciding with increasing cadmium concentrations. It was observed, that at a given cadmium concentration the detrimental effect was greater on the shock loaded unit than on an acclimated unit.

The ability of an acclimated unit to withstand the effects of the cadmium may be attributed to the emergence of cadmium resistant organisms within the unit. A change in the species predominance to the cadmium resistant organisms resulted in greater solids production in the unit, which resulted in a greater yield coefficient for the acclimated unit.