SANITARY LANDFILL LEACHATES

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CHAPTER I

INTRODUCTION

Water is a basic requirement for the growth and development of modern society. Quality of water is important from the health point of view. Today, water supplies are continuously polluted by various pollutants one way or another. In ground water, these pollutants are transmitted by water from one part of the ground to the other.

The accumulation and disposal of solid waste is another growing problem. The methods of disposal of these solid wastes are among the most challenging current national problems which are now receiving nationwide attention.

The sanitary landfill is one of the approved methods for disposal of solid wastes (1). Solid waste consists of garbage, refuse and other discarded solid materials resulting from industrial, agricultural and domestic operations. It is estimated that 900 million pounds of solid waste of all types are produced in the United States every day (2), or 4.5 pounds per capita per day (3). Research on the treatment of leachate resulting from landfill is one of the least investigated problems of ground water pollution. Most of the disposed waste will come in contact with ground and surface water. Leachate resulting from landfill sites and other solid waste disposal facilities will contact ground water and consequently pollute it. It has been concluded that solid waste can pollute water, but the interrelationships and factors that determine the extent and degree of pollution are not well defined.

The sanitary landfill has been recommended for large and small communities by most of the state health departments. Sanitary landfills have low operating and capital cost, simple and flexible operation, and an ability to accommodate all types of materials without need for separate collection (4). With efficient storage and collection, this method will prevent diseases and greatly improve environmental sanitation conditions in a community (5). It is also an effective method of permanent disposal of all types of non-salvageable refuse (6). Experience has indicated that where suitable land is available this method of refuse disposal is economical and has a definite value for the reclamation of useless land.

Solid waste disposal with its influencing role in both water and air pollution is becoming of increasing concern because of the growing magnitude and complexity of urban environmental pollution problems. This problem must be solved efficiently so that air and water pollution resulting from solid waste will be prevented or completely stopped.

The purpose of this research was to determine the pollutional characteristics of the leachate obtained from a sanitary landfill. The characteristics and rate of decomposition at four different rainfall intensities were studied.

CHAPTER II

LITERATURE REVIEW

Solid Waste

Solid waste consists of putrescible and non-putrescible materials. It includes garbage, rubbish, ashes, incinerator residues, street cleansings and industrial and agricultural wastes. Municipal wastes chiefly contain garbage, rubbish and other decomposable organic refuse. It includes empty tin cans, metals, paper and paper products, cloth and clothing, wood and wood products, lawn clippings, hair, hide and bones, small dead animals, roofing paper and tar paper, market refuse, etc., (7). This solid waste ultimately comes in contact with the land in a dump or in a sanitary landfill or by simply placing the waste on or in the ground. From this we are faced with the possibility of contaminated water (8). Directly or indirectly, surface water and ground water supplies are contaminated through disposal of solid waste (9).

Disposal Methods of Solid Waste

There are four methods (10) used to dispose of refuse on land. A discussion of each follows.

1. Open Dumping

Open dumping is the process in which all of the refuse or all of the separate classes of refuse are disposed of without any cover.

2. Controlled Dumping

This is a process of dumping and burning in which refuse is unloaded onto a prepared dirt bank, usually 12 feet high with a 40-degree slope. The refuse is evenly distributed by hook, and this prepared dump is ignited on the downwind edge.

3. Refuse Filling

In this method there is a systematic and periodic operation conducted to compact and cover the refuse. It is similar to a sanitary landfill except that equipment is not used daily and covered on a daily basis.

4. Sanitary Landfill

Sanitary landfilling is a method of disposing of refuse on land without creating nuisances or hazards to public health or safety. This is done by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation or at such frequent intervals as may be necessary (11). This is the most desirable land disposal method. Physical characteristics, biological quality and chemical composition of surrounding waters are affected by the quality and quantity of solid waste (7).

Sanitary Landfill Operation

The sanitary landfill operation is carried out by either the "Area Method" or the "Trench Method" (10). The "Area Method" is used where there are gulleys or low areas. The refuse is dumped in natural or excavated depressions, compacted with a tractor and then covered with earth hauled in or taken from the adjacent hillsides. The refuse is deposited and compacted in lifts from 6 to 10 feet in depth. A 2-foot minimum earth cover is placed on the finished fill. The "Trench" type of landfill is similar to the "Area" type except that the trench operation requires the excavation of a trench with a bulldozer or drag-line. After the trench or a portion of it is excavated, refuse is placed in it, compacted and then covered with earth taken from the trench. There is also a "Ramp Method" (7), in which man-made or natural depressions are filled. Such depressions include ravines, canyons or quarries. In this method, the refuse is deposited and spread in layers on an angle against the side of the ravine, canyon or quarry to a predetermined height (40 to 50 feet or higher). The choice of the type of landfill operation is often dependent upon the type of land available.

Decomposition

Very little is known about reaction rates, mechanisms, pathways, intermediate steps, and end products in ground water pollution. Ground water differs from surface waters in various ways including biochemical degradation (12). In ground water, the ratio of surface area of the soil to the quantity of flow is tremendous. This area-volume ratio influences the rate of biochemical action. Many of these reactions are faster under large surface area conditions. Detention periods are long and even the slower reactions may go to completion. Ground waters are often anaerobic and frequently under high pressure. The higher organisms found in ground water are readily removed by filtration through soil and consequently biochemical action may be limited to the lower forms of organisms or perhaps even to enzyme effects. Considerable biological action may occur in a landfill which can assist in achieving maximum refuse volume reduction (13). The progress of decomposition generally depends upon the physical nature of the fill material. In some cases BOD and solids content of the decaying matter have been determined and employed in the estimation of decomposition (14). Data of this type presented by Gerson Chanin (14) show that very good decomposition has been obtained. Thus decomposition is reflected by the lowering of the BOD, the percentage of volatile solids and the sulfide concentration. Inorganic solids and ash are not decomposed, but most organic solids are converted to gases and liquids.

The time required for the refuse to stabilize depends on a number of variables and cannot readily be predicted. Decomposition of the organic degradable materials present in the landfill is dependent on the moisture available, temperature, and the type of materials present in the landfill. Other important factors may be the age of the landfill and its degree of compaction (2). Smith (13) observed in the landfills he studied that the maximum temperature for the entire year was generally about 15^{o} F greater than the average daily air temperature. Temperatures in sanitary landfills, between 110^{o} and 190^{o} F have been observed by Merz (15). It was found that the landfill temperature also depends upon time and aeration (15).

The rate at which the material in the landfill is oxidized by microbial activity is a function of the level of available nutrients, temperature of the landfill and the amount and type of assimilable food (16). Merz (15) observed that fire hazards are minimized in aerobic landfill operations by controlling both the oxygen and carbon dioxide concentration, and the moisture content. The effective temperature observed by Merz in the landfill was between 110^{o} and 190^{o} F for aerobic decomposition. A high nitrogen content was also a characteristic of an aerobic landfill observed by Merz (15). Carbon dioxide, oxygen and nitrogen are the main gases found in aerobic sanitary landfills.

Ground and Surface Water Pollution by Landfills

Undesirable substances are introduced into ground water through dumps or sanitary landfills by different processes (17) such as: infiltration and percolation; refuse decomposition; gas production and movements; leaching and ground water travel. The amount of water that enters a refuse fill from the surface will be governed by the rate of water application, the nature of the refuse cover and the climatic conditions. In an area of high precipitation, the percolation of rainfall through a refuse fill has been observed and estimated. Water balances indicate that heavy irrigation and high precipitation may produce substantial percolation through permeable fills and dump covers. Percolation may be delayed for years if the moisture content of fills is high and if it is retained for a long time. Heat is liberated by decomposition and may accelerate evaporation. Three basic mechanisms are reported (17) to be responsible for imparting undesirable quality to ground waters. They include: (i) direct horizontal leaching of refuse by ground water; (ii) vertical leaching by percolating water; (iii) transfer of gases produced during decomposition by diffusion and convection. Contaminants may be found in either leachate or gas form.

Non-burnable or non-biodegradable materials present a potential pollution problem only if they can be dissolved and percolated (18). Glass, plastic, ceramics, stone, concrete and bricks do not pose a pollution problem.

There are a number of factors by which the actual path of travel of ground water is controlled. The major factors are: (i) the sequence and hydrologic properties of earth materials; (ii) the topography and elevation of the top of the zone of saturation; (iii) pumpage in the area. Ground water flows parallel to the slope of the ground surface and vertically. The vertical component is much less obvious than the horizontal component, but when there is an upward component to ground water flow, leachate from a waste disposal operation near the ground surface cannot move downward to pollute deeper water (2). Also, when a downward component of flow is present, the possibility of leachate moving downward to pollute the deeper water must always be considered.

Ground water contamination will increase with greater use of sanitary landfills. The generation and movement of water-borne contaminants in a sanitary landfill is dependent upon the landfill content, its spacial distribution, and the time variation of moisture within that landfill. Change in moisture storage is represented by the equation of continuity for any soil layer.

$$\Delta Q = Q - Q_o$$

where ΔQ = the change in moisture storage in that layer

Q = the moisture flow into the layer

Q_o = the moisture flow out of the layer.

Gas Production

Refuse contains mineral and organic substances in quantities capable of seriously damaging underground water supplies. The organic material will undergo aerobic and anaerobic decomposition and produce large amounts of gases. In sanitary landfills, decomposition is carried out by the degradation of decomposable organic materials by bacteria and other microorganisms. Decomposition of the organic material is facilitated both by the inherent moisture content of the sanitary landfill and by additional moisture from the surrounding soil seeping into the material (3). Gram (17) has represented the decomposable refuse by the empirical formula $CH_aO_bN_c$.

If oxygen is present, decomposition will be an aerobic process.

$$CH_aO_bN_c + \tfrac{1}{4}(4+a-2b-3c)O_2 \rightarrow CO_2 + \tfrac{1}{2}(a-3c)H_2O + CNH_3$$

In the absence of oxygen, decomposition will be an anaerobic process.

$$CH_aO_bN_c + \tfrac{1}{4}(4-a-2b+3c)H_2O \rightarrow 1/8(4-a+2b+3c)CO_2 + 1/8(4-a-2b-3c)CH_4 + cNH_3$$

Initially, since oxygen is available in the fill, decomposition will be aerobic. But as time passes and if diffusion and convection are not adequate, oxygen will be exhausted and anaerobic decomposition will start. Gases resulting from the decomposition of sanitary landfill materials include nitrogen, oxygen, carbon dioxide, hydrogen, methane and hydrogen sulfide (3, 10, 12, 15, 17, 18, 19, 20, 21, 23, 24). The gases produced by anaerobic decomposition are carbon dioxide, nitrogen, methane and hydrogen sulfide (12, 17, 20, 21). The concentration of methane depends upon the moisture content.

The mechanism of anaerobic fermentation in a landfill consists of two steps: (1) Carbohydrates are broken down to organic acid by various saprophytic organisms; (2) The organic acids are subsequently converted to carbon dioxide and methane. Cells are continuously produced and destroyed by metabolic processes. Most of the nutrients, the most significant being nitrogen, are cycled through successive generation of microorganisms. When proteins are broken down, nitrogen is released. The moisture content in a fill is of major importance because biological activity will not proceed without moisture.

Studies by Merz and Stone (20) to see the change in methane concentration in the anaerobic landfills under dry and moist conditions showed that the concentration of methane increased with an increase in moisture content. Methane varied from a little more than trace amounts in the landfill without water to that of a major component (greater than 50 percent) in saturated landfills. Methane gas also increased with time. The gases produced within an aerobic landfill consist of carbon dioxide and nitrogen. Hydrogen and hydrogen sulfide have not been found to any great extent in sanitary landfills. The gases produced within the landfill diffused laterally and vertically downward into the surrounding earth, as well as upward through the top cover. Investigations carried out by the California State Water Pollution Control Board (17) showed that carbon dioxide produced by decomposition of sanitary landfill materials can seriously degrade ground water by dissolving calcium, magnesium, iron and other substances which at high concentrations are undesirable. The carbon dioxide gas can account for carbonic acid in some leachates. Carbon dioxide may cause an explosion problem. Although very little information is available on the actual occurrence and movement of gases through the soil, and their relation to the quality of water in the upper fringe of the ground water table, it is known that these gases are diffused into the soil and come in contact with the ground water. Equilibrium is reached by Henry's law (13) and these gases are dissolved in the water. Thus chemical pollution of ground water can result from gas diffusion. Investigation made by Engineering Science, Inc. (18) on gas production and movement showed that the quality of water in a well 600 feet from a sanitary landfill was impaired due to the solution of carbon dioxide gas which resulted in increased hardness in the water. The source of carbon dioxide was from decomposing refuse in the sanitary landfill. Experimental results showed that the carbon dioxide concentration was 89.4 percent by volume approximately one month after completion of the fill. This possibly indicates a rapid decomposition of certain carbohydrates and other easily degradable constituents (18). Small amounts of carbon monoxide were also detected which nearly disappeared after two years of operation. With time the concentration of carbon dioxide and hydrogen decreased, but the methane concentration increased. It was estimated that 1.2×10^6 pounds per acre per year of carbon dioxide escaped to the atmosphere (19). The escape of carbon dioxide into the atmosphere is regulated by the effect of cover materials and thickness of the cover materials, the type of vegetation grown on the top of the cover, and the uses of the reclaimed land.

It has been indicated that the rate of movement of methane by diffusion or dispersion is considerably slower through soils with fine particles than through soils with coarser particles (7).

Compaction and Settlement

It has been shown that there was no significant difference in the degree of compaction in a sanitary landfill of refuse with water added in amounts ranging from 5 to 20 percent of the weight of refuse. After about 2 months of operation of a sanitary landfill, settlement of the material occurs. It was reported that a 20-foot depth test fill settled an additional 4 feet after one year (13). Merz and Stone (15) observed that in the first year the rate of settlement in the aerobic landfill was four times greater than the anaerobic landfill of comparable construction. Rogus (4) has reported that fills on marshy lands, in boggy areas, and in ponded or open waters will have greater settlement and higher rates of settlement due to accelerated decomposition, possible leaching action, and sub-surface subsidence. As a rule about 90 percent of the total settlement occurs in the first two to five years.

Use of Completed Site of Sanitary Landfill

There are a number of uses of completed sanitary landfill sites. Ultimate use of reclaimed sites (5, 7) are: (i) athletic fields, (ii) botanic gardens, (iii) golf courses, (iv) golf driving ranges, (v) parks, (vi) parking lots, (vii) playgrounds, (viii) salvage and storage yards, (ix) commercial and industrial buildings, and (x) trailer parks.

Features of Refuse Fills

There are certain features which are common to all types of refuse fills (4). Following is a discussion of the main features of all sanitary landfills.

1. Refuse

All types of materials can be disposed of in fills. Segregation or separate collection of materials is not necessary. Quantity and composition vary with climate, geographic location, season and years. Typical present-day composition of refuse from urban areas averages about 20 percent garbage (food wastes), 45 percent rubbish (organic and inorganic), and 35 percent ashes. Over-all moisture content, as collected, averages 20 percent, while densities range from 275 to 500 pounds per cubic yard, depending largely on the ash content and degree of compaction in the refuse collection truck.

2. Settlement

Initial shrinkage in dumped refuse is produced by compaction from the heavy operating equipment and the weight of the refuse and cover overburden. Subsequent shrinkage develops from filling in of voids left by the rusting out of the semi-empty tin cans, and the decomposition of the organic materials in the sanitary landfill.

3. Bearing

(A) Dynamic loading: Freshly placed compacted refuse will support repeated loadings of large rubber-tired equipment in excess of 25,000 pounds per tire. This supporting value is somewhat lower for older refuse fills, particularly when uncovered and wet. Rubber tires provide better load distribution than steel crawler treads, produce less edge shear and decrease degradation of the refuse.

(B) Static loading: Well seasoned refuse fills placed in wet areas will support uniform loads of the order of 2500 pounds per square foot if subjected to an equivalent preload for at least one year.

4. Decomposition

Tin cans and other metals rust out at varying rates. Those at or near the surface will mostly break up within about one year, and remaining materials decompose at varying rates over a period up to five years. Breakdown of the putrescible organics is aerobic in the top 2 to 4 foot layer, and anaerobic at greater depths. The aerobic decomposition is quite rapid and inoffensive. Anaerobic decomposition is slower and may release odorous gases through settlement cracks to produce an offensive nuisance.

5. Odor Control

Odorous gases are the products of surface putrefaction or of deep-seated anaerobic digestion. The best controls are: (i) rapid and continuous coverage of freshly placed refuse; (ii) sealing of surface cracks in completed areas to control or stop emission of gases; (iii) elimination of surface pools, side leaching action and seepages at toes of filled embankments; (iv) spraying with suitable deodorants.

6. Fire Control

Accidental fires within the freshly placed materials or even within the completed fills are not infrequent. The causes are dumping of hot ashes or incinerator residue and/or spontaneous combustion of highly flammable materials. Fire creates a smoke and odor nuisance.

Site Selection and Preparation

When a sanitary landfill is selected for solid waste disposal, provision for control of water pollution, control of odor and nuisance, and elimination of disease-carrying vectors must be considered (4).

When selecting a site for a sanitary landfill, economic haulage distance from the collection area, cost of acquisition, probable future assessed valuation, cost of site preparation, seasonal wind direction, surrounding traffic conditions, and public acceptance should be considered. Generally site preparation can be executed profitably by private contract. Its principal components consist of stockpiling suitable cover materials for the whole job, creating proper drainage facilities, screens, tide gates, berms, fences, dikes, accessways, etc. It should also include removal of old structures, trees, etc., and construction of temporary truck scales, housing and sanitary facilities, extending water lines, electric lighting and telephone facilities where necessary.

Cover materials should be clean earth and should be free from organic matter, tree roots, large stones, bulky waste building materials and if possible with low clay contents (4). All these will be helpful in reducing settlement, in rodent control and in surface cracking. Soil cover will control the velocity and direction of movement of soil water through the soil beneath the landfill trench. The sandy cover will allow rapid movement and channeling while the clayey units will retard the movement of soil water. Final cover on the completed fill should have a compacted depth of 24 inches (4) including 6 inches of top soil for permanent rodent and insect control, as a protection against odor and gas emission and to support normal grass or vegetation.

Most Objectionable Leachate Characteristics

The California Water Pollution Control Board (17) has reported that the most objectionable characteristics from refuse leaching into a ground water supply are hardness, iron, nitrates and total dissolved solids. Gases resulting from decomposition are also objectionable. It is not that all the substances leached through the landfill are soluble (16), but most of the substances are in a soluble state after biological and chemical activity and leach from the landfill easily after a period of time.

Sanitary Landfill Problems

There are many problems associated with sanitary landfills if they are not properly constructed and operated. Either failure or partial success of a sanitary landfill can also create problems with regard to refuse storage and collection. Fly emergence, insect trouble, odor and nuisance are among the most troublesome problems (5, 22, 23). If these problems are not solved, then diseases may be spread throughout the community. Fly emergence through the soil could be prevented by compacting the soil at or near the optimum moisture content. It should be compacted in layers from 1 5/8 inches to 2 1/4 inches in thickness. Black and Barnes (22) stated that a 3- to 6-inch compacted cover would prevent fly emergence under field conditions. There are four essential factors that are necessary to stop fly emergence. They are:

1. Soil that can be compacted
2. Suitable equipment for compacting the soil
3. Adequate range of soil moisture
4. Adequate thickness of cover

Factors Influencing the Characteristics of Leachate Composition

It is difficult to forecast the exact composition of leachate which may be associated with a landfill. Leachate production is a more serious problem than gas production in humid areas because it is more common and more mobile (3). Leachate can be defined as a liquid, high in biological and chemical oxygen demand, high in dissolved chemicals, particularly iron, chlorides, sodium and hardness (3). Leachate is the result of rainfall infiltrating through the landfill, facilitating the passage into solution of various chemicals as this water passes through the refuse. It also results from saturation of the refuse with water due to placement below the ground water table. Factors which are believed to influence the characteristics of a leachate (7) are:

1. Materials in the fills: organic, inorganic, degradable, non-degradable, soluble, insoluble
2. Conditions in the fill: temperature, pH, moisture, age of the fill
3. Characteristics of incoming solvent water
4. Surrounding soil characteristics

An investigation made by the University of Southern California (25) showed that continuous leaching of an acre-foot of sanitary landfill will result in a minimum extraction of approximately 1.5 tons of sodium plus potassium, 1.0 ton of calcium plus magnesium, 0.91 ton of chlorides, 0.23 ton of sulfate, and 3.9 tons of bicarbonates. Removal of these quantities would take place in less than one year. This removal would continue with subsequent years, but at a very low rate. It is unlikely that all ions would ever be removed. It was found that leachate from a landfill will change in chemical and biological composition with time. Experimental results (7) showed a marked reduction in mineral content, and both BOD and COD after passing through 50 feet of soil. Self-purification by percolation through soil was found to involve physical, chemical and biological systems which are interrelated and mutually dependent.

Effect of Sanitary Landfills on Ground Water Quality

The action of various liquids trapped in the pores of the fill on decomposition of organic materials and other soluble substances may impart undesirable qualities within the solid waste materials and constitute a source of potential ground water impairment. Among these contaminants are leachate and gas resulting from decomposition of the degradable materials in the fill. There are a number of ways by which water may enter a landfill. They are (7):

1. Water applied to the surface which percolates vertically through the soil cover
2. Water from an adjacent source moving horizontally through the side of the fill
3. Water entering from the bottom of the fill due to a rise in the ground water table or capillary action
4. Water being present in the fill site prior to or during placement of refuse material

If by some means leachate reaches the ground water, dilution of the leachate by the ground water may take place (7). This water may then enter a well and be pumped out or it may disperse into the adjacent ground water during flow. As decomposition proceeds with time, gases are evolved from it. Free carbon dioxide is undesirable in water supplies because it will increase the corrosiveness and aggresiveness of water (7). Dissolved carbon dioxide will react with water to form carbonic acid as shown below:

$$CO_2 + H_2O \rightleftarrows H_2CO_3$$

Carbonic acid dissociates and forms bicarbonate ion.

$$H_2CO_3 \rightleftarrows H^+ + HCO_3^-$$

If calcium carbonate is present in the fill, carbonic acid will react with it to form soluble calcium bicarbonate and this increases hardness.

$$CaCO_3 + CO_2 + H_2O \rightleftarrows Ca^{++} + 2HCO_3^-$$

This increase in hardness is an undesirable effect associated with carbon dioxide in ground water.

Bacterial contamination also takes place, but it is believed that during the deep percolation of water, the bacterial population is filtered out. Experimental results from soil water samples showed a great deterioration of the water quality (1). This deterioration indicated the downward movement of leachate through the soil beneath the landfill trench. It also showed that pollution increases with time at the shallower depth and that pollution is always more severe at the shallower depth than at the next deeper sampling point.

In a sanitary landfill, initial leaching of water could be due to the channeling effect which allows some water to travel all the way through the refuse. Experimental results showed that the chloride concentration at shallower depth is higher than at deeper depths. This indicates that there is a reduction in the concentration of chloride in a polluted soil water as it passes to a deeper depth. This reduction could be due to ionic exchange, adsorption, chemical precipitation, dilution and a dispersion effect (1).

Leachate Pollution Prevention

To prevent pollution of surface and ground water by leachate resulting from a sanitary landfill, it should be lined with a liner such as polyethelene sheeting and grouted with an impervious material such as compacted clay. However, these are costly and impractical in a large landfill. Pollution could also be prevented by allowing the leachate to migrate at a known rate and direction from a landfill to a leachate disposal site. In this manner, knowledge of local hydrology is used for leachate disposal site.

CHAPTER III

EXPERIMENTAL SETUP AND ANALYTICAL METHOD

1. Experimental Apparatus for Sanitary Landfill

Four tanks as shown in Figure 1 were employed as operational units for the sanitary landfills. All the tanks were made of plastic. A 6-inch free board was left at the top to accommodate the added water. Approximately 4 inches from the bottom was placed a plastic net over which iron screening was placed so that solid waste could be supported and water could percolate down through the fill. The percolated water was stored in the bottom of the tank. Small holes were provided at the bottom of the tanks to collect the leachate.

2. Procedure

All four tanks were filled with municipal solid waste. The solid waste was only a day or two old when it was collected from the Stillwater municipal sanitary landfill. A soil cover was obtained from the Stillwater sanitary landfill site and was placed on all units. Rainfall was simulated by adding distilled water to the top of each unit. The rainfall rates were 12 inches per year in the first tank, in the second tank 36 inches, in the third 60 inches and in the fourth 120 inches per year. Distilled water added in the first tank was 2 liters every month; in the second tank, 3 liters every 20 days; in the third tank, 3 liters every 10 days; and in the fourth tank, 5.05 liters every week. As per the fixed schedule distilled water was added to the

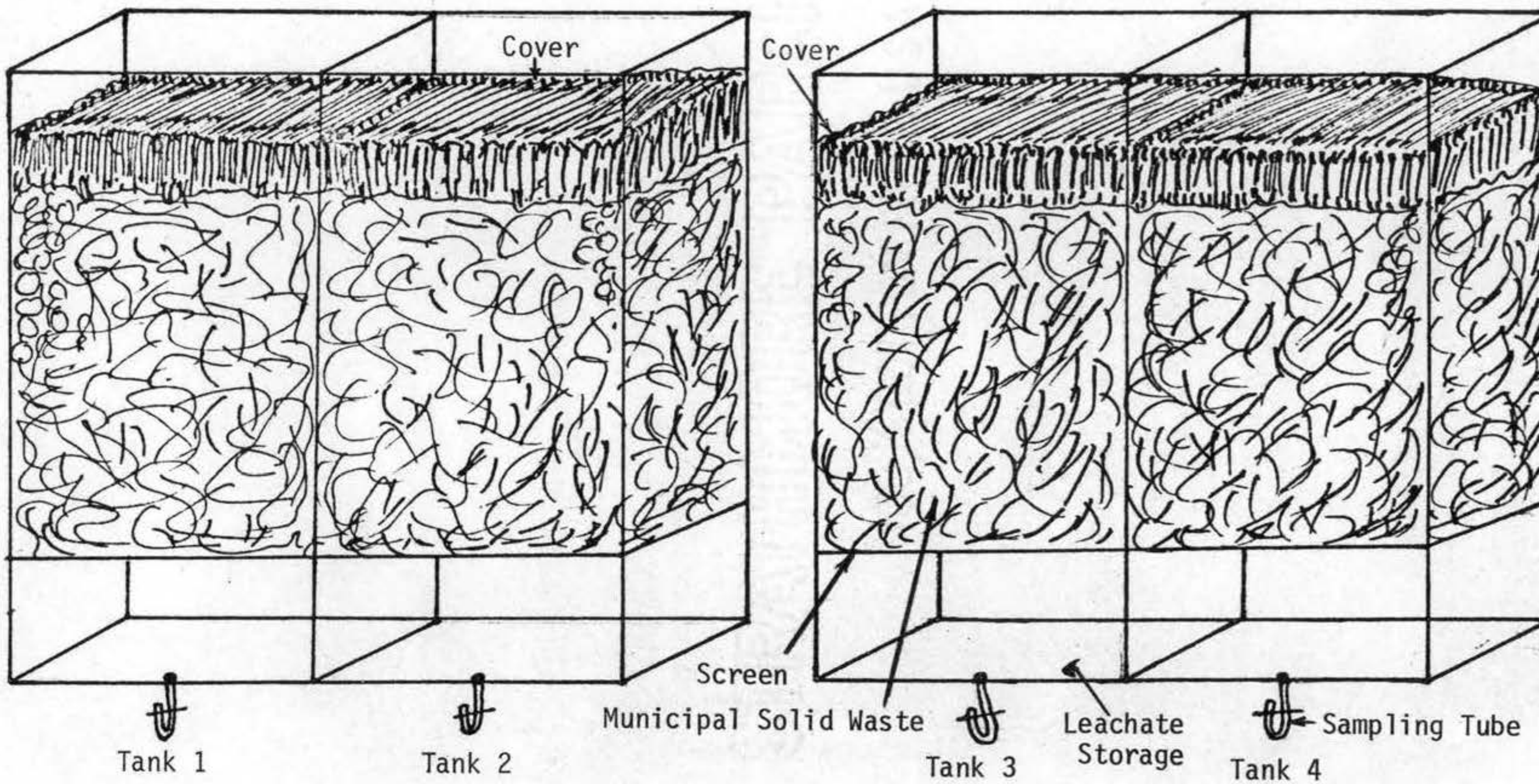

Figure 1. Schematic Drawing of the Laboratory Sanitary Landfills.

tank at night and was allowed to percolate through the solid waste overnight. By morning, after most of the water had percolated through the bed, a sample from the bottom storage was collected and analyzed for pH, total solids, alkalinity, chlorides, chemical oxygen demand, nitrate nitrogen, nitrite nitrogen, inorganic phosphate and total plate count.

3. Analytical and Experimental Methods

The pH measurement was carried out immediately after collecting the sample from the tank. Total solids were determined by the membrane filter technique (Millipore Filter Co., Bedford, Mass. HA 0.45 μ dia.) as described in the Standard Methods (26). On the filtrate from the above solid determination, the chemical oxygen demand was determined by taking 1 ml of filtrate and diluting it to 20 ml with distilled water. The rest of the procedure followed was the same as given in Standard Methods. Alkalinity and chloride determinations were carried out as outlined in W.P.C.F. simplified procedure (27). Inorganic phosphate concentration was determined by a colorimetric method as outlined by Ramnathan and others (28). The total plate count was done by the spread plate technique following the same procedure given by Ramnathan and others (28). A total plate count was run at least once a month. Nitrate nitrogen, nitrite nitrogen and phosphate analyses were run on the filtrate by colorimetric methods as described in Standard Methods.

CHAPTER IV

RESULTS

A. Response of Tank 1 to 12 Inch Rainfall per Year

Table I shows the date and amount of water added to tank 1. The unit was put into operation on October 1, 1969, at which time 0.54 liter of distilled water was added to the unit. No leachate resulted from this addition, i.e., all of the 0.54 liter was absorbed by the landfill. Therefore, on October 9, 1969, one week later, 1.62 liters of water were added. Very little leachate resulted. However, this was sufficient for analysis. The 1.62 liters did not provide as much leachate as desired, therefore on October 16, 1969, 2.0 liters of water were added. This provided a satisfactory volume of leachate. After this 2.0 liters of water were added every month to provide a yearly rainfall of 12 inches.

Tables II and III show the results of analysis made on the leachate from tank 1. The pH of the leachate obtained on the 10th day of operation was 6.7. This was the first leachate obtained from the unit. The pH remained at this level during the next sampling period, but on day 45 the pH had dropped to 5.6. The pH remained at this level on day 75 and dropped later. The total solids concentration was 256 mg/l in the first leachate analyzed. This dropped to 70 mg/l on the 45th day, however it increased to 130 mg/l on the 75th day and then remained in this general range. The alkalinity of the leachate was rather high

TABLE I

VOLUME OF WATER ADDED IN TANK I

Day	Date	Volume of Water Added in Liters	Cumulative Volume of Water Added in Liters
1	Oct. 1, 1969	0.54 (Absorbed)	0.54
9	Oct. 9, 1969	1.62	2.16
16	Oct. 16, 1969	2.00	4.16
44	Nov. 13, 1969	2.00	6.16
74	Dec. 13, 1969	2.00	8.16
103	Jan. 11, 1970	2.00	10.16
132	Feb. 9, 1970	2.00	12.16

About 12" rainfall per year (every 30 days).

TABLE II

pH, TOTAL SOLIDS, ALKALINITY, CHLORIDES, IN MG/L, TANK I

Day	pH	Total Solids in mg/l	Alkalinity in mg/l	Chlorides in mg/l
2		----- Water Absorbed -----		
10	6.7	256	889	338
17	6.7	224	700	215
45	5.6	70	715	210
75	5.6	130	415	128
104	5.1	161	360	115
133	5.3	110	490	180

TABLE III

CHEMICAL OXYGEN DEMAND, NITRATE NITROGEN, NITRITE NITROGEN, INORGANIC PHOSPHATE (FILTRATE) IN MG/L AND PLATE COUNT, TANK I

Day	COD in mg/l	NO_3-N in mg/l	NO_2-N in mg/l	PO_4 in mg/l	Plate Count number/ml
2			----- Water Absorbed -----		
10	5016	--	--	--	--
17	3393	0.52	--	--	--
45	2473	1.37	0.79		1.72×10^6
75	2222	1.60	0.68	--	3.20×10^9
104	2820	1.77	0.70	--	--
133	2190	1.74	0.70	7.7	4.58×10^6

throughout the study. The initial alkalinity was 889 mg/l. It did exhibit a general decrease with time and reached a low value of 360 mg/l. The chloride concentration reacted in the same general manner. The chloride concentration of the initial leachate was 338 mg/l and progressively decreased with time until it reached a low of 115 mg/l at day 104. However, the next analysis was made on day 133 and the chloride concentration had increased to 180 mg/l.

From Table III it can be seen that the COD of the initial leachate was extremely high, 5016 mg/l. The COD did decrease with time, reaching a low of 2190 mg/l on day 133. This is still a very high concentration. The nitrate and nitrite concentrations remained low throughout the study. The nitrates remained below 2.0 mg/l and the nitrites remained below 1.0 mg/l. However, the nitrates did increase with time, whereas the nitrites remained fairly constant. A determination of phosphates was made only on the last sample and this was determined to be 7.7 mg/l. Plate counts were made periodically and it can be seen that they remained fairly high, being in the order of 10^6 to 10^9 organisms per ml.

B. Response of Tank 2 to 36 Inch Rainfall per Year

The date and quantity of water added to tank 2 are shown in Table IV. On October 1, 1969, 1.62 liters of water were added to the unit. This resulted in no leachate, as all of the water was absorbed. The application of the water was first increased to 3.24 liters and then to 4.0 liters before finally deciding on 3.0 liters every 20 days. A total of 31.86 liters was added to the unit during the study.

The results of the analysis made on the leachate from tank 2 are

TABLE IV

VOLUME OF WATER ADDED IN TANK 2

Day	Date	Volume of Water Added in Liters	Cumulative Volume of Water Added in Liters
1	Oct. 1, 1969	1.62 (Absorbed)	1.62
9	Oct. 9, 1969	3.24	5.86
16	Oct. 16, 1969	4.00	9.86
23	Oct. 23, 1969	4.00	13.86
42	Nov. 11, 1969	3.00	16.86
61	Nov. 30, 1969	3.00	19.86
80	Dec. 19, 1969	3.00	22.86
99	Jan. 7, 1970	3.00	25.86
118	Jan. 26, 1970	3.00	28.86
137	Feb. 14, 1970	3.00	31.86

About 36" rainfall per year (every 20 days).

shown in Tables V and VI. In Table V it can be seen that the leachate started out with a pH close to neutral, 7.1, but on day 17 the pH had dropped to 5.4 and stayed in this general range. The total solids, alkalinity, and chlorides were very similar to tank 1 except that the values were somewhat higher. The alkalinity is especially interesting in that it is 2 to 3 times greater than that observed in the leachate from tank 1.

As seen in Table VI the COD of the leachate of tank 2 is again quite high in the beginning of the study. But instead of decreasing, the COD increases to a high of 14,150 mg/l. The nitrates and nitrites remained fairly low throughout the study. The nitrates remained below 4.0 mg/l and the nitrites remained below 2.0 mg/l, except for day 43, in which the concentration was 2.17 mg/l. It is interesting to note that the nitrates and nitrites in tank 2 were higher than in tank 1. Only two samples were analyzed for phosphates and both were quite high, the concentrations observed being 25.15 mg/l and 24.0 mg/l. The plate counts taken varied from 4.2×10^4 organisms per ml to 5.9×10^{15} organisms per ml.

C. Response of Tank 3 to 60 Inch Rainfall per Year

The date and volume of water added to tank 3 are shown in Table VII. A volume of 2.71 liters was added at the beginning of the study. This was increased to 4.0 liters and then a final volume of 3.0 liters every 10 days was determined to be the most desirable application rate to provide 60 inches per year. A total of 54.42 liters of water was added during the study.

The analysis of the leachate from tank 3 is presented in Tables VIII and IX. The pH at the beginning of the study was close to neutral,

TABLE V

pH, TOTAL SOLIDS, ALKALINITY, CHLORIDES IN MG/L, TANK 2

Day	pH	Total Solids in mg/l	Alkalinity in mg/l	Chlorides in mg/l
2		------ Water Absorbed ------		
10	7.1	120	1610	260
17	5.4	210	920	347
24	5.5	221	1720	553
43	5.5	231	1340	487
62	5.7	306	1642	555
81	5.8	210	1770	411
100	5.4	155	1030	274
119	5.4	194	1910	476
138	5.4	246	3430	594

TABLE VI

CHEMICAL OXYGEN DEMAND, NITRATE NITROGEN, NITRITE NITROGEN, INORGANIC PHOSPHATE (FILTRATE) IN MG/L AND PLATE COUNT, TANK 2

Day	COD in mg/l	NO_3-N in mg/l	NO_2-N in mg/l	PO_4	Plate Count Number/ml
2			----- Water Absorbed -----		
10	5645	0	--	--	--
17	6570	0.65	0.5	--	--
24	7580	3.80	--	--	42000
43	9848	1.94	2.17	--	--
62	14150	1.34	1.49	--	7.31×10^2
81	12800	2.39	1.45	--	5.9×10^{15}
100	8400	1.2	1.32	--	--
119	9050	1.32	0.96	25.15	2.46×10^6
138	7350	3.82	1.53	24.00	4.92×10^6

TABLE VII

VOLUME OF WATER ADDED IN TANK 3

Day	Date	Volume of Water Added in Liters	Cumulative Volume of Water Added in Liters
1	Oct. 1, 1969	2.71	2.71
9	Oct. 9, 1969	2.71	5.42
16	Oct. 16, 1969	4.00	9.42
23	Oct. 23, 1969	3.00	12.42
32	Nov. 1, 1969	3.00	15.42
41	Nov. 10, 1969	3.00	18.42
50	Nov. 19, 1969	3.00	21.42
59	Nov. 28, 1969	3.00	24.42
68	Dec. 7, 1969	3.00	27.42
77	Dec. 16, 1969	3.00	30.42
86	Dec. 25, 1969	3.00	33.42
95	Jan. 3, 1970	3.00	36.42
104	Jan. 12, 1970	3.00	39.42
113	Jan. 21, 1970	3.00	42.42
122	Jan. 30, 1970	3.00	45.42
131	Feb. 8, 1970	3.00	48.42
140	Feb. 17, 1970	3.00	51.42
149	Feb. 26, 1970	3.00	54.42

About 60" rainfall per year (every 10 days).

TABLE VIII

pH, TOTAL SOLIDS, ALKALINITY, CHLORIDES IN MG/L, TANK 3

Day	pH	Total Solids in mg/l	Alkalinity in mg/l	Chlorides in mg/l
2	6.8	254	1200	191
10	6.6	310	1040	427
17	5.5	340	1060	355
24	5.6	214	1232	329
33	5.3	145	772	210
42	5.4	236	1020	188
51	5.4	194	645	480
60	5.4	50	1240	314
69	5.4	80	970	456
78	5.3	112	690	199
87	5.3	31	700	230
96	5.3	138	850	216
105	5.3	81	540	487
114	5.3	129	700	101
123	5.3	88	765	158
132	5.3	80	720	115
141	5.2	92	750	134
150	5.2	48	635	115

TABLE IX

CHEMICAL OXYGEN DEMAND, NITRATE NITROGEN, NITRITE NITROGEN, INORGANIC PHOSPHATE (FILTRATE) IN MG/L AND PLATE COUNT, TANK 3

Day	COD in mg/l	NO_3-N in mg/l	NO_2-N in mg/l	PO_4 in mg/l	Plate Count in Number/ml
2	9920	1.20	--	--	--
10	5715	0.50	--	--	--
17	5720	1.80	0.80	--	--
24	4242	1.69	0.72	--	78000
33	4050	1.21	0.62	--	--
42	5045	1.27	0.70	--	--
51	4010	0.83	1.60	--	2.81×10^6
60	8100	1.69	0.93	--	--
69	6900	1.92	1.25	--	--
78	4520	1.32	1.21	--	--
87	4340	1.75	0.60	--	--
96	4960	1.02	0.62	--	5.6×10^8
105	3900	1.40	0.58	--	--
114	3670	1.34	1.40	--	--
123	3962	0.60	0.63	40.00	10.54×10^6
132	3080	1.32	0.76	44.00	--
141	3460	0.78	0.67	24.00	--
150	3200	1.95	0.80	32.32	--

6.8. After 17 days of operation the pH had decreased to 5.5 and slowly decreased to a pH of 5.2 towards the end of the study. The total solids was initially 254 mg/l and in general decreased throughout the study to a low of 48 mg/l. The alkalinity was 1200 mg/l at day 2 and as the total solids, the alkalinity generally decreased with time. The low value was 540 mg/l. This occurred at day 105. There was a great deal of variation in the chloride concentration and really no pattern to the variation. The variation was from a high of 480 mg/l to a low of 101 mg/l.

It can be seen from Table IX that the COD was quite high at the beginning of the study and slowly decreased with time, the high value being nearly 10,000 mg/l and the low value being 3200 mg/l. The nitrate and nitrite concentrations were low throughout the study. In both cases the concentration never exceeded 2.0 mg/l. It is quite interesting to observe the high phosphate concentration. Only four analyses were made and all four were quite high, the low value being 24.0 mg/l and the high being 44.0 mg/l. The plate count remained generally in the range of 10^6 organisms per ml.

D. Response of Tank 4 to 120 Inch Rainfall per Year

The date and volume of water added to tank 4 are shown in Table X. The study of tank 4 was initiated on October 1, 1969, as for the study of the other three tanks, and 5.04 liters of water were added to the tank once each week throughout the study. A total volume of 110.88 liters was added during the study.

The analysis of the leachate from tank 4 is presented in Tables XI and XII. In general the results compare very closely to those found

TABLE X

VOLUME OF WATER ADDED IN TANK 4

Day	Date	Volume of Water Added in Liters	Cumulative Volume of Water Added in Liters
1	Oct. 1, 1969	5.04	5.04
9	Oct. 9, 1969	5.04	10.08
16	Oct. 16, 1969	5.04	15.12
23	Oct. 23, 1969	5.04	20.16
30	Oct. 30, 1969	5.04	25.20
37	Nov. 6, 1969	5.04	30.24
44	Nov. 13, 1969	5.04	35.28
51	Nov. 20, 1969	5.04	40.32
58	Nov. 27, 1969	5.04	45.36
65	Dec. 4, 1969	5.04	50.40
72	Dec. 11, 1969	5.04	55.44
79	Dec. 18, 1969	5.04	60.48
86	Dec. 25, 1969	5.04	65.52
93	Jan. 1, 1970	5.04	70.56
100	Jan. 8, 1970	5.04	75.60
107	Jan. 15, 1970	5.04	80.64
114	Jan. 22, 1970	5.04	85.68
121	Jan. 29, 1970	5.04	90.72
128	Feb. 5, 1970	5.04	95.76
135	Feb. 12, 1970	5.04	100.80
142	Feb. 19, 1970	5.04	105.84
149	Feb. 26, 1970	5.04	110.88

About 120" rainfall per year (every week).

TABLE XI

pH, TOTAL SOLIDS, ALKALINITY, CHLORIDES IN MG/L, TANK 4

Day	pH	Total Solids in mg/l	Alkalinity in mg/l	Chlorides in mg/l
2	7.1	380	1070	188
10	6.7	200	950	210
17	5.6	102	1320	320
24	5.6	205	760	169
31	5.5	200	850	205
38	5.2	97	963	195
45	5.4	84	1025	211
52	5.5	191	605	130
59	5.5	78	1160	206
66	5.55	123	860	165
73	5.5	66	1010	175
80	5.5	123	675	95
87	5.5	77	700	102
94	5.5	85	780	115
101	5.5	127	790	106
108	5.4	89	570	220
115	5.4	59	550	156
122	5.45	89	525	124
129	5.4	56	525	57
136	5.4	41	500	114
143	5.3	32	590	81
150	5.3	28	550	53

TABLE XII

CHEMICAL OXYGEN DEMAND, NITRATE NITROGEN, NITRITE NITROGEN, INORGANIC PHOSPHATE (FILTRATE) IN MG/L AND PLATE COUNT, TANK 4

Day	COD in mg/l	NO_3-N in mg/l	NO_2-N in mg/l	PO_4 in mg/l	Plate Count
2	9000	0.80	--	--	--
10	4667	0.60	--	--	--
17	3637	0.90	--	--	--
24	2588	1.46	--	--	58000
31	4360	0.91	3.35	--	70000
38	5105	1.05	4.31	--	204000
45	4363	1.34	1.30	--	1.51×10^6
52	3500	0.94	2.58	--	--
59	6770	1.30	2.59	--	--
66	4470	0.50	1.30	--	5.82×10^{12}
73	4900	1.82	1.29	--	--
80	3630	1.46	1.52	--	--
87	2620	1.54	1.30	--	--
94	2532	1.50	1.40	--	4.3×10^{12}
101	3840	1.78	1.48	--	--
108	2140	1.38	0.65	15.30	--
115	2470	2.35	2.60	15.20	--
122	2366	2.18	1.52	15.30	--
129	1955	3.13	6.74	16.65	3.76×10^6
136	1995	2.74	7.15	8.08	--
143	1950	1.11	2.20	5.20	--
150	1920	2.80	4.30	9.97	--

in tanks 1 and 3. The initial pH was 7.1 but quickly decreased to 5.6 and then slowly decreased to 5.3. The total solids were initially 380 mg/l but decreased to 28 mg/l over a 150-day period. The initial alkalinity was 1070 mg/l and decreased to a low in the range of 500 mg/l. The chlorides again varied a great deal from a high of 320 mg/l to a low of 53 mg/l.

The initial COD was 9000 mg/l and this decreased to a low of 1920 mg/l. The nitrates were again fairly low and never did exceed 3.13 mg/l. The nitrites were also fairly low but this was the only tank in which they exceeded the nitrate concentration. The high nitrite concentration was 7.15 mg/l. The phosphate concentration was much lower than that in tanks 2 and 3, the high value being 16.65 mg/l and the low value being 5.20 mg/l. Again a fairly high plate count was observed from the leachate.

E. Comparison of the Four Tanks

One objective of this study was to compare the leachate from a sanitary landfill that was subjected to different yearly rainfalls. A comparison of the analysis of the leachate from the four tanks is presented in Figures 2-6. It is quite interesting to note that for all analyses conducted tanks 1, 3, and 4 compare very favorably; i.e., the alkalinity, total solids, chlorides, COD and nitrates were approximately the same in all three tanks. However, in all cases the concentrations were higher in tank 2.

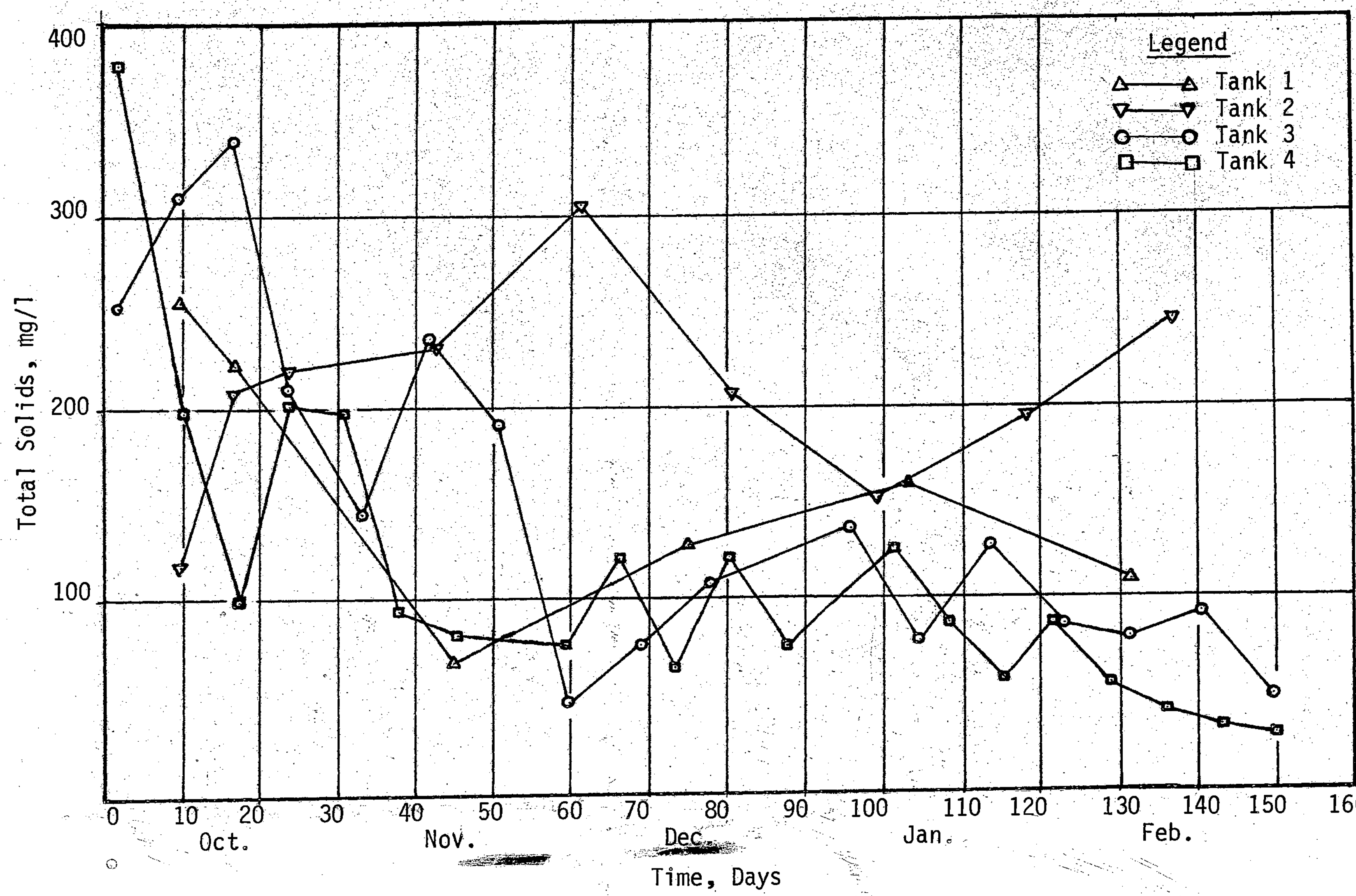

Figure 2. Relative Solids Concentrations with Time in Fills.

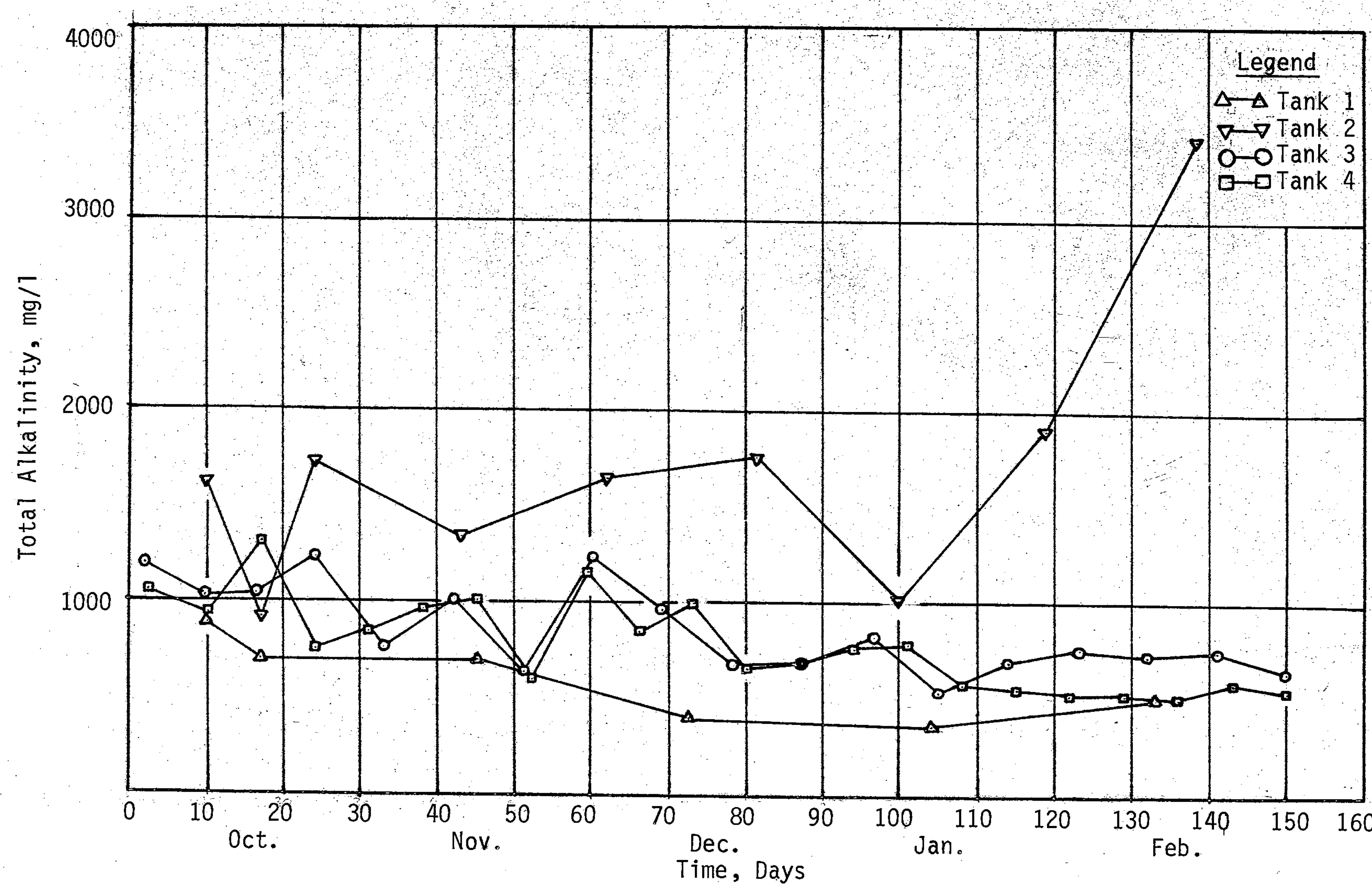

Figure 3. Relative Alkalinity Concentration with Time in Fills.

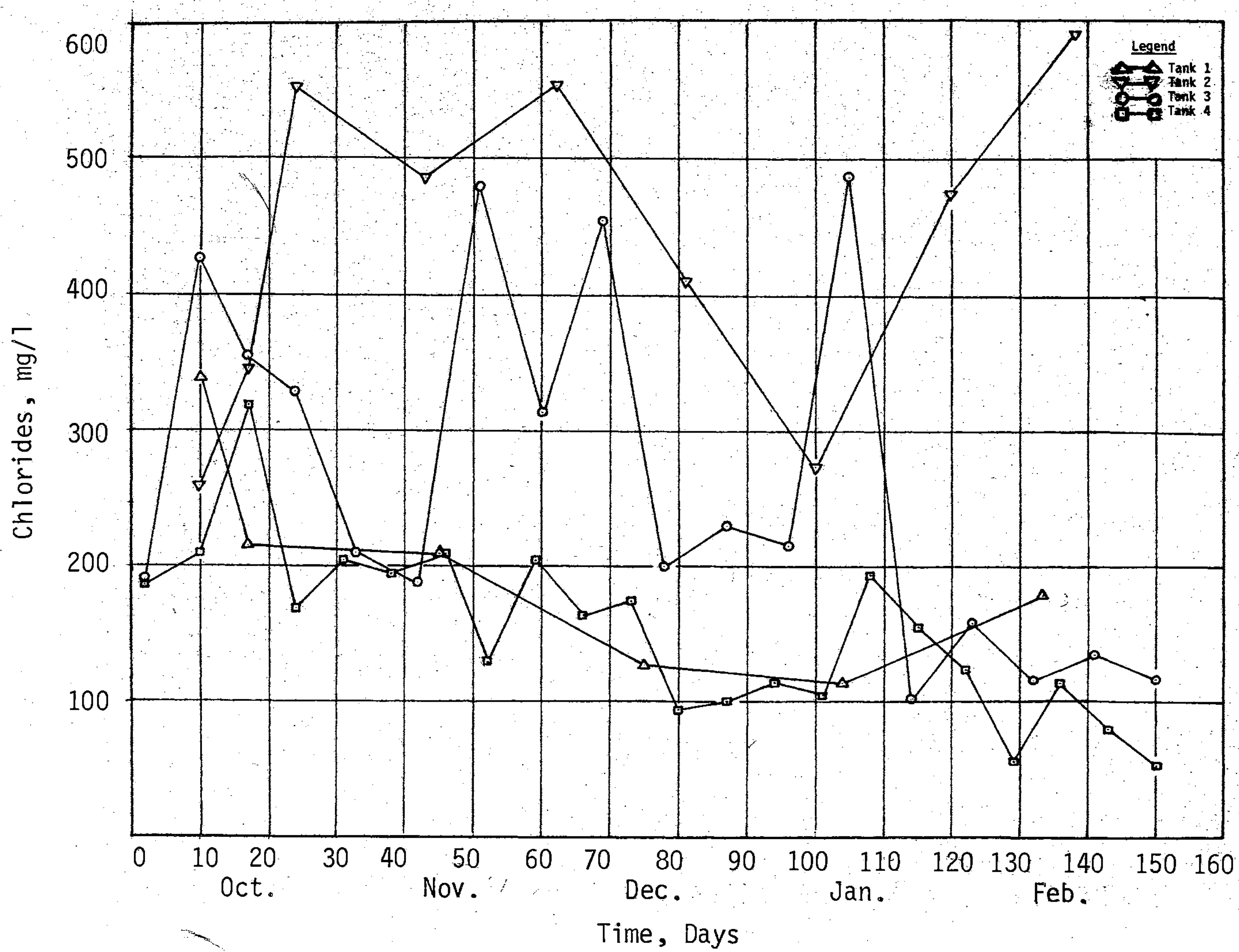

Figure 4. Relative Chloride Concentration with Time in Fills.

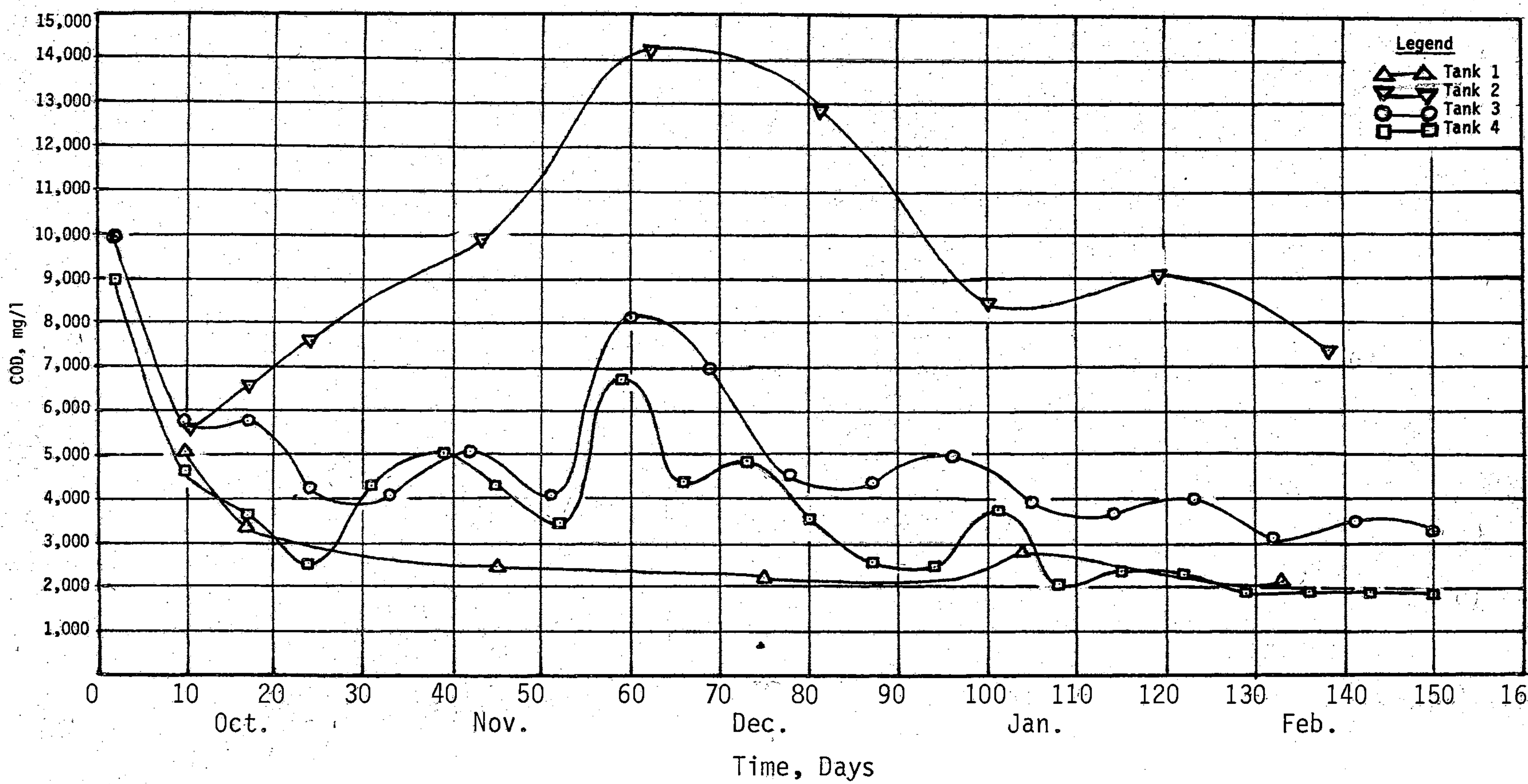

Figure 5. Relative COD Concentration with Time in Fills.

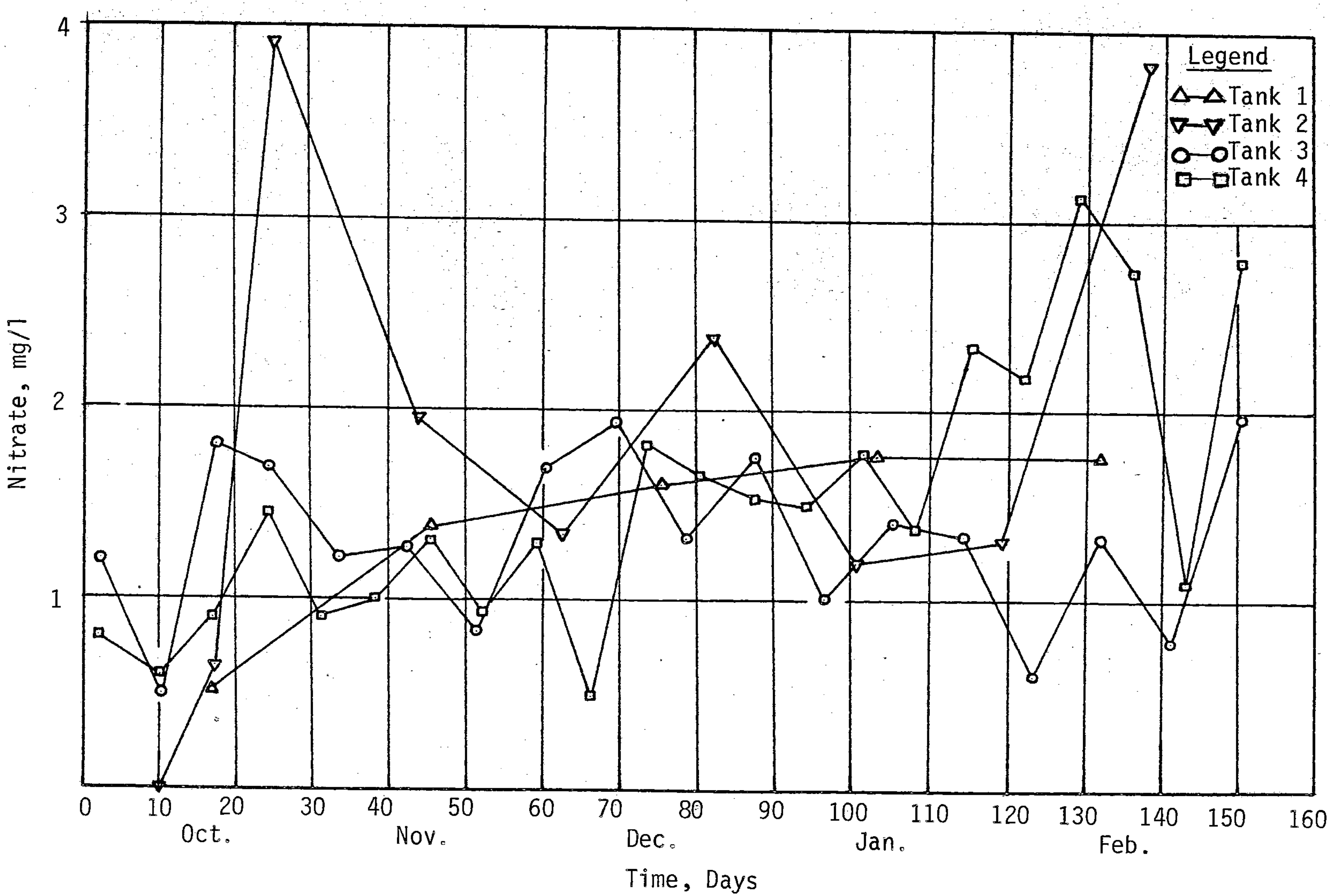

Figure 6. Relative Nitrate Nitrogen Concentration with Time in Fills.

CHAPTER V

DISCUSSION

Legrand (29) stated, "The upper part of the zone of saturation in the populated parts of the earth may be considered as a galaxy in which millions of enclaves of contaminated water are scattered throughout uncontaminated water." He attributes the source of contamination to the accidental or deliberate disposal of waste at or near the ground surface. Different characteristics determined and observed for this research, which may contaminate ground and surface water supplies in one way or another, are discussed in the following.

The pH of the leachate tended to remain acid. However, when the units were first started, the pH in tanks 2 and 4 was alkaline and the pH in the other two tanks was close to neutral, as shown in Tables II, V, VIII and XI. It was also found that the pH continuously dropped in all four tanks. The reason for the lowering of the pH could be due to the production of carbon dioxide, resulting from the decomposition of organics and other such degradable materials in the landfill. Thus the carbon dioxide gas would mix with the percolating water or moisture which is already there, and carbonic acid would be produced. This would lower the pH of the leaching water. This evolved carbon dioxide gas is not desirable because it would increase the corrosiveness and aggressiveness of the water (7). Carbonic acid as produced would dissociate and upon dissociation would form hydrogen ions and bicarbonates. If calcium carbonate is present in the landfill, the carbonic acid would react with it and form soluble calcium bicarbonate which would increase the hardness of the percolating water (7). Different rainfall rates were found to have very little effect on the pH in all four tanks. This slight variation in pH may be due to the production of carbon dioxide gas in varying concentrations.

As shown in Tables II, V, VIII and XI, the total solids concentrations of the leachate from each of the tanks were high at the beginning, and then gradually decreased. The initial high concentration of solids may be due to direct flushing. Due to the high solids concentrations, the leaching water was turbid. As shown in Figure 2, total solids concentrations show a decreasing trend in tanks 1, 3 and 4 and an increasing solids concentration in tank 2. Intermediate increasing and decreasing may be due to some filtering effect. It could be that after putting the sanitary landfill into operation, the solids concentration might increase as decomposition of organic materials takes place, and the solids particles may become embedded in the soil pores as they pass through the landfill and consequently be filtered out.

Alkalinity of natural water is due primarily to the salts of weak acids (30). Bicarbonates represent the major form of alkalinity. They are formed from the action of carbon dioxide upon the materials from the soil. Alkalinities in the leachates from all four tanks were very high. In the first tank the alkalinity was high in the early stages of operation but decreased with time as shown in Table II, while alkalinity in the second tank increased on the 61st, 80th, 118th and 137th day. The reason for the increased alkalinity could be due to the production of carbon dioxide in high concentrations, which in turn combines with water to form carbonic acid. Carbonic acid dissociates into H^+ and HCO_3^- and the increased bicarbonate concentration increases the alkalinity. As decomposition proceeds, the concentration of bicarbonates might be reduced and therefore the alkalinity would be reduced. Leachates from tanks 3 and 4 also showed a high alkalinity in the beginning but decreased with time. From Figure 3, it is seen that the alkalinities in tanks 1, 3 and 4 all decrease with time, while in tank 2 it increases. A rainfall rate of 36 inches per year may just be sufficient to produce a high concentration of carbon dioxide from the decomposition of the organic materials, and consequently tank 2 shows higher alkalinities.

Lane and Parizek (1) observed that the chloride concentration was higher at the shallower depth than at deeper depths below a sanitary landfill. This reduction was probably due to ionic exchange, adsorption, chemical precipitation, dilution and dispersion effect. As shown in Table II, the chloride concentration initially in tank 1 was 338 mg/l but later decreased. The initial high concentration might be due to a washing away of the material in the landfill. As shown in Figure 4, the chlorides concentrations in tanks 1, 3 and 4 show a decreasing trend, while showing an increasing trend in tank 2. The intermediate fluctuation might be due to flushing action. Initial high concentrations of chlorides may be due to direct leaching from the tanks. There was no way that lateral leaching could occur, consequently chlorides originated from the vertical percolation of water. Landon (3) pointed out that chlorides have migrated down through relatively impermeable clay fills at a rate of approximately 1 foot per hour. Chlorides have been reported to be the best indicator of both leachate (3) and migrating pollutants. Studies made at four landfills (3) in Northeastern Illinois, in which precipitation has moved downward through the landfill surface to produce leachate had shown that at each site mineralization of the ground water within the landfill declined with increasing age of the fill. This indicated that the landfill was being flushed and was progressing toward stabilization. As shown in Figure 4, the concentration of chlorides in tanks 1, 3 and 4 was decreasing with time. From this study it could be inferred that laboratory landfills were progressing toward stabilization. The pollutional load due to chlorides was reduced with age. It was not possible to say with any certainty that the rainfall rate affected a reduction in chlorides concentration. Chloride content increases as the mineral content increases (30). Landon (3) reported that chloride concentration decreased uniformly from an area adjacent to a sanitary landfill to an area some distance away from the landfill. The chloride concentration in the area adjacent to the landfill was found to be in the range of 100 ppm to 1000 ppm. In the area some distance away from the landfill, the chloride concentration was found to be in the range of 10 ppm. It has been observed that chlorides have migrated a distance of 1200 feet from a sanitary landfill.

COD is a good parameter for measuring the pollutional strength of any waste water such as domestic, industrial or leachate resulting from the percolation of water through the sanitary landfill. Initially when a sanitary landfill is filled with fresh refuse, ground water or rainwater percolates through it and organic materials become dissolved in it causing the percolating water to have a high COD. As shown in Tables III and VI, the COD of the leachate from tanks 1 and 2 was

5016 mg/l and 5645 mg/l, while in tanks 3 and 4, the COD was even higher as shown in Tables IX and XII. This may be due to the higher rate of rainfall applied to tanks 3 and 4. It could be that the large amount of water may have flushed a large amount of organic material with it. As the organic material was decomposed, the concentration of organic material decreased and the chemical oxygen demand also decreased. After 3 months of operation, the COD of the leachate in all four tanks had decreased. This indicates that the organic material in the tanks had been decomposed. The COD percentage decrease in all the four tanks was considerable in the five months of operation. Maximum COD reduction in tank 1 was 56.20 percent, in tank 3 it was 68.80 percent and in tank 4 it was 78.60 percent. From these percentage reductions in COD, it could be concluded that rainfall rate does affect the decomposition phenomena. COD percentage reduction was higher at the higher rainfall rates. Slow reduction in COD showed that decomposition of the organic materials present in the fill was slow. The Illinois study (3) showed that the COD was relatively high in young refuse. This component did not appear to travel far from the landfill sites except in highly permeable zones. In highly permeable zones organic materials migrate in high concentrations and may cause organic pollution. Due to direct channeling of rainwater in the fill, and after percolation of this water through some distance, it may provide an opportunity for organic particles to move along with the leachate. COD was rapidly decreased by natural reduction, adsorption, ion exchange and filtration as leachate left the landfill (3). COD values were initially high, which might have been due to liquid already present in the refuse (24).

The drop in COD concentration is believed to be due to dilution by water that has channeled through the landfill.

An increase of nitrate nitrogen concentration indicates that decomposition of organic material was taking place. The highest concentration of nitrate nitrogen occurred in the first tank on the 103rd day as shown in Figure 6. In tank 2, the peak value was reached on the 138th day and during other days, there was a fluctuation in the values as shown in Table VI. In tanks 3 and 4, peak values were reached on the 150th day and the 129th day, respectively, as shown in Tables IX and XII. The concentration of nitrate nitrogen increased in all four tanks as shown in Figure 6. In tank 4 the increase in concentration of nitrate was rapid after the 108th day of operation. This might have been due to the large amount of water percolated through the fill. A high rate of application of water might have provided more suitable conditions for the organic materials to decompose at a faster rate. After 120 days of operation an increase in the concentration of nitrate was large in tanks 2, 3 and 4. From Figure 6, it was seen that the nitrate concentration in all four tanks increased with time, indicating that decomposition of the filling material was taking place. The increase in the concentration of nitrate nitrogen was not high, but a slight increase in concentration showed that there was a slow decomposition and stabilization of the materials present in the landfill. There were many erratic fluctuations in the curve as seen in Figure 6. These fluctuations might be due to factors such as cell temperatures, amount of available oxygen and the degree of saturation of the refuse (1). These factors may influence the rate of production of nitrogen and nitrogen compounds. All these factors may vary widely in the first two months after the refuse is placed into the fill. These factors vary from landfill to landfill because the composition of solid refuse waste is not of the same character everywhere. Stewart et al. (31) showed that nitrate moved through soil and into the ground water under certain feed lots. In Manitoba, Leclaire (32) showed that organic refuse (manure and other organic waste) was the source of nitrate contamination of ground water. Nitrate nitrogen is quite soluble in water (33) and may leach readily through the soil. This soluble nitrate might travel from one part of the ground to the other and may contaminate ground water supplies.

Nitrite nitrogen is an unstable substance that may be readily reduced or oxidized by either chemical or biological processes (33). Nitrobactor is the most important species of bacteria responsible for the nitrification of nitrite nitrogen to nitrate nitrogen under aerobic conditions as $2NO_2^- + O_2 \rightarrow 2NO_3^-$. Nitrites are also formed by reduction of nitrates and in turn are destroyed by reduction to nitrogen gas by anaerobic denitrification by heterotrophic bacteria. As shown in Tables III, VI, IX and XII, considerable variation occurred in nitrite nitrogen concentrations during the five months of operation. Factors that affect nitrate nitrogen fluctuation might affect nitrite nitrogen also. As shown in Table III, the concentration of nitrite nitrogen is quite low throughout the operation of the first tank. In all the other three tanks, there was considerable variation. Due to fluctuation in the values of nitrite nitrogen in all four tanks, a definite evaluation could not be made as to whether or not an increase in rainfall rate increases the production of nitrite nitrogen.

Phosphorus determinations are becoming more and more important in sanitary engineering (30) because they are useful in assessing the potential biological productivity of surface waters. Phosphorus is a biological nutrient. Inorganic phosphate is utilized to form ATP, which in turn is utilized by organisms for life activities. Research has shown that both phosphorus and nitrogen are essential for the growth of algae and if both are plentiful, algal blooms may occur which may produce a variety of nuisance conditions in surface water supplies. If nitrate and inorganic phosphate are leached in considerable quantities from a landfill, they may aid in establishing algal growth in surface water supplies. In the early stages of this research, due to reagent trouble, inorganic phosphate was not determined, but later determinations showed that the phosphate content of tanks 2 and 3 was higher than tanks 1 and 4. As shown in Tables III, VI, IX and XII, the highest concentrations of phosphate in tanks 1, 2, 3 and 4 were 7.70, 21.15, 44.00 and 16.65 mg/l, respectively. The higher concentration of phosphate in tanks 2 and 3 may be due to more elemental phosphorus in the filling materials.

Total plate counts gave the picture of production of organisms during the decomposition process. As shown in Table VI, the highest plate count was 5.9×10^{15} in tank 2 on the 81st day, while it was 5.82×10^{12} in tank 4 on the 66th day as shown in Table XII. The highest plate count in tank 1 was 3.2×10^{9} on the 75th day as shown in Table III and in tank 3 it was 5.6×10^{8} on the 96th day as shown in Table IX. The highest concentration of plate counts in all four tanks was reached between 66 and 96 days of operation. Exact count of organism was impossible because it could be that much of the culture was filtered out in the landfill and would not give a true picture of the number of organisms present. Still an increase in organism numbers showed that the biological population was increasing as time passed and decomposition of the organic matter present in the bed occurred. Rainfall rate might affect the production of organisms, but a true picture of bacterial count was impossible to obtain due to the filtering effect of the landfill.

CHAPTER VI

CONCLUSIONS

Following this research, these conclusions could be drawn:

(1) During the operation of the sanitary landfills, unpleasant odors were detected in the percolating water and in the atmosphere. This shows that decomposition of the refuse was taking place.

(2) The pH dropped and remained in the acid range. Different rainfall rates had no effect on the pH of the leachate.

(3) Pollutional load of leachate due to chlorides decreased with increasing age of the fills. Chemical quality of ground water contaminated by leachate is bound to be impaired due to high concentration of chlorides being leached from the fills. With time, the concentration of chlorides decreased and consequently the degree of impairment of ground water by chlorides also decreased.

(4) The 36 inches per year rainfall leached greater concentrations of pollutants from the landfill than did any other rainfall rate.

(5) COD concentration was high initially in all the tanks. Consequently, organic contamination would occur if these leachates were introduced into the ground water. At higher rainfall rates, decomposition increased. COD was reduced at a faster rate at higher rainfall rates.

(6) Decomposition of the refuse was taking place at a slow rate

as indicated by a slow increase in concentration of nitrate nitrogen during the five months of operation.

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