Treatment of Septic Tank Effluent

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Abstract

The objective of this research was the investigation of tertiary treatment for septic tank effluent.

The tertiary treatment was carried out in a separate tank under aerobic conditions. The oxygen requirements were provided by the electrolysis of water.

key words: septic tanks, Electrolysis, pure oxygen, Bubble size

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
cm	Centimeter
m	Meter
mm	Millimeter
mg	Milligram
mg/l	Milligram per liter
NH_4^+	Ammonium
SS	Suspended Solids
O.D.	Outside Diameter
VSS	Volatile Suspended Solids
TSS	Total Suspended Solids
^oC	Degrees Celsius
^oF	Degrees Fahrenheit
Hg	Mercury
Ca	Calcium
Pb	Lead
B	Boron
P	Phosphorus
N	Nitrogen
D.O.	Dissolved Oxygen
rph	Revolutions Per hour
$CaCO_3$	Calcium Carbonate
ml	Milliliter
Zn	Zinc

Na	Sodium
pH	Negative log of hydrogen ion concentration
EC	Electrical conductivity
TDS	Total Dissolved Solids
v	Volts
Mn	Manganese
Fe	Iron
l	Liter
STE	Septic Tank Effluent
STEU	Septic Tank Extender Effluent
mhos	Measure of electrical conductivity
min	Minutes
KWH	Kilowatt Hours

INTRODUCTION

In rural and sparsely populated areas where there are no community sewerages, other methods of sewage disposal have to be used, the most common method being the use of septic tanks.

The use of septic tanks has always been criticized as a pollutant to the environment. This criticism goes back to early America when septic tanks were first associated with typhoid fever and other gastrointestinal diseases. Then, in the late 1950's and early 1960's, septic tanks were criticized for their high failure rates. In more recent years, with the increased interest in the environment, septic tanks have once again come in for criticism as a pollutant to the groundwater. With passage of the National Safe Drinking Water Act of 1974 (1), which regulates underground injection, it has been left up to the individual states to regulate the use of septic tanks. With the regulation of septic tanks left to the discretion of the states, there has been some fear that the use of septic tanks may be banned in some places.

Other than banning septic tanks, an alternative would be to have some kind of additional treatment added to the septic tank. It is this additional proposed treatment that was considered in this research. The proposed additional treatment was that of tertiary treatment of septic tank effluent by electrolysis. The additional treatment was called tertiary because the septic tank was considered to have two main separate functions: (a) the

separation of the solids from the liquids, and (b) the anaerobic digestion of the settled, suspended and dissolved solids.

The objective of this research was the design of tertiary treatment for septic tank effluent by electrolysis based on COD reduction.

PROPOSED TERTIARY TREATMENT

A method of tertiary treatment of septic tank effluents has been proposed by Clark (2) so that an improved system of treating septic tank effluents could be provided. The treatment would result in effluent more suitable for infiltration into the soil and that could be used for the irrigation of ornamental plants.

The tertiary treatment would take place in what Clark (2) calls his "Septic Tank Extender" Unit (Figure 1). The Septic Tank Extender Unit is to be placed between the septic tank and the drain field (Figure 2). The effluent enters the Extender Unit from the septic tank and is treated in the Extender Unit, which is designed for a 24-hour minimum detention time. The treated effluent then flows to the drain field or is pumped out for irrigation. In the Septic Tank Extender Unit, the septic tank effluent is treated using aerobic bacterial digestion. The aerobic digestion was accomplished by aerobic bacteria and protozoa utilizing the bacteria as food.

The oxygen to the Septic Tank Extender Unit for the aerobic bacteria and protozoa was supplied by a pair of electrodes placed in the unit (Figure 2). The oxygen was produced by the electrolysis of water at the electrodes, which produced molecular oxygen and hydrogen. The oxygen was dissolved into the water as it rose through the water in the unit, and the hydrogen gas provided mixing as it rose through the water.

The oxygen transfer efficiency of the unit was nearly 100 percent, whereas aeration efficiencies with normal atmospheric oxygen usually are between 1 and 10 percent.

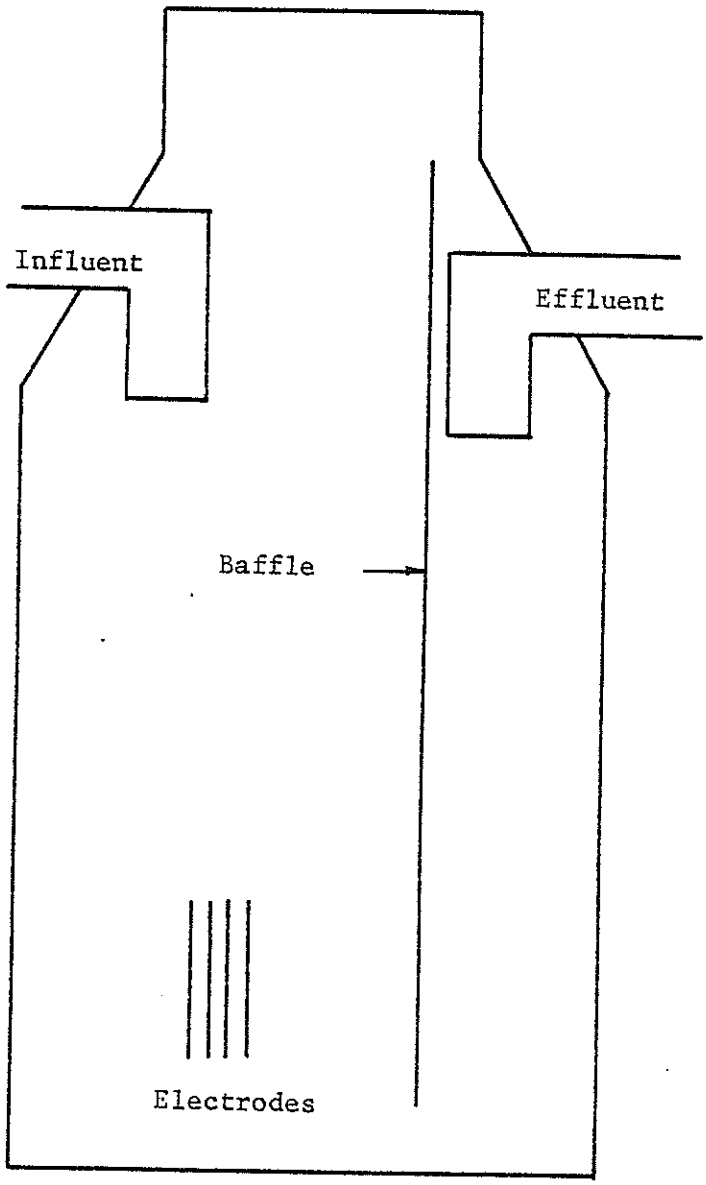


Figure 1. Septic Tank Extender Unit.

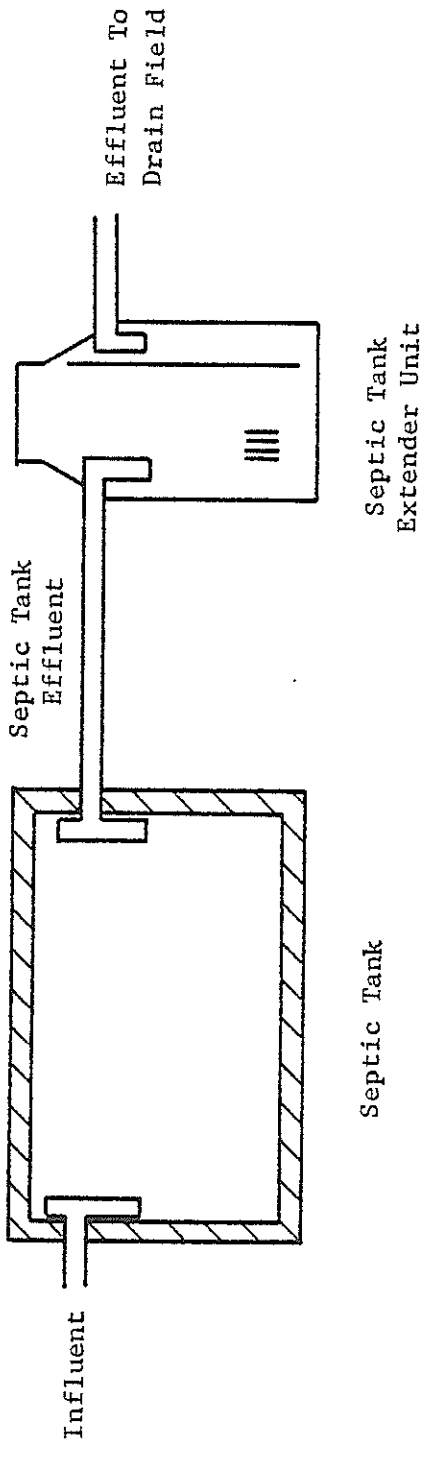


Figure 2. Septic Tank Extender Unit Placement.

LITERATURE REVIEW

History

The first reported use of septic tanks was approximately 100 years ago in France. For the first 100 years, the septic tank has remained virtually unchanged. The septic tank was first introduced in the United States in 1884 with the design of the two-chamber tank (Figure 3).

Prior to World War II, the use of the septic tank was largely restricted to rural areas. The widespread use of septic tanks in rural areas provides for both the convenience and safety of interior plumbing. After World War II in the post-war building boom, septic tanks were used in many areas beyond the city sewage limits. It is presently estimated by Viraraghavan and Warnock (3) that approximately 50 million Americans and 4 million Canadians use septic tanks for the disposal of household wastewaters.

Although septic tanks have been a great advantage in allowing the use of indoor plumbing in areas without community sewerages, they also have had some disadvantages, the most serious disadvantage being the high rate of septic tank failures. McGauhey and Winneberger (4) found that as many as one-third of the septic tanks in a subdivision failed within the first three or four years of use, causing the possibility of contamination. There have also been reports of contamination of drinking water from the use of septic tanks (5, 6).

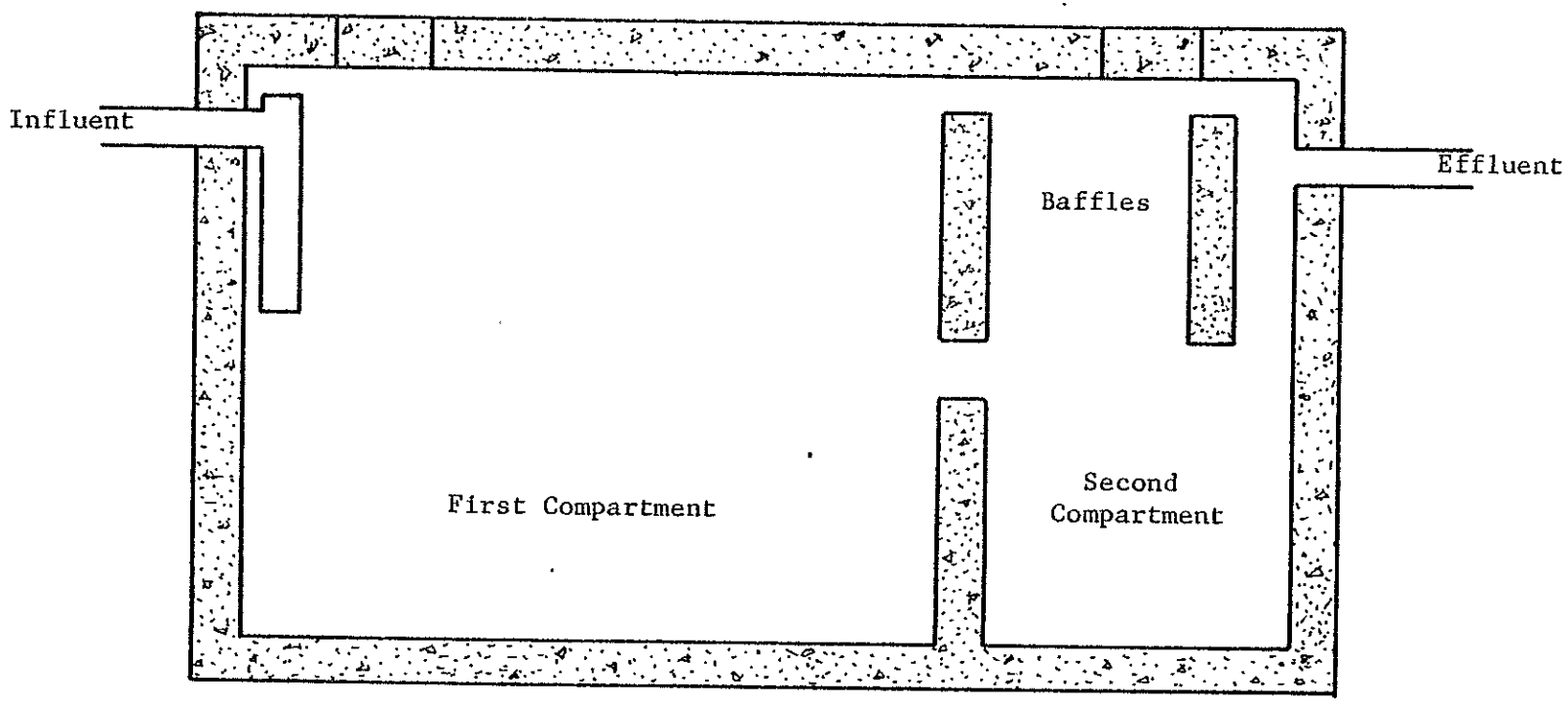


Figure 3. Typical Two-Compartment Septic Tank (31).

Septic Tank System

The use of septic tanks is the simplest and the most convenient method of disposal of domestic sewages within the confines of the individual lot. The septic tank systems consist of two parts:

(1) The septic tank

(2) The drain field

Septic Tank. Essentially the septic tank provides for the collection of domestic waste water in a buried vault. The most common type of septic tank is the two-chamber tank (Figure 3), although the single-chamber tank (Figure 4) is also used.

In the septic tank, there are basically three functions that take place. The first function is that of the separation of the liquids from the suspended solids. This is usually done by providing at least a 24-hour detention time in the septic tank, although in some cases it is acceptable to have shorter detention times (7). The second function of the septic tank is the anaerobic digestion of the settled solids and the dissolved solids. At the liquid surface, a scum layer is formed, which prevents the transfer of oxygen from taking place. The scum layer is the accumulation of grease, hair and other floatable solids. The third function of the septic tank is the storage of sludge and scum. Both the sludge and the scum undergo anaerobic decomposition which reduces their volume, but due to accumulations over time, they must be removed periodically.

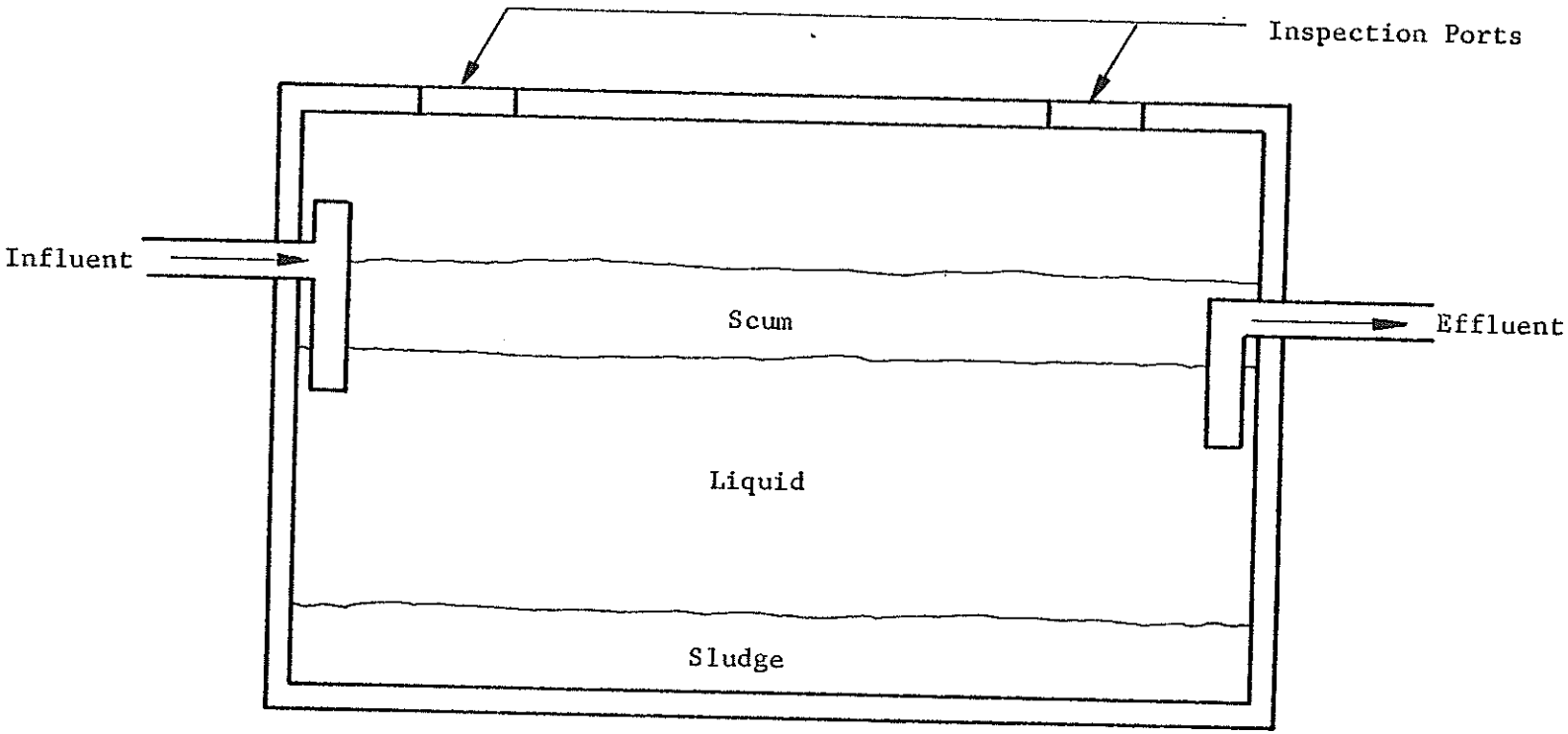


Figure 4. Typical Septic Tank.

Drain Field. The septic tank drain field is probably the most important part of the septic tank, because it is here that most of the failures occur. There are several reasons for the failure of a drain field. The two most common reasons are:

(1) Infiltrative capacity of the soil is not acceptable.

(2) Anaerobic clogging of the infiltrative surface.

The first, that of inadequate infiltrative capacity, is not as serious as the second because there have been percolation systems developed for these areas. McGauhey (8) lists some percolation systems that have been developed, but there is still the problem of anaerobic clogging of the soil.

There are three factors that contribute to soil clogging:

(1) chemical;

(2) microbiological;

(3) physical.

Of the three factors, the one that contributes the most to the failure of drain fields is the microbiological. The drain field is constantly supplied with organics which act as food to microorganisms which are present in large numbers. If the soil is used for long periods of time with normal septic tank effluent, the population of anaerobic microorganisms builds up and their resultant chemical reactions (the formation of ferrous sulfide) with the soil will clog the drain field.

The most important factor in prevention of biological clogging of a drain field is the maintenance of aerobic conditions. In order to do this, the drain field must be

periodically reaerated to restore aerobic conditions. Under aerobic conditions the ferrous sulfide, which clogs the soil under anaerobic conditions by filling the soil pores, is oxidized to soluble ferrous sulfate.

Anaerobic Digestion

In a septic tank the energy for metabolism used by the microorganisms is obtained from the organic substrate. The majority of this organic matter is in the form of insoluble complex solids. In order for the microorganisms to utilize this organic matter, it has to first be hydrolyzed. This is brought about by extracellular enzymes elaborated by bacteria. These enzymes hydrolyze the complex solids into simpler soluble compounds that can be utilized by the microorganisms. The cellulose and starches are hydrolyzed into soluble sugars while the proteins are broken into amino acids (9), and the fats into fatty acids. In anaerobic conditions, the soluble organic matter is decomposed into intermediates and products, such as organic acids and alcohols, along with the production of carbon dioxide and water.

The energy in the substrate is released by the process of biological oxidation followed by the transfer of hydrogen or electrons to an ultimate acceptor (10). The higher the hydrogen acceptor is on the electromotive scale, the greater the energy yield released from the oxidation of one mole of a given substrate. The aerobic metabolism has the highest energy yield because of the use of oxygen as the ultimate acceptor. The

anaerobic metabolism has the least energy yield because of the limited amount of hydrogen acceptors.

The relationship between metabolism, energy and synthesis is important in the understanding of biological treatment process. The metabolism of the organic matter produces energy, and the energy is in turn used for synthesis.

The major limitation in anaerobic digestion is energy. Since there is a limited supply of hydrogen acceptors, there is only a certain amount of energy which can be made available. Due to this limited energy, there is an incomplete digestion or breakdown of the organic matter. This means that there will be some unused energy sources in the effluent of the septic tank that can be utilized with the introduction of a hydrogen acceptor, such as oxygen. The relative energy conversions of the anaerobic and aerobic metabolisms are shown in Figures 5 and 6.

Prior Work

In the past there has been little interest in the treatment of septic tank effluent. Although there have been alternative systems to the septic tank, most of these alternatives are aerobic systems. Bennett et al. (11) and Otis et al. (12) have all worked with the development of these aerobic treatment systems. All used an aerobic unit similar to the one shown in Figure 7 for their studies. These units were designed to function as small Extended Aeration Activated Sludge treatment plants. Aeration was provided with compressed air or mechanical stirring.

The aerobic units were found to provide higher BOD_5 removal compared to septic tanks, but the units had a TSS removal no

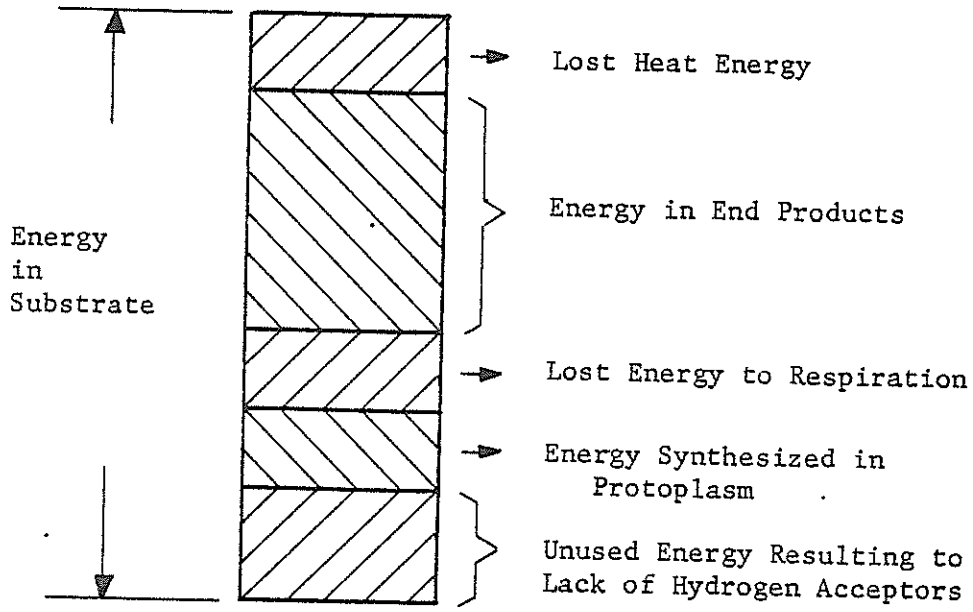


Figure 5. Energy Conversion in Anaerobic Metabolism (10).

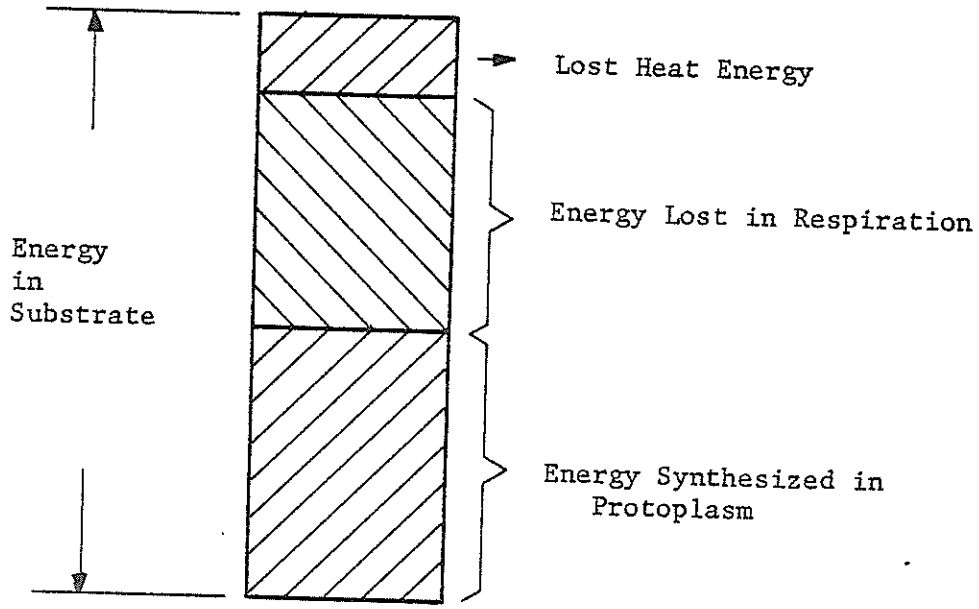


Figure 6. Energy Conversion in Aerobic Metabolism (10).

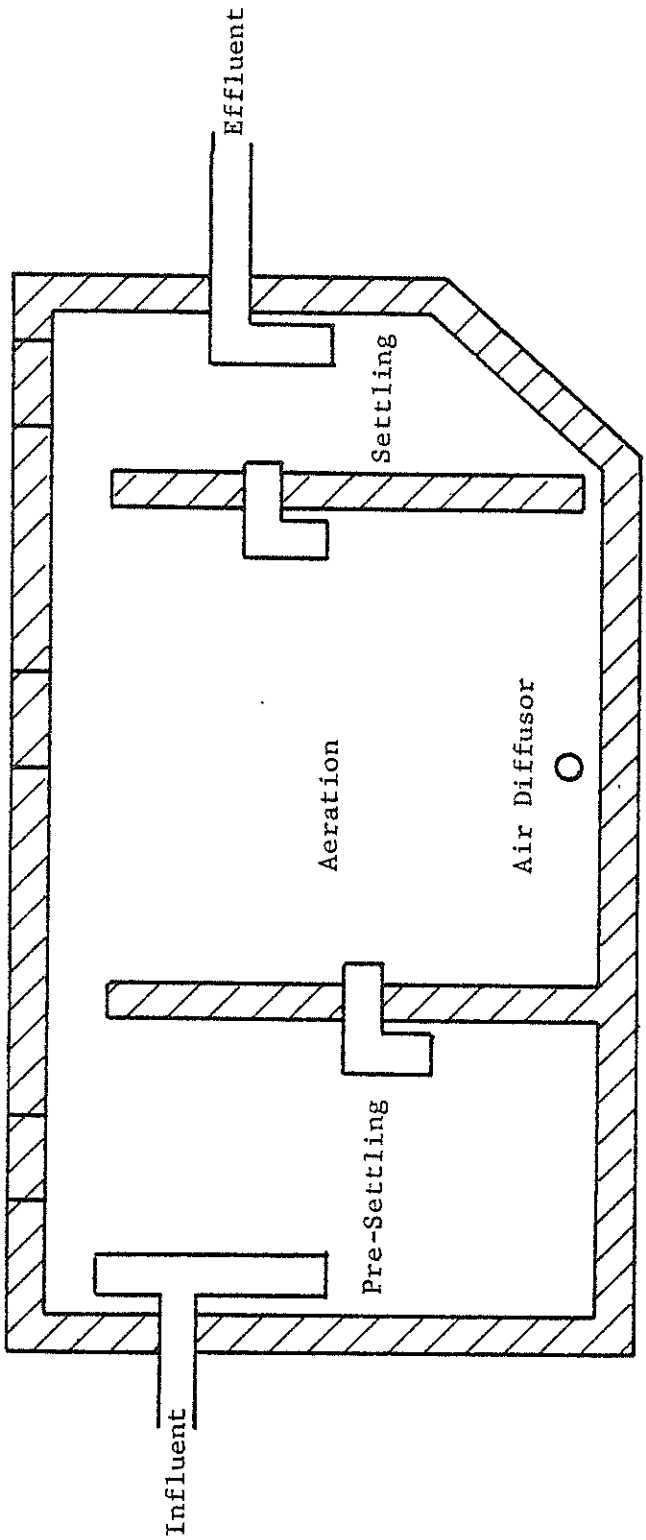


Figure 7. Aerobic Unit Using Compressed Air (11).

better than in the septic tank. The TSS concentrations were almost the same in the effluent as in the aeration chamber. This meant that the aerobic units functioned more as aerated ponds and not as Extended Activated Sludge units.

The main disadvantages of aerobic units and reasons why they have not become successful are:

(1) the high initial cost;

(2) periodic maintenance required;

(3) large volume of sludge produced by aerobic unit;

(4) the short life of the mechanical equipment;

(5) operating costs.

These are responsibilities which the homeowners have not been willing to accept.

Electrolysis

The knowledge of electrochemical methods for the treatment of wastes has been known since the early history of electrochemical technology. The basic idea has been to use the reactions produced at the anode and cathode, by the use of direct current, in solution for the stabilization and/or decomposition of wastewaters. Around 1880 there was so much interest in the area of electrolytic treatment of sewage that there were even a few electrolytic treatment plants built.

In the last few years most of the uses and research of electrochemical treatment have been centered around industrial wastes where many have become an established method of treatment.

Recently there has been a revival of the interest in the area of electrochemical treatment of sewage.

History of Electrochemical Treatment

The earliest reported application of electrolytic treatment of sewage, which used dissolvable anodes, was in 1880 in London, England (13). Following this time and early into the twentieth century there was much activity in the area of electrolytic treatment of sewage. There were even several electrolytic treatment plants built in Europe and North America at this time (14). This flurry of activity lasted until about 1930 when interest declined, reportedly because of the high cost of electricity and skepticism over the process and the lack of suitable electrode materials (15, 16). It was not until the late 1950's, when Mendia of Italy and Foyn of Norway used electrolysis for the treatment of sewage, that there was a revival in the use of electrochemical treatment of wastewaters. This new interest led to the building of an electrolytic sewage treatment plant in England on the Island of Guernsey, which was serving a population of approximately 20,000 when it was completed (13). In the late 1960's, many United States companies that were conducting research in the areas of aerospace and defense turned to research and development of electrochemical treatment methods as part of their development programs. This led to the issuing of many patents for various electrolytic water and wastewater treatment processes for private companies (13).

Electrochemistry is defined as the branch of chemistry

which deals with the relationship between chemical changes and electrical energy and how one is converted to the other. Electrochemistry is divided into two areas; electrolysis and electromotive chemistry. The first area, electrolysis, deals with the conversion of electrical energy to chemical changes. The second area, electromotive chemistry, deals with the conversion of chemical changes to electrical energy. The first of these two areas, electrolysis, is the one which has applications to wastewater treatment and therefore the one to be examined.

The passage of electricity (direct current) through an electrolytic conductor between two electrodes is known as electrolysis. The electrolytic conductor, most often called the electrolyte, is a substance whose molecules dissociate in solution to charged ions (17). Aqueous solutions of acids, bases, most inorganic salts and many organic compounds can act as electrolytes. Solutions of organic solvents are also capable of acting as electrolytes although their capacity for conduction is less than that found in aqueous solutions.

During the electrolysis process, the constituents of the electrolyte move through the solution to either the positive electrode (anode) or the negative electrode (cathode) and are liberated or decomposed by oxidation or reduction reactions at the electrodes (oxidation takes place at the anode and reduction takes place at the cathode). Around the cathode the solution becomes alkaline and around the anode the solution becomes acidic.

The electrolysis process is governed by the law discovered in 1832 by Michael Faraday and known as Faraday's Law of Electrolysis. The law can be stated as follows (18):

I. During electrolysis the weight of an element liberated at a given electrode is directly proportional to the quantity of electricity passing through the solution.

II. The weight of various elements liberated at various electrodes by the same quantity of electricity is directly proportional to the gram equivalent weights of these elements.

Depending on the type of electrode material used, there are two different types of electrolysis possible. The two possible types of electrolysis are:

(1) That which uses an anode made of dissolvable material such as iron or aluminum and puts metallic ions into the solution as they dissolve.

(2) That which uses anodes made of inert material such as platinum.

In the electrolysis process, there are several problems that must be overcome and considered in the selection of a suitable electrode if the second type of electrolysis is desired.

During the electrolysis process, depending on the current density, surface area, spacing between plates and mineral content of the water, there will be a mineral deposition on the cathode plate. This deposition, if allowed to continue, will completely cover the cathode, reducing the current density (Figure 8), therefore also reducing the efficiency of the electrode. The deposition

on the plate acts as an insulator increasing the resistance of the cathode, therefore reducing the efficiency of the electrode. It will eventually bridge completely over to the anode, further reducing the efficiency of the electrode if allowed to continue unchecked. This deposition will be firmly attached to the plate. Beck et al. (19) have shown that this deposition is mainly sodium carbonate. In order to maintain the high efficiency of the electrode, it has to be cleaned periodically. In theory, this is simply accomplished by reversing the current to the electrodes, which would drive off the deposition. In real situations, it is not that simple if inert electrodes are to be used. While almost any conductor will act as a cathode, there are very few which can act as an anode without decomposition.

Beck et al. (19) have also shown that this decomposition takes place in the form of pitting. This decomposition also reduced the efficiency of the electrode. They also showed that the pitting was also affected by the current density of the plate. The higher the current density, the faster pitting occurred.

Electrochemical Treatment of Industrial Wastes. Many industrial waste solutions contain substances such as cyanide, copper, cadmium and nickel compounds which make them highly toxic. These waste solutions must, therefore, be detoxified before they can be discharged. When using chemical treatment, this becomes difficult, but when electrolysis is used, it becomes a simple matter. The use of electrolysis also has several advantages over chemical treatment. For example, in the processing of copper and copper alloys, an oxide film is formed on the surface of the copper.

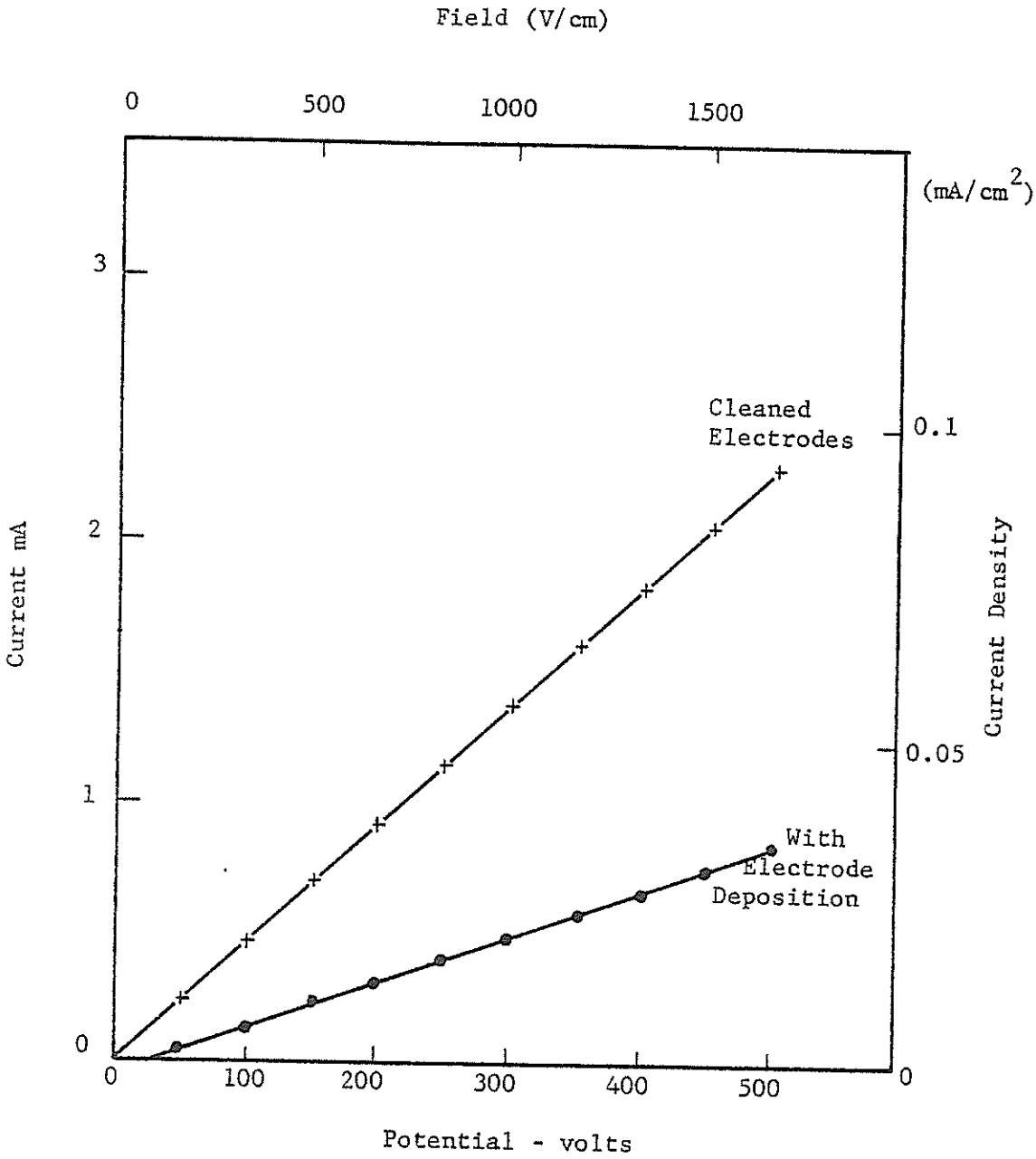


Figure 8. Current Potential Curves Before and After Electrolysis (19).

To remove this oxide film, the copper is pickled with a sulfuric acid solution. The sulfuric acid and the copper react and produce copper sulfate. When the copper in the sulfuric acid pickling solution reaches a certain level, the pickling solution is no longer useful but cannot be disposed of because of the high copper concentrations. By using electrolysis, the copper is removed from the pickling solution, and as a result, the sulfuric acid is regenerated and can be reused. The following reaction is proposed for the removal of the copper (16):

$$2CuSO_4 + 2H_2O \longrightarrow 2Cu + 2H_2SO_4 + O_2$$

The same is true with photographic fixing solutions. As the fixing solution is used, silver is introduced, making it less efficient as the concentration of silver increases. The used fixing solutions are very toxic due to the high silver concentrations and, therefore, cannot be discharged without detoxification. Using electrolysis, the silver is recovered, and the fixing solution is regenerated (20). These types of electrolytic treatment use only inert electrodes.

Electrocoagulation and electrofloatation are also used in industrial waste treatment. Electrocoagulation uses dissolvable aluminum or iron anodes. Upon electrolysis, the anode dissolves, releasing aluminum and iron ions into solution. These ions then form metal hydroxides which act as coagulant agents and by neutralizing the zeta potential of colloidal particles, form a floc with the suspended matter (15, 16, 21). At the same time, the

cathode is liberating hydrogen gas from the electrolysis of water. These small gas bubbles entrain the hydroxide floc and finely dispersed particles and float them to the surface of the liquid forming a foam that is removed by skimming the water surface. This process of lifting the floc and dispersed particles to the surface is called electrofloatation. Electrocoagulation and electrofloatation is commonly called electroflocculation. Electroflocculation is mostly used in the treatment of oil refinery wastewater, wastewaters from paper pulp industry, wastewater from steel rolling mills and other wastewaters which contain colloidal and suspended matter such as sewage.

Tunturi (15) has reported on work in which chemical treatment of wastewaters from pulp and paper factories was compared to electroflocculation. The combination of both chemical treatment and electroflocculation was also compared to the individual methods. The wastewaters used were from the pulp industry clarifier, barking effluent and the chlorination effluent from leaching. The electroflocculation was carried out using aluminum anodes. Tunturi reported the following differences: Within one to five minutes after the start of electroflocculation, the suspended matter had formed a floc and had been floated to the surface where it was easily removed, leaving a very clear water. With chemical treatment, it took from five to ten minutes to form a floc which then had to be settled in a sedimentation basin. Also, in order to form a good floc with chemical treatment, the pH had

to be adjusted. With electroflocculation, the pH of the wastewater was always increasing so no pH adjustment was necessary unless the wastewater was very acidic or alkaline as with the chlorination effluent.

Electrochemical Treatment of Sewage. Interest in electrochemical treatment of sewage was revived by Mendia of Italy and Foyn of Norway. Both of these men introduced the two major methods of electrochemical sewage treatment used today. The two methods are: (1) electroflocculation using dissolvable electrodes with sterilization; and (2) deodorization and sterilization. Both methods use seawater mixed with sewage in order to achieve sterilization using inert electrodes. By adding seawater to the wastewater, the conductivity of the wastewater is increased and chlorine is then liberated from the seawater and used for sterilization. This method is known as the Norwegian Foyn Purification Method for water, especially sewage (15).

The Foyn process was developed with the purpose of removing nitrogen and phosphate from sewage. The nutrients in the sewage which was being discharged into Oslo Bay were causing heavy algae growth. In order to limit the algae growth, Foyn mixed seawater with sewage and passed it through an electrolysis cell. The mixture became alkaline upon electrolysis, and the magnesium ions in the seawater acted as the precipitating agent and removed the phosphate and nitrogen in the form of magnesium ammonium phosphate. At the same time the precipitate was floated to the

surface along with suspended matter and was removed by a scraper. At the anode,hypochlorite was being produced which was used for sterilization.

The Mendia process was simpler than the Foyn process because the removal of nutrients was not the objective. The Mendia process placed its emphasis on the sterilization and deodorization of sewage. The sterilization agent was made from seawater passed through platinum-plated titanium anodes and iron cathodes. From the electrolysis of the seawater a hypochlorite solution was produced which was then mixed with the sewage, sterilizing it before being discharged into the sea. This was the method that the Island of Guernsey used for the electrolytic treatment plant that was built on the island.

Poon and Brueckner (22) have also done work which follows that of Foyn. Their work used the same principles as Foyn with the research objectives of:

(1) identifying the mechanism of phosphate and nitrogen removal;

(2) identifying the control variables and methods;

(3) conducting a continuous-flow study to compare to batch studies.

Batch studies were used for the purpose of defining the mechanisms of organic and nutrient removal. When the electrolysis was started, the following pattern was observed: The pH increased to between 10 and 11 within the first fifteen minutes. Flocculant particles became visible followed by the accumulation of floc

at the liquid surface (brown in color). This was accompanied by a reduction in turbidity. Most of the nitrogen and phosphates were removed after 45 minutes with the pH still between 10 and 11, and the solution continued to clear. Between 45 and 60 minutes, white flocculant was observed beneath the brown floc. Most of the removal BOD was gone by this time, and the DO level was near saturation. At this time, the pH began to drop and the chlorine concentration began to increase.

From the batch studies Poon and Brueckner (22) identified that phosphates were removed mainly by absorption onto $Mg(OH)_2$ flocs. Phosphates could also be removed as calcium phosphate. The nitrogen was removed by the formation of NH_2Cl and its destruction

$$2NH_2Cl + HOCl \longrightarrow N_2 \uparrow + 3HCl + H_2O.$$

As the pH dropped below 8, the nitrogen was removed by the formation of dichloramine.

With a wastewater-seawater ratio of 9:1 and a treatment of 40 to 50 minutes, there was on the average, removal of 85 percent of the BOD, 85 percent of the ammonia nitrogen, 98 percent of the orthophosphate and total phosphate, and 87 percent of the suspended solids. The DO in the effluent was also near the saturation level and the effluent was disinfected.

The continuous-flow model Poon and Brueckner (22) used is shown in Figure 9.

The results of the flow-through model are shown in Table 1 and when compared to the batch study, they show a much less

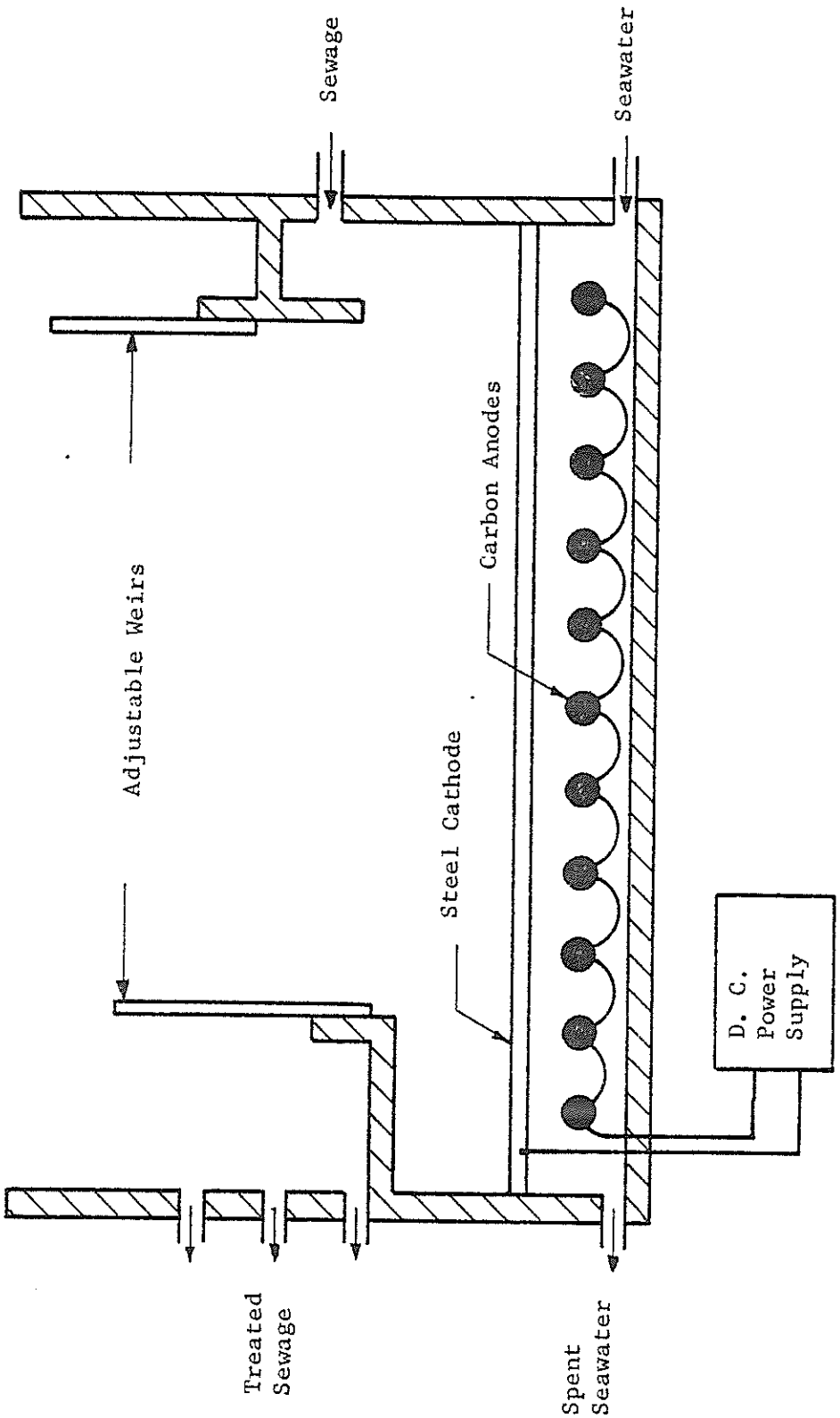


Figure 9. Schematic of Flow-Through Electrolytic Cell (22).

Table 1. Performance of a Flow-Through Model in Electrolytic Treatment of Wastewater (22).

Parameter	Treatment Efficiency (%)
SS removal	66.7 - 85.0
BOD removal	59.8 - 73.4
NH_3-N removal	67.5 - 100
Total N removal	59.0 - 94.5
Ortho PO_4 removal	74.0 - 85.6
Total PO_4 removal	78.6 - 90.2

Experimental conditions are: Wastewater:seawater ratio, 2:1 to 3:1; wastewater detention time, 40 to 60 min; power consumption, 6 to 8 kwh/3,785 l; and the mixing time of treated wastewater and spent seawater, 40 to 50 min. Ref. 22.

efficient system than that indicated by the batch study. It was also found that there was a tradeoff between the removal of phosphate and nitrogen due to the pH level in the model. Another reason for the flow-through model not being as efficient was the lack of a skimming device for the removal of the scum which allowed flocculated solids to exit from the model in the effluent.

Onstott et al. (23) have also done work in the area of phosphate removal for wastewater using electrochemical methods. For their work, there were three methods used: electroflocculation using iron anodes, lanthanum chloride precipitation of untreated sewage, and electroflocculation followed by $LaCl_3$ precipitation. Also noted were the effects on COD and TDS. The wastewater used in these studies was secondary effluent.

The orthophosphate removal by electrolysis using an iron anode showed that the removal was constant at approximately 80 percent with iron concentrations of 30 to 67 mg/liter. At higher concentrations of iron, the efficiency of phosphate removal was not increased. Orthophosphate removal with $LaCl_3$ shows better results for electrolyzed effluent than for untreated secondary effluent.

The three methods showed a reduction in both the COD and TDS. Table 2 shows the results of the three methods for TDS. Table 3 shows the results for the COD's. In both cases, the best results were attained with the use of iron anodization with $LaCl_3$ precipitation.

Hemphill and Rogers (24) used a 12-volt automobile battery

Table 2. Change in Total Dissolved Solids (TDS) (All Samples Were Filtered With 0.47 pm Membrane Filter) (23).

Number of sewage samples (1)	Treatment (2)	Mean TDS in sewage, in milligrams per liter (milligrams per cubic decimeter) (3)	Mean TDS in product, in milligrams per liter (milligrams per cubic decimeter) (4)	Reduction in TDS, as a percentage (5)
7	Fe anodization	413	375	9.2
6	$LaCl_3$ pptn.	445	426	4.3
12	Fe anodization plus $LaCl_3$ pptn.	418	379	9.3

Table 3. Change in Chemical Oxygen Demand (COD) (Product Samples Were Rough Filtered to Remove Precipitate) (23).

Number of sewage samples (1)	Treatment (2)	Mean COD in sewage in milligrams per liter (milligrams per cubic decimeter) (3)	Mean COD in product in milligrams per liter (milligrams per cubic decimeter) (4)	Reduction in COD, as a percentage (5)
7	Fe anodization	55.8	43.1	23
6	$LaCl_3$ pptn.	54.5	27.6	49
12	Fe anodization plus $LaCl_3$ pptn.	60.7	30.2	50

for their electrolysis of sewage. The objective of their work was to determine the nature and rate of organic degradation and the changes in organic carbon produced by lead-lead dioxide electrolysis. Hemphill and Rogers (24) showed that the COD concentration faction C/C_o decreased proportionately to the applied electrical energy.

The data plotted in Figure 10 shows that the general trend of COD reduction follows first-order kinetics and that 80 percent reduction is achieved with less than 25 watt-hours of applied electrical energy. The results also showed that equal amounts of COD concentration fraction were removed by equal amounts of applied electrical energy irrespective of the concentration. This relationship can be expressed by

$$C/C_o = e^{-KE}$$ where

C_o = initial organic concentration as COD mg/l

C = concentration at some value of E

K = reaction rate constant, watt-hours^{-1}

E = electrical energy, watt-hours.

The above expression satisfactorily describes COD decay as a function of electrical energy when applied to the dotted line in Figure 10. The K value for the data in Figure 10 is 0.077 watt-hours^{-1}.

Blanc (25) has developed a method for controlling the pH level in anaerobic processes. Figure 11 shows the model used by Blanc (25) for his studies in the controlling of pH. The pH was controlled by using the reaction taking place at the cathode.

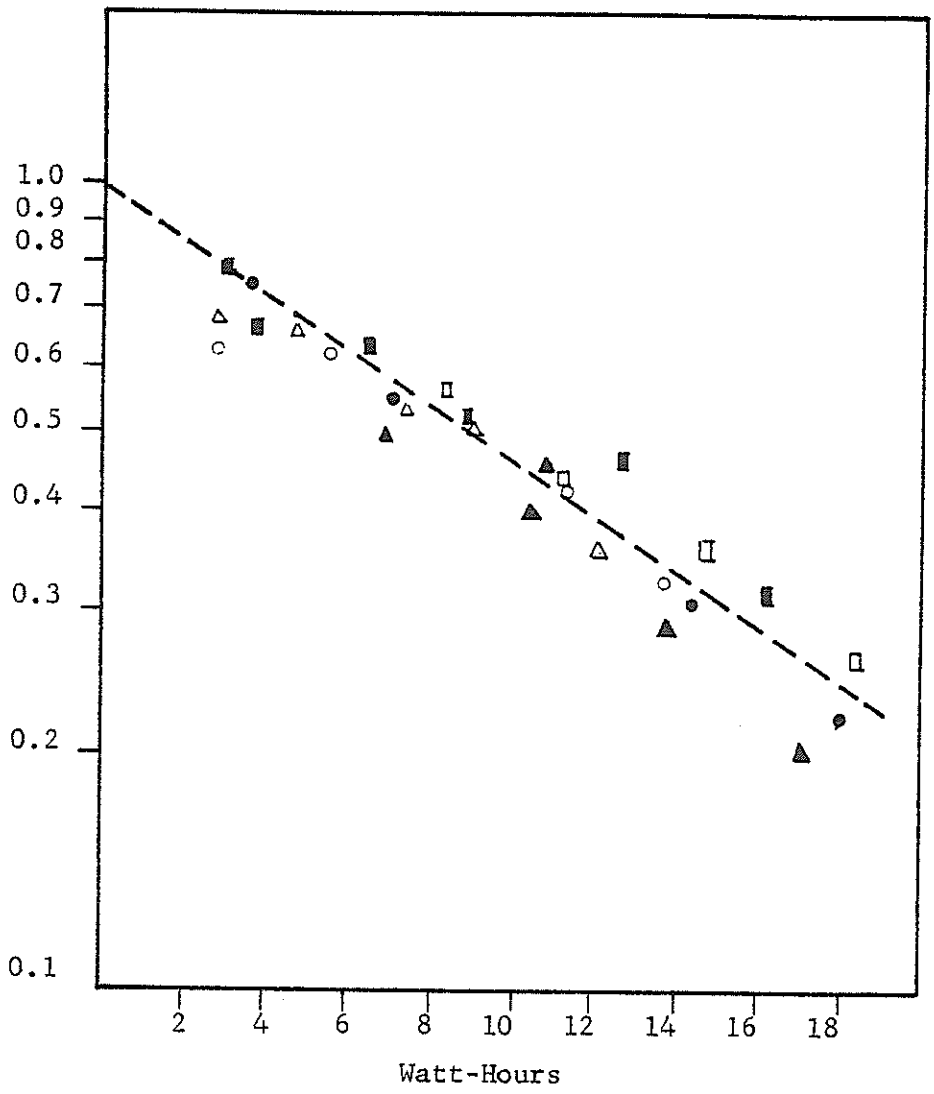


Figure 10. COD Reduction by Electrolysis (24).

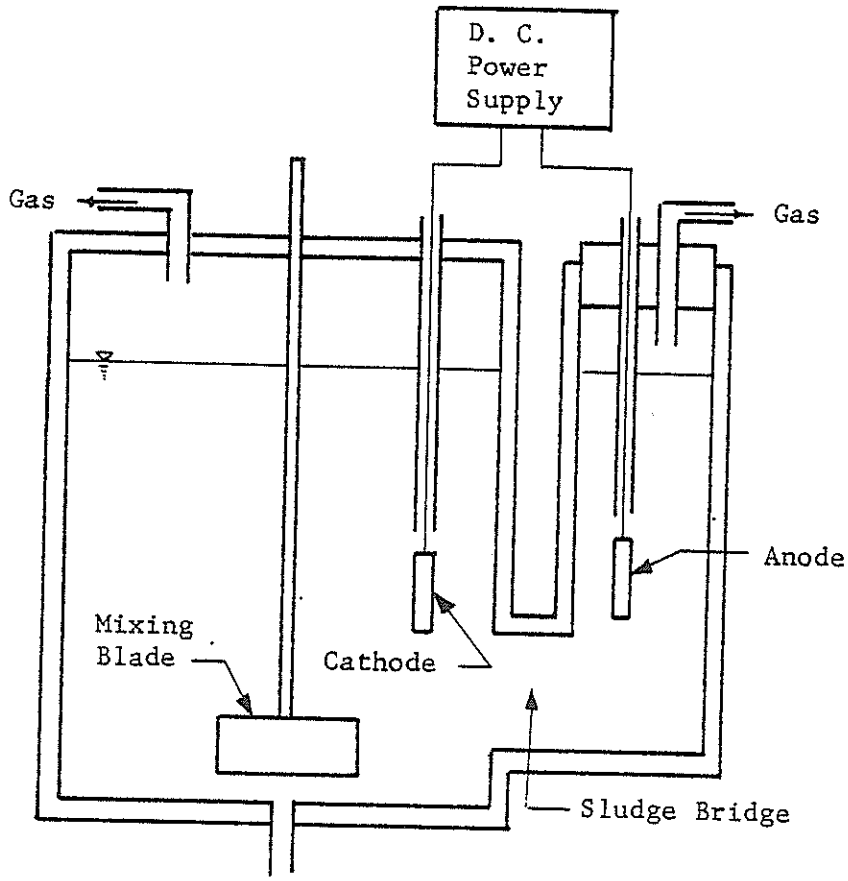


Figure 11. Electrolytic Control With Sludge Bridge (25).

At the cathode hydrogen gas is liberated,which allows the dissolved carbon dioxide to ionize increasing the bicarbonate alkalinity.

Blanc (25) has proposed the following reactions:

At cathode: $2H^+ + 2e^- \longrightarrow H_2$

At anodic area: $2H_2O \longrightarrow O_2 + 4H^+ + 4e^-$

$Cl_2 + H_2O \longrightarrow HOCl + Cl^- + H^+$

$HOCl \longrightarrow H^+ + OCl^-$

In solution: $H_2CO_3 \longrightarrow HCO_3^- + H^+$

$CH_3OOH \rightleftharpoons CH_3COO + H^+$

Blanc (25) has estimated that the area required for each electrode for control of municipal wastewater anaerobic digestion units has to be approximately 10 to 15 percent of the sidewall area of the digestion unit.

In the treatment of sewage, all of the electrochemical methods have used chlorine produced at the anode to disinfect or sterilize the sewage when the removal of solids and/or nutrients was required or electroflocculation was used. No one has used biological treatment in conjunction with electrolysis to treat sewage.

In the Septic Tank Extender Unit, the septic tank effluent is received and with the electrolysis of water is treated using aerobic biological digestion. The effluent from the septic tank, which contains larger numbers of facultative bacteria such as Pseudemonas, Flavobacterium, Alcaligenes, Escherichia, and Aerobacter plus intermediate and unused energy sources (food), can be used with oxygen.

The aerobic digestion process is carried out by mixtures of bacteria growing in mutual association with other microscopic plants and animals. A schematic diagram of the population dynamics of an aerobic system is shown in Figure 12.

Protozoa, which are not active in septic tanks, feed on living organic matter in aerobic systems and are the main means of treatment. They grow in association with bacteria in what is a prey-predator relationship; that is, the bacteria utilize the sewage and the protozoa then consume the bacteria. With the consumption of bacteria by the protozoa, there are two major benefits. First, the removal of the bacteria kills off the bacterial forms that do not thrive in an aerobic environment and stimulates the growth of those that extract the organic matter from the solution. Second, the liquid is clarified and large amounts of energy are utilized by going from the lower to higher animal life forms.

The oxygen to the Septic Tank Extender Unit was supplied by electrolysis. The electrolysis of the water in the extender unit produced molecular oxygen and hydrogen gas. The oxygen dissolves back into solution as it rises through the water, and the hydrogen provides the mixing within the tank as it rises.

Oxygen Transfer

In the Septic Tank Extender Unit, the bubbles produced at the electrodes are pure oxygen.

In a pure oxygen aeration system, there are three gas transfer mechanisms that can occur:

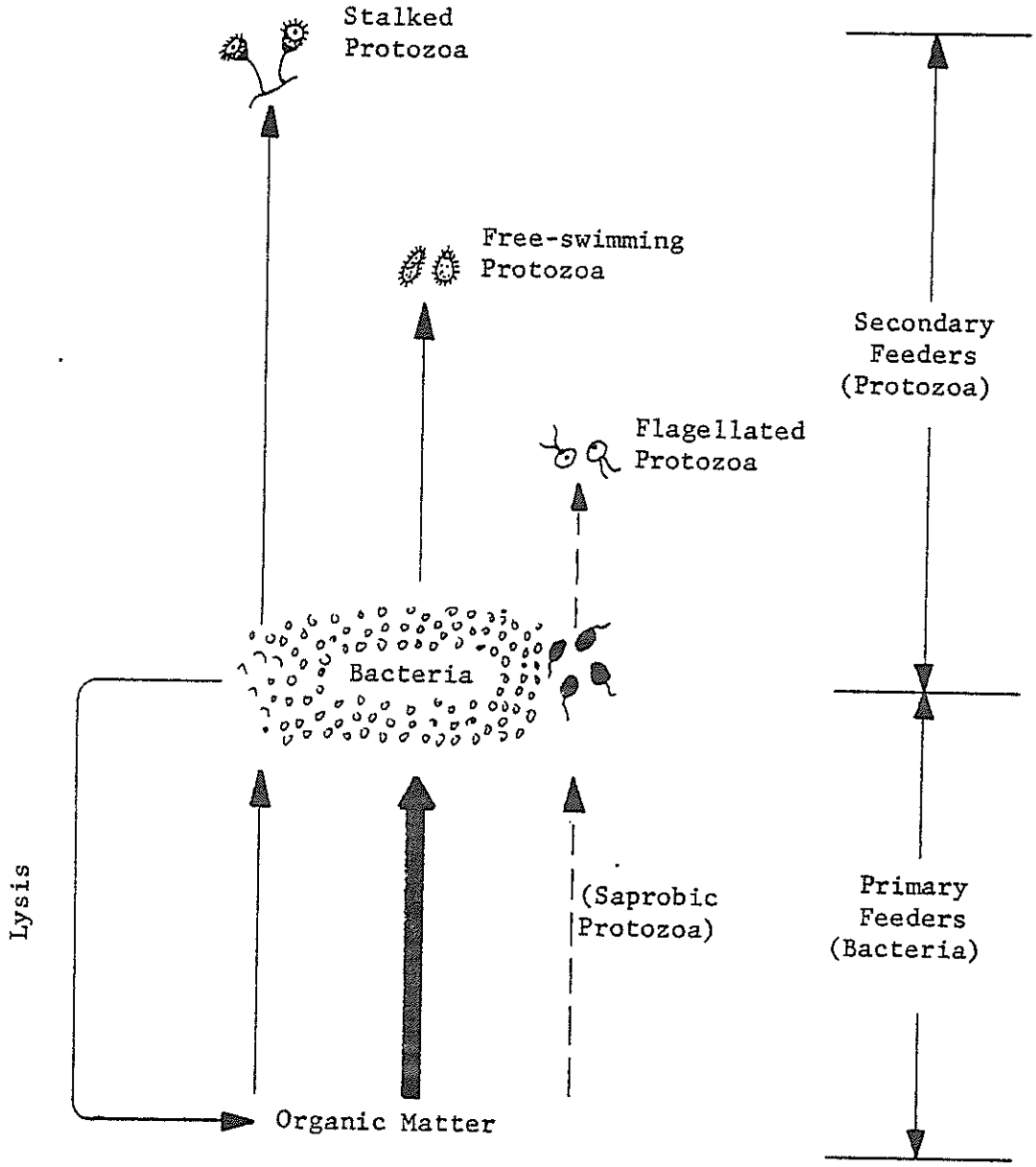


Figure 12. Schematic Diagram of Population Dynamics (10).

(1) Oxygen (O_2) is transferred from the gas phase to the liquid phase;

(2) Nitrogen (N_2) originally in liquid phase is transferred to the gas phase;

(3) Carbon dioxide (CO_2) produced by the biological reactions is transferred to the gas phase.

The rate of oxygen transferred across the gas-liquid interface is proportional to the driving force available for oxygen transfer ($C_s - C_L$) as follows (26, 27, 28):

$$\frac{dC_L}{dt} = K_L a(C_s - C_L)$$

where

C_L = Oxygen concentration in solution (mg/liter)

C_s = Oxygen saturation concentration (mg/liter)

$K_L a$ = Oxygen transfer coefficient (1 hr.$^{-1}$).

In the pure oxygen system, the saturation concentration is related to Dalton's Law of Partial Pressures (29) and Henry's Law (29, 30). Henry's Law describes the relationship:

$$C_s = H_1 P_1$$

where

H_1 = Henry's constant for oxygen

P_1 = Oxygen partial pressure in gas phase.

With bubble aeration, where bubbles are forced upward through a tank of water, transfer occurs across the interface of the bubble, as indicated in Figure 13. For a total volume of gas released in a volume of water, the smaller the bubbles the greater the

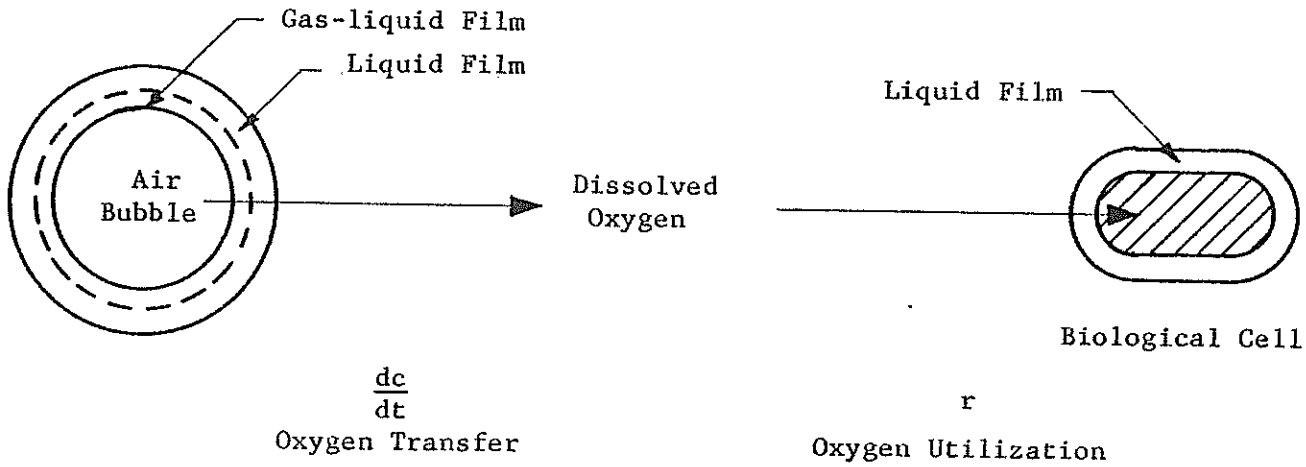


Figure 13. Schematic Diagram of Oxygen Transfer (10).

interfacial area and the greater the interfacial transfer area per unit volume of solution. For a given set of physical conditions, there is an optimum bubble size at which there will be a maximum overall transfer coefficient. If the bubble size is decreased from this optimum size, film resistance may increase to such an extent as to outweigh the gain in interfacial area. It is estimated that the oxygen transfer efficiency of a pure oxygen system is nearly 100 percent whereas that of conventional aeration is between 1 and 10 percent (10). This is based on the bubble size being such that as it rises through the water the bubble is completely dissolved and never reaches the water surface.

In the electrolysis process, the size of the bubble that is produced is dependent on the current density and the spacing between the electrode plates. The higher the current density, the larger the bubble size that is produced. The closer the plates are together, the higher the current density and the larger the bubble size.

For the aeration of water by electrolysis, it is desired that the bubbles (oxygen) not break the water surface. If the bubble size is too small, it will attach itself to suspended matter and float it to the water surface, in what is known as electro-floatation. Also, if the bubble size is too small, mixing will not be provided within the extendeer unit. The desirable bubble size has been found to be between 60 to 600 microns in diameter.

EXPERIMENTAL SYSTEM AND PROCEDURES

The septic tank-aeration system used for this research consisted of the following:

(1) the septic tank unit, which included the constant head tank;

(2) the Septic Tank Extender Unit;

(3) the electrical system which includes the power supplies and switching mechanisms.

A schematic flow diagram of the system is shown in Figure 14.

The system consisted of a 15 gallon (56.78 liters) constant head tank which provided a constant flow rate to the septic tank through a flow splitter which also enabled the constant head to be used for two or more septic tanks. The flow throughout the system was maintained by gravity.

The septic tank consisted of a 55 gallon (208.5 liters) steel drum with a plastic liner. The flow rate to the septic tank was such that a 24-hour detention was maintained in the septic tank. The effluent from the septic tank then entered the Septic Tank Extender Unit.

The Septic Tank Extender Unit was the same in size and construction as the septic tank with the exception that it (the Septic Tank Extender Unit) contained two sets of electrodes. It was through the electrolysis of water provided in this tank that aerobic digestion of the septic effluent took place. The effluent from the extender unit then flowed to a drain where it was wasted.

The power to the electrodes was supplied by two Kepco D. C. power supplies. The power supplies were set to be voltage-

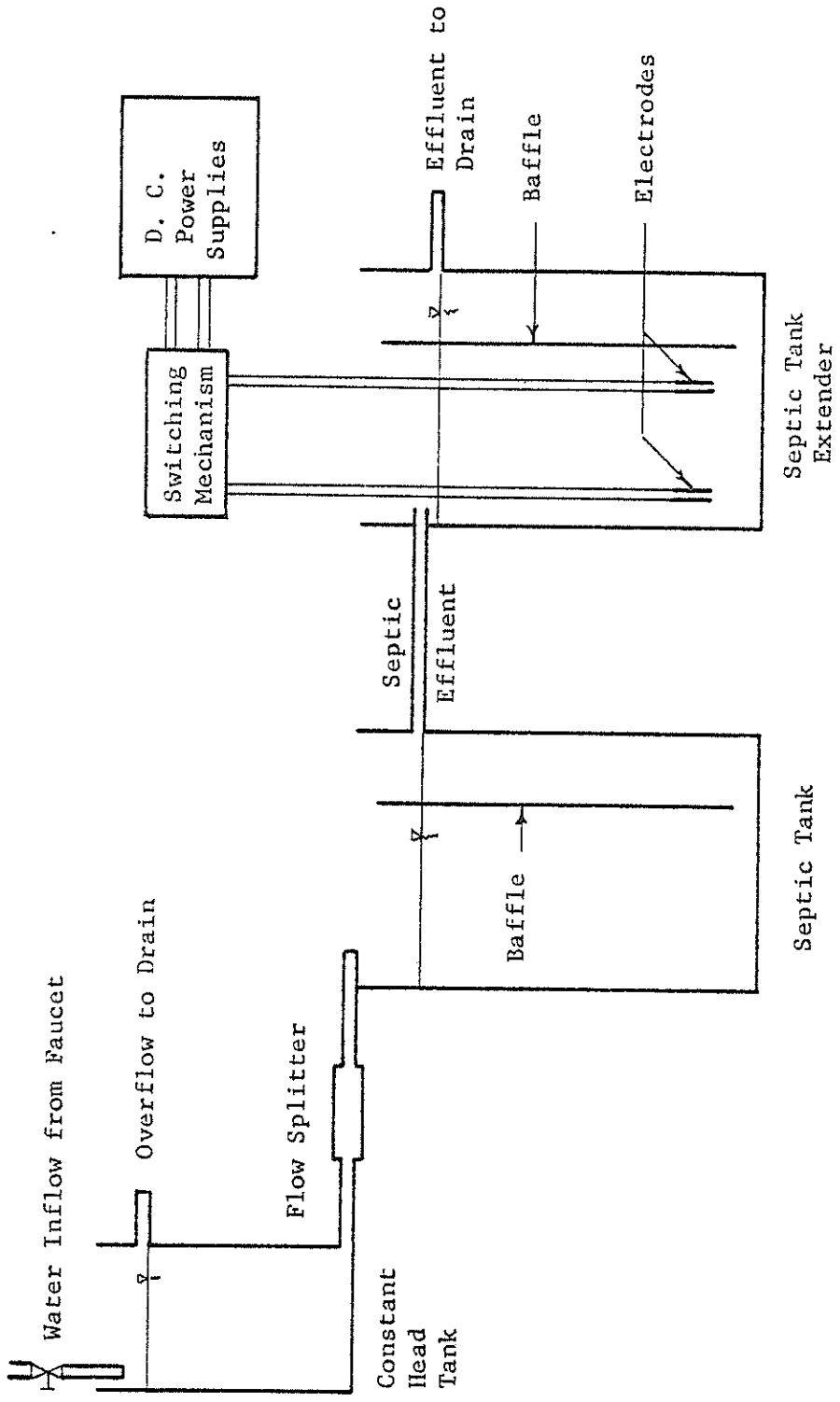


Figure 14. Schematic Flow Diagram of Septic Tank System.

limiting at a voltage of 10 volts D.C. The current to the electrodes was reversed every five minutes using a synchronous motor and a series of relays. The current was reversed in order to keep the electrodes free of deposition.

Septic Tank Unit

The septic tank unit consisted of a constant head tank, flow splitter and the septic tank. The use of a constant head tank provided a constant flow rate to the septic tank.

The septic tank was constructed from a standard 55-gallon (208 liters) fuel drum with the top removed, and a plastic liner inserted to prevent corrosion of the metal. The plastic liner was taken from a cardboard 55-gallon (208 liters) drum that the New Mexico State University Physical Plant receives chemicals in for treatment of cooling tower water. The tank was baffled into two sections containing approximately 46.8 gallons (158.4 liters) and 6.2 gallons (23.3 liters). An outlet for the tank was provided at approximately the 48-gallon (181.7 liters) level. The actual volume of the tank was calculated to be 53 gallons (200.6 liters). The outlet consisted of a P.V.C. threaded nipple to which a 12-inch (30.5 cm) long piece of 1-inch (2.54 cm) O.D. pipe was attached. This was later changed to a 1.5-inch (3.81 cm) O.D. pipe due to clogging of the 1-inch (2.54 cm) O.D. pipe (Figure 15).

Most septic tank designs are based on a 24-hour detention time (31, 32). The septic tank model used in this research provided a 24-hour detention time. The 24-hour detention time was accomplished by having water flowing through the septic tank at a rate of approxi-

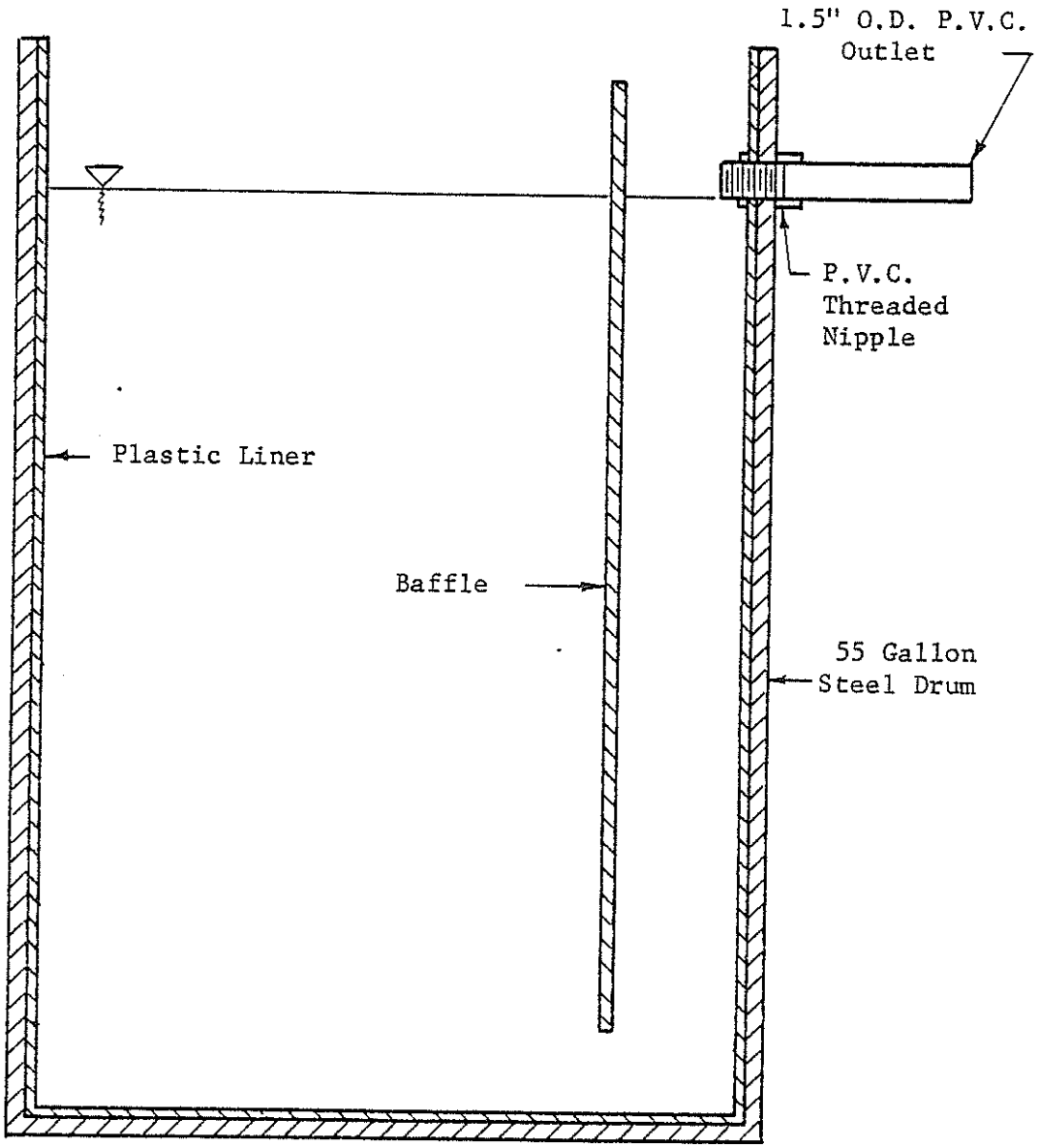


Figure 15. Cross Section of Septic Tank.

mately 139 ml per minute. The water to the septic tank was originally obtained directly from a water faucet. This, however, proved to be undesirable because of fluctuations in the flow rate throughout the day. This deficiency was overcome with the use of a constant head tank which provided the constant flow rate required.

The constant head tank consisted of a 15-gallon (56.8 liters) plastic tank. The tank was filled with water from a faucet and a constant water level was maintained by the use of an overflow which drained any excess water to a drain in the floor. The water from the constant head tank flowed out of the bottom of the tank to a 2.25-inch (5.72 cm) O.D. plexiglas tube, 13.5 inches (34.3 cm) long, which had a series of valves. The plexiglas tube also acted as a flow splitter and each valve controlled the flow rate to individual septic tanks.

Septic Tank Extender Unit

The Septic Tank Extender Unit consisted of the aeration tank, electrodes and the electrical system.

The construction of the septic tank extender was the same as that of the septic tank. The only difference between the septic tank and the extender is that in the septic tank extender, two sets of electrodes were suspended approximately 3 inches (7.62 cm) from the bottom of the tank (Figure 16).

Electrodes

The electrodes used for this research were DSA electrodes manufactured by the Electrode Corporation, a subsidiary of the Diamond Shamrock Corporation.

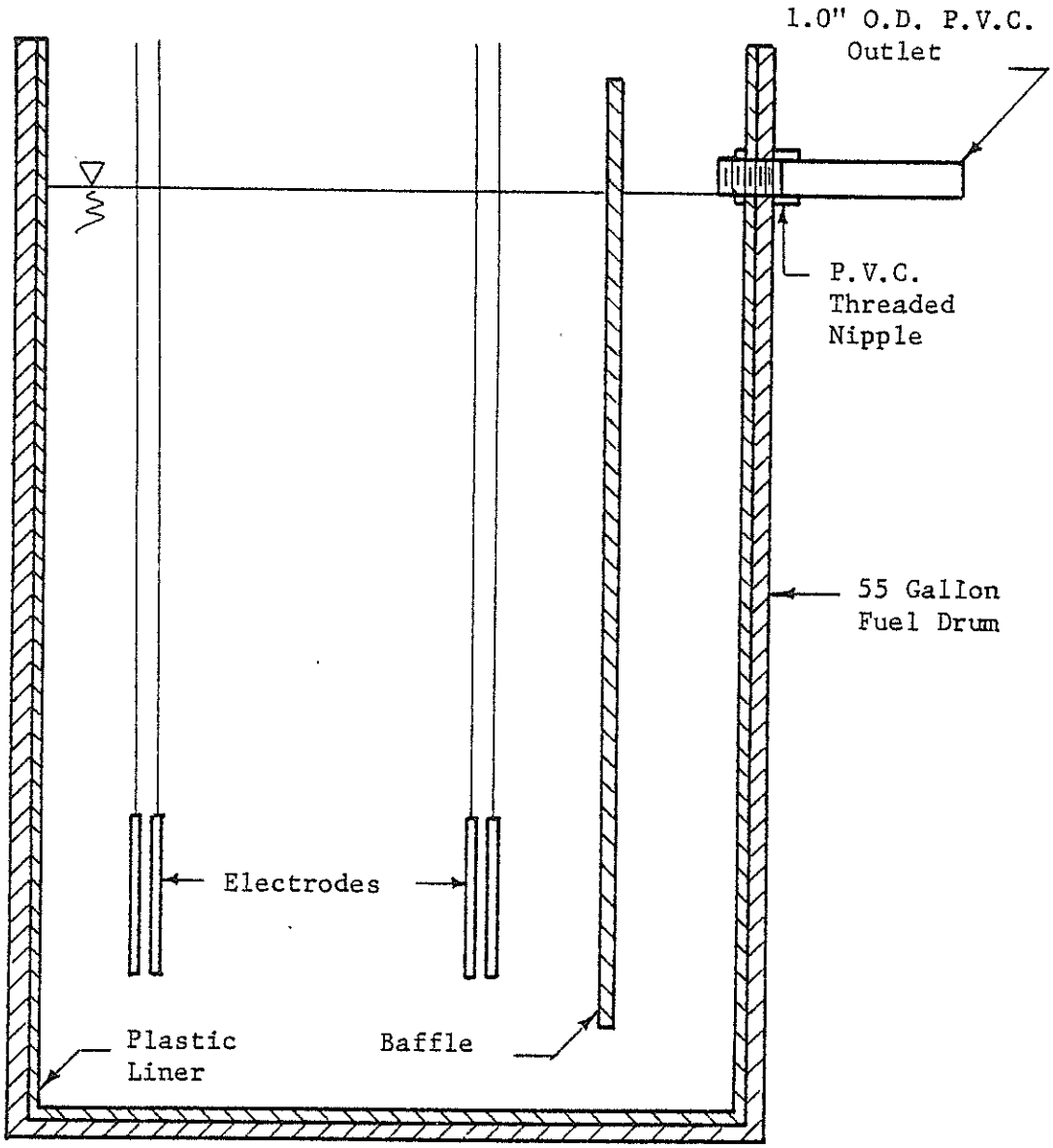


Figure 16. Cross Section of Septic Tank Extender.

Both the anode and cathode electrode plates were DSA electrode plates (Fig. 17). The dimensions of each plate were 10 inches (25.4 cm) long by 6 inches (15.24 cm) wide for a total surface area of 60 square inches (152.4 cm). The spacing between the plates was .25 inches (6.4 mm), which was provided by using a .25 inch (6.4 mm) thick piece of plexiglas or spacer between the plates. The plates were held together by using two 6 - 32 x 3/8 inch nylon screws at the bottom corners, and two 6 - 32 x 1/2 inch nylon screws at the upper corners. The longer screws were used at the top to provide the electrical connections to the plates with 1/16 inch (1.6 mm) diameter titanium rods. The titanium rods were then connected to #18 copper wire which in turn was connected to the switching relays. The connections to the titanium rods were covered with silicone for waterproofing.

Electrical System

Power to the electrodes was supplied by two Kepco D.C. power supplies Model CK 18-3. The power supplies were kept in the voltage-limiting mode in order to provide a constant voltage to the electrodes. In the voltage-limiting mode, the current to the electrodes was allowed to vary.

The current to the electrodes was reversed approximately every five minutes in order to keep the plates free of any mineral deposition. The switching mechanism consisted of a 12 rph synchronous motor and a circular rotating disc, geared to 6 rph, which was in contact with on-off switches. The discs had a total cycle of 10 minutes and were set so that the maximum time the switch was on or

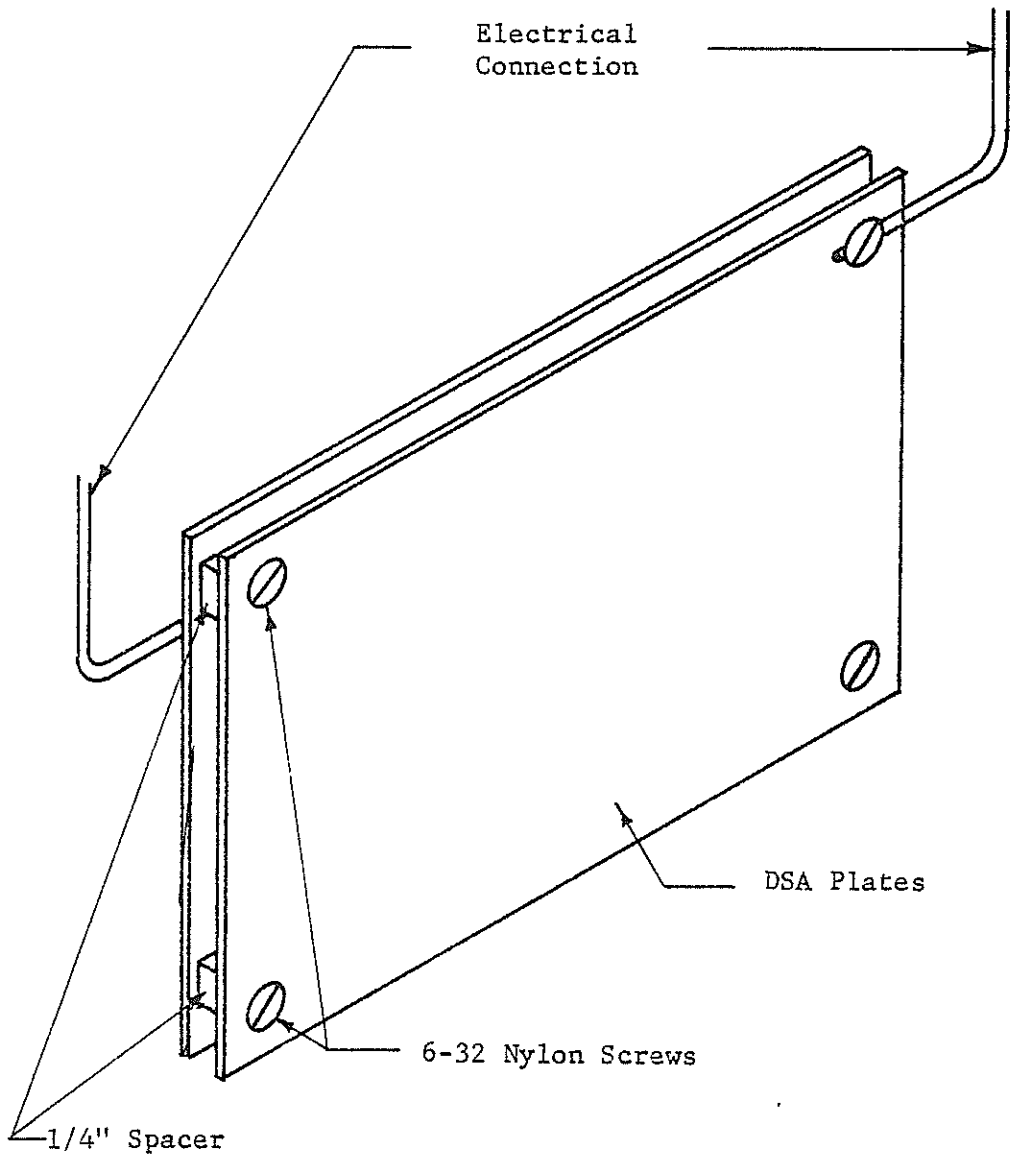


Figure 17. DSA Electrode.

off was five minutes. The switches were connected to 12 volt D.C. double pole relays to which the power supplies and electrodes were also connected. By turning the relays on and off the current to the electrodes was reversed.

Operational Conditions

The Septic Tank - Septic Tank Extender system used in this research was operated for a period of approximately 18 months of which the first 14 months were required for construction of the tank system, start up and working out of operational problems.

The temperature of the system was $77^{o} \pm 2^{o}F$ ($25^{o} \pm 1^{o}$ C). The temperature was controlled by room temperature conditions.

The septic tank was fed daily, usually in the late afternoon, 1 liter of primary sludge, which was calculated to be the equivalent of 1 person per day based on the COD being equal to two times the BOD and .17 pounds BOD per person per day.

The electrodes were run at 10 volts D.C. and a minimum of 2.25 amperes. This provided the electrodes with a current density of 37.5 mA per square inch (1.48 mA per square centimeter). When the current in one or both of the electrodes fell below 2.25 amperes, they were removed and physically cleaned of any depositions. Upon cleaning, the electrodes were replaced and the current once again rose above 2.25 amperes.

Operation of System

The system was put into operation in October of 1977. The septic tank was seeded with 5 gallons (18.93 liters) of primary sludge and filled with water. In the septic tank extender, an

electrode measuring 6 x 15 inches (15.24 x 38.10 cm) was placed.

The first electrode consisted of three plates; a DSA anode, steel grid cathode, and a titanium cathode for cleaning purposes (Figure 18). For removal of the deposition on the steel grid, the grid was made the anode and used with the titanium cathode. The reason for this was that the information available on the DSA electrode led us to believe that it (DSA) could not withstand reversal of current. The electrode was cleaned daily, once in the morning for five minutes, and once in the evening for an additional five minutes.

The use of the three-plate electrode had excellent bubble production and acceptable COD reduction. There was, however, the problem of deposition on the steel grid plate. Even with the reversal of current to the plate twice daily, there was an increase of deposition from day to day, and the plate had to be cleaned by hand every three to four days. Due to the tendency of steel to decompose when used as an anode, the cleaning cycle was kept to what was thought to be a reasonable time period without inducing too much damage to the plate.

Since the electrode was most important to the research, a more suitable electrode had to be found.

The suitable electrode was an electrode which had to meet the following criteria:

(1) must be capable of withstanding current reversal;

(2) must clean itself of deposition;

(3) have sufficient current density to have good bubble

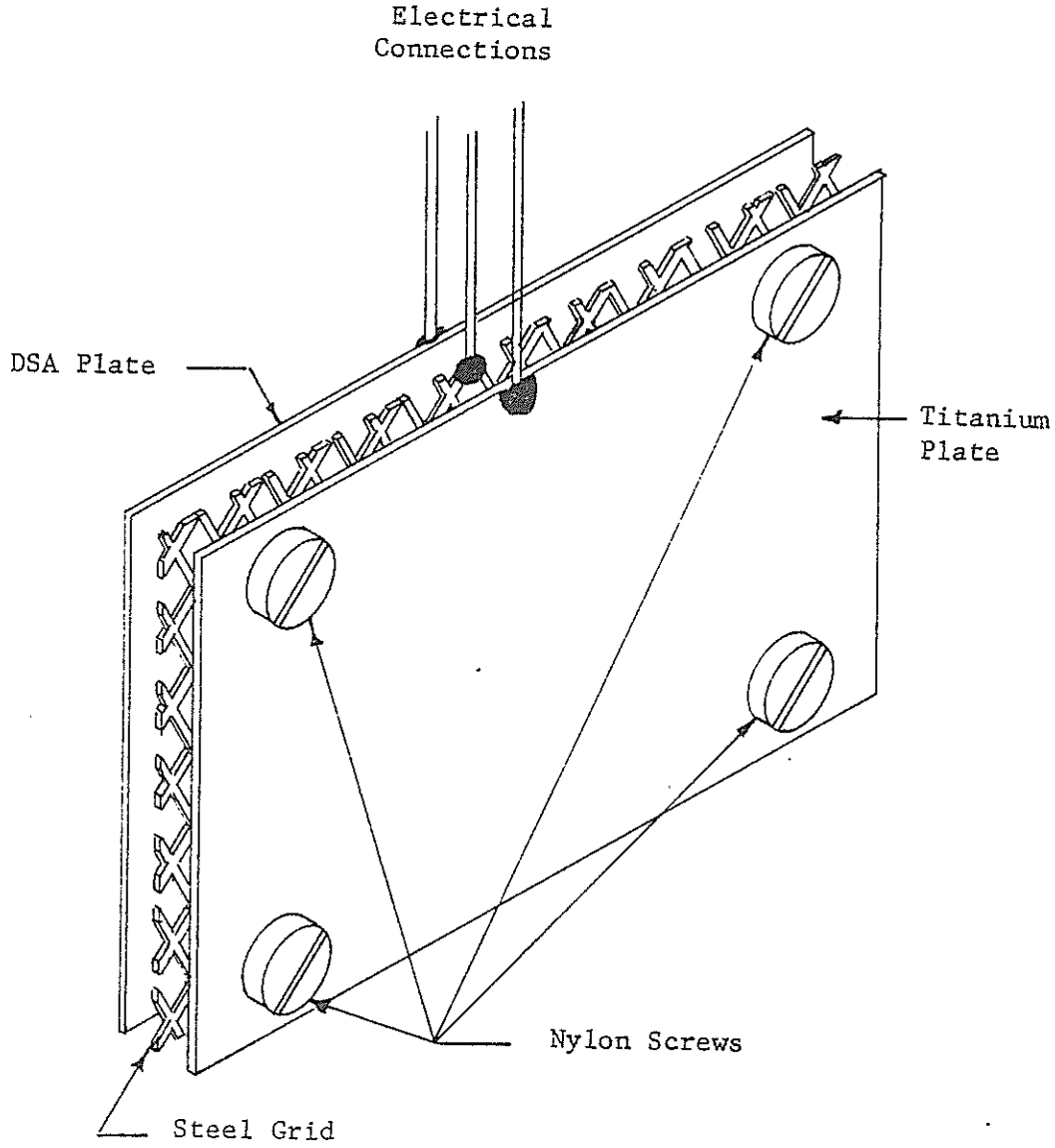


Figure 18. DSA - Steel Grid-Titanium Electrode.

production.

In order to find a more suitable electrode, four different electrodes were studied, the four being:

(1) DSA - titanium wire (DSA - anode);

(2) Lead dioxide - lead (lead dioxide anode);

(3) DSA electrode (DSA anode and cathode);

(4) Tin oxide (tin oxide anode and cathode).

Two of the electrodes (the DSA-titanium wire and the lead dioxide-lead) were tested in the septic tank extender. The other three were tested in a 2 x 2 x 3 foot (.61 x .61 x .91 meter) tank constructed of one-half inch (1.27 cm) plexiglas.

DSA - Titanium Wire. This electrode was constructed of a 6 x 10 inch (15.24 x 25.40 cm) DSA plate for the anode and several titanium wires for the cathode (Figure 19). This electrode was operated under the same conditions as the three-plate electrode originally used. The only difference was that the anode was used as a cathode during the cleaning cycle.

The use of this electrode was found to be unsuitable because the cathode was not self-cleaning. There was a constant build up of deposition on the wires. Upon cleaning of the wires, there also appeared to be some decomposition of the wires. The DSA plate showed no unusual wear due to the reversal of current. This led to the idea of the DSA-DSA electrode.

Lead Dioxide - Lead. The electrode was made from the plates of an ordinary 12-volt automobile battery. Hemphill and Rogers (24) used this same type of electrode for their research and

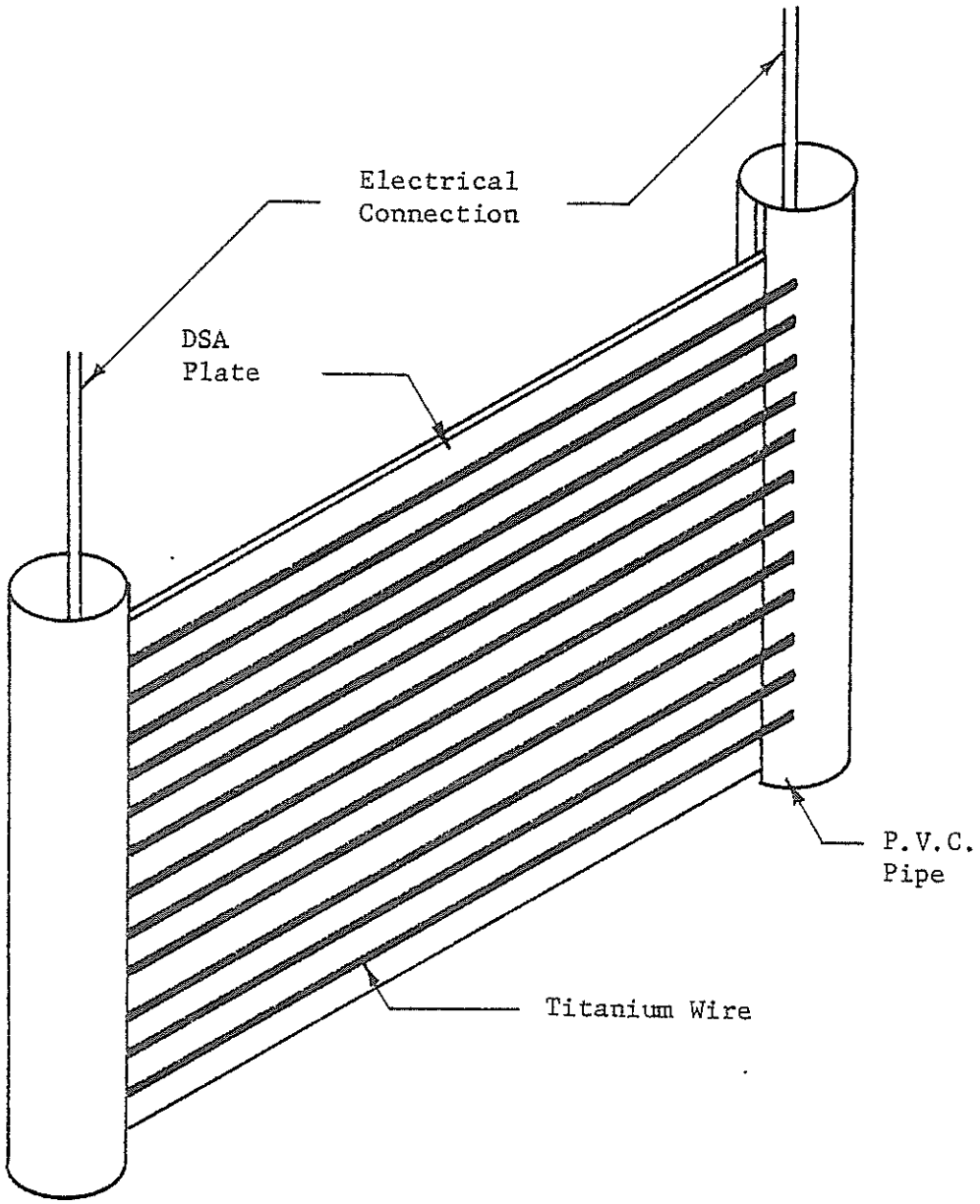


Figure 19. DSA - Titanium Wire Electrode.

reported satisfaction with the electrodes.

The use of the lead dioxide - lead electrode was unsatisfactory due to poor electrolysis of the water.

Tin Oxide. The tin oxide plates used in this electrode were developed by Corning Glass Works and were supposed to be able to take current reversal without decomposition. There were two sets of this type that were studied. The first one was made of 1 x 1 x 10-inch (2.54 x 2.54 x 25.40 cm) bars of tin oxide. The second electrode was made of 1 x 10 x 10-inch (2.54 x 25.40 x 25.40 cm) plates.

This type of electrode was found to be unsuitable because of the following reasons:

(1) The electrode material was heavy and hard to handle. The electrode made of the two bars weighed approximately 4.5 pounds (2.04 kg) and the electrode made of the plates weighed approximately ten times as much.

(2) The tin oxide could not be cut, drilled or soldered by equipment available.

(3) Last but most important, it had a very low current density.

This electrode did, however, resist decomposition at low voltages and currents. At high voltages and currents, the material flaked off when the current was reversed.

DSA Electrode. This electrode was constructed of two 3 x 6 inch (7.64 x 15.24 cm) DSA plates after the use of the DSA-titanium wire electrode showed that the DSA electrode was capable of withstanding current reversal without decomposition.

The DSA electrode was suspended along with the tin oxide electrode in the plexiglas tank and observed for a period of six months. The DSA electrode was cleaned twice daily for five minutes at a time. This was later changed to having the current reversed every five minutes with a switching mechanism because the twice daily cleaning cycles allowed for build up of deposition on the plates.

With the current reversal every five minutes, there was still deposition on the plates but it was limited to the outside of the plates. The inside surface of the plates remained free of any deposition and showed very little sign of wear due to current reversal over the six months of operation.

The ability of this electrode to take current reversal and also being able to remain free of deposition on the inside of the plates led to it being chosen as the electrode to be used in the research.

Upon completion of the electrode testing, one of the DSA electrodes was placed in the septic tank extender and run for a period of two weeks. At the end of the two-week period, there was no improvement of the CODs. The D.O. level of the extender unit was found to be approximately one part per million. At this time, a second electrode of the same size was placed in the extender and the feeding rate was cut back to one liter of sludge per day.

Substrate

The substrate used in this research was primary sludge from the primary clarifiers of the Las Cruces Municipal Wastewater Treatment Plant. The primary sludge was collected approximately

every ten days in two five-gallon (18.93 liters) plastic carboys. The carboys were then refrigerated at 37.4°F (3°C).

Sampling

Sampling of the treated effluents from the septic tank and septic tank extender was done on the grab sample basis. Samples were taken daily usually in the morning. Samples were taken below the outlet pipes.

Analytical Procedures

The following analytical procedures were used in monitoring the system.

Total COD. Total COD determinations were made following the procedure for the test as outlined in Standard Methods for Examination of Water & Wastewater (33) which shall be referred to as Standard Methods.

Solids. SS and VSS determinations were made following the procedures outlined for the respective test in Standard Methods.

Coliform. Total and fecal coliform determinations were made using the Membrane Filter Method for the determination of coliform, as outlined in Biological Analysis of Water and Wastewater (34).

Dissolved Oxygen. D. O. profiles were made using the Yellowsprings oxygen meter Model 54A and D.O. probe Model 5739. The profile was made using the following procedure:

(1) Oxygen meter and probe were calibrated by the air calibration procedure outlined in the instruction manual for Model 54A oxygen meter (35).

(2) Dissolved oxygen was measured along one radius of the tank at distances of 2 inches (5.08 cm), 5 inches (12.70 cm), 8 inches (20.32 cm) and 11 inches (27.94 cm) from the edge of the tank and at the following depths measured from the water surface: 6 inches (15.24 cm), 12 inches (30.48 cm), 18 inches (45.72 cm), 24 inches (60.96 cm), and 27 inches (68.58 cm).

It was assumed that the dissolved oxygen was uniform throughout the tank as to the values measured at specific distances from the edge of the tank and depths from the water surface.

Chemical Water Analysis. Nitrate (+ Nitrite), ammonium, total N, orthophosphorus, total phosphorus, boron, sulfate, extension irrigation test (domestic plus), Hg and Pb, were determined by the N.M.S.U. Department of Agronomy, Soil, Plant and Water Testing Laboratory following the procedures outlined in Methods for Chemical Analysis of Water and Wastes (36) and Diagnosis and Improvement of Saline and Alkaline Soils (37).

Testing Frequency

The analytical tests described above were performed with the following frequency:

(1) Total COD determinations were performed on a daily basis.

(2) VSS and SS determinations were each performed three times a week.

(3) Total and fecal coliform determinations were each performed once a week.

(4) D. O. profiles were performed three times a week.

(5) Nitrate (+ Nitrite), ammonium, total nitrogen, ortho-phosphorus and total phosphorus each were performed once a week.

(6) Mercury, lead and boron determinations were each performed for three consecutive days to determine reduction of each through the system.

(7) Sulfate and extension irrigation test (Domestic Plus) determinations were each performed three times throughout the testing period.

RESULTS AND DISCUSSION

Chemical Oxygen Demand

The total COD was the main criteria for the determination of the system's performance. Total COD determinations were made on the septic tank effluent and the septic tank extender effluent. Total COD concentrations of the two effluents are shown in Table 4. The septic tank effluent concentrations varied between 104 - 319 mg/liter with an average of 150 mg/liter; while the septic tank extender concentrations varied between 20 and 95 mg/liter with an average of 52 mg/liter. The high COD concentrations in the septic tank effluent were due to high concentrations of suspended solids in the effluent because of sludge build up in the septic tank. The total COD removal efficiency of the system, with an average power input to the Septic Tank Extender Unit of 47.4 watts, averaged 63 percent.

Solids

The solids analysis consisted of determinations of suspended and volatile suspended solids. The solids concentrations for the septic tank and Septic Tank Extender Unit effluent are given in Table 5.

The suspended solids concentrations in the septic tank varied from 15 - 164 mg/liter with an average of 52 mg/liter, while concentrations in the Septic Tank Extender Unit varied from 0 - 29 mg/liter with an average of 11 mg/liter. The average suspended solids removal efficiency was 74 percent. The reason for this high removal efficiency is that there was settling of the suspended solids in the Septic Tank

Table 4. Chemical Oxygen Demand.

Septic Tank Effluent (mg/l)	Septic Tank Extender Effluent (mg/l)	Percent Reduction (%)	Power Input (Watts)
141	88	38	43.6
168	92	45	43.5
194	81	58	43.6
104	52	50	41.0
152	76	50	40.3
151	88	42	44.8
104	76	27	43.1
174	73	58	45.3
118	25	79	53.6
143	37	74	53.1
154	60	61	56.0
159	37	77	49.5
195	41	79	47.1
138	45	67	49.3
162	40	75	47.8
121	49	60	48.0
144	36	75	48.9
126	41	68	47.5
126	24	81	47.3
163	37	77	47.8
126	45	64	48.3
304	44	86	47.6
166	40	76	47.0
141	56	60	48.3
129	44	66	47.3
125	44	65	47.0
108	80	26	50.0
133	76	43	51.5
107	95	11	51.5
110	33	70	-
171	20	88	48.5
121	38	69	48.5
179	58	68	47.1
133	36	73	46.0
319	56	82	48.0
128	48	63	47.0
196	40	80	47.0
112	36	68	46.3
159	44	72	47.0
124	40	68	48.3
142	53	63	45.5
129	60	53	45.0
150 Avg.	52 Avg.	63 Avg.	47.4 Avg.

Table 5. Suspended and Volatile Solids

Septic Tank Effluent		Septic Tank Extender Effluent		Percent Reduction		
SS (mg/l)	VSS (mg/l)	SS (mg/l)	VSS (mg/l)	SS (%)	VSS (%)	
30	27	14	14	53	48	
47	24	19	17	60	29	
49	41	22	22	55	46	
48	48	24	24	50	50	
108	42	3	3	97	93	
60	44	14	14	77	68	
38	38	12	12	68	68	
62	19	20	18	68	5	
53	37	29	29	45	22	
37	21	0	0	100	100	
36	33	8	8	78	76	
65	49	23	23	65	53	
20	20	3	3	85	85	
48	36	11	11	77	69	
36	30	4	4	89	87	
38	31	3	3	92	90	
15	15	9	9	40	40	
164	118	-	-	-	-	
50	43	5	5	90	88	
33	33	0	0	100	100	
34	30	24	24	29	20	
41	33	11	11	73	67	
44	36	9	9	80	75	
29	19	20	20	34	0	
61	61	14	14	77	77	
35	35	6	6	83	83	
137	100	10	10	93	90	
71	59	5	5	93	92	
28	28	2	2	93	93	
48	34	3	3	94	91	
45	45	9	9	80	80	
52	40	11	11	74	67	Avgs.

Percent Organic (of Total)

77% 100%

Extender Unit. This was shown to be the case when the septic tank extender had to be cleaned because settled solids were causing anaerobic conditions, and the solids were being suspended by the mixing in the tank. Upon removal of the solids from the septic tank extender, the system returned to normal operation.

Volatile suspended solids of the septic tank were found to average 77 percent of the suspended solids. In the Septic Tank Extender Unit, the volatile suspended solids were found to be 100 percent of the suspended solids. Therefore, all of the nonorganic matter was removed in the Septic Tank Extender Unit, most likely by settling or deposition. The average reduction in volatile suspended solids was 67 percent.

Nitrogen

In the Septic Tank Extender Unit, nitrogen removal was expected to take place by biological nitrification with Nitrosomonas and Nitrobacter. The Nitrosomonas would oxidize ammonia to nitrite and the Nitrobacter would oxidize the nitrites to nitrates by the following equations (10, 38):

$$\text{Organic N} \xrightarrow[\text{decomposition}]{\text{bacterial}} NH_3 + \text{energy}$$

$$NH_4^+ + 1.5O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2H^+ + H_2O + \text{energy}$$

$$NO_2^- + 5O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- + \text{energy}$$

$$NO_3^- \xrightarrow[\text{denitrification}]{\text{bacterial}} N_2 + \text{energy}$$

Table 6 shows the nitrogen concentrations for the septic tank and Septic Tank Extender Unit. The nitrate (+ nitrite) nitrogen concentrations showed that the Septic Tank Extender Unit had slightly

Table 6. Nitrogen Analysis.

NH_4 - N		Organic Nitrogen		$NO_3^- + NO_2^-$ - N	
mg/l		mg/l		mg/l	
STE	STEU	STE	STEU	STE	STEU
5.85	2.95	4.57	3.19	.01	.03
5.25	3.00	2.17	4.42	.01	.01
6.62	5.38	3.13	1.93	0	1.99
4.20	4.25	1.57	4.90	.01	.01
3.90	5.50	2.74	2.15	.16	.24
5.80	7.00	2.70	0.60	.01	.04
5.00	5.80	2.70	2.10	.07	.15
4.95	7.80	1.43	-	0	.05
6.75	6.70	0.23	-	.15	.37
7.12	6.95	1.28	0.74	.10	.07
2.60	3.35	0.86	2.01	.02	.50
3.10	3.95	5.20	8.43	.01	.40
4.00	4.80	1.17	0.36	.01	.02
5.01	5.90	2.29	2.80	.04	.16 Avgs.

higher concentrations than the septic tank as would be expected. The nitrate nitrogen concentrations in the septic tank effluent varied from 0 to 0.16 mg/liter with an average of .04 mg/liter. The septic tank extender effluent concentrations ranged from .01 to .50 mg/liter with an average of 0.16 mg/liter. The concentrations of ammonium and organic nitrogen were also found to be higher in the septic tank extender. The ammonium ranged from 2.60 to 7.12 mg/liter with an average of 5.01 mg/liter for the septic tank and from 2.95 to 7.8 mg/liter with an average of 5.90 mg/liter for the septic tank extender. The organic nitrogen concentrations ranged from .23 - 5.20 mg/liter for the septic tank with an average of 2.29 mg/liter, while the septic tank extender ranged from 1.36 - 8.43 mg/liter with an average of 2.80 mg/liter. The increase in the nitrogen concentrations in the septic tank extender was due to the release of nitrogen by the anaerobic digestion of the sludge which accumulated in the bottom of the Septic Tank Extender Unit. This was also the method by which the phosphorus concentrations were increased in the septic tank extender. The septic tank effluent ammonium nitrogen concentrations were found to be approximately 69 percent of the total nitrogen, while in the septic tank extender it was found to be approximately 82 percent of the total nitrogen. The organic nitrogen was 31 percent of the total for the septic tank effluent and 18 percent of the total nitrogen for the septic tank extender effluent.

Phorphorus

Phosphorus, along with nitrogen, is considered a key element in causing water fertilization which brings about the eutrophication

of lakes and streams (39, 40). Most of the phosphorus found in the septic tank is in the form of orthophosphate and comes from human excreta and synthetic detergents.

Table 7 shows the concentrations of phosphorus in the septic tank effluent and the septic tank extender effluent. Approximately 85 percent of the total phosphorus from the septic tank effluent is in the form of orthophosphate and 82 percent of the septic tank extender effluent is in the form of orthophosphate. There were no significant changes in the concentrations of phosphorus in the system, although it was believed that the deposition caused by the electrolysis process would reduce the phosphorus concentrations. This might make up for the 3 percent reduction in orthophosphate in the septic tank extender. The lack of removal was due to the fact that most phosphorus removal is accomplished by chemical coagulation, biological coagulation, or the combination of the two methods.

Bacteriological Examination

Coliforms in water are considered indications of the possible presence of pathogenic enterobacteria plus other enteric pathogenic bacteria and viruses. Coliforms are widely distributed in nature and many are native to the gut of warm-blooded animals and man.

The total coliform count for the system showed a 73 percent reduction in the septic tank extender, while the fecal coliform showed an 88 percent reduction (Table 8). The values of total coliform in the septic tank effluent and septic tank extender effluent are

Table 7. Phosphorus Analysis

Septic Tank Effluent (mg/l)		Septic Tank Extender Effluent (mg/l)		
Total P	Ortho P	Total P	Ortho P	
2.24	1.40	2.08	1.16	
1.68	1.32	1.68	1.30	
1.68	1.24	1.44	1.24	
1.28	1.18	1.68	1.26	
1.11	1.08	1.23	1.14	
1.28	1.16	1.48	1.18	
1.35	1.16	1.62	1.04	
1.41	1.20	1.71	1.56	
1.47	1.32	1.53	1.50	
1.75	1.50	1.50	1.35	
.99	.96	1.17	1.14	
1.02	1.02	1.05	.90	
1.11	1.06	1.28	1.20	
1.41	1.20	1.50	1.23	Avgs.
Percent of Ortho P to Total P				
85		82		

Table 8. Bacteriological Examination

Total Coliform (#/100 ml)		Fecal Coliform (#/100 ml)		Percent Reduction		
*STE	+STEU	STE	STEU	Total Coliform	Fecal Coliform	
12000	5400	5100	40	55	99	
25300	9400	-	-	63	-	
18500	5000	6850	-	73	-	
15000	3700	6400	1200	75	81	
15000	2800	6300	1400	81	78	
15000	-	6800	620	-	91	
18700	3500	11000	1400	81	87	
20700	3000	19300	1700	86	91	
17525	4567	8821	1272	73	88	Avgs.

* STE - Septic Tank Effluent

\+ STEU - Septic Tank Extender Unit Effluent.

considered to be low because the primary sludge used as the substrate was refrigerated until it was needed, and there might have been some die-off during the refrigeration. There was also the problem of bad counts due to contamination. This was the reason for the missing data in Table 8. The method used was the Millipore Method for the determination of total and fecal coliform. This method was used over the MPN Method because of its ease and the shorter amount of time required.

Heavy Metals

Heavy metals were introduced to the septic tank in order to determine if there would be a reduction in heavy metals through the septic tank extender.

There were three heavy metals introduced to the system: mercury, lead and boron. The metals were introduced by dissolving 1 gram each of boric acid, mercuric chloride, and lead acetate into three liters of distilled water. The solution was then introduced to the septic tank. Table 9 shows the initial concentrations introduced and the results for 3 consecutive days.

The initial concentrations of mercury, lead and boron were 167, 142 and 37.5 mg/liter, respectively. At the end of the first day, the concentrations in the septic tank effluent were Hg - .316 mg/liter, Pb - .268 mg/liter, and B - .33 mg/liter, or over 99.8 percent removal in the septic tank itself. This meant that the removal was accomplished by capture of the heavy metals in the sludge. The average reduction through the septic

Table 9. Heavy Metals

	Mercury (mg/l)			Lead (mg/l)			Boron (mg/l)		
	*STE	+STEU	% Reduction	STE	STEU	% Reduction	STE	STEU	% Reduction
Initial		167			142			37.5	
Day									
1	.316	.082	74	.268	.093	65	.33	.17	48
2	.086	.041	52	.060	.036	40	.13	.18	-
3	.027	.013	52	.045	.009	80	.08	.13	-
Average			59			62			48
Reduction in Septic Tank		>99%			>99%			>99%	

* STE - Septic Tank Effluent

+ STEU - Septic Tank Extender Unit Effluent

tank and the septic tank extender was 59 percent for mercury, 62 percent for lead and 48 percent for boron. The boron showed an increase in concentrations for the last two days, but the concentrations were so small that the accuracy of the analytical procedures are in question. Reduction in the septic tank extender of the heavy concentrations was also believed to have been aided by the settling of solids in the Septic Tank Extender Unit.

Mineral Deposition

The mineral deposition on the plates of the electrodes was analyzed to determine the major constituents. The results are shown in Table 10. The deposition was found to have as its major constituent calcium, which made up an average of 19.08 percent of the deposition, and not sodium as Beck et al. (19) reported. The calcium was believed to be in the form of calcium carbonate. The other constituents were found to be sodium at 3207 mg/liter, magnanese at 286 mg/liter, phosphorus at 282 mg/liter, zinc at 276 mg/liter and iron at 159 mg/liter. These concentrations were based on dry weight of the deposition.

Dissolved Oxygen

Dissolved oxygen profiles were run to determine the dissolved oxygen concentrations at different depths and distances from the edge of the Septic Tank Extender Unit. The average dissolved oxygen concentrations are shown in Figure 20.

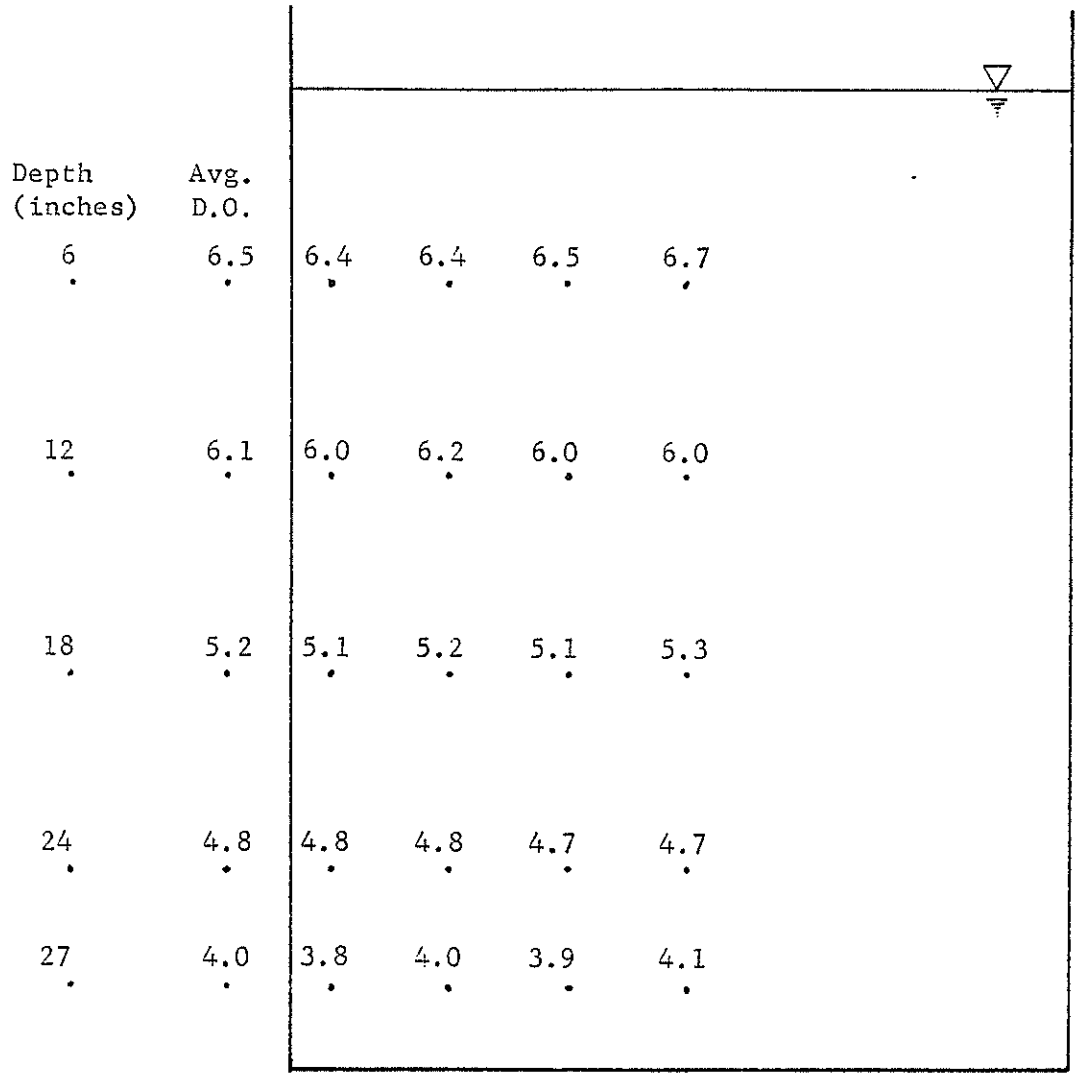
The profile shows that the dissolved oxygen decreased as

Table 10. Mineral Deposition on Electrode +

	Fe	Mn	Zn	P	Na	% Ca	$\%CaCo_3$ (equiv)*
	- - - - - - - mg/l - - - - - - - -						
#1	160	280	276	276	3127	20.61	approx. 100
#2	157	292	276	288	3287	17.56	
Average	159	286	276	282	3207	19.08	

+ Based of Dry Weight.

* Method Not Accurate for this High Concentration.



Avg. Saturated D.O. = 7.3 mg/1

Figure 20. Dissolved Oxygen Profile in Septic Tank Extender Unit. (For explanation see pages 55 and 56.)

depth increased. The D.O. for each depth was found to be fairly consistent. The oxygen levels went from an average of 6.5 mg/liter at six inches (15.24 cm) below the water surface, to an average of 4.0 mg/liter at a depth of 27 inches (68.58 cm). It was noticed during the duration of the research that the dissolved oxygen became critical at approximately 2 mg/l, and the conditions went anaerobic below this value. The fall in dissolved oxygen was caused by an increase in solids from the septic tank effluent or a buildup of solids in the septic tank extender that became suspended by the mixing in the tank.

Effluent Analysis

The analysis of the effluents is shown in Table 11. The analysis was performed to determine the effects of the electrolysis on the effluents. In the first analysis there was a large increase in sulfates in the septic tank extender. This was most likely due to oxidizing of the hydrogen sulfides, produced by anaerobic bacteria, to sulfates by the oxygen. In the first analysis, the sulfates were increased by 2.5 times in the septic tank extender. In the second analysis the sulfates showed a decrease in concentration. There was also a marked increase in chloride in the second analysis, from 95.7 mg/liter in the septic tank, to 126.9 mg/liter in the septic tank extender, an increase of about 25 percent. This is suspected to be due to the deposition of the sodium on the electrodes which would free chloride ions.

Cost

The cost of this treatment was determined on the basis of

Table 11. Analysis of Wastewater.

		pH	EC mmhos	Ca	Mg	Na	K	Cl	CO_3	HCO_3	SO_4	TDS
				mg/l								
STE	#1	7.23	.59	49.7	9.8	44.1	6.2	46.8	0	211.1	28.8	456
	#2	6.88	.87	84.6	15.9	46.2	7.0	95.7	0	173.3	63.4	560
STEU	#1	7.30	.58	50.3	10.1	44.1	6.2	47.2	0	202.6	62.4	416
	#2	7.18	.98	92.2	18.4	58.4	7.4	126.9	0	276.0	51.6	624

STE - Septic Tank Effluent

STEU - Septic Tank Extender Unit Effluent

the amount of electrical power used by the electrodes. The cost analysis was limited to the additional cost per month to the individual to his or her electrical bill. The cost of the installation of the Septic Tank Extender Unit to an existing septic tank system, the cost of building of a new septic tank-septic tank extender system, or the cost of the electrodes was not determined due to the many factors that would be involved in such an analysis.

The cost estimation was based on the residential rate of 4.48 cents per kilowatt-hour. This rate was used because the average household was assumed to consume approximately 200 kilowatt-hours per month (See Appendix; Cost Estimations) without the electrodes. The power consumed by the electrolysis process was what was required for one person, based on the BOD loading to the septic tank. The average power consumed per month was 34.2 kilowatt-hours.

The estimated additional cost to the homeowner for tertiary treatment of septic tank effluent by electrolysis was $1.53 per person per month.

When analyzing the data, there are two factors that must be kept in mind: (1) The substrate that was used to feed the septic tank was primary sludge and not the normal domestic wastes that would be found entering a septic tank system; (2) The system that was used was a model system, and the septic tank was prone to solids plugging and solids overflow to the Septic Tank Extender Unit. The plugging and solids overflow was due to

overloading in the septic tank and led to reduced performance of the septic tank system.

CONCLUSIONS

The objective of this study was to determine the design parameters for the tertiary treatment of septic tank effluent by electrolysis. The main criteria for the evaluation of the tertiary treatment was the determination of total COD reduction, although there were other analyses performed.

The tertiary treatment of septic tank effluent by electrolysis was found to be an effective, low maintenance method of meeting the ever-increasing demands for improvement in the treatment of domestic wastewaters in rural communities.

The treatment was evaluated on a loading of one liter per day of primary sludge. This loading rate was equivalent to one person per day. From the determination of the total COD, which averaged 63 percent, the reduction in COD was found to be dependent on the total electrode area available and the power input to the electrodes. For this study, the electrode area that was required for an acceptable COD reduction was 240 square inches (1548.4 cm^2) per person at an average power consumption of 47.4 watts. This was estimated to cost the individual an additional $1.53 per month in power consumption. From the above information, it was concluded that the design of tertiary treatment must be based on one parameter, the area of the electrode available. For this study, this parameter was 240 square inches (1548.4 cm^2) per person. The life of the DSA electrodes used has to date not been determined. After approximately two months of continuous use, the DSA electrodes have shown very little sign

of wear or deterioration, although it was determined that use at high ampere levels was detrimental to the electrode.

The COD reduction efficiency could be increased by increasing the electrode area. Treatment would also be improved if the method were actually used in a septic tank system where the detention time, in the Septic Tank Extender Unit, would be a minimum of 24 hours with actual detention time being longer. The life and effectiveness of the drain field would also be improved due to the aerobic conditions that the septic tank extender effluent would maintain in the soil of the drain field.

The power consumption and electrode area could also be reduced if an electrode that had a higher conductivity and operated at a higher current density was used. This could be accomplished with the present electrodes if they could be sandwiched between a better electrical conductor, such as copper.

The conclusions made about the study were that the tertiary treatment of septic tank effluent by electrolysis is:

(1) applicable to any septic tank system;

(2) applicable to rural communities that are too small for community sewerages or where the cost of such sewerages is too high;

(3) a method by which septic tanks can possibly be used, where they were previously unsuitable;

(4) an effective method of reducing the potential of ground water contamination based on bacteriological examination.

(5) capable of meeting EPA standards for wastewater discharge (BOD);

(6) capable of prolonging the life of the drain field by prevention of clogging by ferrous sulfide, by minimizing biological clogging, and by maintaining aerobic conditions in the soil.

(7) attractive to the home owner due to its low maintenance requirements.

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APPENDIX

COST ESTIMATION

Power Input	47.4 watts (.0474 KW)
Power Input Per Day	.0474 KW x 24 hr/day = 1.14 $\frac{\text{KWH}}{\text{day}}$
Power Input Per Month	1.14 $\frac{\text{KWH}}{\text{day}}$ x $\frac{30 \text{ days}}{\text{month}}$ = 34.2 $\frac{\text{KWH}}{\text{month}}$
Cost of Power Per KWH	$.0448 per KWH
Cost of Treatment	34.2 $\frac{\text{KWH}}{\text{month}}$ x $\frac{\$.0448}{\text{KWH}}$ = $1.53/month

Cost of Power to Residential Customers*

First 50 KWH	$4.13 Minimum Charge
Next 150 KWH	4.8 cents per KWH
Next 600 KWH	4.48 cents per KWH
All Additional	3.7 cents per KWH

Does not include tax and fuel adjustment cost.

* Cost from El Paso Electric Company, Mesilla Valley Division.