A STUDY OF GARBAGE COMPOSTING IN CONTROLLED, INSULATED BARRELS

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Robert L. Braithwaite
1956

This is to certify that the

thesis entitled

A Study of Garbage Composting in Controlled,
Insulated Barrels

presented by

Robert L. Braithwaite

**has been accepted towards fulfillment
of the requirements for**

M.S. **degree in** Civil Engineering

Date Nov 28, 19[illegible]

I.Y.

A STUDY OF GARBAGE COMPOSTING IN CONTROLLED, INSULATED BARRELS

By

Robert L. Braithwaite

A THESIS

Submitted to the School of Graduate Studies of Michigan
State University of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Civil and Sanitary Engineering

Year 1956

6-11-20

6

ACKNOWLEDGEMENTS

This thesis was only possible with the sincerely appreciated guidance of Dr. John R. Snell, former Head of the Civil Engineering Department, Professor Frank Theroux, and Dr. Robert McCauley.

The tireless and concientious laboratory assistance of Mr. S.W. Kao, supported by an N. I. H. grant, is also deeply appreciated.

The author is indeed grateful to Dr. W. L. Mallmann for his valuable assistance in the field of bacteriology, and to Dr. Harold Hart for his valuable suggestions pertaining to organic chemistry.

ABSTRACT

Composting is a sanitary and potentially, an economic method of municipal refuse disposal. The end-product may provide a valuable fertilizer and soil conditioner. Although the process has been used for a number of years in other countries, scientific knowledge concerning the processes of decomposition is still limited. Before adequate design criteria for commercial plants can be established, many fundemental problems must be solved. It was the purpose of this thesis to aid in the unraveling of a few of these enigmas.

In order to simulate field conditions in such way as to provide sufficient controls and measurements, a small insulated fiber barrel was used as a container for ground garbage. Compressed air was circulated through the barrel. The contents were subjected to various physical and chemical measurements; such as air flow, volume, weight, temperature, pH, moisture, ash, volatile acids, and nitrogen. The percentages of carbon dioxide and oxygen at the outlet and in the material were also determined.

To demonstrate the relationships that were found to exist, some of these results have been plotted directly. In other cases further calculations were made to determine

the weights of the dry material, gases utilized and evolved, and the water evaporated.

One of the major findings was that the temperatures sometimes reached in the composting process can be detrimental to rapid composting. Also, the anaerobic fermentation of sugars during the initially wet period seemed to account for the decrease in pH; and lastly, by utilizing the moisture content, the approximate weight of a certain volume of homogeneous, finely ground compost could be determined, regardless of the stage of decomposition. Moisture imparted very little swelling to the material.

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

I. INTRODUCTION

Composting refers to the decomposition of solid organic material, by microorganisms, to a relatively stable humus.

A. Advantages of Composting

The advantages of composting garbage are twofold. It provides a method of disposal of refuse and a means of obtaining a suitable fertilizer.

As a method of disposal, it must be compared to existing methods in the United States. Incineration is a costly process resulting in a complete loss of all the valuable organic solids. Landfill is an unsightly method, requiring the acquisition of land remote from the municipality.

Composted garbage may in some cases be regarded as a suitable fertilizer, and in certain respects may be superior to commercial fertilizer. While the commercial fertilizers may have much larger amounts of the principle nutrients, composted garbage has a greater variety of nutrients that may be more readily available to plants. In contrast to the commercial fertilizers, nutrients contained in the organic material will not readily leach out of the topsoil. Composted garbage, because of its organic nature, will improve the soil by promoting better aeration and moisture retention.

The possibility of disease resulting from the use of the composting end-product is extremely remote. It is doubtful that any pathogens would be found in a municipal garbage. If so, the organisms would undoubtedly be destroyed during the composting process, because of the very high temperatures encountered. The maximum growth temperature for most pathogenic bacteria lies between 40 and 50 C. Temperatures of 60 and 70 C. are not uncommon during garbage composting.

B. Composting Methods

There are two general processes employed in the composting of municipal refuse. One of these, the anaerobic process, is slow with objectionable odors. The second, aerobic composting is presently being investigated in this country. It is a rapid process and can be conducted under controlled conditions in a manner free from stench problems.

Systemized anaerobic composting began about thirty years ago. However, the recent trend in this country has been toward aerobic decomposition. The two principle methods of the aerobic composting process advocated in the United States are the windrowing method, and the silo or digester method. The high-rate composting plant at Michigan State University was of the digester type, with processing periods ranging from four to six days.

C. Purpose of this Thesis

Until recently, very little scientific data could be found concerning the composting process. A great deal of the literature was highly opinionated with very little supporting scientific facts. However, certain industries, governmental groups, and universities are currently carrying out constructive research programs.

The decomposition phenomena and the various conditions encountered in the garbage throughout the process are not yet fully understood. It is the purpose of this thesis to contribute information within the limitations of the methods employed.

II. APPARATUS AND PROCEDURE

A. Experimental Apparatus

In a study of these problems, on a scientific basis, a volume of material large enough to be representative of actual composting conditions, yet small enough to facilitate daily shredding was required. Since loss of heat was a critical factor in simulating the central portion of a large mass of material, insulation was needed. An insulated barrel seemed satisfactory in meeting those requirements.

The barrel used was composed of fiber, of the type used to ship dried milk. The container measured about 21.5 inches in diameter and 26 inches high. Small pipes were fitted along the side of the barrel, at the extreme top and bottom, to permit the circulation of air. To allow uniform circulation of this air through the material, a screen was installed four inches from the bottom. The available space for the material was 3.8 cubic feet.

To record the temperatures of the material, and the percentages of oxygen and carbon dioxide at different levels, three additional short pipes were installed 3, 8½, and 14 inches above the screen. Several coats of shellac were applied to the inner and outer surfaces of the barrel. One inch spun glass insulation was glued to the outside surface and to the top of the tight fitting metal cover. Aluminum foil was applied to the inner surface of the barrel to resist the attack of moisture and acids. This foil also served as an added insulating material. Air leakage around the cover was prevented by incorporating a snap-ring sealed with roofing compound.

The barrels were placed on a low rack in a heated building. The source of air was a compressed air reservoir tank. Air passed through a pressure reducer and regulator, through rubber tubing to an air flow proportioning device, and into the inlet of the barrel (either at the top or bottom). Usually the apparatus for measuring air volume was attached to the outlet pipe. This air metering apparatus consisted of a wet flow meter together with a commercial gas meter. The insulated barrels and air meters are shown in Plate 1.

To reduce particle size of the garbage, two types of grinders were used. The screw type Ray-Mo grinder, utilizing a crushing-squeezing action similiar to a household grinder, was used for the initial grinding of the fresh garbage. The resulting material possessed a very small particle size. A Kemp soil shredder was principally used to break up wet chunks that formed during the composting process. This shredder was a semi-portable machine possessing a shredding-throwing action, developed by heavy blades rotating at a high speed. The particle size resulting from this operation was quite large, with a certain percentage

PLATE 1

EXPERIMENTAL APPARATUS

Top view of barrel
with screen support

Top view of barrel
with screen

Insulated barrels and gas
meters (without the connecting air tubing)

A preliminary air supply
arrangement

of garbage passing through unmodified. However, the particles were progressively reduced in size through successive shreddings.

B. Material Used

In each experiment, fresh garbage was the source of organic material for composting. Garbage was either shredded in the Kemp soil shredder, or ground in the Ray-Mo grinder. If the latter method was employed, the resulting dense-wet mass was subsequently shredded to provide adequate aeration. Seeding was accomplished with partially or nearly composted end-product of former windrow and barrel experiments.

C. Experimental Procedure

During the periods of observation of barrel experiments, measurements were made and observations noted each day prior to disturbing the contents. Gas was sampled at the three levels of the barrels by inserting a glass tube, sealed with a rubber stopper, about eight inches into the material. While compressed air was entering the barrel, the gas was allowed to displace salt water in a filled sample bottle. Precautions were taken to blow the tube free of air prior to sampling.

Temperatures were recorded at the three levels at an eight-inch penetration. The temperature of the inlet air was usually around 18 C. Each gas meter reading and the time were recorded. The volume and weight of the compost material were also noted.

The material was then removed and shredded to disentegrate the wet clumps that tended to form. Toward the latter part of each experiment, the material was dry enough to omit grinding and was raked and turned. Water was sometimes added at this point of the experiment in an attempt to reestablish the optimum moisture content. After a thorough mixing, a small sample was removed for laboratory analysis, and the remaining material returned to the barrel.

D. Laboratory Procedure

The gas sample was analyzed to determine the percentage carbon dioxide and oxygen present. This analysis was accomplished in the usual manner; that is, passing the sample through potassium hydroxide, then through pyrogallol, measuring the gas absorbed in each case.

The compost samples were subjected to varied analyses. Percentage moisture was computed on the basis of the moist weight of the material. Moisture was first determined by employing a Cenco Moisture Balance, using a five-gram sample. The determination was later carried out by drying a sample for 24 hours at 102 to 104 C., and obtaining the loss in weight on an analytical balance. Percentage of ash, on a dry-weight basis, was ascertained by burning the dried sample in an electric muffle furnace at a temperature of 650 to 700 C. for at least three hours.

Percentage of volatile acids (as acetic acid) was determined by employing a modified procedure of the tenth edition of Standard Methods for the Examination of Water and Sewage. Approximately 10 grams of wet sample was used; 5 milliliters of concentrated sulfuric acid and 200 milliliters of water were then added, and 100 milliliters of distillate was collected. Percentage volatile acids were based on the dry-weight sample. Results were reported as total volatile acids (as acetic acid), including the volatile acids and their salts.

A further determination was made to differentiate the salts of volatile acids from volatile acids as such. A sample was first dried, then subjected to the same procedure described just above. Results from this analysis were reported as salts of volatile acids (as acetic acid), upon the assumption that the volatile acids would evaporate during drying, leaving the salts.

The pH of the fresh sample was determined by using a Beckman pH meter. A sample was placed in a closed test tube, moistened, then incubated for 24 and 48 hours. The pH and odor were then noted. Foul odors after incubation and excessive drop in pH were considered to be indicators of incomplete composting.

Ammonia and total nitrogen (see appendix), expressed as nitrogen, were determined by the Kjeldahl method. Three 1 to 4-gram samples were used in each determination.

E. Calculations

Since only the volatile solids (organic matter) was oxidized during decomposition, all weights and volumes plotted were based on the weight of the initial dry volatile solids in the particular barrel. The weight of the dry volatile solids was the difference between the dry weight of the garbage and the weight of the ash in the barrel. The dry weight was computed from the moisture content and the weight of the moist material. The bulk density was determined by dividing the dry weight by the volume occupied by the moist compost. The weight of the water evaporated daily was calculated by the difference of the measured moist weight and the calculated dry weight.

Percentage nitrogen, expressed as percentage of initial dry volatile solids, was obtained by multiplying the percentage nitrogen of the sample by the factor: the percentage of initial dry weight of the sample divided by the percentage of initial dry volatile solids of the barrel contents.

The volume of air was the difference in gas readings each day. Since the average barometric pressure was 761 mm. and the average temperature of the air was 18.4 C., the correction for standard conditions was negligible (1.01). The percentage of oxygen utilized by the material was determined from the assumption that the atmosphere contained 21 per cent oxygen (although a blank was collected each day to determine the reliability of the chemicals). On the premise that one mole of the gas was contained in 22.4 liters, the weights of the respective gases were calculated from the percentage carbon dioxide evolved, percentage oxygen utilized, and the volume of air passing through the barrel.

The respiratory quotient was calculated by dividing the percentage carbon dioxide evolved by the percentage oxygen utilized.

III. THE CONDITIONS OF DECOMPOSITION

As a preliminary test, two barrels, Barrels 1 and 3, were filled with fresh garbage and composted. Typical tests were run throughout, but due to inexperience with the method, serious questions were raised regarding validity of data. This data is therefore omitted from this discussion.

The second experiments were with three new barrels, designated as Barrels 4, 5, and 6. Barrel 4 contained fresh garbage, finely ground in a Ray-Mo grinder. It was seeded with approximately 10 per cent end-product from the previous barrel. The seeding material contained a moisture content of 35.3 per cent and a pH of 7.8; and was alkaline for about two weeks before being used as a seeding material.

End-product from the high-rate composting plant (composted fresh garbage) was utilized in Barrel 5. Finely ground fresh garbage in Barrel 6 was composted after Barrel 4 was completed. This material was seeded with approximately 10 per cent of the Barrel 4 end-product.

A. The pH

The pH, in general, denoted the progress of aerobic decomposition. Strictly fresh garbage had a pH of around 6 or 7, depending upon its contents. Upon being ground, broken vegetable cells released a large amount of free water.

The moisture contents of the material were plotted in Figs. 1 through 3. High moisture levels, which inhibited aerobic activity and favored anaerobic decomposition, were noted during the first few days in Figs. 1 and 3. Among the by-products of this type of decomposition were organic acids. These acids were apparently utilized (the pH climbing to an alkaline range) by the aerobic bacteria when the moisture content dropped enough to permit oxygen to permeate between the particles. The condition of higher pH was reached on the seventh day in Barrel 4 (Fig. 1) and on the fifth day in Barrel 6 (Fig. 3). This initial stage had already taken place within the material of Barrel 5 (Fig. 2) while still in the pilot plant.

B. A Comparison of Air Rate, Moisture, Temperature

The prevailing temperatures of the compost were plotted versus time in Figs. 1, 2, and 3. In Figs. 1 through 3, a recurring temperature cycle was evident. The first cycle in Fig. 1 occurred between Days 0 and 17 (with the exception of Days 4, 11, and 14 -- low air supply); the second cycle, between Days 17 and 22; and the beginning of a third cycle, after the twenty-second day. Four or five cycles are shown in Fig. 2. The peaks of these temperature cycles occurred on the second, eighth, fourteenth, and possibly the twenty-third day, respectively. One cycle is evident in Fig. 3; the lower temperature on the fourth day

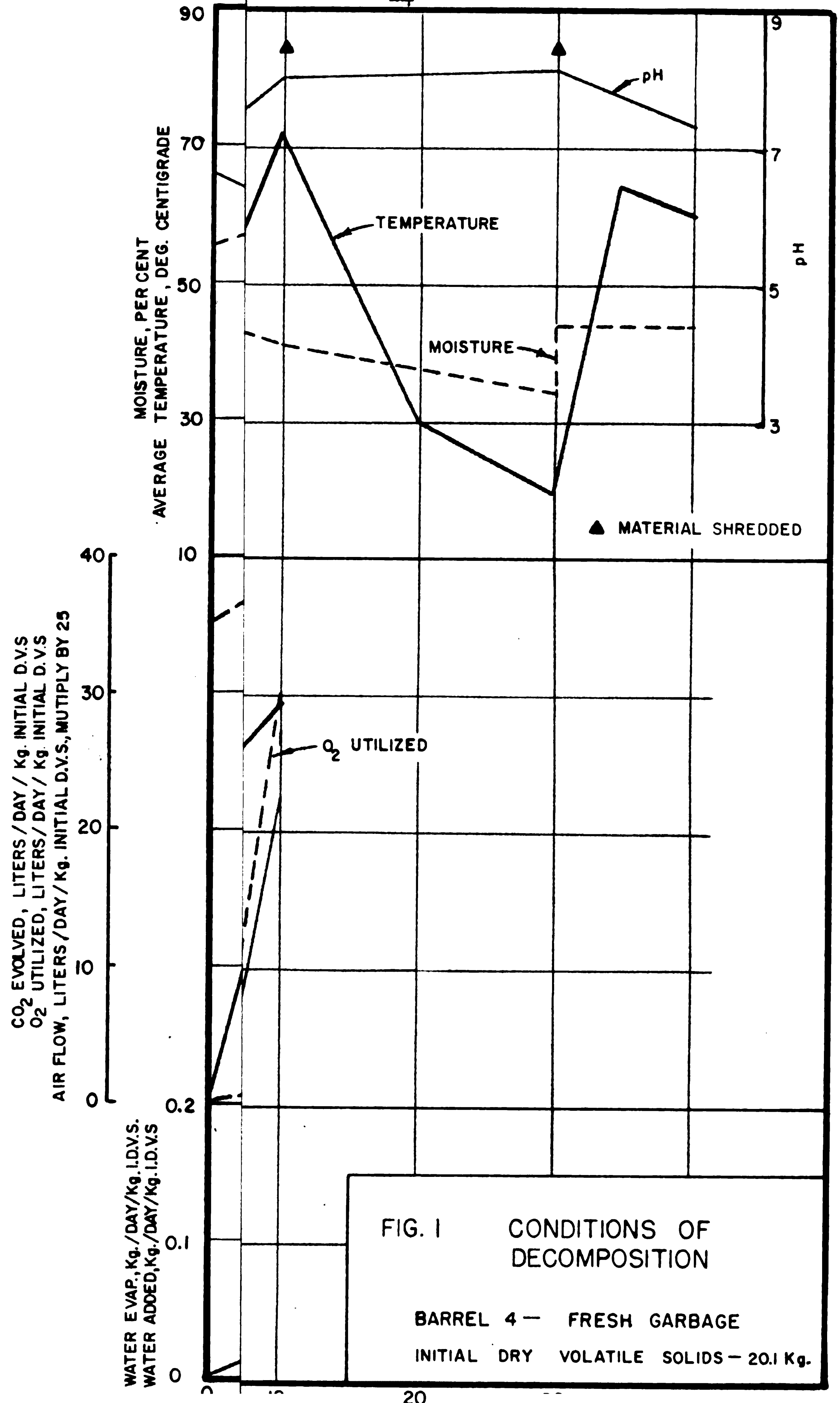


FIG. 1 CONDITIONS OF DECOMPOSITION

BARREL 4 — FRESH GARBAGE

INITIAL DRY VOLATILE SOLIDS — 20.1 Kg.

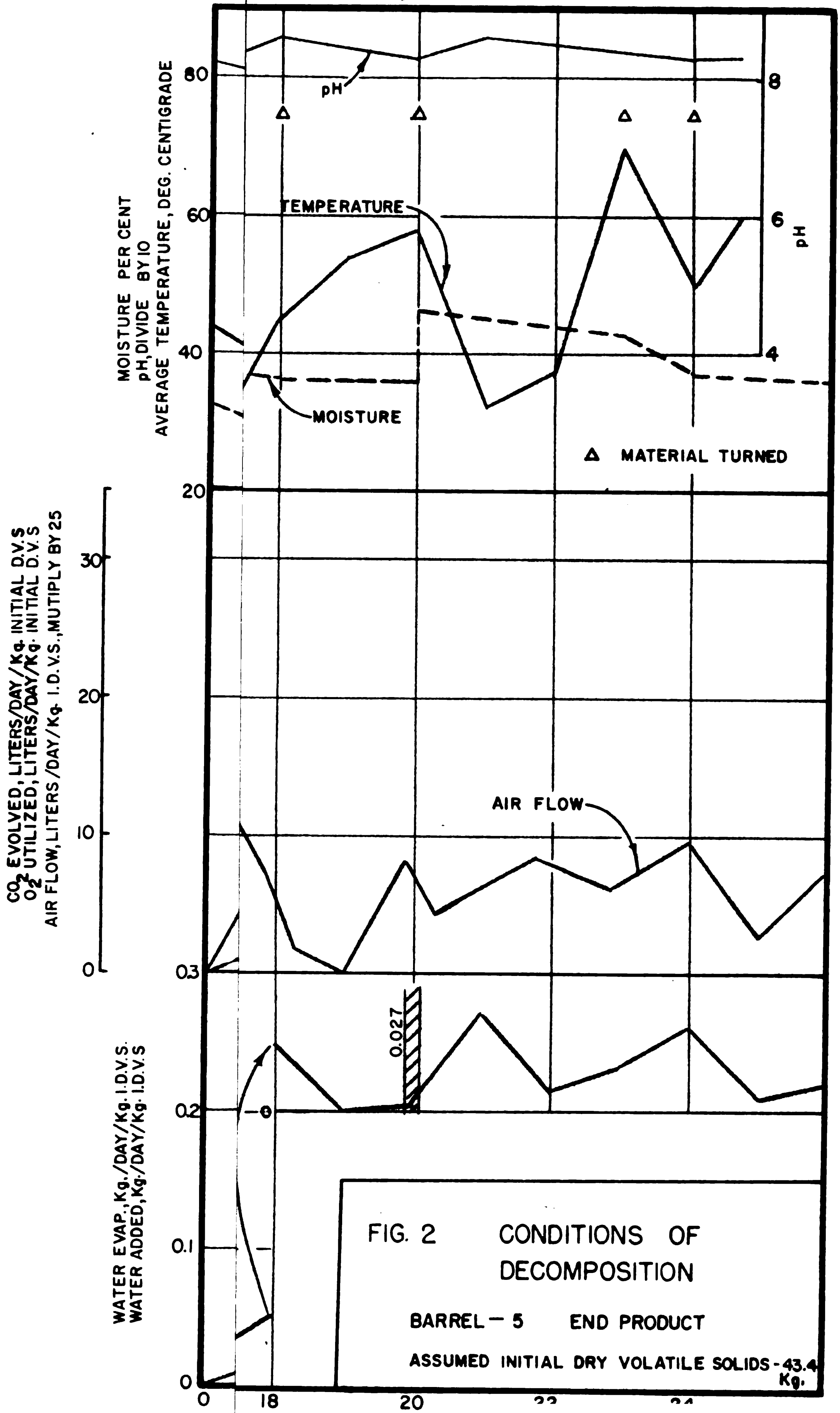


FIG. 2 CONDITIONS OF DECOMPOSITION

BARREL — 5 END PRODUCT

ASSUMED INITIAL DRY VOLATILE SOLIDS - 43.4 Kg.

being caused by a decreased air rate. In each case, when an extreme temperature was reached (70 to 75 C.), the curves showed a sudden drop. After a short recovery period, a similar cycle of increase and temperature drop was noted. It has been presumed that the enzymes of the microorganisms were destroyed at temperatures of 70 to 75 C., necessitating the growth of a new culture.

In general, no direct relationship between the air supply and temperature could be demonstrated. In spite of this fact, a certain minimum quantity of air was required to maintain the maximum rate of bacterial oxidation. This requirement was illustrated on the fourth, eleventh, and fourteenth days in Fig. 1, when the air supply dropped to approximately 10 liters daily per kilogram of initial dry volatile solids. A lagging temperature drop, following a lowered air supply, may have been the condition responsible for the temperature behavior on the seventeenth and twenty-first days of Fig. 2. No relationship between the air supply and temperature was found in Fig. 3, providing the air supply was adequate.

Oil, from the air compressor, found its way into Barrel 6 (Fig. 3) after the sixth day. The resulting oil coating diminished bacterial activity, as indicated by the lowered temperature.

With a moisture content lower than 40 per cent, decomposition was difficult to maintain, as shown in the latter 12 days of Fig. 1 and parts of Figs. 2 and 3. Fig. 2, after the fifteenth day, illustrates that a moderate air rate considerably lowered the temperature when accompanied by such a low moisture content. By lowering the air rate, a very slow recovery of the temperature was noticed. Figs. 1 and 2, on the seventeenth and twelfth day respectively, also illustrated that the temperature declined when the moisture content fell below 40 per cent.

A moisture content of around 50 per cent, maintained in the initial period of Barrel 4 and at various days in Barrel 5 (Figs. 1 and 2), seemed to have the most beneficial effect upon the composting process. More heat, an indication of bacterial activity, was produced at this level of moisture. In the latter stages of Barrel 4 (Fig. 1) and during the entire period of composting of Barrel 5 (Fig.2), an effort was made to maintain a moisture content of 50 per cent, by adding a computed amount of water; and later, by soaking the material until the moisture appeared to be excessive. Unfortunately, an insufficient amount of water was added during these periods, resulting in moistures of less than 40 per cent.

The temperature differential at varying depths was also analyzed. The corresponding data were not included in this report. The analysis illustrated that the rate of temperature climb decreased as the distance from the air source increased. Furthermore, the rate of increase generally appeared greater at a higher initial temperature (near the source). An exception (little or no increase in temperature with increased depth) seemed to have occurred when the material had a comparatively high moisture content. However, two other factors which might have been responsible for this exception were: (1) a low viable bacterial population, and/or (2) a high volatile solids content. The increase in temperature per unit depth of material varied from 0.18 to 5.20 C. per inch.

C. Oxygen Utilization and Carbon Dioxide Evolution

The amount of oxygen utilized (and carbon dioxide evolved) was a direct measurement of the progress of bacterial oxidation. Values for oxygen uptake and carbon dioxide evolved, expressed in liters daily per kilogram of initial dry volatile solids were plotted in Figs. 1 through 3.

Since heat is a by-product of bacterial oxidation, a direct relationship between the oxygen utilized and the temperature would be expected. Such a relationship was demonstrated in Fig. 1, Days 3 through 11 and 16 through 18; in Fig. 2, Days 4 through 16; and throughout all of Fig. 3.

Air and moisture affected oxygen utilization generally in the same manner as the temperature. There was no direct

relationship between the air supply and oxygen utilization, except that a certain minimum amount of air was required. Varying moisture conditions generally produced similar oxygen utilization and temperature variations.

At certain times, however, a direct relationship did not exist. A lag of the temperature to the oxygen consumed was apparent during previous periods of high moisture content. This was illustrated in Fig. 1 on the fourth through eleventh day. On the seventh day in Barrel 5 (Fig. 2), the oxygen consumption was lowered by the very low moisture content, whereas the temperature, because of the inherent insulating characteristics of the garbage, was not always a precise measurement of the progress of decomposition.

More oxygen was utilized in Barrel 4, (fresh garbage -- Fig. 1) than in Barrel 5 (pilot plant end-product -- Fig. 2). This could have been due to the low air rate introduced in Barrel 5, which was approximately 12 liters per kilogram of initial dry volatile solids per day. However, a lower moisture content was also prevalent. The low oxygen consumption in Barrel 6 (Fig. 3) during the last half of the composting period was undoubtedly due to an oil coating on the compost particles, discussed previously.

D. The Effect of Heat on Biological Activity

Since a great deal of heat was generally evolved during the aerobic decomposition of organic matter, the effect of temperature on biological activity was one of the most important questions concerning the composting of garbage. Very high temperatures (75 C.) were produced in the process. Most authors agree that the speed of an enzymic reaction is increased by an increase in temperature, to an optimum point; and that enzymes are rapidly deactivated above 50 C., and destroyed between 70 to 80 C. The effect of temperature on enzymic activity and thus on composting, is therefore important.

The effect of temperature on the number of viable bacteria was determined by counting the total number after plating out a dilution of the barrel sample in tryptose-glucose-eosin agar. The sample was incubated at both mesophilic and thermophilic temperatures for 24 hours. The cultures from Barrel 4 were incubated at 25 and 55 C., while those from Barrel 6 were incubated at 37 and 55 C. The counts at 55 C. in Barrel 6 were incomplete because of laboratory difficulties. Counts were based on 1 gram of dry material.

Since the barrel sample was obtained after a thorough mixing of the contents, the approximate temperatures of the largest portion of the material was noted.

On examination of Table 1, it may be seen that the vast majority of organisms were mesophiles, favoring a moderate temperature. While a few thermophiles (incubated at 55 C.) actually increased after being subjected to a temperature of 74 C. for one day, most of the bacteria (mesophiles) were almost entirely attenuated. (Note the high mesophilic count in the end-product of the pilot plant; 0 days -- Barrel 5).

In Barrel 6, almost all of the bacteria occurring initially were mesophiles, (favoring temperatures in the vicinity of 37 C.). Even after seven days of composting in Barrel 6 with temperatures of around 40 and 50 C., the thermophiles present were only of token number. The mesophilic count rose sharply on the sixth day in Barrel 6, when the temperature was lowered from 67 to 54 C.; and the population increased still further when the temperature dropped to 45 C.

Undoubtedly, the drop in temperature after the material had reached 75 C., was due to the attenuation of the organisms through the destruction of their enzymes.

Therefore, though higher temperatures momentarily increased oxidation in garbage compositng, more rapid overall decomposition would probably have resulted if lower temperatures were maintained.

E. Amount of Water Evaporated

The water evaporated daily (per kilogram of initial dry volatile solids) is shown if Figs. 1 through 3. No direct relationship between water evaporated and temperature, nor between the water evaporated and air flow, was evident.

TABLE 1

THE TOTAL BACTERIOLOGICAL COUNT ON TRYPTOSE-GLUCOSE-EOSIN AGAR OF GARBAGE COMPOST

Barrel No.	Time (Days)	Average Moisture Content (%)	pH	Prevailing Temperature of Material (Deg. C.)	Bacteriological Count (Million per Gram of Dry Material)	
					Incubation Temperature	
					25 C.	55 C.
4	9	52.7	7.9	74	400	3.5
	10	47.8	8.0	73	0.01	10
5	0	32.4	8.2	44	198	10
6					(37 C.)	(55 C.)
	0	65.5	5.9	14	22	0.86
	1	63.5	4.8	20	540	-
	2	62.3	5.0	40	630	-
	3	59.6	5.0	45	340	-
	4	57.9	5.4	37	120	-
	5	51.7	7.4	67	120	-
	6	45.1	7.7	54	8,100	100
	7	37.4	8.3	45	19,000	470
	8	49.1	7.9	37	4,400	-

A combination of air flow and temperature would be expected to influence the amount of water lost. Figs. 1 through 3 demonstrate that generally, such direct relationship did exist.

The results of a further analysis, however, pointed to a third influencing factor -- the ash content. Solid organic material apparently possessed the ability to retain moisture. The amount of water evaporated was directly related to a combination of temperature, air flow, and ash content of the composting garbage.

An effort was made to control water loss by reversing the flow of air through the barrel (downwards) in order to block rising water vapor. The desired effect was partially accomplished, as illustrated at the twelfth day in Fig. 2, and at the fourth day in Fig. 3, though a great deal of evaporation still occurred.

Air saturated with water (at room temperature) entered Barrel 4 after the fourth day (Fig. 2). This saturation was accomplished by allowing the incoming air to pass through an outside container of water. However, a large amount of moisture was subsequently absorbed from the compost material as the air passed through it, because of the considerable difference in saturation points of the fresh air (at room temperature) and the exhausted air (at high temperatures). Therefore, little benefit was derived from the presaturation of air at room temperatures.

Saturated fresh air, coupled with a relatively low temperature of the material, could have been responsible for the gradual increase in moisture content noticed in Barrel 4 (Fig. 1) on Days 11, 15, and 17.

Very little water was noticed at the very bottom of the barrel below the screen; indicating that evaporation, and not the draining of water downwards through the material, was responsible for the largest share of the water loss.

F. Change in pH

In an effort to find a suitable method for demonstrating the degree of decomposition, a single incubation test was used in connection with the composting material. In this test, a small amount of the composting garbage was placed in a vial daily, soaked to about 80 per cent moisture, and incubated at 35 to 40 C. A putrid odor was noted in every case, except for some material that had composted for one year.

The change in pH seemed to be of little significance as an indication to the degree of decomposition.

IV. PARAMETERS OF DECOMPOSITION

A. Volatile Acids

Volatile acids were determined in order to investigate the processes of acid production and utilization during the composting process. In general, organic acids that contain ten or less carbon atoms are water soluble. The organic acids containing up to, and including, six carbon atoms are the only acids that may be distilled under atmospheric pressure. The salts of the weak acids can be converted to fatty acids by adding a strong mineral acid.

This determination had several weaknesses. Some dibasic acids lose carbon dioxide upon heating. Any atmospheric carbon dioxide in the distillate alters the results. Moreover, depending upon the nature of the acids and the distillation rate, it has been found that as much as 32 per cent of the acids will not be distilled off.

In every case, the quantity of acid produced by the microorganisms increased on the first or second day. This was probably due to the anaerobic decomposition of the sugars, yielding fatty acids. Anaerobic conditions probably prevailed in the material during the first few days because of the very high moisture content. A certain amount of anaerobiosis always existed within the particles, even at the end of the compost period.

It is of interest that an unseeded barrel (not previously mentioned in this report) containing identical material was subjected to the same conditions as Barrel 6. The experiment was discontinued after the end of the sixth day because of wet anaerobic conditions. The moisture content remained at about 64 per cent during the duration of the experiment. Volatile acids in this barrel (initially, the same as Barrel 6, Fig. 6) continued to accumulate, and on the second day, contained 2 per cent volatile acids (as compared to less than 1 per cent in Fig. 6). This level fell to around 1 per cent on the fourth day (as compared to 0.5 per cent in Fig. 6). The "seeding" of Barrels 4 and 6 with about 10 per cent of end-product probably had the effect of reducing the overall initial moisture content, and of increasing the amount of free air space.

A definite relationship was found to exist in Barrels 4, 5, and 6 (Fig. 4, 5, and 6) between the amount of free acids and the hydrogen-ion concentration. This would account for the low pH that always occurred during the first few days of composting. Free volatile acids were not present when the compost was alkaline, probably due in part to the ammonia production.

The initial period, characterized by free acids and a high total acid content, was not noticed in Fig. 5 (pilot plant end-product). The acid stage of decomposition had

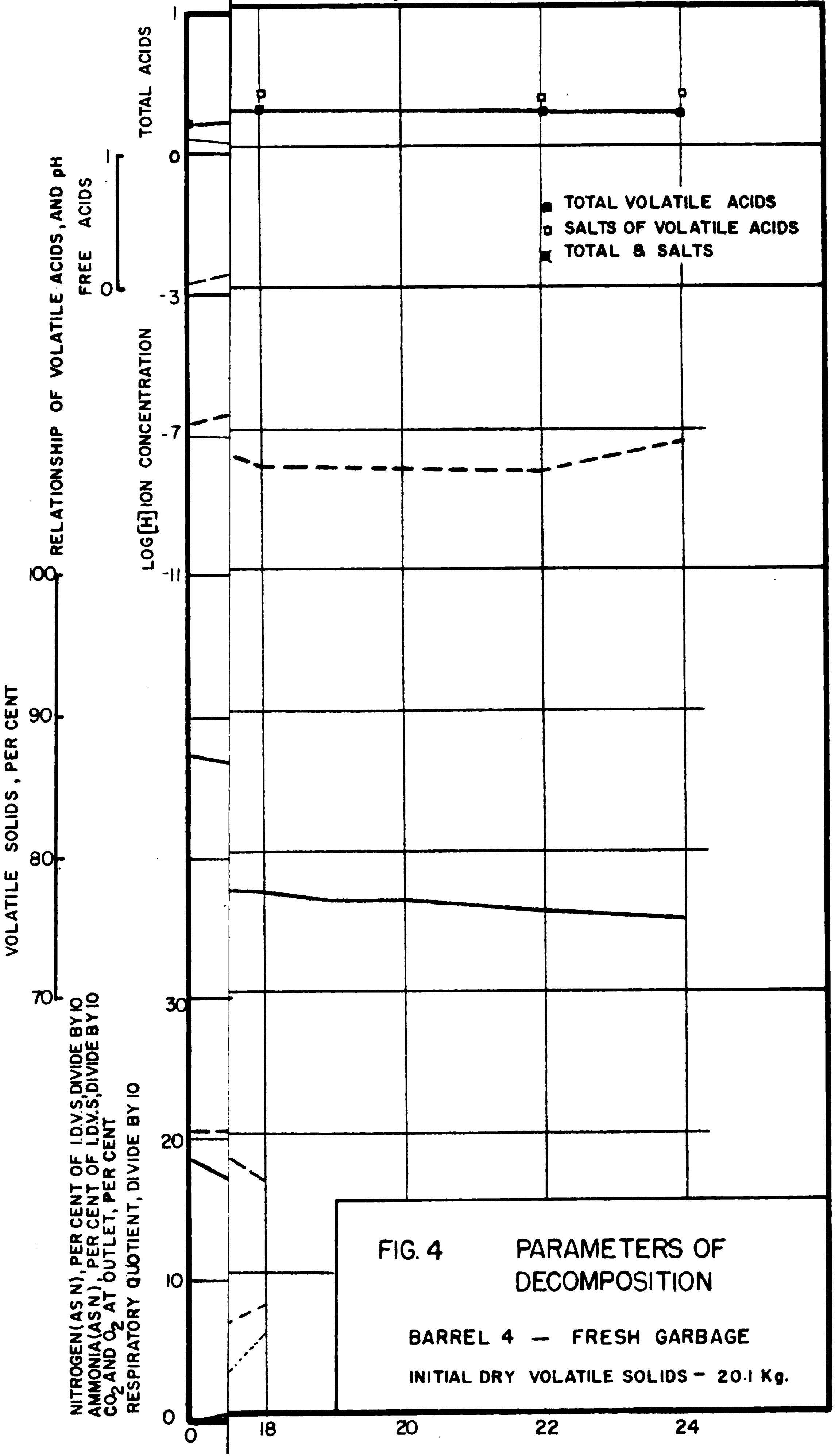


FIG. 4 PARAMETERS OF DECOMPOSITION

BARREL 4 — FRESH GARBAGE

INITIAL DRY VOLATILE SOLIDS — 20.1 Kg.

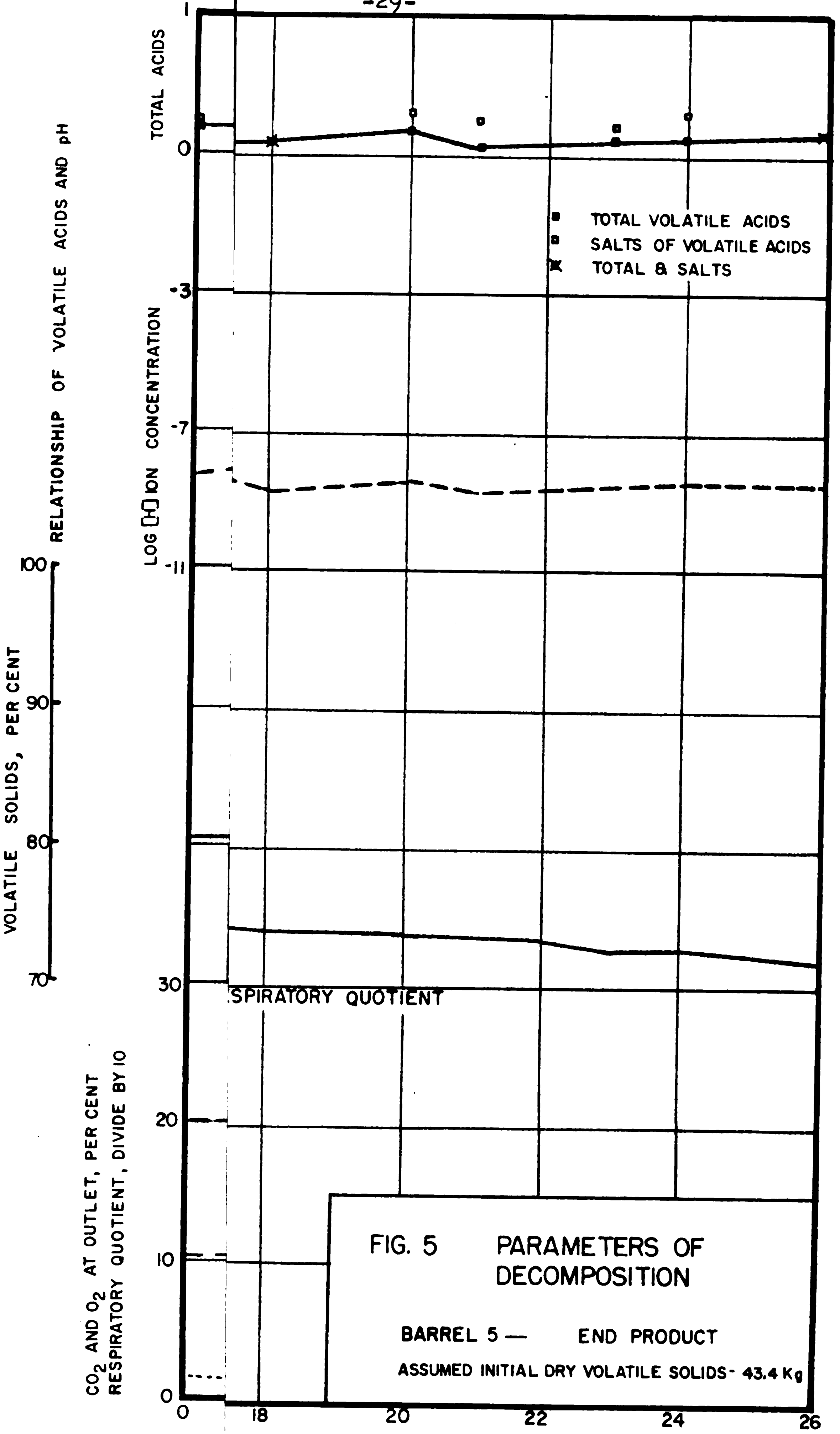


FIG. 5 PARAMETERS OF DECOMPOSITION

BARREL 5 — END PRODUCT

ASSUMED INITIAL DRY VOLATILE SOLIDS- 43.4 Kg

•

e

e

•

ls

already occurred in the material while in the pilot plant; therefore, only the salts of the organic acids were present.

Only the salts remained during the latter period of composting in each experiment, and a slight decrease in total volatile acids with the passage of time was noted, indicating that these salts were being utilized by microorganisms.

Volatile acid graphs of Barrels 1 and 3 were omitted from this report. These graphs demonstrated the occurrence of acids in the initial period as described above. In these barrels (1 and 3), the fresh material apparently contained a large amount of volatile acids. The hydrogen-ion concentration was also noticeable higher (pH lower). However, the general pattern remained the same: the hydrogen-ion concentration reaching 7 when the volatile acids disappeared.

An exact agreement between the percentage volatile acids and the hydrogen-ion concentration was not expected. Varying proportions of acids with different dissociation constants would result in a changing pH. Many acids were not represented by this determination. (Oxalic acid has a very high dissociation constant).

B. Volatile Solids

Percentages of volatile solids throughout the experiments are plotted in Figs. 4, 5, and 6. The volatile solids content was found to be a fair indication of the extent of decomposition, on a comparative basis; with the slope of the curve generally indicating the rate of decomposition.

Barrels 4 and 6 (Figs. 4 and 6) had a higher initial volatile solids content than Barrel 5 (Fig. 5). This was to be expected, since the material in Barrel 5 was already partly composted in the pilot plant. It is interesting to note that the initial material in Barrel 5 had reached the same degree of treatment in the high-rate pilot plant as that obtained in Barrel 4 in nine days; and in Barrel 6, in seven days.

The highest rate of decomposition occurred during the first twelve days in Barrel 4, and during the first seven days in Barrel 6. The reduction in volatile solids was constant (0.3 per cent per day) following this initial, high period in Barrel 4; and diminished at the same constant rate throughout the experiment in Barrel 6. This would suggest that a considerable further reduction in volatile solids could be expected, if the curing were allowed to continue.

C. Nitrogen

Nitrogen is one of the most important factors in establishing the fertilizer value of compost. Total and ammonia nitrogen, as nitrogen (the difference being organic nitrogen) expressed as the percentage of the initial dry volatile solids, are shown for Barrels 4 and 6 in Figs. 4 and 6.

The variations in total nitrogen in Fig. 4 were probably the result of excessively small samples analyzed. The total nitrogen increased from 1.9 to 2.2 per cent of initial dry volatile solids (a 0.3 per cent increment) during the first few days. The ammonia nitrogen increased from 0 to 0.3 per cent of initial dry volatile solids during the same period, and then diminished.

The fresh contents of Barrel 6 (Fig. 6) had a very high ammonia content (1.0 per cent). The total nitrogen increased slightly from 2.3 per cent to 2.4 per cent during the first two days (either by nitrogen fixation or by experimental error), and then steadily diminished. The ammonia content fell sharply during the first two days; remained constant until the sixth day; and then gradually diminished. The garbage was acidic for the period proceeding the fifth day.

An ammonia odor was noticeable in Barrel 4 on the sixth day while the material was still acidic, though a much stronger odor was noticed on the eighth day when the garbage turned alkaline. The large increase in ammonia production that was evident on the fourth day could have marked the initiation of protein decomposition. The decomposition of nitrogenous compounds normally occurs only in the absence of rapidly utilizable carbohydrates. The diminishing ammonia content in Barrel 4 after the fourth day, along with the accompanying decrease in total nitrogen, was undoubtedly the result of ammonia escaping to the atmosphere.

Though some of the initial ammonia in Barrel 6 may have been converted to organic nitrogen, a considerable portion continually escaped to the atmosphere throughout the experiment. Apparently, this loss occurred at a greater rate when the material was alkaline.

Ammonia is an end-product of protein decomposition along with carbon residue, and is always liberated when protein is decomposed. After ammonia has been liberated it may be (1) used by the soil organisms to synthesize proteins, (2) absorbed by colloidal matter and bound as ammonia, (3) oxidized by autotrophic bacteria first to nitrites, then to nitrates, or (4) lost in the atmosphere.

D. Respiratory Quotient

The ratio of the amount of carbon dioxide produced to the oxygen utilized by the bacteria is known as the respiratory quotient.

A respiratory quotient of zero indicated an absence of bacterial activity, with an oxygen absorption only by the substrate. A high respiratory quotient indicated that there was a larger volume of carbon dioxide evolved than oxygen utilized. Normally this would have indicated anerobic decomposition. However, on the second day of Fig. 4, the respiratory quotient was 1.5 while a high level of oxygen was consumed (only 3.5 per cent remained). This result pointed to an accelerated aerobic decomposition coupled with decarboxylation of the organic acids.

Respiratory quotients approaching zero were noticed on several days, indicating very little or no bacterial respiration. Initially in Fig. 4, a very low temperature was encountered, resulting in no bacterial growth. The air supply was interrupted on the eleventh day in Fig. 4 producing the same results. On the twelfth day in Fig. 5, the organisms were apparently attenuated by the preceding high temperatures. On the sixteenth day, Figs. 2 and 5 illustrated that a sudden lowering of the air flow, coupled with a moisture content of less than 40 per cent, produced a sudden increase in temperature and a sudden reduction in the respiratory quotient. In spite of the high temperature, the lowered respiratory quotient denoted decreased bacterial activity.

While respiration ceased when the air supply was interrupted on the eleventh day of Fig. 4, anaerobic conditions prevailed on the fourth day, probably because of the higher moisture content. Aerobic activity continued in spite of the air cessation on the fourth day of Fig. 6.

Oxygen remained in the material at all times. This would indicate that a certain pressure was sometimes necessary to force the oxygen into the available free air space.

While the respiratory quotient denoted the type or absence of bacterial activity, the previously discussed volume of consumed oxygen indicated the relative amount of activity.

On complete oxidation, a carbohydrate yields the same volume of carbon dioxide as the oxygen consumed; therefore, the theoretical respiratory quotient of a carbohydrate is 1.00. In like manner, the theoretical respiratory quotient of a protein is 0.80, and that of a fat is 0.70. Figs. 4 through 6 show a respiratory quotient of 1.0 during the first several days (except as noted above) and a progressively lower quotient during the remainder of the composting period. This suggests that easily utilizable carbohydrates were first ingested, followed by proteins and fats.

The carbon dioxide and oxygen differential at varying depths was analyzed in the manner previously discussed in part III-B, with the results being very similar. The increase in percentage carbon dioxide per unit depth of material varied from 0 to 0.92 per cent per inch. The decrease in percentage oxygen per unit depth of material varied from 0 to 1.03 per cent per inch.

E. The Decomposition of Cellulose

Methods for obtaining a rapid digestion of cellulose remains as one of the most perplexing problems in the composting process. Many microorganisms are capable of cellulose decomposition. These organisms include: bacteria, actinomyces, and molds.

A white mold growth was frequently noticed during the composting process. On the assumption that this mold was a cellulose digestor, conditions under which it existed were noted. This growth was apparent during a wide range of temperatures (14 to 70 C.) and at an alkaline pH range. The fungus seemed to favor moist areas (top, bottom, and wall), though at times growing under very dry conditions (30 per cent moisture). A certain amount of oxygen seemed to be required by the mold, since growth ceased when aeration was discontinued.

The important conditions appeared to be (1) an alkaline reaction, (2) a sufficient supply of oxygen (even if obtained through the agency of unfavorably dry conditions); and (3) a certain stage of decomposition (growth was observed the fourth day of Barrel 5 and the eleventh day of Barrel 6).

V. WEIGHT RELATIONSHIPS DURING DECOMPOSITION

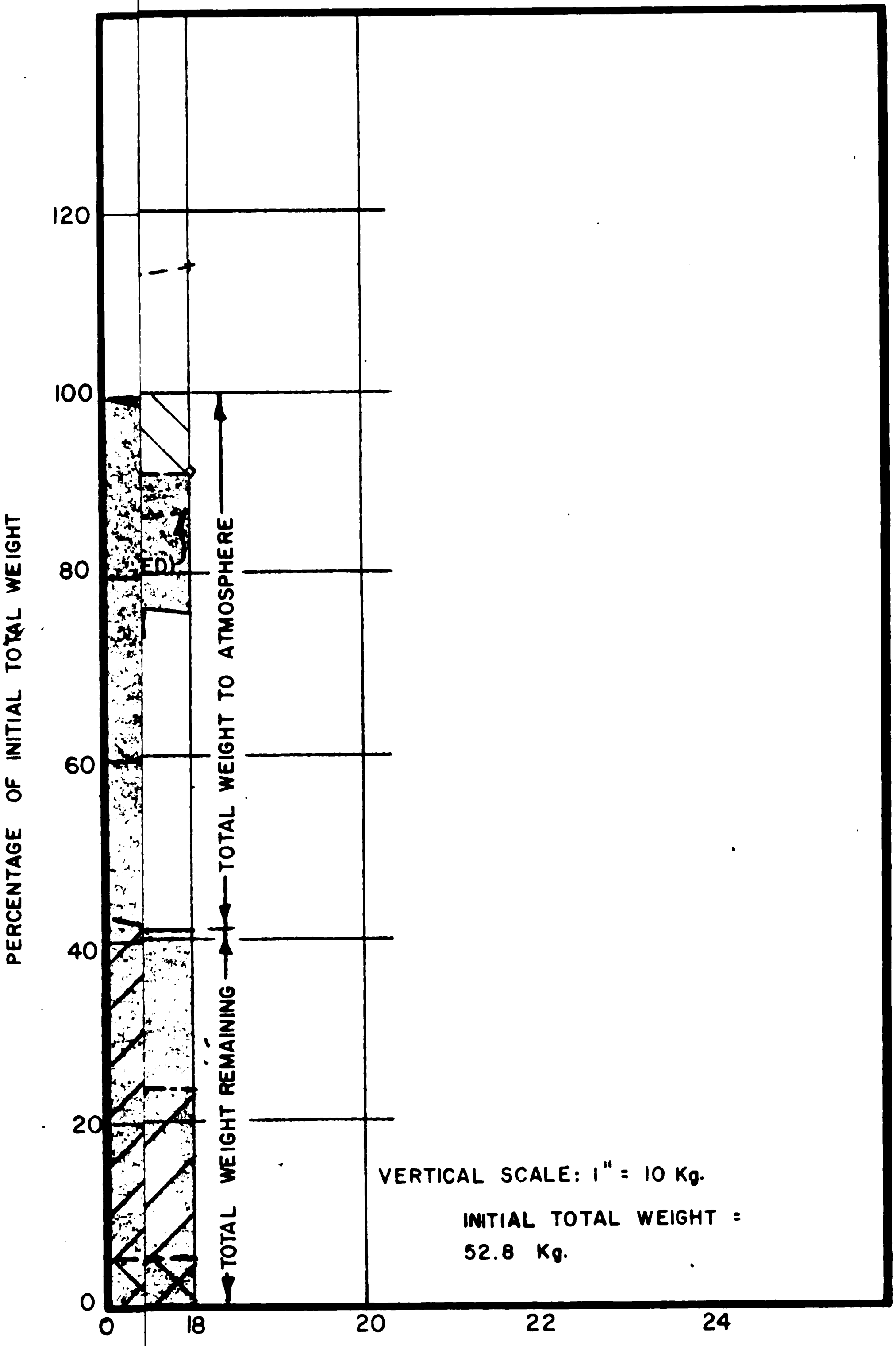
A. Analysis of Weight During Decomposition

The lower shaded section of Fig. 7 denotes the total weight of the garbage remaining at any day during composting. The upper section represents the accumulated daily weights that escaped to the atmosphere. Both were expressed as a percentage of the initial total weight.

The accumulated total water evaporated was added to the total weight of the remaining garbage. To this was added the accumulated carbon dioxide evolved. Oxygen consumed was then subtracted. The difference between the resulting figure and the initial weight represented the water and ammonia produced by the oxidation of the carbohydrates, fats, and proteins.

The weight of the water added to the material to maintain a favorable moisture content was subtracted from the total water evaporated. The difference between this line and the line produced by subtracting the oxygen consumed, represented the carbon evolved.

If the carbon evolved portion of the graph were transposed to the upper line of the dry weight portion, a nearly level line would result. The slight decrease would be due to the miscellaneous gases not measured.


PERCENTAGE OF INITIAL TOTAL WEIGHT
120
100
80
60
40
20
0
0
18
20
22
24
TOTAL WEIGHT TO ATMOSPHERE
TOTAL WEIGHT REMAINING
VERTICAL SCALE: 1" = 10 Kg.
INITIAL TOTAL WEIGHT = 52.8 Kg.

Water evaporation accounted for 60 per cent of the loss in total weight; carbon escaping (as carbon dioxide), 27 per cent; and miscellaneous gases, 13 per cent.

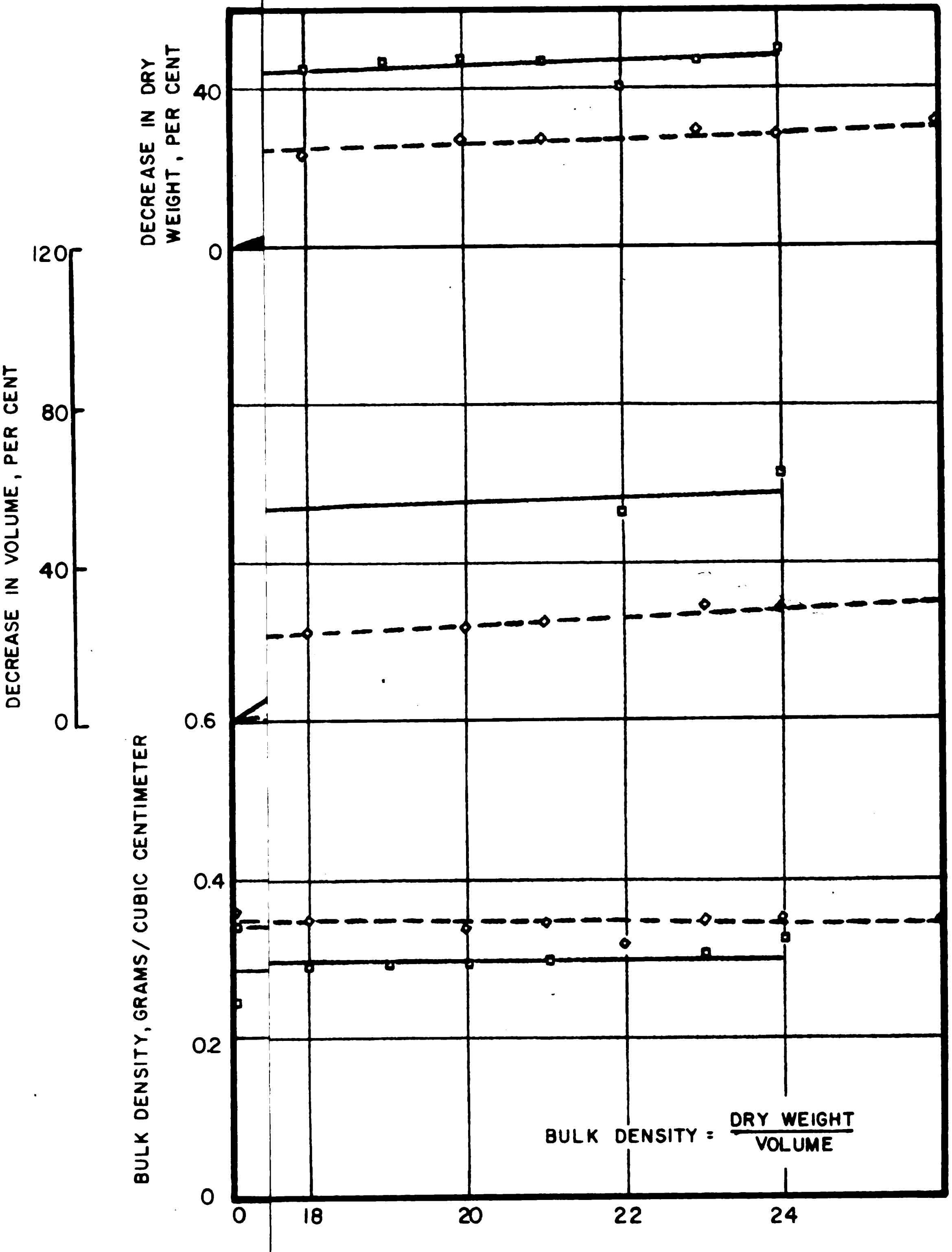
Escaping carbon accounted for about 80 per cent of the loss in dry weight.

B. The Relationship of Dry Weight to Volume

In these experiments, the unit volume was based on the total volume of the material remaining each day. The material was removed and agitated almost daily (though the volume was measured after a settlement of at least one day).

Fig. 8 illustrates that the percentage decrease in dry weight in each barrel was followed by an almost identical decrease in volume. As the material decomposed, the volume occupied was proportional to the weight of the dry material remaining. The dry material consisted principly of organic solids. Therefore, very little swelling of the particles occurred due to the presence of water. The decrease in volume was due only to the loss of water, ammonia, and carbon.

The bulk density can be defined as the weight of the dry material in a unit volume occupied by the moist material. Since the volume was proportional to the dry weight, the bulk specific gravity was nearly constant in each of these barrel experiments. The bulk specific gravities were 28.5, 35.0, and 34.0 grams per cubic centimeter in Barrels 4, 5, and 6 respectively.


DECREASE IN DRY WEIGHT, PER CENT
40
0
120
80
40
0
DECREASE IN VOLUME, PER CENT
0.6
0.4
0.2
0
BULK DENSITY, GRAMS/CUBIC CENTIMETER
BULK DENSITY = DRY WEIGHT / VOLUME
0
18
20
22
24

VI. CONCLUSIONS

The following conclusions result from the work described in this thesis:

1. While the moderately high temperatures may have been beneficial to composting, the extreme temperatures that sometimes developed (70 to 75 C.) were detrimental to bacterial activity, and thus to the composting process.

2. A certain minimum air supply was required to accomplish a favorable rate of oxidation; but a higher rate seemed to have no effect except to evaporate larger quantities of water.

3. The combination of temperature, air flow, and ash content directly influenced the amount of water evaporated. Since a moisture content of less than 40 per cent was found to be detrimental, moisture adjustments were constantly required. These adjustments were more frequent during a high rate of evaporation.

4. The rate of bacterial oxidation could be quickly estimated by noting the prevailing temperature. However, the amount of oxygen consumed was a more precise indication, since the moist garbage had an inherent heat-retaining characteristic.

5. The respiratory quotient denoted the presence of bacterial activity and helped distinguish between anaerobic

and aerobic decomposition. The respiratory quotient also showed that carbohydrates were first utilized, followed by proteins and fats.

6. A high moisture content (very little free air space) in the fresh garbage was responsible for an anaerobic condition during the first few days. Anaerobic bacteria converted easily utilizable carbohydrates into organic acids, indicated by a low pH during this period.

7. The rate of decomposition was relatively high during the first part of the composting experiment. After the material reached a volatile solids content of 80 per cent, however, the reduction in volatile solids leveled off to approximately 0.3 per cent per day.

8. The bulk density of the garbage remained nearly constant throughout each experiment. This suggests that very little swelling of the garbage occurred, since the voids contained most of the moisture.

VII. APPENDIX

A. The Determination of Total Organic Nitrogen by Kjeldahl

1. Weigh out 1-4 gms. of sample and place into Kjeldahl flask.
2. Add 1-2 gms. of $CuSO_4$
3. Add 4-5 gms. of K_2SO_4
4. Add 25-30 ml. of H_2SO_4 and begin to digest using a low flame until frothing ceases.
5. Increase flame after frothing ceases and boil until a clear solution appears (green color).
6. Digest for 1 1/2 hours at a high flame after solution clears.
7. Cool and add 200 ml. of water.
8. Add 2 or 3 pieces of granulated zinc (to decrease bumping). Add sufficient NaOH to make solution alkaline, (about 40-60 ml. if solution is alkaline, deep blue color appears).
9. Distill off about 150 ml. into a measured quantity of standard acid (15 ml.).
10. Titrate with standard NaOH using Methyl Red as an indicator.
11. Color change from red to yellow.

$$\% \text{ N} = \frac{1.4 \times \text{N. Acid}}{\text{gms. of sample}} \times \text{ml. acid used up by } NH_3$$

$$\text{ml. acid used up by } NH_3 = \text{ml. of acid used} - \frac{\text{N base}}{\text{N acid}} \times \text{ml. base}$$

B. The Procedure for Determination of Ammonia Nitrogen

1. Weigh out 1-4 gms. of sample and place in Kjeldahl flask.

2. Add about 200 ml. of distilled water.

3. Add 2 gms. of MgO, free from carbonates.

4. Connect flask to condenser and distill off about 100 ml. into a measured quantity of standard acid (20 ml.).

5. Titrate with standard alkali solution, using Methyl Red as an indicator.

6. Color change from red to yellow.

$$\% \ NH_3 \text{ as } N = \frac{1.4 \times .1875}{\text{wt. of sample}} \times \text{ml. acid used to neutralize } NH_3$$

$$\text{ml. acid used to neutralize } NH_3 = \text{ml. acid added} - \frac{N \text{ base}}{N \text{ acid}} \times \text{ml. base}$$

VIII. LITERATURE CITED

American Public Health Association, Standard Methods for the Examination of Water, Sewage, and Industrial Wastes, ed. 10, 1955, 522 pp.

Mc Gauhey, P.H., and Gotaas, H.B., Stabilization of Municipal Refuse by Composting, Proceedings of the American Society of Civil Engineers, New York, Separate no. 302, volume 79, October, 1953.

Salle, A.S., Fundemental Principles of Bacteriology, ed. 4, McGraw Hill, New York, 1954, 782 pp.

Storroff, R.P., Capitalizing on Municipal Wastes by Composting, Proceedings of the American Society of Civil Engineers, New York, separate no 545, volume 80, November, 1954.