

PHASE I FINAL TECHNICAL REPORT ON:
"PHOSPHORUS REMOVAL WITHIN INDIVIDUAL SEPTIC TANK SYSTEMS"

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GENERAL OVERVIEW

The use of septic tank systems for waste disposal is common in many areas of the United States, including many remote resort areas. As the population throughout these areas increases, the inability of many septic tank systems to treat wastes properly will result in the discharge of large amounts of nutrients, e.g., phosphorus, nitrogen, etc., to nearby bodies of water. In regions where water quality is presently very high, this increased nutrient discharge could cause rapid and undesirable decreases in water quality.

If it were practicable to replace these septic tanks with central wastewater treatment facilities, present levels of water quality could be maintained or indeed even improved. However, large seasonal variations in populations often make such facilities economically unfeasible, to say nothing of physical difficulties that might be encountered due to local geological characteristics. It is necessary, therefore, to develop a means of improving the septic tank system.

The purpose of this project in Phase I has been to conduct a laboratory investigation which would serve as a basis for the design of a method for improving septic tank performance. More specifically, this phase of the project investigated the process of phosphorus removal by chemical precipitation to determine its potential for use in septic tanks. In this process, chemically precipitated phosphorus would settle to the tank bottom and eventually be removed with other normal sludge deposits during regular tank cleaning. Thus the laboratory investigations in Phase I were concerned with the following questions: 1) Would the addition of the appropriate chemical (in this case a ferric chloride compound) adversely affect normal activity of those microorganisms present in the septic tank; 2) How much of this chemical would be required; 3) Would the additional sludge formed due to precipitation drastically alter the frequency and method of tank cleaning; and 4) Would the system as a whole be efficient enough to remove significant amounts of

phosphorus without otherwise impeding normal functioning of the septic tank.

The results obtained indicate that it may very well be possible, under certain conditions, for a chemical precipitation process to be successful. In addition to the need for additional confirmatory laboratory studies, there exist certain aspects of the system which necessitate field evaluation. The potential value of such a system requires that a full-scale pilot study be set up to further investigate and evaluate the feasibility of phosphorus precipitation in septic tanks.

INTRODUCTION AND OBJECTIVES

In many rural recreational and some suburban areas of the United States, the most common method of domestic waste disposal is via a septic tank-soil absorption system. These systems have long been recognized as a poor substitute for central sewage treatment. However, it is likely that the use of presently existing systems will continue, especially in recreational areas, where large seasonal variations in population as well as local geomorphology make central sewage treatment facilities unfeasible. In view of the fact that improper installation and/or poor soil types render many if not most septic tank systems inadequate, their presence poses a very real threat of undesirable nutrient input to and subsequent decline in the water quality of lakes and streams.

The purpose of this project has been to determine the feasibility of employing a chemical precipitation system for removal of phosphorus, an important limiting nutrient, within the septic tank and thus preventing its discharge into nearby bodies of water. The first phase was involved in attempting to elucidate (in vitro) the effect(s) chemical addition might have on the microbiological activities associated with such a system; to determine if the precipitated phosphorus complex remained insoluble; to examine the amount of additional sludge accumulation; and to determine the amount of chemical(s) necessary to effect desirable efficiencies of phosphorus removal. The information gathered from this investigation would then be used to establish guidelines for the implementation and operation of a full-scale trial system in the field.

METHODOLOGY AND REASONS

The laboratory investigation carried out to date has sought to accomplish the following objectives:

- 1) To determine the effect of ferric chloride addition on the metabolic

activity of those microorganisms characteristic to a septic tank environment,

- 2) To determine ferric chloride dose levels required for phosphorus removal in the septic tank,
- 3) To determine if increased sludge accumulation from such precipitation would be extensive enough to adversely affect the system, and,
- 4) To determine the fate of the precipitated phosphorus under anaerobic conditions, such as exist in septic tanks.

All parameters measured in the course of these experiments were done so according to the appropriate procedures listed in Standard Methods (10). The following list indicates more specifically some of the common analyses performed:

<u>pH</u>	: Beckman Century SS pH meter
<u>Alkalinity</u>	: 0.02 N sulfuric acid filtration to endpoint pH 3.7
<u>Total and Total Soluble Phosphorus</u>	: Persulfate digestion followed by Vanadate-molybdate color development. Absorbancies were obtained using a Bausch and Lomb Spectronic 70 at a wavelength of 440 mu in a 1 cm cell
<u>Orthophosphate</u>	: Vanadate-molybdate color development. Absorbancies obtained using a Bausch and Lomb Spectronic 70 at wavelength 440 mu in a 1 cm cell
<u>Total Organic Carbon</u>	: Combustion-Infrared method using a Beckman Model 915 Total Organic Carbon Analyzer and a Mine Safety Appliances Infrared Analyzer Model LIRA 200-S

The composition of the substrate used in the Warburg experiments is shown in Table 1.

TABLE 1. SUBSTRATE COMPOSITION*

<u>Component</u>	<u>Concentration, mg/l</u>
Glucose	390
$(\text{NH}_4)_2 \text{SO}_4$	146
$(\text{NH}_4)_2 \text{HPO}_4$	43
Phosphorus, as P	10
Dried Milk	6
Yeast Extract	3
NaHCO_3	0 + 150

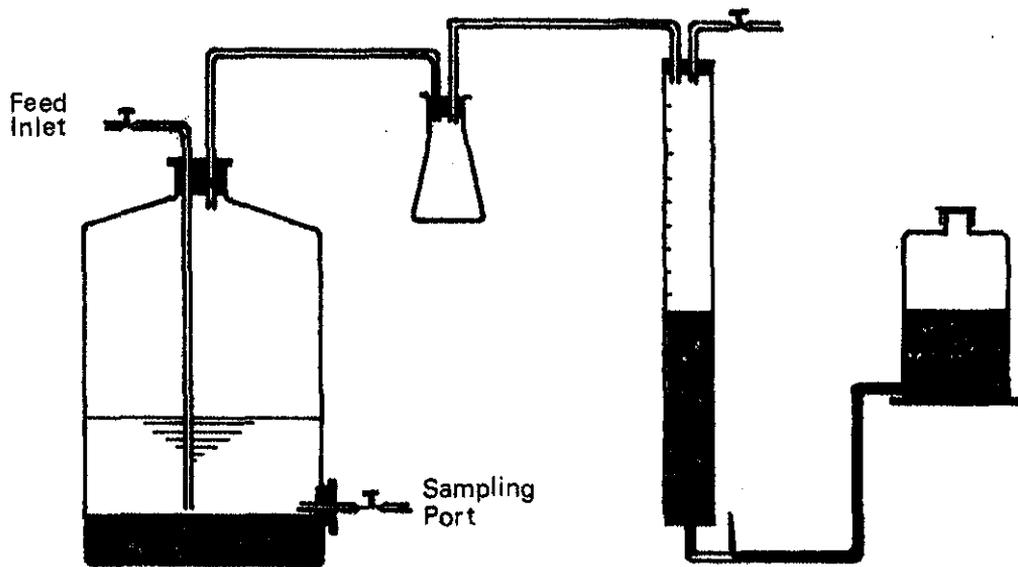
* All components listed are reagent grade with the exception of Dried Milk, which was obtained from Saratoga Dairy Farms, Saratoga, New York.

1. Effects of Ferric Chloride on Metabolic Activity of the Bacteria

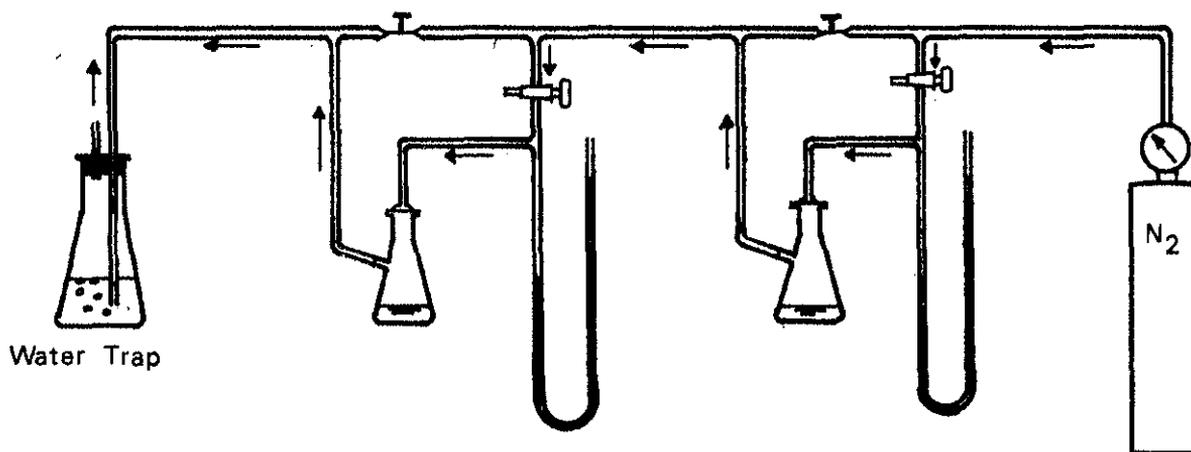
The process of waste breakdown and stabilization in the septic tank is carried out by two groups of bacteria, the "acid-formers" and the "methane producers." Of these two, the methane bacteria are the more sensitive to environmental conditions; also, they are responsible for the final step of waste stabilization, utilizing the volatile acids produced by the acid-formers to produce CH_4 and CO_2 (6). Thus, it was decided to measure possible effects ferric chloride might have on bacteria by measuring its effect on the activity of the methane producers. This was accomplished by comparing gas production as well as carbon utilization and initial and final pH in an apparatus similar to a Warburg respirometer. Basically, 25 ml of substrate and the appropriate amount of ferric chloride were combined in a 125 ml flask which was then attached to a manometer and purged with nitrogen at a flow rate of one liter/minute for 1-1/2 hours to remove oxygen (see Figure 1) (8). Next 10 ml of inoculum from a digester (see next paragraph) was transferred anaerobically to the flask to give a total volume of solution in the flask of 35 ml. The flask was again purged with nitrogen for another 15 minutes to remove any oxygen which may have entered the flask during the transfer operation. The manometer with flasks attached were removed from the gas manifold and the flasks were placed in a constant temperature water bath. Gas production was measured for at least 48 hours or until gas production ceased, whichever was longer. At this point the flasks were removed from the water bath, disconnected from the manometers, and the pertinent chemical analyses were performed on each sample.

The inoculum used in these experiments was taken from a laboratory scale anaerobic digester. This digester was originally filled with 2.5 liters of sludge obtained from a digester at Schenectady Sewage Treatment Plant diluted 1:1 with warm tap water. The digester itself was a 15 liter glass jug, with a sampling port just above the sludge layer and

FIGURE 1: Schematic illustrations of digester
and gas purging apparatus



(a) LABORATORY DIGESTER



(b) GAS MANIFOLD FOR PURGING FLASKS

a feed inlet, and was connected to a manometer column (see Figure 1). This digester was batch fed one liter of the substrate used in the Warburg experiments every 2-4 days, with one liter of supernatant being withdrawn for every liter of feed. This insured effective bacterial utilization of the substrate.

The selection of the composition of the substrate was based upon available information on synthetic substrates (5, 9) as well as upon desired levels of Chemical Oxygen Demand (COD), nitrogen and phosphorus in the substrate. In addition, sodium bicarbonate was added to provide sufficient alkalinity to maintain the pH. However, the final alkalinity of the Warburg flask solution was not allowed to exceed that of average septic tank effluent, 228 mg/l as CaCO_3 (1). The exact composition of the substrate has been shown in Table 1. The decision to combine 25 ml of substrate with only 10 ml of inoculum was based upon a desire to control and/or decrease the number of possible variables contained in the experimental solution (present in the Warburg flask) which might affect the microbial activity. In addition, initial experimentation showed that 25 ml of substrate provided sufficient nutrients to support microbial activity for the desired observation period (48 hours).

In order to determine initial conditions in the flask, duplicates were prepared containing the substrate, ferric chloride and inoculum, and subsequently analyzed.

Carbon utilization was determined by measuring the differences in initial and final total organic carbon of the solution in the Warburg flasks. This difference was assumed to represent the carbon which had been utilized by the bacteria and would be present in the gas produced in the course of the experiment as CO_2 or CH_4 . For analysis on the carbon analyzer, 5 ml of well-mixed unfiltered sample was diluted 1:1 with distilled water, and then 2 ml of 0.2 N HCl was added to remove inorganic carbon compounds. A 20 ul aliquot was then injected into the analyzer.

2. Fate of Precipitated Phosphorus

In order to determine what happens to the initially precipitated iron-phosphate complex, initial and final orthophosphate levels have been measured on the Warburg experiments. At the end of a Warburg experiment an aliquot (10-15 ml) is taken from each sample and immediately filtered thru a Millipore 0.45 u filter. The orthophosphate level is then determined colorimetrically as previously described.

3. Increased Sludge Accumulation

Preliminary observations have been made regarding the compaction of precipitate following ferric chloride addition. The amount of additional sludge which will be formed will no doubt vary from sewage to sewage due to variations in phosphorus levels and efficiencies of precipitation.

4. Ferric Chloride Dose Levels

The test employed to determine the relationship of dose level to removal efficiencies was slightly modified from the standard jar test (3, 4). The difference was that no flash mixing occurred and that gentle mixing was conducted for only a short period, approximately 20-30 seconds, following the addition of ferric chloride solution. It was felt that this procedure provided a more reasonable simulation of the degree of mixing that would occur in a system of chemical addition to a septic tank.

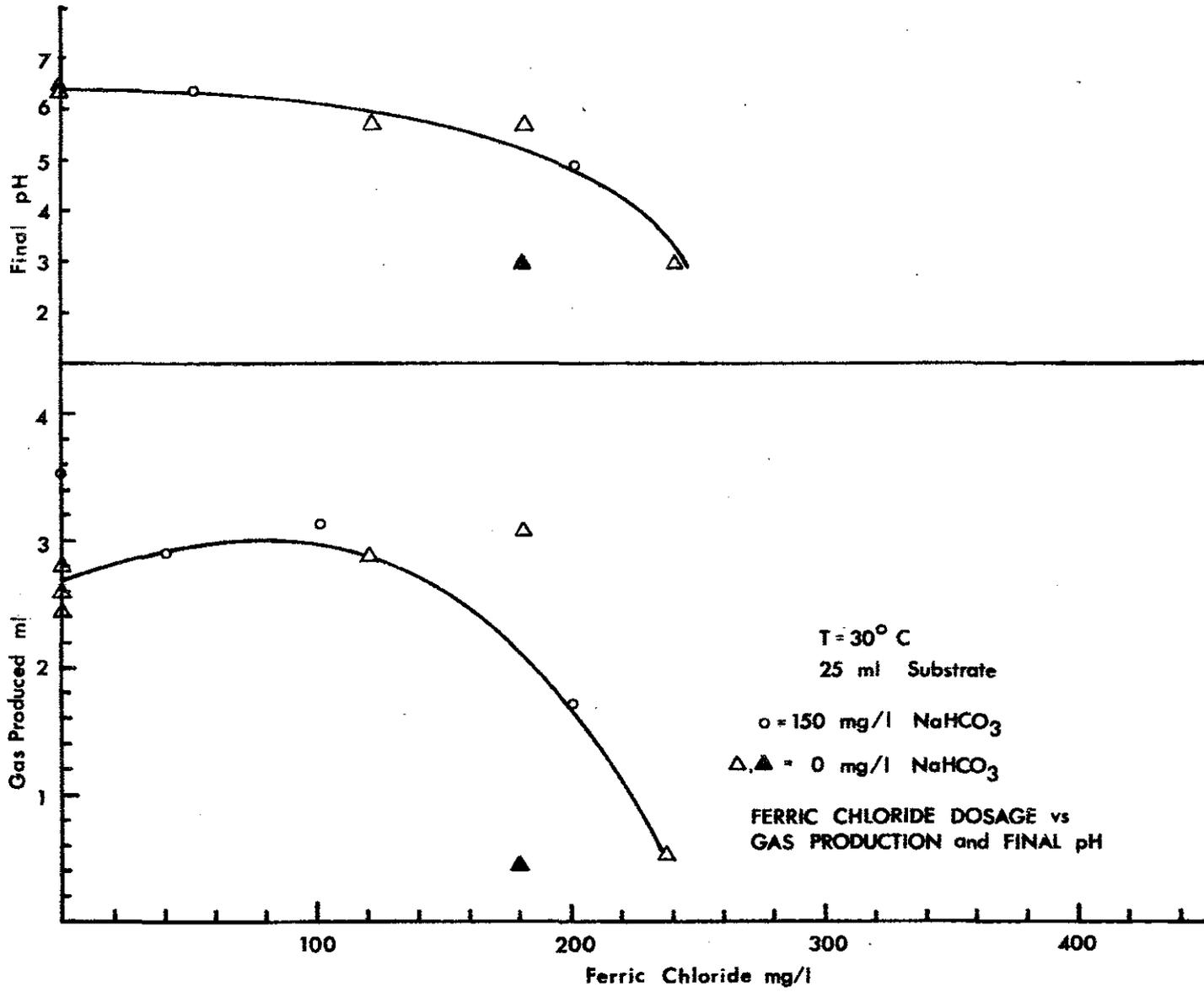
RESULTS AND DISCUSSION

1. Effects of Ferric Chloride on the Metabolic Activity of the Inoculum

The results of the Warburg experiments are summarized in Figures 2 and 3. From these data, it appears that the effect of ferric chloride addition on gas production may be dependent on either the pH and/or temperature of the system.

Figure 2 illustrates the change in gas production and final pH

FIGURE 2: Gas production and final pH response at 30°C of the inoculum to various ferric chloride dosages

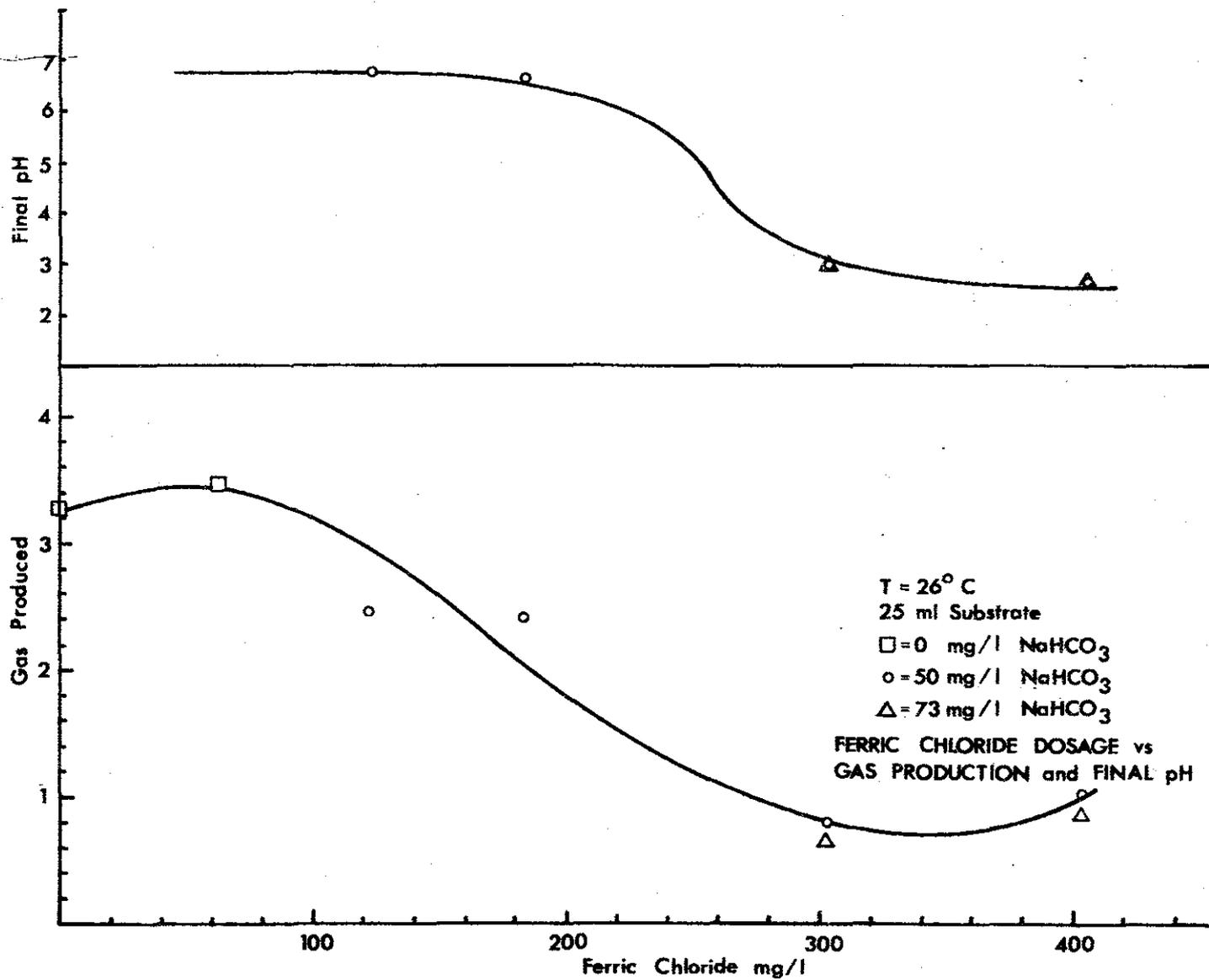


at 30°C as the ferric chloride concentration increases. Up to 120 mg/l ferric chloride, there is very little change in gas production (2.8 to 3.1 ml), nor does the final pH decrease to a significant point (i. e., from 6.45 to approximately 6.0). However, as the ferric chloride concentration approaches 200 mg/l, gas production drops off rapidly (down to approximately 1.6 ml) and the pH drops to less than pH 5.0.

Figure 3 illustrates the change in gas production and final pH at 26°C as the ferric chloride concentration increases. The trend is very much the same as that which occurs at 30°C in that gas production decreases from approximately 3.1 ml as ferric chloride concentration increases beyond 100 mg/l. The rate of decrease in gas production at 26°C is not quite as rapid as that observed at 30°C, nor does the pH decrease as rapidly.

In general, these data indicate that gas production will be depressed by the addition of ferric chloride in excess of 100-120 mg/l. However, it is not evident exactly why this effect occurs. It could possibly be due to the presence of Fe(II), Fe(III), or chloride ions in toxic concentrations. Alternatively, it may be due simply to the lowering of pH caused by the addition of ferric chloride. From Figure 5, it can be seen that even with 150 mg/l of sodium bicarbonate present in the flask, the addition of ferric chloride in excess of 150 mg/l causes the initial pH in the flask to drop below 6.0. Since the ability of the methane bacteria to function optimally requires a pH of 6.6 or greater (2), this may be an inhibition of or interference with the catabolic scheme(s) of these microorganisms. Also, the acid-producing bacteria are less sensitive than the methane bacteria to such adverse environmental conditions; they may continue to function at the lower pH while the methane bacteria function at a much slower pace or not at all, thereby driving the pH even lower. Comparison of the data contained within Figures 2 and 5, for example, shows that the pH (Figure 2) decreases with increasing ferric chloride concentration at a faster rate than the

FIGURE 3: Gas production and final pH response at 26°C of the inoculum to various ferric chloride dosages



residual pH (Figure 5) (equivalent to initial pH), even with 150 mg/l NaHCO_3 present in the flask.

The amount of NaHCO_3 added to the flask would thus seem to play an important role in determining initial pH, final pH, and related gas production. For a given ferric chloride concentration, increasing the NaHCO_3 concentration will raise the pH of the solution. As long as the pH is in the range where methane bacteria can function in optimum or near optimum capacity, gas production should not be affected, and because volatile acids are continually being utilized as they are being produced, the final pH will be relatively high. If there is not sufficient alkalinity present (e.g., as added NaHCO_3) to maintain the pH, then gas production and final pH will be depressed as previously explained.

The data obtained on total organic carbon is shown in Table 2. The samples in this table are listed according to the concentration of ferric chloride that was present in the Warburg flask; the corresponding temperatures listed are those at which the flask contents were digested in the water bath. The initial and final carbon (C) values are the weight of carbon present at that time in the 35 ml of sample. In determining the carbon in the gas, it was assumed that all gas produced was either CO_2 or CH_4 , so that one millimole of gas contained one millimole (12 mg) of carbon. Theoretically, any carbon lost from the liquid sample should appear as carbon present in the gas, i. e., in Table 2 "ΔC" should equal "Carbon in Gas." The "% Difference" column in Table 2 is intended to represent the lack of agreement between values of "ΔC" and "Carbon in Gas," where a small "% Difference" value indicates close agreement and vice versa. For example, at 26°C and 60 mg/l ferric chloride, values of ΔC were 1.850 mg and 1.668 mg, indicating that this amount of carbon had been utilized by the acid-forming and methane bacteria in the production of CO_2 and CH_4 . The values of "Carbon in Gas" for these samples were 1.680 mg and 1.716

TABLE 2. TOTAL ORGANIC CARBON ANALYSES

Sample (mg/l FeCl ₃)	Temp. (°C)	Initial C (mg)	Final C (mg)	Δ C (mg)	Carbon in Gas (mg)	% Difference *
50	25	10.000	8.664	1.336	1.212	9.3
100	25	10.000	7.500	2.500	2.160	13.6
100	25	10.000	7.800	2.200	1.812	23.8
0	30	5.185	3.731	1.454	1.356	6.7
0	30	5.185	3.640	1.545	1.212	21.6
0	30	5.185	3.745	1.440	1.212	15.8
0	30	5.185	3.780	1.405	1.224	12.9
0	30	5.215	4.214	1.001	1.368	(-) 36.7
0	30	5.215	4.130	1.085	1.320	(-) 21.6
0	30	5.215	3.990	1.225	1.152	6.0
0	30	5.215	4.095	1.120	1.584	(-) 41.4
120	30	5.280	2.527	2.753	1.560	43.3
120	30	5.280	2.548	2.732	1.536	43.8
180	30	5.280	2.548	2.732	1.644	39.8
180	30	5.280	2.527	2.753	1.788	35.1
0	26	5.315	3.920	1.395	1.752	(-) 25.6
0	26	5.315	3.864	1.451	1.920	(-) 32.3
60	26	5.315	3.465	1.850	1.680	9.2
60	26	5.315	3.647	1.668	1.716	(-) 2.9

* Calculation of % Difference = $\frac{(\Delta C - \text{Carbon in Gas})}{\Delta C} \times 100$

where Δ C = Initial C - Final C

mg, respectively, with corresponding % Differences of 9.2 and 2.9, thus confirming that the amount of carbon no longer present in the flask solution was equivalent to that present in the gas produced.

At 30°C and ferric chloride levels of 120 and 180 mg/l, the % Differences ranged from 35.1% to 43.8%, indicating poor agreement between the values of ΔC and Carbon in Gas. Closer inspection of the data shows that (i) the Initial C value (5.280 mg) was assumed to be the same for all four samples, (ii) the Final C values were within a very small range (2.527 to 2.548 mg), and (iii) the Carbon in Gas values were also within a relatively small range (1.536 to 1.788 mg). It can be determined that if the values of Initial C or Final C are decreased or increased, respectively, by 1.110 mg, the resulting % Differences for all four samples would be less than 10%. As was previously explained (see Methodology and Reasons, Sec. 1, p.1), initial and final carbon values were obtained from analysis of unfiltered samples. These unfiltered samples often contained varying amounts of particulate matter of varying sizes; consequently, it was difficult to determine if a homogeneous aliquot was drawn into the syringe for injection into the carbon analyzer. The error resulting from the analysis of a non-homogeneous aliquot could account for the large % Differences that were found. Thus, it appears that the lack of agreement among certain data in Table 2 may be due to difficulties encountered in sample analysis rather than due to incorrect assumptions concerning microbial activity as related to carbon utilization and gas production.

2. Fate of Precipitated Phosphorus

The data from the Warburg experiments are listed in Table 3. From these data, it appears that the fate of the initially precipitated phosphorus is dependent upon several factors including pH, temperature, and alkalinity. At 26°C and 50 mg/l NaHCO_3 , the final phosphate removal efficiencies were 75% for a dose of 120 mg/l ferric chloride and 61.7% for a dose of 180 mg/l ferric chloride, with the initial removal

TABLE 3. FATE OF PRECIPITATED PHOSPHORUS

Temp. (°C)	Dose FeCl ₃ (mg/l)	NaHCO ₃ (mg/l)	Ortho-P before dose (mg/l)	Ortho-P after dose (mg/l)	pH (initial)	Final Ortho-P (mg/l)	pH (final)	% Removal (initial)	% Removal (final)
26	0	0	12.9	12.9	--	12.4	--	0%	3.9%
26	60	0	12.9	10.5	--	12.1	--	18.6%	6.7%
26	120	50	6.0	< 2.0	--	1.5	6.8	> 67%	75.0%
26	180	50	6.0	< 2.0	6.5	2.3	6.7	> 67%	61.7%
30	0	150	11.0	11.0	6.85	9.1	--	0	17.3%
30	50	150	10.7	7.5	6.45	---	6.3	30%	-----
30	100	150	11.0	3.0	6.25	8.4	---	72.7%	23.6%
30	200	150	10.7	1.4	5.7	8.75	4.85	86.9%	18.2%

efficiencies for both doses being greater than 67%. However, at 30°C and 150 mg/l NaHCO_3 , the removal efficiencies for doses of 100 and 200 mg/l ferric chloride decreased from 72.7% and 86.9%, respectively, to 23.6% and 18.2%, respectively, during anaerobic digestion. Thus, it appears that at higher temperatures and alkalinities, the initially insoluble iron-phosphate complex is adversely affected to the extent that much of the initially insoluble phosphate returns to the soluble form during anaerobic digestion. In such a case, then, the addition of ferric chloride would not result in significant increases of phosphorus removal within the septic tank. Nevertheless, it is necessary to carry out further experimental work in order to gain a better understanding of the solubility of the iron-phosphate complex under anaerobic conditions.

3. Increased Sludge Accumulation

The preliminary data gathered using jar tests have been with digester effluent that contained an appreciable amount of settleable solids. Since the ferric chloride was added immediately, before the solids were allowed to settle, it is difficult to determine what amount of the sludge was due to precipitation of the phosphorus present. It was observed, however, that the volume of sludge present one hour after the addition of ferric chloride decreased by roughly 67% of this initial sludge volume if allowed to settle for 24 hours.

Barshied (1) found that when using an eight foot settling column with a six inch diameter filled with clarified septic tank effluent containing 6.65 mg/l phosphorus and 120 mg/l suspended solids, sludge accumulation was 4-1/4 inches after 60 minutes for a dose of 120 mg/l ferric chloride. If the same degree of compaction were to occur as described in the previous paragraph, then the volume of sludge after 24 hours would be 33% of 4.25 inches, or 1.4 inches. This would represent a sludge volume (after 24 hours of settling) roughly equal to 1.5% of the volume of wastewater treated.

As the volume and thus the weight of sludge in the septic tank

increases, the degree of compaction which occurs may very well increase due to the increased weight of the sludge. Under such conditions, the additional weight of sludge resulting from phosphorus precipitation could in fact reduce the volume of sludge that accumulates between tank cleanings by increasing the amount of sludge compaction that would occur. However, further investigation along these lines is necessary before any definite conclusions may be reached.

4. Ferric Chloride Dose Levels

Figures 4 and 5 illustrate the relationship between dose level, phosphorus removal, and residual pH. The graph in Figure 4 illustrates the %P removal and residual pH as a function of ferric chloride solution addition to digester effluent; the graph in Figure 5 represents similar experimentation in the Warburg flasks where, as previously explained, 10 ml of inoculum from a digester was added to 25 ml of solution containing substrate and ferric chloride.

In the laboratory tests conducted to date, results have indicated that for a given dose of ferric chloride, efficiencies of phosphorus removal are less than those reported by other investigators (1, 3) for the same dose. For example, from Figure 4, a dose of 200 mg/l ferric chloride resulted in approximately 81% removal of phosphorus for an initial phosphorus level of 19 mg/l; this corresponds to a molar ratio of approximately 2 moles Fe/mole initial P. Barshied (1) found when using ferric chloride that more than 90% removal was possible at a molar ratio of 1.5 moles Fe/mole initial P for a septic tank effluent with an initial phosphorus level of 11 mg/l. Additionally, guidelines found in Culp and Culp (3) indicate that a wastewater stream with 20 mg/l P can be dosed with 138 mg/l ferric chloride to give phosphorus removal efficiencies of at least 85%.

In their discussions, Barshied (1) and Culp and Culp (3) determine removal efficiencies for a given ferric chloride dose based on the use of a typical chemical coagulation-flocculation process, i. e., one that

FIGURE 4: Percent phosphorus removal and residual pH relative to ferric chloride addition to digester effluent

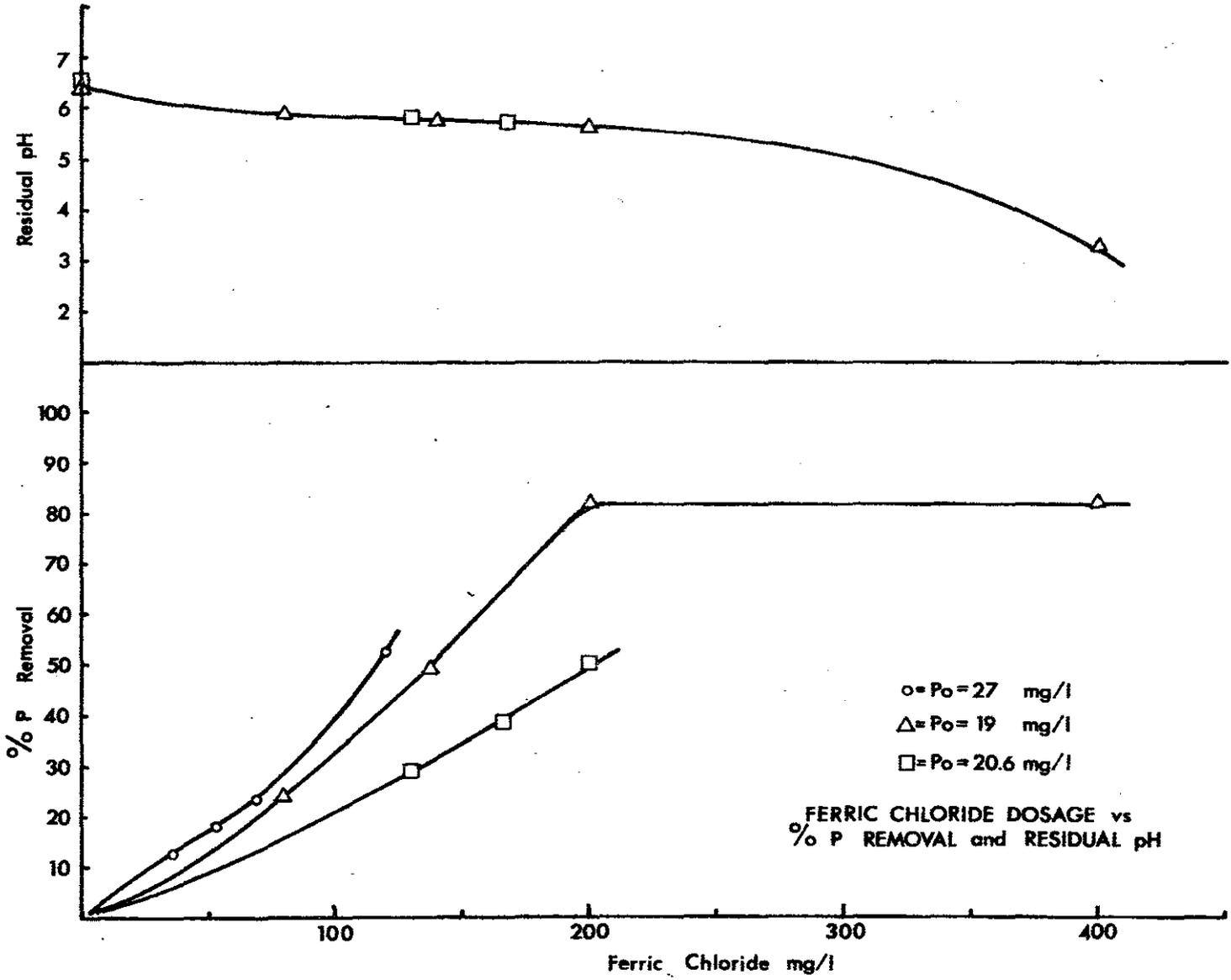
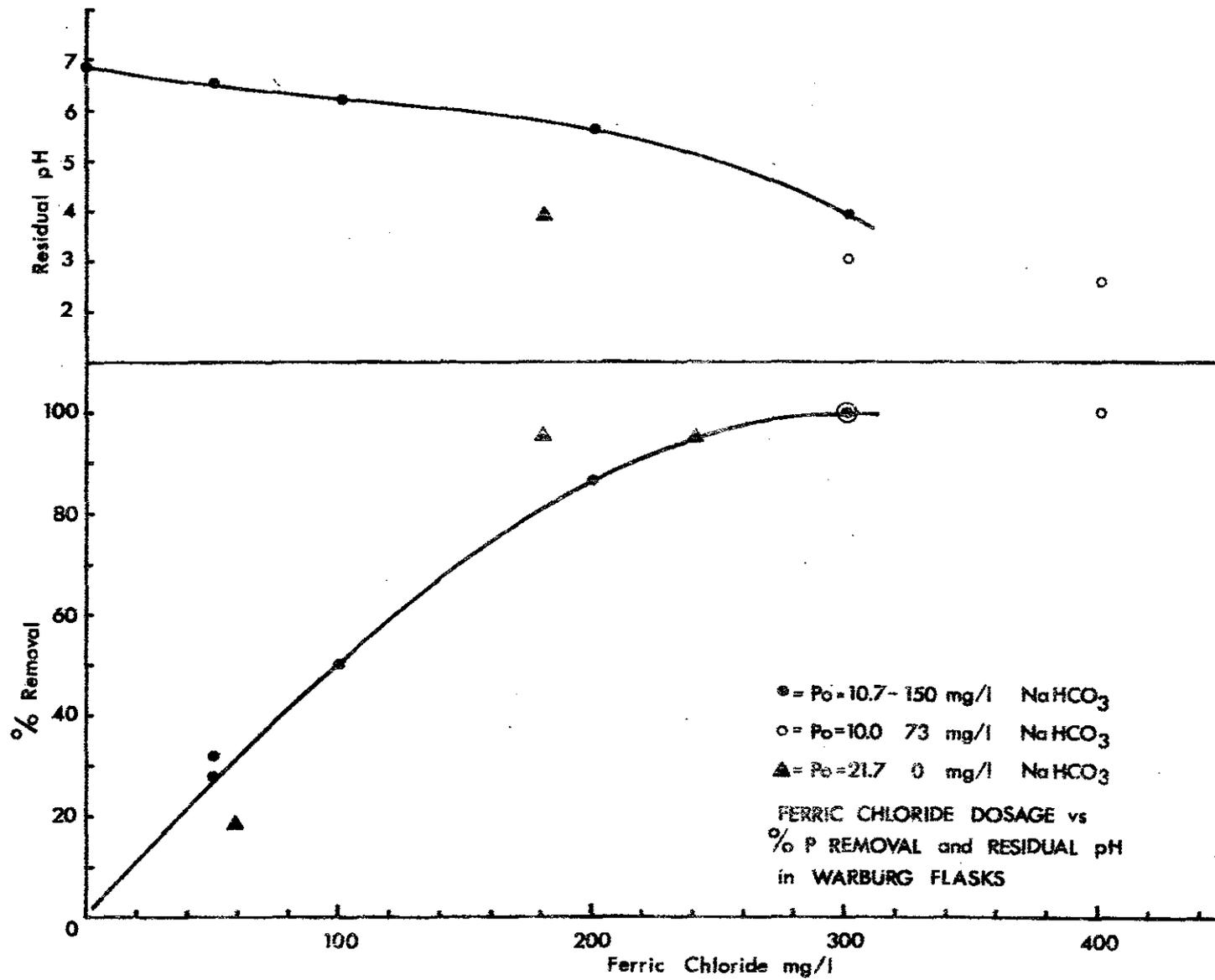


FIGURE 5: Percent phosphorus removal and residual pH relative to ferric chloride concentration in a Warburg flask



includes periods of flash mixing for chemical distribution and gentle mixing to enhance floc growth. The lower removal efficiencies for a given ferric chloride dose found in the modified jar test (see Methodology and Reasons, Sec. 4) of this project may therefore be due to the lack of adequate mixing.

A comparison of Figure 5 data with Figure 4 data shows that removal efficiencies for a given ferric chloride dose were greater in the Warburg flasks (Figure 5). For example, for a dose of 200 mg/l ferric chloride, the removal efficiency in the Warburg flask was 87% as compared to 82% in the jar tests. However, the phosphorus level was only 10.7 mg/l in the Warburg flask as compared to 19 mg/l in the jar. Hence in the Warburg Flask, the ratio of moles Fe/mole initial P was 3.6:1 as compared to 2:1 in the jar test. In terms of the moles Fe/mole initial P ratio, then, the removal efficiencies found in the Warburg flasks are not as high as one might expect.

SUMMARY AND CONCLUSIONS

The addition of ferric chloride to a simulated septic tank environment was found to be non-toxic when the concentrations of ferric chloride was less than 120 mg/l. However, when added in the range of 120 to 200 mg/l, gas production by the methane-producing bacteria was lessened by an increasing amount as the concentration of ferric chloride was increased. The degree of interference also appeared to be related to the change in pH caused by the addition of the ferric chloride; this in turn is related to the alkalinity present in the system which aids in buffering the solution. The greater the pH drop due to ferric chloride addition, the greater the resulting decrease in gas production. This effect can be attributed to the pH sensitivity of the methane-producing bacteria.

The amount of ferric chloride required to attain desired levels, i.e. 70-80%, of phosphorus removal was higher than in normal treatment

methods, apparently due to the lack of adequate mixing that occurs in a septic tank system. Efficiencies of removal for a given dose varied with the initial phosphorus concentration, pH and alkalinity of the sewage. When the dose determination results are compared with the Warburg inhibition studies, these results show that the level of ferric chloride required to achieve desirable phosphorus precipitation is in the range of that level which was found to be capable of inhibiting gas production.

The fate of the initially precipitated iron-phosphate complex appears to be dependent on temperature, dose and possibly pH changes in the system. At 26°C most of the precipitated P remained in the insoluble form for doses of 120 and 180 mg/l ferric chloride and a final pH of 6.7 or greater. However, at 30°C, it was found that less than 25% of the phosphorus remained insoluble for doses of 100 to 200 mg/l ferric chloride. Further experimental work is required to gain a better understanding of this phenomenon.

Available information on sludge accumulation resulting from phosphorus precipitation indicates that the initial volume of sludge will be approximately 1.5% of the volume of wastewater treated. However, the amount of additional sludge will vary as the characteristics of the waste stream and efficiencies of precipitation vary. In addition, there may be significant compaction of the precipitate as solids which are continually entering the system settle on top of the precipitate. As was previously discussed, a decrease in volume (not weight) of solids may accrue due to ferric chloride addition. If such a phenomenon were to occur, it could be economically beneficial to the septic tank system in two possible ways: 1) it might increase the time between tank cleanings, thus decreasing the number of times the tank needed to be cleaned, and 2) the cost of each cleaning is based to some extent on the volume of sludge removed, thus a decreased volume of sludge would lower the cost of each cleaning. Nevertheless, further investigation of this phenomenon is necessary.

In the Warburg experiments conducted to date, a principal concern has been the effect ferric chloride addition might have on the methane bacteria which are responsible for the final step of waste stabilization in the septic tank. These bacteria were found to be less tolerant of pH decreases than those bacteria ("acid-formers") which produce the volatile acids. One might raise a question as to the necessity of the methane bacteria, i. e., can the system function adequately as long as the "acid-formers" are not inhibited. Under such conditions the volatile acids produced would be carried to the tile field for further aerobic decomposition, and the purpose of ferric chloride addition would be to improve the characteristics of the septic tank effluent in terms of reduction of suspended colloidal matter which might otherwise contribute to tile field clogging. Ferric chloride has been found to be an effective conditioning agent because of the ability of the ferric ion to cause a charge neutralization effect on the colloidal particle. This destroys the stability of the hydrophobic colloids and thus allows the formation of larger particles with improved settling characteristics (4).

McGauhey, et al. (10) concluded that sewage solids per se could not cause clogging of a soil field in a magnitude approaching that which resulted from microbial activity in their presence. Further, Winneberger and McGauhey (14) found that in an experimental installation, the reduction of suspended solids in septic tank effluent via coagulant aids produced little or no benefit on the leaching system. McGauhey and Winneberger (11) also concluded that under anaerobic conditions in the soil, the most significant factor in clogging is the rapid growth of slimes in an organic mat. Thus the increase in concentration of volatile acids in the septic tank effluent that would occur if the methane bacteria were not active might increase the rate of formation of this organic mat, thereby enhancing clogging of the soil field. Furthermore, if there were no methane bacteria present in the septic tank, it might be possible for the concentration of volatile acids to reach that level which is self-

inhibitory to the "acid-formers." The occurrence of such an event, however, depends on several factors including nutrient input to the septic tank, residence time, and level of activity of the microorganisms present. Nevertheless, it seems apparent that there is little to be gained by the addition of ferric chloride in excess of those amounts which do not cause inhibition of the methane bacteria.

RECOMMENDATIONS FOR ADDITIONAL RESEARCH

1. Continue the Warburg experiments using ferric chloride as well as aluminum sulfate to determine dosage effects at lower temperatures, e.g., 20°C and to more accurately ascertain the ranges of non-inhibitive doses. At the same time analyze the samples for phosphorus levels to determine the fate of precipitated P.
2. Perform Warburg experiments using time as a parameter to measure rates of phosphorus release and pH change. In addition, measure total organic carbon in the soluble form to trace the path of carbon in the system and thus the metabolic stability of the microorganisms.
3. Continue experimental investigation of the phenomenon of sludge accumulation and compaction in a system exposed to ferric chloride addition.
4. Apply laboratory results to a full-scale septic tank leach field system to determine the feasibility and effectiveness of such a system.

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