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A STUDY CONCERNING THE
ESTABLISHMENT OF A YARDSTICK FOR
GARBAGE DIGESTION BY COMPOSTING

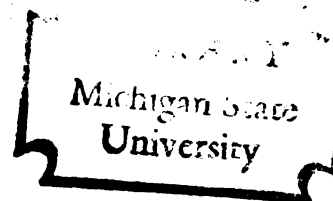
Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

William G. Turney

1954

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A STUDY CONCERNING THE ESTABLISHMENT
OF A YANQUICK
FOR GARBAGE DEGRADATION
BY COMPOSTING

by

William G. Turney

A THESIS

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ABSTRACT

This thesis deals with known biological, chemical, and physical tests, and is a study concerning their applicability to serve as yardsticks for garbage digestion.

The tests studied consisted of tests used mainly in sewage and industrial waste analysis. Because of the physical and chemical differences in the material being tested, modifications were necessary to apply these tests to garbage and compost analysis. Of the tests studied, C.O.D., oxygen consumed by permanganate, and ash seemed to be most applicable in use as good indicators of digestion. Those tests which presented problems in testing and which could probably not be used as yardsticks include relative stability, B.O.D., chlorine demand, and iodine demand. Tests such as pH, temperature, and moisture were eliminated as yardsticks because they are variables in present research.

Representative sampling was found to be one of the main problems encountered in this study, and more work needs to be done on this subject.

The validity of the C.O.D., oxygen consumed, and ash tests must be established over a long period of usage, but present data indicates that these three tests could be used as the basis of economic and efficient composting control.

This thesis is a preliminary study and should be considered as the foundation for further research on the important subject of yardsticks for digestion.

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INTRODUCTION

Investigations appearing in this thesis deal with various tests suggested for use in garbage and compost analysis. Many of the tests considered were modifications of standard tests for sewage and water analysis.

The tests in this paper will be discussed from the standpoint of their ability to serve as indicators in the composting process, and can be classified into two main groups.

1. Those tests which may be able to serve as a yardstick for garbage digestion.
2. Those tests which are beneficial as daily indicators for normal plant operation.

In some cases, tests may be classified in both groups. Both types are of interest in current research which is concerned with both large plant operation and laboratory size experiments. Some tests, that are very helpful in running the large plant, are not quantitative enough in nature to be used in the laboratory. Likewise, some tests used in the laboratory are not practical for plant use.

This paper constitutes the original study at Michigan State College on the subject of compost yardsticks and is preliminary in nature. Some tests discussed warrant more research than time has here allowed. It is hoped that by presenting the vari-

ous problems and findings encountered in this study, this paper will serve as a stepping stone for future research.

COMPOSTING IN GENERAL

Since this thesis is concerned with the determination of a yardstick for high rate composting, it would be well to understand some fundamentals of composting. Composting is the age old process of natural biological decomposition of organic wastes. In early times, organic wastes were stored in piles. This was probably done more or less as a matter of good house-keeping, but soon people recognized the fact that in time these piles changed in odor and appearance. The changes occurring during this transformation were due to the biological breakdown or anaerobic digestion of the organic wastes. This process generates and gives off considerable heat during the decomposition period. As years passed, people experimenting with the composting process, found that if the organic wastes were kept aerobic, the time for digestion was much shorter and in most cases, pasteurization temperatures were obtained.

At the present time, research at Michigan State College is more concerned with aerobic rather than anaerobic digestion because of the time factor. The main purpose of this research is to refine the digestion process to such a degree that it can be used as an efficient means for the disposal of municipal organic wastes. In general, high rate composting is a process creating

no offensive odors, generating temperatures above those needed for pasteurization, and taking less than one week for complete digestion of the organic wastes to a stable organic fertilizer.

DESCRIPTION OF COMPOSTING APPARATUS

Research work at Michigan State College is being done in connection with a large plant size digester, and small one pound size laboratory units. Both types are important in gaining a full understanding of the composting process.

The large digester used at Michigan State College (shown in figure 1) is twenty-three feet high, ten feet in diameter, and consists of eight separate decks. The digester is of steel construction and is insulated with two inches of foam glass brick covered with tar paper.

Composting at the large digester deals primarily with domestic type garbage as described in table 1. The garbage is delivered to the plant in trucks and dumped on the floor. After stray bottles and cans are removed, the garbage is ground and conveyed to a storage tank where the moisture content is reduced by drainage from about 75 percent to about 60 percent. The garbage is then conveyed to the top deck of the digester. Each deck is equipped with plows that slowly aerate the material and drop it from deck to deck. The material takes about two to four days to work its way down through the digester and emerge from the bottom deck as compost.



Figure 1. Large digester used for the composting of municipal garbage at Michigan State College, East Lansing, Michigan.



Figure 2. Large plant digester operations room, showing raw garbage in the left foreground. Finished compost, used as seeding material, is shown at the right.

TABLE 1

COMPOSITION (NET WEIGHT) OF GARBAGE DURING JANUARY,
FEBRUARY, MARCH, AND APRIL, 1954

GARBAGE CONSTITUENT	PERCENT
Paper	18.5
Meat, Fat, Fish, Peanuts, Eggs, Cheese, Milk, and Cream	6.3
Citrus fruits	18.5
Other fruits, Bananas, Grapes, Tomatoes, Apples, etc.	7.4
Green vegetables, Celery, Corn husks, Melons Cabbage, Lettuce, etc.	11.6
Coffee grounds and Tea leaves	5.1
Bread, Cake, Macaroni, Cereal, etc.	9.2
Potatoes, Beans, Corn, Onions, Beets, etc.	14.4
Miscellaneous, Egg shells, Nuts, Bottle caps, Bones, Rags, Rubber, etc.	8.5
	100.0

A small laboratory unit digester is shown in figure 3. These units are of clear plastic construction and are designed to hold about a pound of garbage. Samples are mechanically aerated by slowly revolving arms which are connected to a central drive shaft. This enables the units to be used for direct composting of garbage. The units are also air tight and are equipped for the determination of oxygen uptake,* carbon dioxide production, and other pertinent unknowns involved in the composting process.

THE NEED OF A YARDSTICK AND PURPOSE OF THE STUDY

In almost all manufacturing processes, tests must be developed to determine the condition of material at various points during processing. Composting can certainly be classified as a manufacturing process, and must be controlled by scientific tests if an economic and efficient process is to be expected. Composting is concerned with the stabilization of unstable, putrescible, organic matter. Very few quantitative tests have been used in controlling this stabilization process because composting has developed as an art rather than as a science. A quantitative test is needed, however, to obtain answers to the following questions.

1. When is the composting process finished?
2. When is the point of diminishing returns reached?

*

See figures 4 and 5

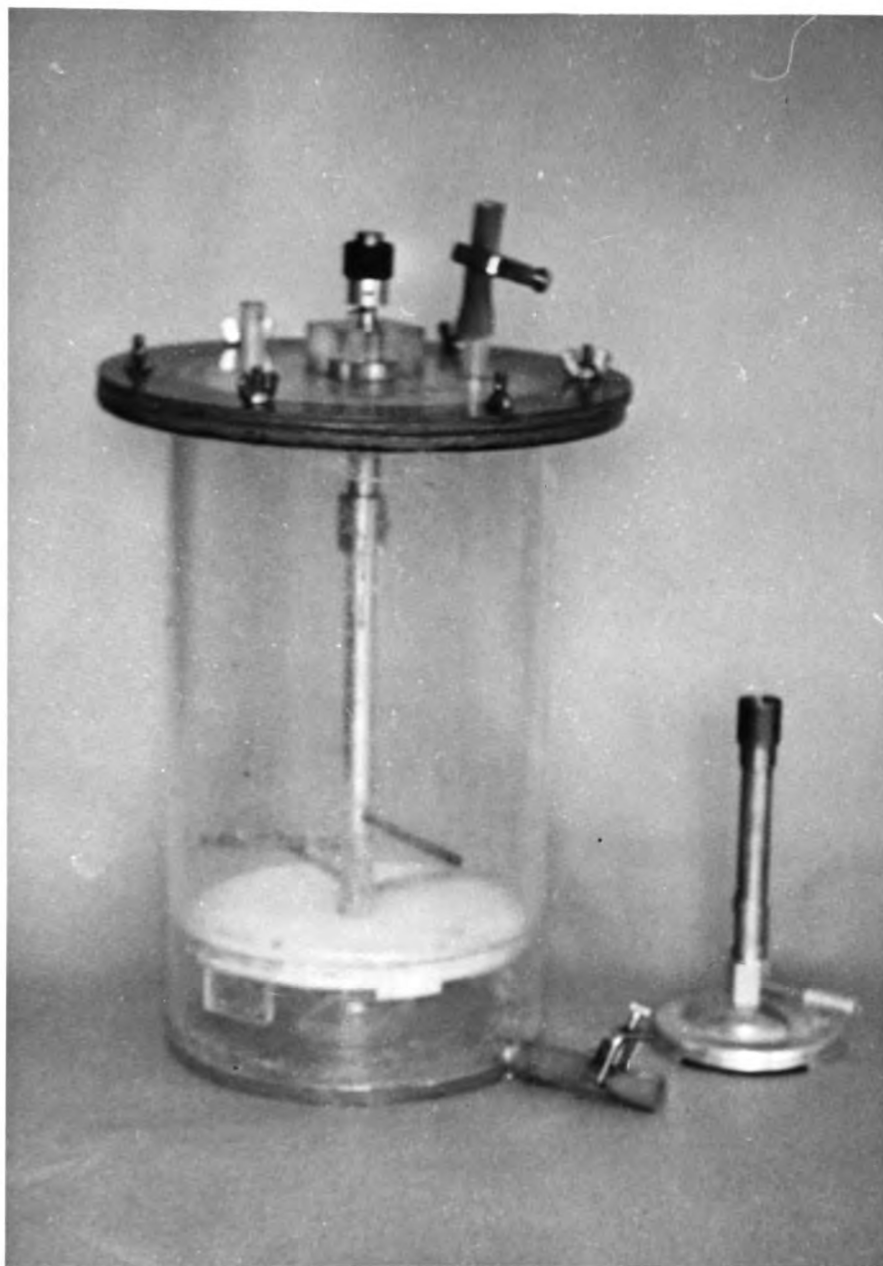


Figure 3. Small laboratory type digester.

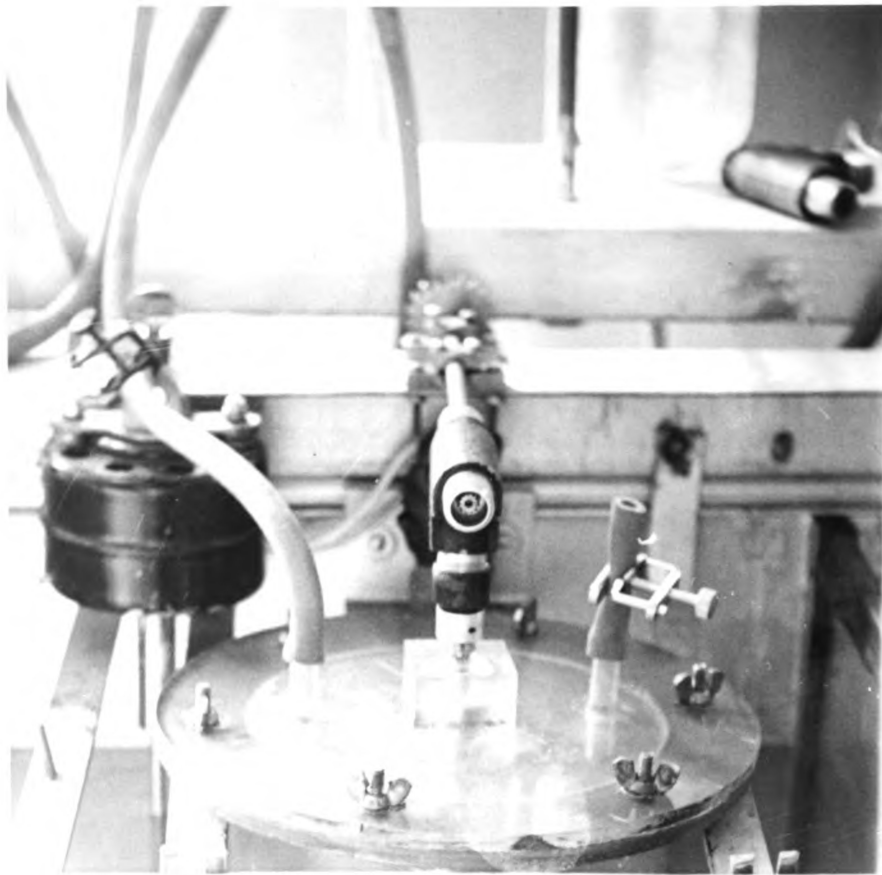


Figure 4. Laboratory digester in temperature control tank. Note drive system.



Figure 5. Temperature control tank for laboratory digesters, and oxygen uptake apparatus.

3. What stage in the composting process is most important in the breakdown of certain known constituents?

4. What are the best conditions for composting?

Answers to these questions could be determined if a test were devised to indicate a decrease or increase in some characteristic property or constituent of the compost.

REVIEW OF LITERATURE

The scientific study of composting, especially high rate composting, is very new. Little work has been done on establishing a scientific yardstick. There are only a few processes in which a definite test has been utilized in the attempt to control composting.

Earp-Thomas Process: The Earp-Thomas yardstick for digestion is based on temperature. Mr. Earp-Thomas advises that for outdoor composting, the pile be turned or aerated when certain temperatures are attained. For example, the pile is turned when the temperature reaches 35°C., again at 40°C., and so on throughout the digestion period. In his continuous flow digester, which consists of about 5 to 8 decks, the temperature is closely regulated for optimum incubation of bacteria during each stage of digestion.¹

Temperature might be used as a yardstick to indicate the degree of digestion in some composting processes; but in our

¹ See Bibliography.

research, where constant temperatures are maintained during the composting process, it is of no value.

Frazer-Eweson Process: In Zaragoza, Spain, a Frazer-Eweson compost plant is controlled entirely by temperature and carbon dioxide concentration. Their digester has five compartments and is of the continuous flow type. The aeration system is closed and forced air is closely controlled. They stated that alkaline pHs are not desirable in the composting process.²

There is a composting plant in Chicago that is operating in direct contradiction to this last statement. In fact, the Chicago plant tries to obtain high pHs and has developed a yardstick based on this criterion. It has been reported that the yardstick is as follows. The material (manure) is composted until it has developed a pH of 8. A sample is then incubated in a closed container for 24 hours. If the pH does not drop below 7.5 during this period, the compost is considered finished.

Both the Frazer-Eweson and the Chicago plants seem to be operating satisfactorily on the basis of their tests, but neither could be used in our process. The pH test as used in Chicago only indicates when the composting is finished and cannot be used for intermediate values. In our research this test cannot be used because we intend to regulate the pH chemically.

Probably one reason for maintaining low pHs in the Frazer-Eweson process is because at alkaline pHs, carbon dioxide reacts

with the compost. This limits the carbon:Nitrogen test considerably. Another bad feature of this test is that it is not run on the compost material itself, which is what we want to do.

New Zealand Process: In New Zealand, the Committee of the Utilization of Organic Wastes has been experimenting with outdoor composting. They list the following tests as being helpful in obtaining information on the progress of decomposition.

Temperature	Ash
Nitrogen	Moisture
Carbon	Acidity

They stated, "The temperature record is a measure of the progress of reactions. Thus the thermometer is the best single tool in the hands of the compost maker." They place great emphasis on the above tests, but with the exception of temperature they seem to use them more as indicators for the adjustment of refuse composition rather than as a yardstick. The New Zealand process is an outdoor, windrow type that takes about eight months of digestion. The material is turned about two or three times during this period. In their bulletin the following data was presented.³ Also see graph 1.

Age of Heap in Weeks	N%	C/N ₁	C%	Ash%
0	1.7	28	48	14
10	2.1	20	42	25
20	2.3	15	35	37
30	2.4	13	31	44

This table shows four possible yardsticks, but their paper fails to mention their use as such.

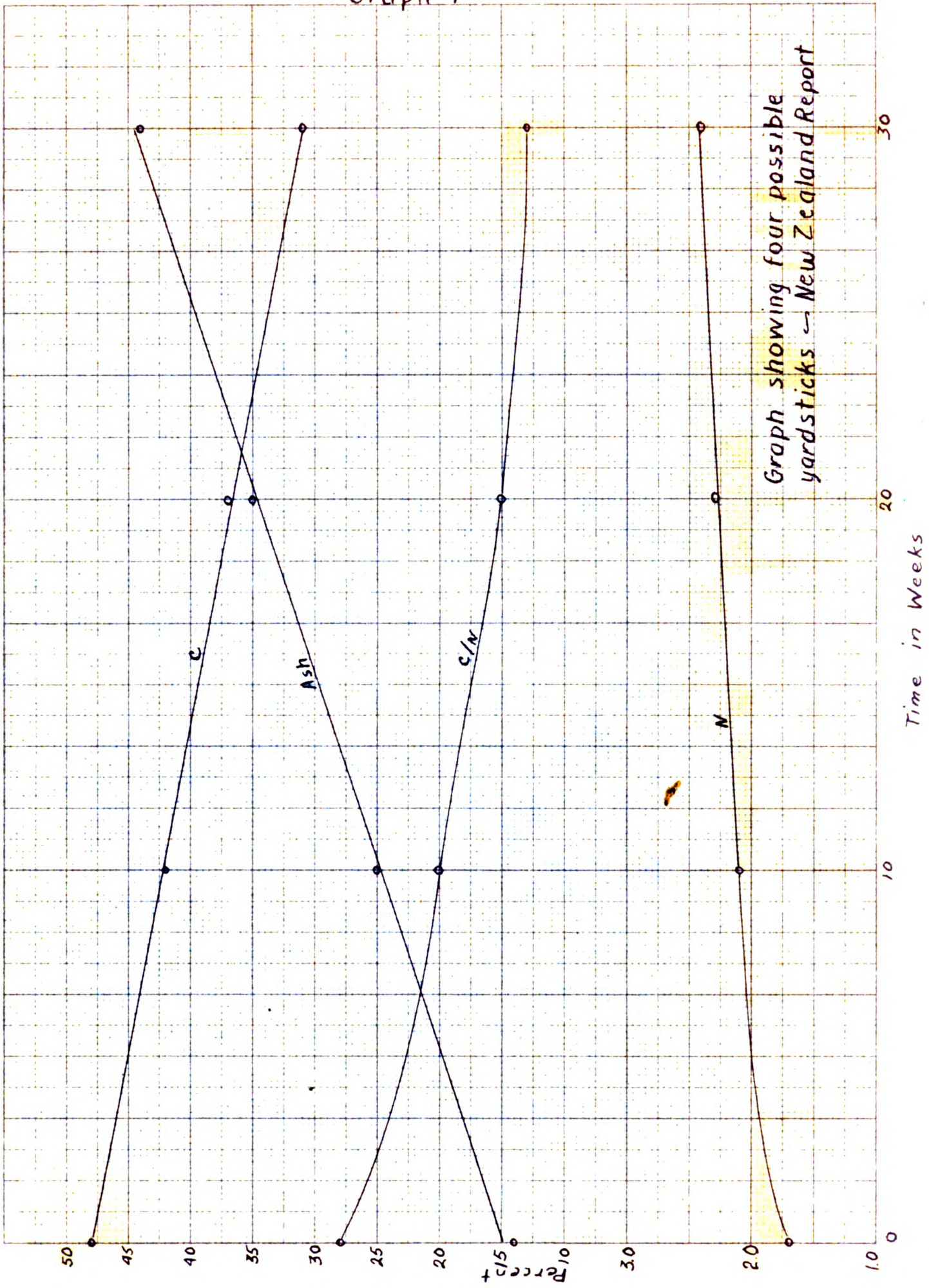
* Added by author Ash% = $100 - 1.8(C\%)$
as in New Zealand report

California Process: The University of California at Berkeley has done research on windrow type composting. Their process takes about two to three weeks for digestion. They believe that the C/N ratio is a useful yardstick, and stated, "The C/N of raw material gives a clue to the length of time required for composting, and that the change in C/N ratio during the process measures the degree of decomposition and establishes the suitability of the final product for agricultural soils."⁴ California advises that for all practical purposes, the carbon content can be computed on the basis of ash content by utilizing the formula $C\% = \frac{100 - ash\%}{1.8}$, which they adopted from the New Zealand report.

In an aerobic decomposition there is very little change in nitrogen content, so that the C/N ratio is almost entirely dependent on the carbon content. If the carbon is determined on the basis of ash, then it would seem logical to use the ash determination alone as the yardstick.

Iodercle Process: Iodercle Laboratories, in Pearl River, New York, have been experimenting with composting as a means of sludge digestion. They use an indoor batch type process which takes about three weeks for digestion. They have adopted the chemical oxygen demand test for use as a yardstick. This test was investigated and is discussed later in this thesis.⁵

Graph 1



COMPARISON WITH SEWAGE ANALYSIS

In the control of sewage plant operations, there have been many tests devised that give the operator an indication of the efficiency of the plant. Some of the tests, such as settleable solids and total solids, apply only when the waste is in liquid form. Sewage usually runs over 99.9% moisture, and therefore a test like settleable solids is applicable in measuring the mechanical efficiency of the plant. Our garbage, on the other hand, seldom has a moisture content above 75% which means that settleable solids and similar tests would have no application in garbage and compost analysis. Most sewage tests are based on the number of milliliters of sample used. All quantitative tests in composting are based on dry weight or a definite moisture content. This one fact causes more trouble in compost testing than any other single factor. In sewage analysis one can take small samples (100 ml.) over a period of time, mix the collected samples, use a small portion of the mixed sample, and obtain very representative and accurate results. The semiconcentrated form of garbage and compost makes this procedure impossible to use. To my knowledge, no efficient means of obtaining truly representative samples of garbage or compost has been devised yet. Much work is needed along this line because all data is dependant upon the samples used to obtain it.

There are several tests in sewage analysis that would seemingly apply very well to composting. The B.O.D. test, which

is probably the most widely used test in sewage analysis, seemed to be the type of test we were looking for and was investigated in this thesis. The relative stability and oxygen consumed tests also seemed to offer possibilities and were investigated.

DESIRED CHAR. CHARACTERISTICS OF A YARDSTICK

The need of a yardstick has been firmly established. The desired characteristics of the test or yardstick was considered next. The following items were thought to be most desirable in connection with our research.

Laboratory Test: It is very desirable to have a test that can be run on isolated samples in the laboratory, as opposed to a test that must be run at the site of the composting process.

Short Running Time: The shorter the testing procedure; the faster results can be established. This is very important in any yardstick. For all quantitative tests in composting, results must be computed on the basis of dry weight. This means that one of the two following procedures must be used.

1. The sample is dried, weighed, and tested.
 2. The sample is mixed in an aqueous solution. A known volume is dried to determine the sample's dry weight.
- Either case involves drying for about 24 hours, which means

that the shortest possible time that results can be obtained is one day after the sample has been taken.

Wide Reduction or Increase in Results: A test with 5 to 10% reduction in results between raw garbage and finished compost would have little meaning because of the inaccuracy in obtaining representative results. A difference of 25% or more is needed to establish a useful curve.

Indicator of Unstable Organic Matter: Composting is the stabilization of unstable organic material, and it is therefore logical to develop some test that measures this unstable material. It is known that biological activity is intensified by the presence of unstable organic matter. With this fact in mind, known biological tests were investigated first. The tests that were considered for yardstick study are listed below.

BIOLOGICAL	CHEMICAL	PHYSICAL
Relative stability	C.O.D.	Moisture
B.O.D.	Chlorine demand	Appearance
Oxygen uptake	Iodine demand	Odor
	pH	Ash
	Carbon nitrogen	Temperature
	Oxygen consumed	

BIOLOGICAL TESTS

Relative Stability: The relative stability test is based on the fact that methylene blue dye is decolorized when oxygen is absent. Because of this fact it was thought that a short time test could be set up to indicate the degree of digestion.

The original thought was to put a known amount of garbage in a sample bottle, add dilution water and methylene blue, and observe the time needed for the sample to go colorless. The more unstable organic matter present in the sample, the shorter would be the time to go colorless. If a sample did not go colorless within a certain period it would be declared stable.

The relative stability test, as found in Standard Methods,⁶ is as follows:

1. Fill completely to overflowing a 6 to 8 ounce glass stoppered bottle with the sample to be tested.
2. Add 0.5 milliliters of methylene blue by means of a pipette extending the tip just below the surface of the liquid.
3. Insert the stopper so that no air bubbles are entrained beneath it.
4. Keep the bottle at 20°C.
5. Observe the bottle and record the time necessary for the disappearance of the color.

The test used in our research on garbage and compost samples was a modification of the above test.

The first attempt with this test was set up on a dry weight basis. The garbage sample was dried, ground, and a definite amount weighed out for the test. The following problems were encountered using this procedure.

1. The finely ground sample adhered to small air bubbles when the water was added. As a result of this, most of the sample rose into the neck of the bottle.
2. This test is dependant on biological action and through it, the depletion of oxygen. By drying the sample at 100°C., most of the bacterial population is eliminated. This means there is a time lag while the remaining bacterial population is building up.

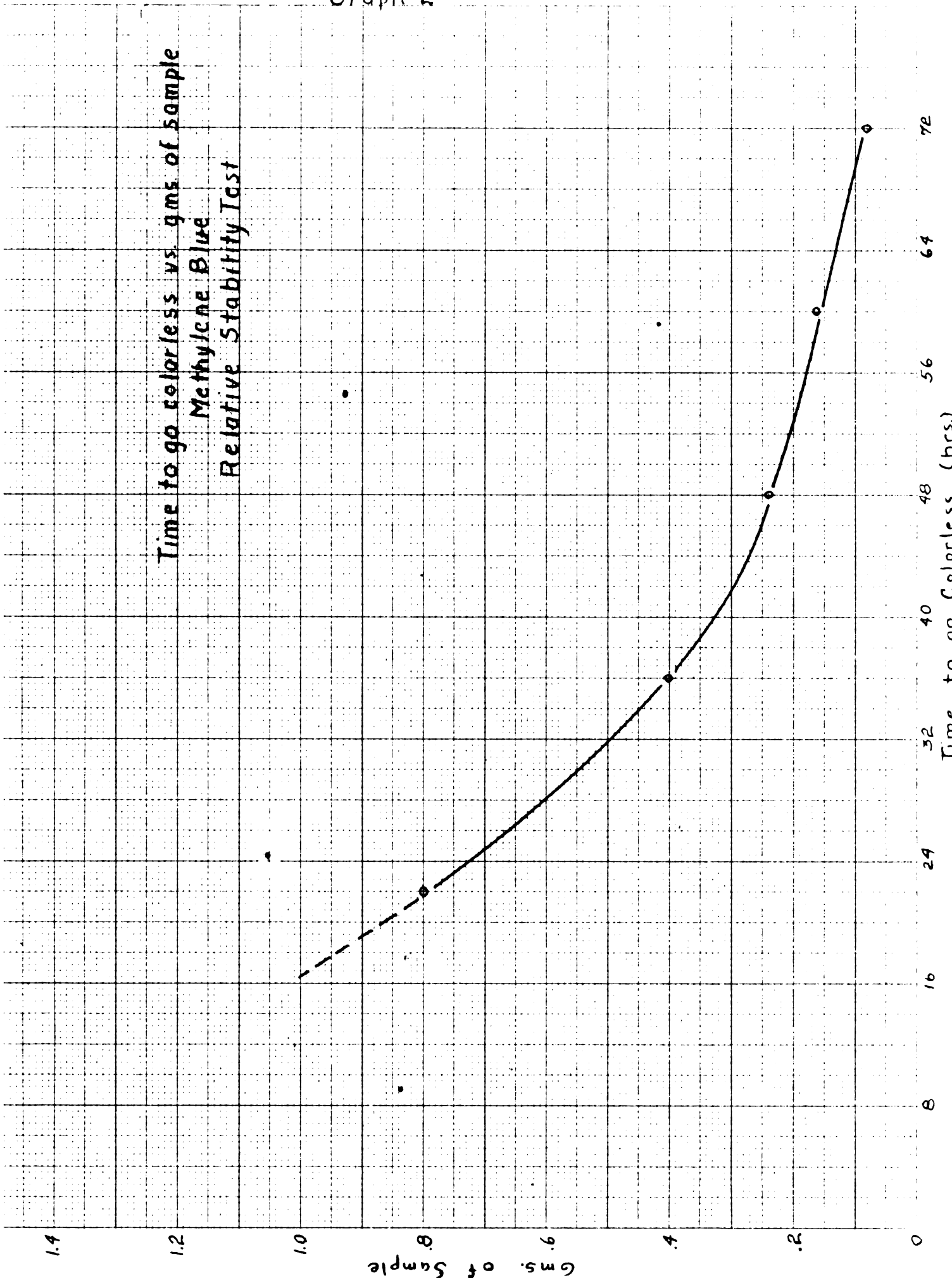
As a result of the above facts, the following tests were run on a wet basis. The first test was made on cured compost as follows:

A blend was made by taking about one half cured compost and one half water by weight and blending the two in a mixer. Known volumes were pipetted into 300 ml. sample bottles and three 5 ml. samples were pipetted into evaporating dishes for dry weight determinations. One milliliter of methylene blue was added to each bottle and the bottle was then filled to the top with B.O.D. water. The main purpose of this experiment was to establish some time ranges for the methylene blue test. Results are shown on graph 2. The wet process was satisfactory in eliminating those difficulties experienced when using dry samples.

A series of tests were run to determine the effect of seeding, incubation temperature, and size of sample. Results of these tests are as follows:

Graph 2

Time to go colorless vs. gms of sample
Methylene Blue
Relative Stability Test



In all cases, the unseeded samples overcame the starting population deficit in a matter of a few hours. It would appear from this that seeding is not necessary even for a short time test. An increase in incubation temperature, from 20°C. to 35°C., had the effect of more than doubling the oxygen depletion, or shortening the time to go colorless to less than half. It was found that samples, containing more than about one gram (dry weight) per 300 ml. of water, completely absorbed the 1 ml. portion of dye making it impossible to obtain results.

It is doubtful that the relative stability test could be used as a yardstick because of several shortcomings.

1. The test is not quantitative in nature.
2. At best, this test would serve only as a rough indicator of stability.
3. If a short time test were established, the necessity of observing samples at short intervals would present a definite inconvenience for the operator.

Biological Oxygen Demand: The B.O.D. test is similar to the relative stability test. It is, however, a quantitative test. In essence, this test is a measure of the oxygen depletion in a given length of time. Measurements of the dissolved oxygen in a sample, before and after incubation, are made by means of a starch iodine titration.* This is a very well known test and has been refined to a high degree in water and sewage analysis. Aerobic bacteria attack unstable organic material in the sample

and utilize oxygen during the process. The more organic material there is in the sample, the greater will be the oxygen utilization or demand.

Many B.O.D. tests were run on compost samples to develop standard conditions and procedures. Good results were obtained when compost samples were used, but trouble was experienced on raw garbage samples. All B.O.D. tests are based on the determination of dissolved oxygen in which starch is used as the titration indicator. The dissolved oxygen titration is only accurate when the starch is added very near the end point. If the starch is added when a large amount of iodine is present, a blue starch-iodine adsorption complex is formed. This adsorption complex does not decolorize at the equivalence or end point, and inaccurate results are obtained.⁷ All raw garbage contains starch in varying amounts, so accurate results cannot be expected from this test. Because yardstick determinations are based on the reduction from the raw garbage sample, the B.O.D. test could probably not be used until the starch problem has been eliminated. There is the possibility that by the addition of certain enzymes, the starch could be converted to sugars in a matter of hours. This would probably not appreciably change the B.O.D. of the sample and would eliminate the starch interference. This and the questions of particle size and immediate oxygen adsorption as related to the B.O.D. test, constitute problems for future research and are not within the scope of this paper.

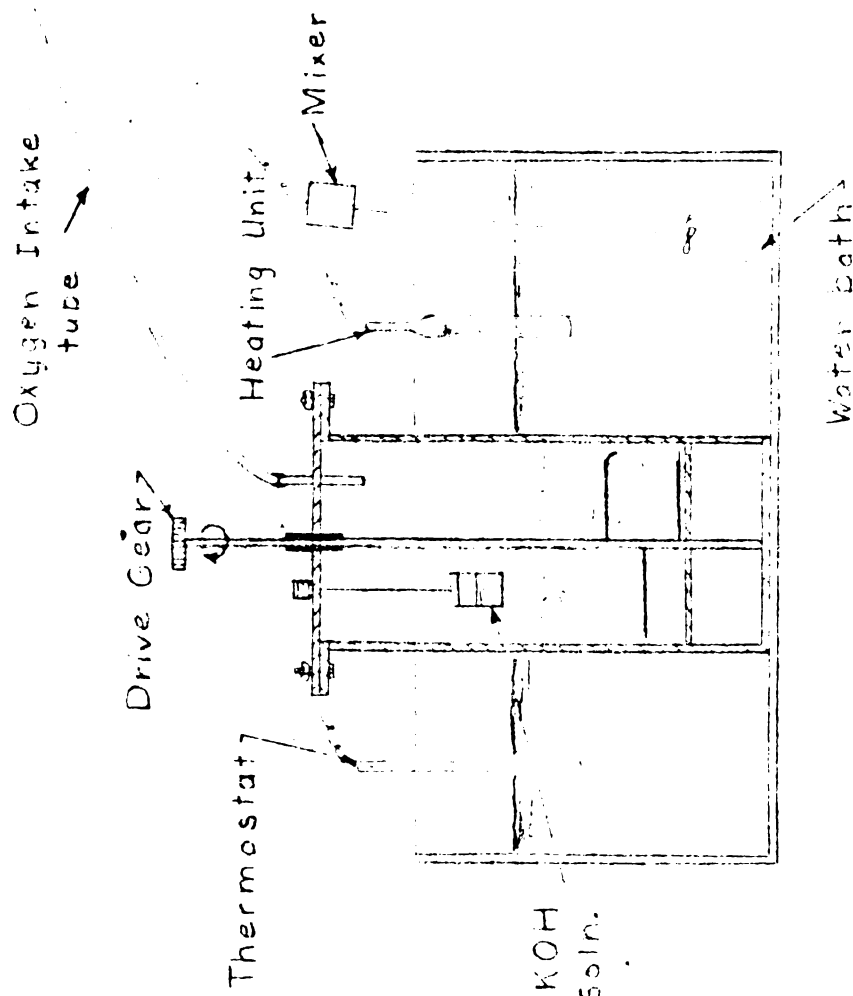
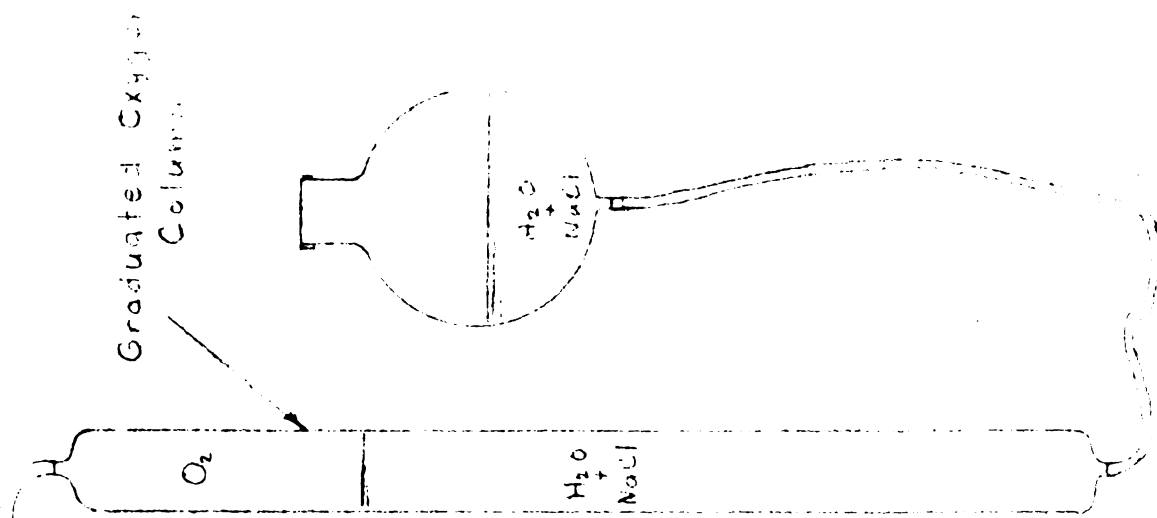
Oxygen Uptake: The oxygen uptake test is still in the early stages of research. It is measured in the laboratory as shown in figure 6. Samples are placed in airtight units, which are then hooked up to a closed system with an oxygen tube. The material is slowly stirred and the oxygen uptake is measured on the calibrated oxygen tube. Fundamentally this test is an immediate B.O.D. test, and there is the possibility that it may eventually be used as a yardstick. This test is being used primarily to obtain information on the amount of aeration needed in the composting process. More work is needed before conclusions may be drawn concerning its applicability as a yardstick.

CHEMICAL TESTS

Chlorine Demand: This is a short time test and has been used successfully in sewage plants for many years. In recent years the B.O.D. has replaced the chlorine demand test and most other tests of its kind, because the B.O.D. represents a truer picture of plant operation.

The chlorine demand test is based on the fact that chlorine enters into an irreversible reaction with certain organic compounds. By adding chlorine water of a known strength and measuring the chlorine in the sample before and after a contact period, the chlorine demand can be calculated.

Figure 6



Laboratory Experiment in Composting, 1954
 Michigan State College, 1954

The first test was run on a dry weight basis, using .2500 gm. of dried and ground sample. Fifty milliliters of water were added to each sample along with 5 ml. of chlorine solution. The samples had a contact period of 15 minutes. The excess chlorine was determined by means of a starch-iodine titration. Results were as follows:

	Raw Garbage	Cured Compost
Chlorine Demand	12,420 ppm.	14,200 ppm.

These results were very strange. By all logical reasoning, the raw garbage should have had the larger demand. At first the difference was attributed to the fact that dry samples were used. So another test was run using undried samples.

One gram of sample was diluted and blended with 1000 ml. of water. One hundred milliliters of this blend were used as a sample. Another 100 ml. was dried to establish the dry weight of the sample. The test was run on the same basis as the previous test. Results were as follows:

	Raw Garbage	Cured Compost
Chlorine Demand	96,300 ppm.	132,000 ppm.

The results of this test showed a higher demand in each case, but in such the same proportion as the first test. Upon further study of the action of chlorine, it was found that the above results were probably due to the particle size and structure of the materials being tested. Raw garbage contains particle structures that are not as easily penetrated by the

chlorine as the particles of cured compost. It is known that chlorine does not possess high penetrating powers at neutral or higher pHs. As soon as the pH of chlorine solutions are lowered, however, chlorine is lost due to its high volatility. The possibility of running this test at a low pH would necessitate special equipment and procedures, and was thought to be impractical as a routine test.

Iodine Demand: Iodine demand is run the same as the chlorine demand but iodine has the theoretical advantage of low volatility at low pHs. Then again, by using iodine as a test agent, one can eliminate a step in the starch-iodine titration. A preliminary test was run on the following basis:

Dried samples of .2500 gms. were used. Twenty-five milliliters of colloidal iodine solution (7.36 mg./ml.) were placed in the sample flask and allowed to react for 15 minutes. The samples were back titrated with .025 N sodium thiosulfate solution. Results were as follows:

	Raw Garbage	Cured Compost
Iodine Demand	210,000 ppm.	159,000 ppm.
	about 25% reduction	

The above results looked very encouraging even though an accurate end point was hard to obtain on the raw garbage due to the presence of starch, as discussed on page 23.

Another test was run by the same method ~~≡~~ using a straight acid solution of pure iodine ($I_2 + H_2O + HCl$). The solution

had a pH of one, and was 2.425 mg./ml. Results were as follows:

	Raw Garbage	Cured Compost
Iodine Demand	150,000 ppm.	103,000 ppm.

These results are comparable to those of the previous test, but the problem of starch in the raw garbage was still present.

It was thought that by adjusting the pH, the starch interference could be eliminated. A test was set up to investigate this possibility in the following manner.

Three samples were run at a pH of 0.9. Two samples were titrated at this pH, and the third was brought up to high pH and adjusted back down to 0.5 before titration. Results were as follows:

Sample	1	2	3
pH	.9	.9	6.5
Iodine Demand	25.7 mg.	25.7 mg.	122.0 mg.

This procedure did not eliminate starch interference and results show that not all the iodine known to be present was titratable at the higher pH. Further tests confirmed this fact, and showed the impossibility of titration at a pH above three. The best pH for titration, in regard to the recovery of excess iodine seemed to be about pH 1.

Another technique was tried as a possible means of obtaining more accurate titrations. A known quantity of iodine was added to 50 ml. of water containing a raw garbage sample. After the contact period, an immiscible agent (CCl_4) was added to

adsorb the excess iodine. The water was then decanted, and the agent titrated. It was found that although good end points could be obtained, only about 90% of the titratable iodine could be recovered in control samples. As a result of this, the procedure was abandoned.

Many more tests were run using iodine, but in every case of the raw garbage sample, poor results were obtained due to starch interference. This starch interference is very bad because if one cannot establish starting values for digestion, later results cannot be judged quantitatively. Actually starch interference indicates a shortcoming of the iodine demand test. Even after contact periods of one hour or more, starch still caused interference. This indicates that iodine is not digesting the starch to any great extent, and may not be reacting in irreversible reactions with the garbage or compost. If this is true, the iodine demand test is not measuring iodine demand at all. The possibility of using enzymes to eliminate starch interference, as proposed on page 23, might also be used with the iodine demand test.

C.O.D.: Due to the fact that the previous biological and chemical tests did not give satisfactory results, a test giving complete chemical oxidation of organic matter was investigated. ⁵Leister Laboratories in Pearl River, New York, has adopted a standard procedure of C.O.D. determination for use as a yardstick in compost digestion. The procedure is as follows:⁵

1. Dry over-night compost sample in 110°C . oven.
2. Grind and blend dry sample.
3. Weigh out 0.2500 grams of dry sample.
4. Add sample to 300 ml. flask.
5. Add 50 cc. distilled water.
6. Attach to flask a water cooled condenser (1 $\frac{1}{2}$ inches in length). See figure 7.
7. Add 100 cc. of concentrated sulfuric acid slowly from the top of condenser.
8. Reflux for one hour.
9. Cool to room temperature and dilute to one liter with distilled water.
10. Titrate 250 cc. of diluted sample with 0.5 N Ferrous Ammonium Sulfate solution, using as an indicator O-phenanthraline.
11. Answer = 25 - cc. of Ferrous Ammonium Sulfate solution
X 0.40 = C.O.D. units.

A series of C.O.D. tests were run to establish a curve for our composting process. Results of these tests are shown on graph 3. A typical C.O.D. curve for Lederle Laboratories is shown on graph 4. These data indicate that the C.O.D. could be used as a good yardstick.

Oxygen Consumed: Although the C.O.D. test gave accurate and consistent results, the test takes about six hours to run.

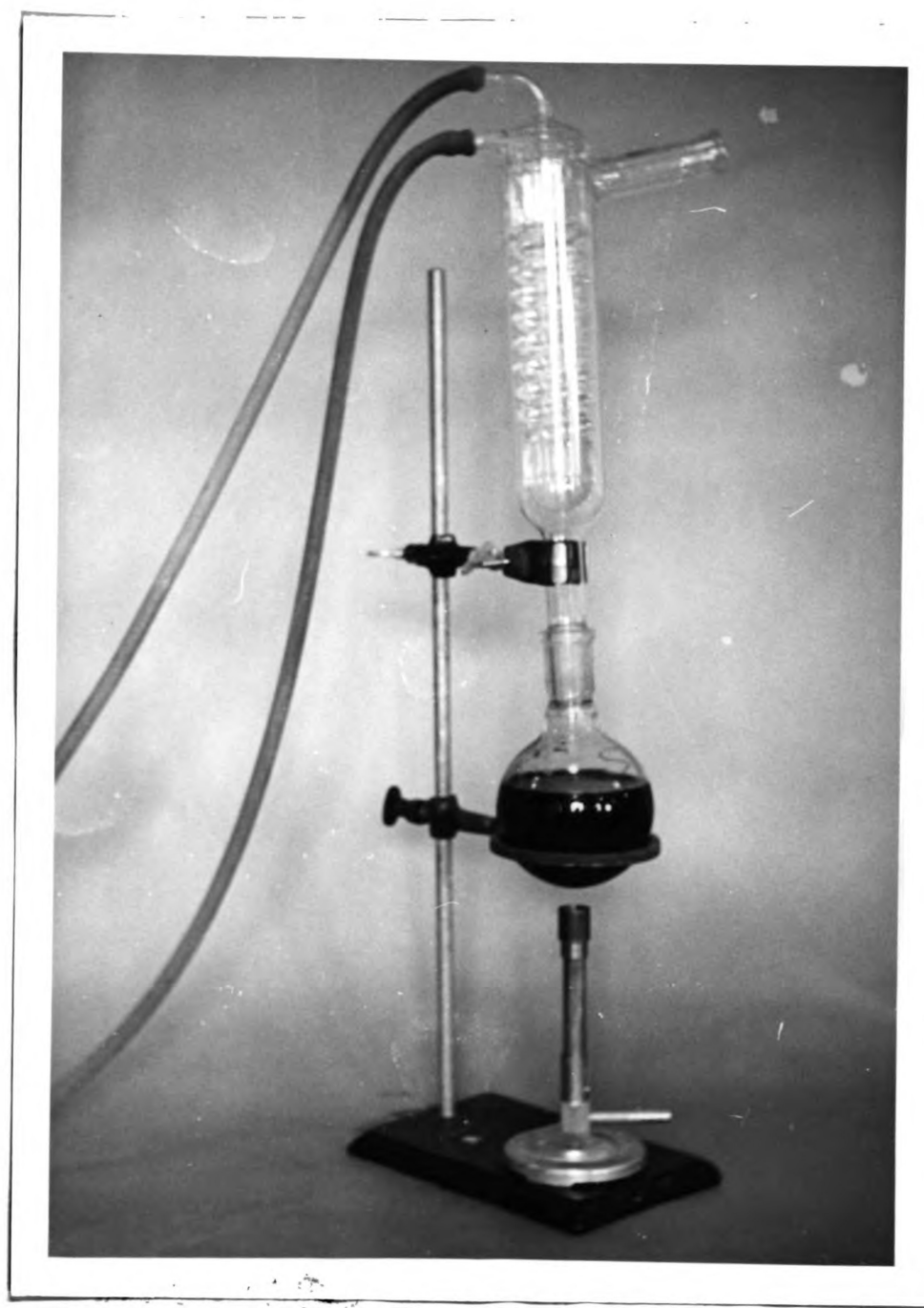
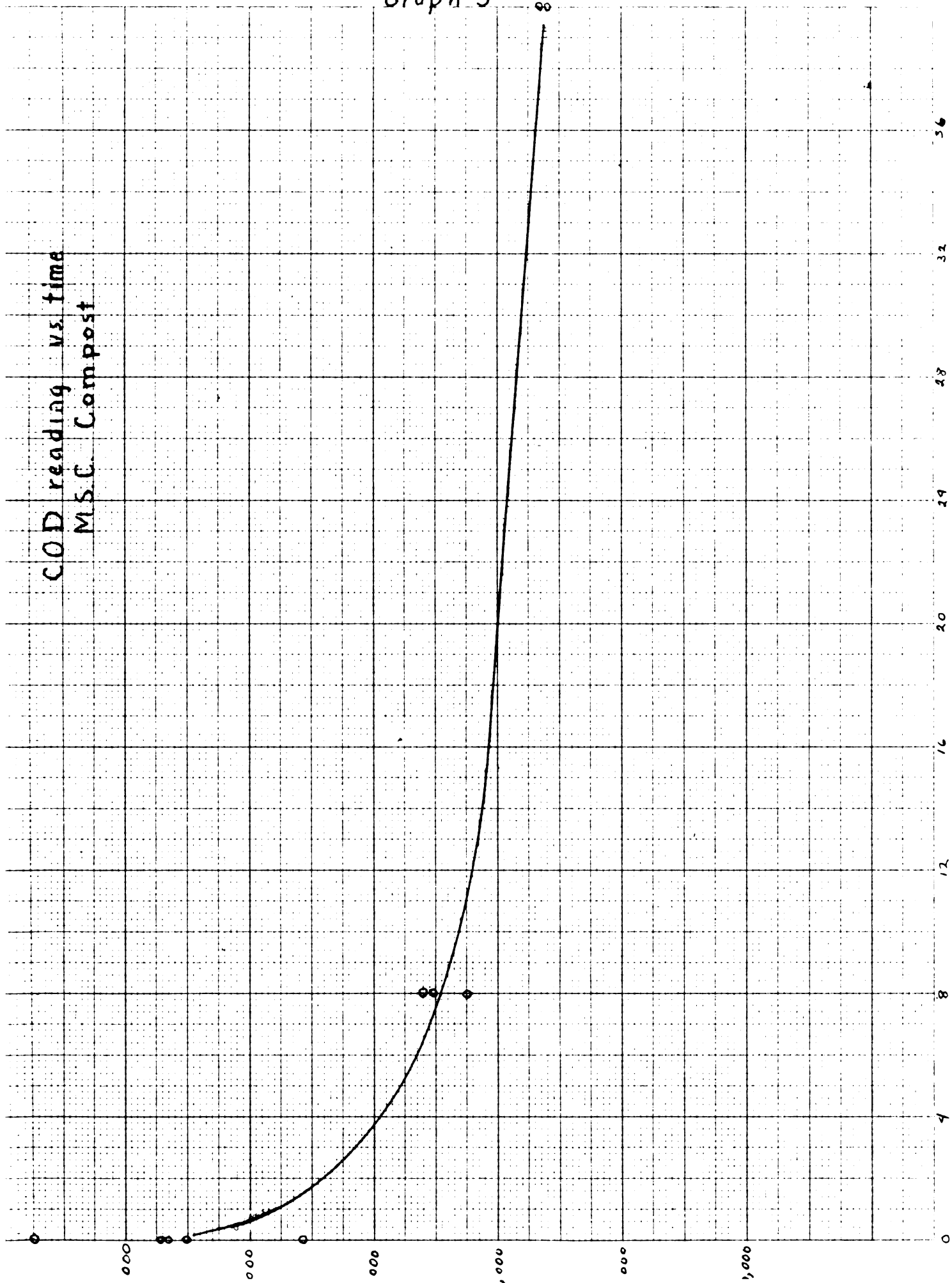


Figure 7. Reflux unit used in C.O.D. determinations.

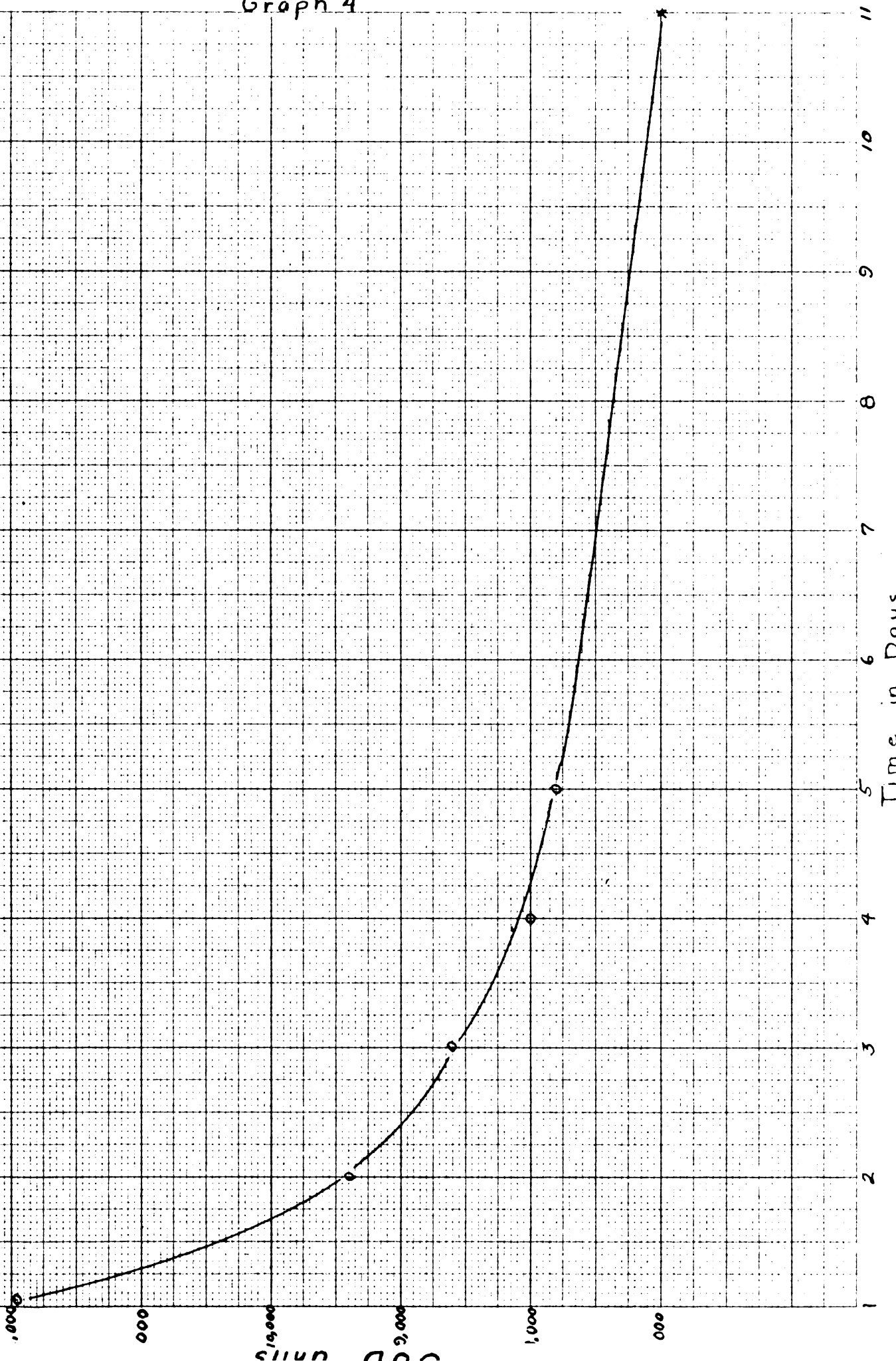
Graph 3

COD reading vs. time
M.S.C. Compost



Graph 4

COD reading vs. time
Lederle Compost



It was thought that a chemical oxidation test on a simpler basis might possibly be more practical as a routine laboratory test. The old sewage test of oxygen consumed by potassiumate was investigated to explore this possibility. The test procedure was taken from Standard Methods⁰ and modified to some degree. The test as developed in our research is as follows:

1. About 200 gm. samples were taken from various sampling points.
2. The samples were dried at 110°C. for 24 hours.
3. The dried samples were ground and sieved. Material passing through a #40 sieve was used in the tests.
4. .2500 gms. were placed in a 300 ml. flask.
5. Ten milliliters of 1-3 H_2SO_4 and 100 ml. of .125 N $KMnO_4$ was added.
6. The samples were digested for 30 minutes in boiling water.
7. At the end of 30 minutes, 25 ml. of .125 N Ammonium Oxalate was added and the samples were back titrated with $KMnO_4$ to the first permanent pink color.

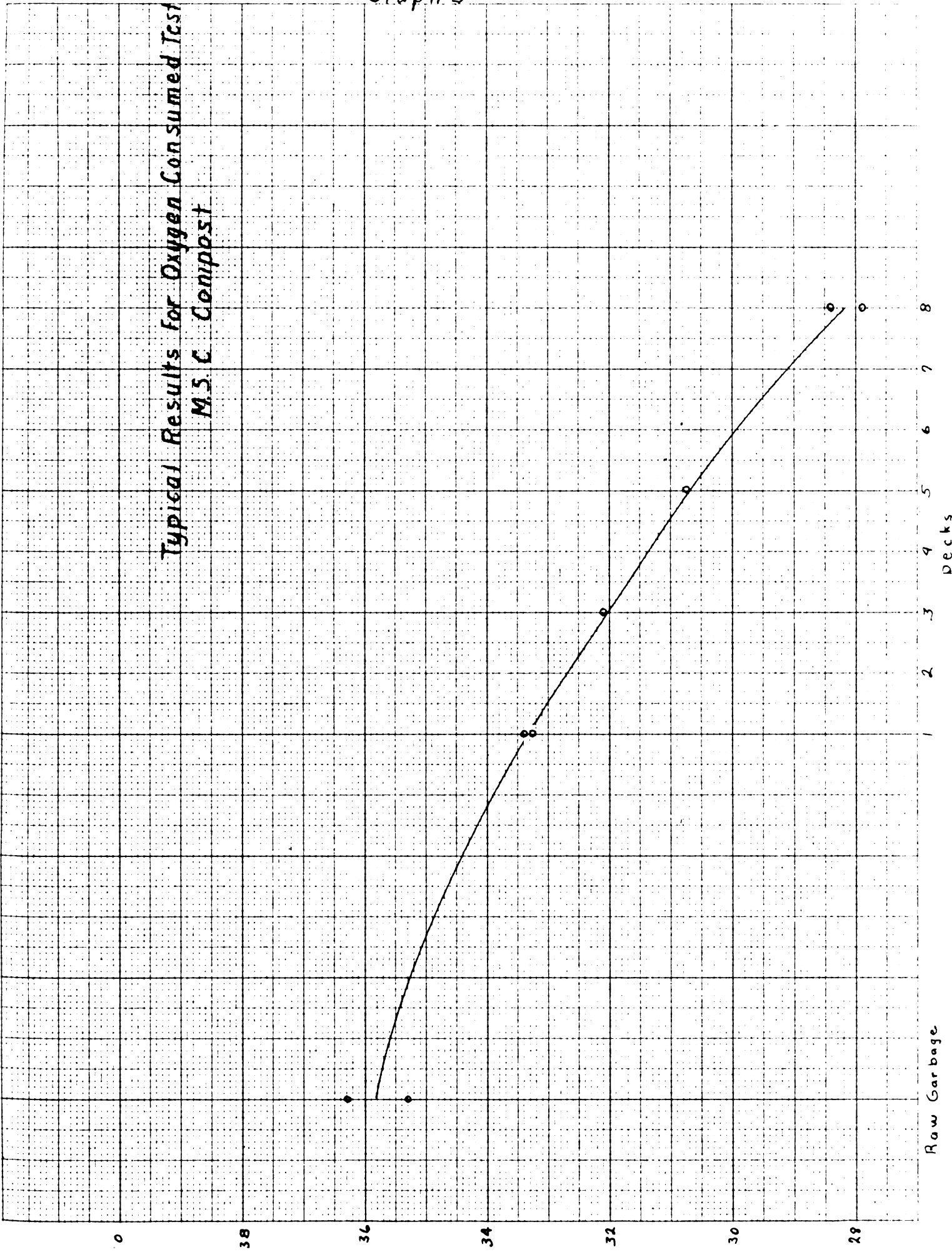
Procedure Not covered

Typical results for a run are shown on graph 5. These results show a reduction of about 25% which is comparable to results as obtained from the C.D.D. test. This test is easy to run and offers great possibilities in use as a yardstick.

Carbon Nitrogen: The basic qualification of the C/N ratio as a yardstick lies in the fact that during the composting pro-

Graph 5

Typical Results For Oxygen Consumed Test
M.S.C. Compost



cess carbon is reduced, being lost mainly in the form of carbon dioxide.

The carbon test is an expensive test requiring special equipment and several hours work. California and New Zealand studies have indicated that the carbon content may be estimated within 2-10% from the percentage ash by the use of the following equation.

$$C = \frac{100 - \% \text{ ash}}{1.8}$$

If this process is reliable within the stated accuracy, it would seem impractical to use the C/N. Because the nitrogen content is nearly constant in an aerobic decomposition process, and the carbon is the significant factor in this test, it would seem that ash determination would be more practical to use.

More work must be done on this subject to establish the merits or shortcomings of the C/N test, and was beyond the scope of this research. A carbon train was not available for this research.

pH: A test for acidity or alkalinity is another test that seems to be a good plant operations indicator. Under normal conditions, pH rises during the composting process. In our plant, the pH of raw garbage is around 5.5. After storage in the preconditioning tank, the pH drops to 4.5. This is an anaerobic storage, and a drop in pH is very indicative of anaerobic

conditions. The pH of finished compost is about 6.5, but to say that compost not attaining a pH of 6.5 is not digested thoroughly, would not always be true. In the laboratory, good compost has been produced at pHs below 7. As shown by graph 6, there is a definite rise in pH in our plant digester. This rise, however, is not uniform and could probably not be used as a quantitative variation for digestion. It is possible that an alkalinity test by methyl orange and phenolphthalein might be more useful than the pH test. This could well be investigated in future research.

PHYSICAL TESTS

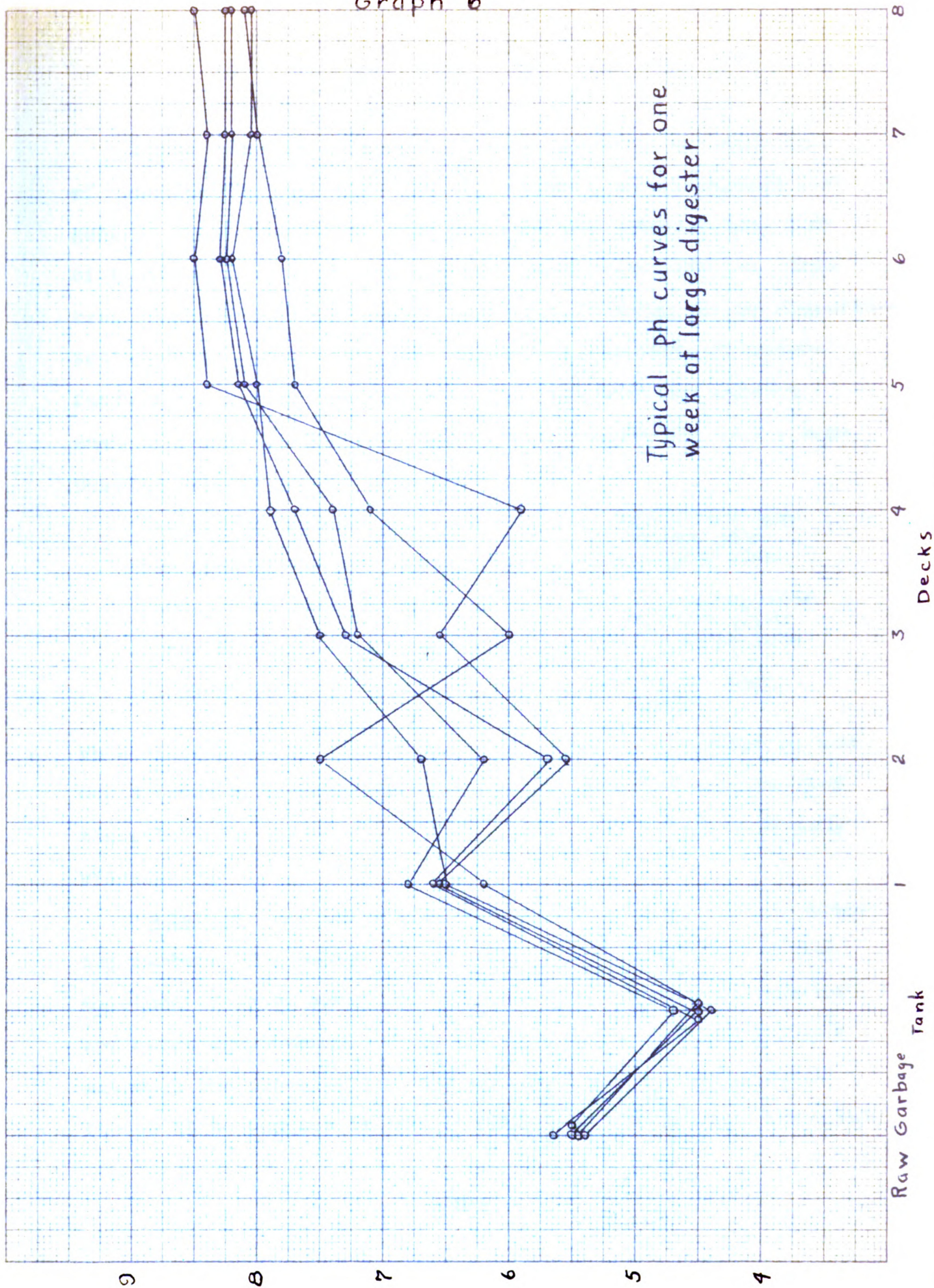
Appearance: In many operations, the process is controlled by an experienced operator who merely judges the product by appearance. While doing research on several of the tests discussed in this paper, definite characteristic appearances of ground samples were noticed.

All raw garbage samples when dried and ground have a straw brown color and are very fibrous in appearance. As the composting process takes place, the samples change to a dark colored, powdery appearance.

Although this type of test could not be used in any quantitative determinations, it is interesting and may be helpful in judging the general condition of the sample.

Graph 6

Typical ph curves for one
week at large digester



Odor: Odor is another test that offers no possibilities of quantitative analysis. It is, however, very important for general plant operation. The operator can obtain a good idea of the condition of the material by merely smelling it. High rate composting is an aerobic process, and being so has characteristic odors. If the material develops an anaerobic or putrefactive smell, the operator knows at once that the material must be aerated. Characteristic odors accompanying in the composting process are as follows:

Raw ground garbage.....	sweet, fresh vegetable odor
Raw garbage stored several days.....	sweet acid odor
Normal composting material.....	sweet cooking odor but not acid
Anaerobic composting material.....	putrefactive odor
Finished compost.....	earthy or musty smell

This classification would vary with different individuals, and could never be considered as absolute. The fact remains that characteristic odors are helpful in judging certain operating procedures.

Moisture: In any composting process, moisture is a deciding factor. The reason for this is due to aeration. If the moisture is above about 65% in our plant, anaerobic conditions are often encountered. This is probably due to the fact that although the material is aerated, the high moisture content causes it to compact in large clumps and inhibits the diffusion

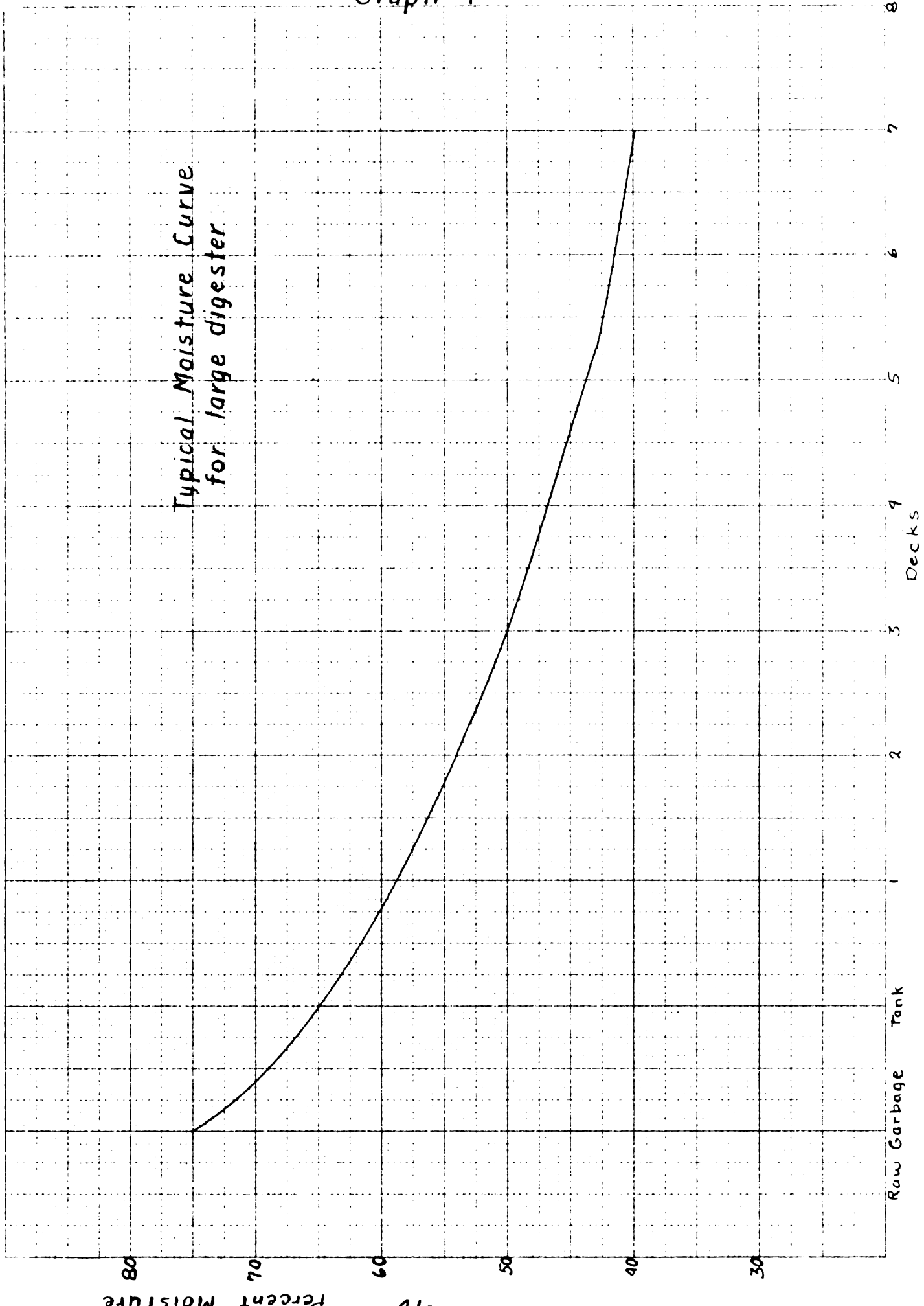
of oxygen into the particles. Graph 7 shows the typical drop in moisture throughout our plant composting process, but this again could never be used as a yardstick for digestion. To say that material which has dropped to a moisture content of 40% was finished compost would be absurd. Moisture tests are important because the finished compost should be as dry as possible to facilitate handling of the material. Also the composting process is seemingly inhibited when the moisture content drops below about 30%.

Ash: Ash determination by ignition is another routine plant test that exhibits interesting results. Tests show an increase from about 10% to about 20% by dry weight in our plant digester. It is believed that ash content may be of value as a yardstick in connection with the C/N ratio as discussed earlier on page 34. This test is very dependant upon good sampling, and results are erratic if foreign material, such as glass or stones should happen to be in the sample. Graph 8 illustrates the problem of obtaining consistent quantitative results by ash determinations. One week's ash determinations are plotted in dotted lines and the average values for three weeks are shown by the solid line. Some scheme must be devised to eliminate these wide fluctuations in results before ash content can be used as a yardstick.

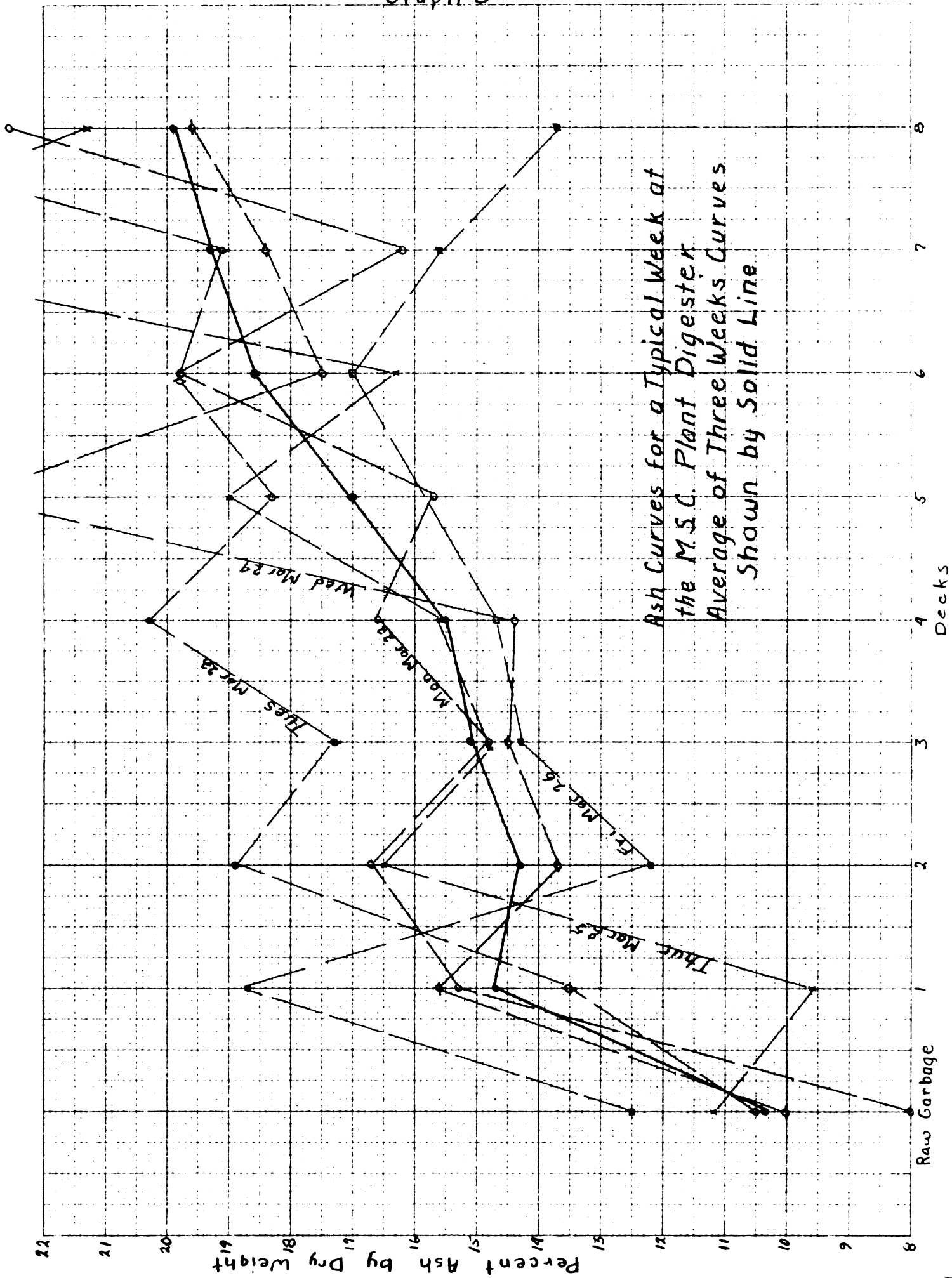
Temperature: As mentioned before, heat is generated by the biological action during composting. In most aerobic composting processes, there is a steady rise in temperature. These

Graph 7

Typical Moisture Curve
for large digester



Ash Curves for a Typical Week at
the M.S.C. Plant Digester
Average of Three Weeks Curves
Shown by Solid Line



temperatures are not directly related to ambient temperature. As proof of this; piles of partly digested garbage, at a temperature of $50^{\circ}\text{C}.$, were placed out of doors in $-10^{\circ}\text{C}.$ weather. After one week, the temperatures in these piles were in excess of $70^{\circ}\text{C}.$

Temperatures are dependent on such factors as moisture, insulation, and aeration, and may be good indicators for the control of these factors. A yardstick might possibly be set up on an empirical basis for certain plants, but an absolute scale could hardly be devised. Graph 2 shows temperature curves for a typical week at our plant digester.

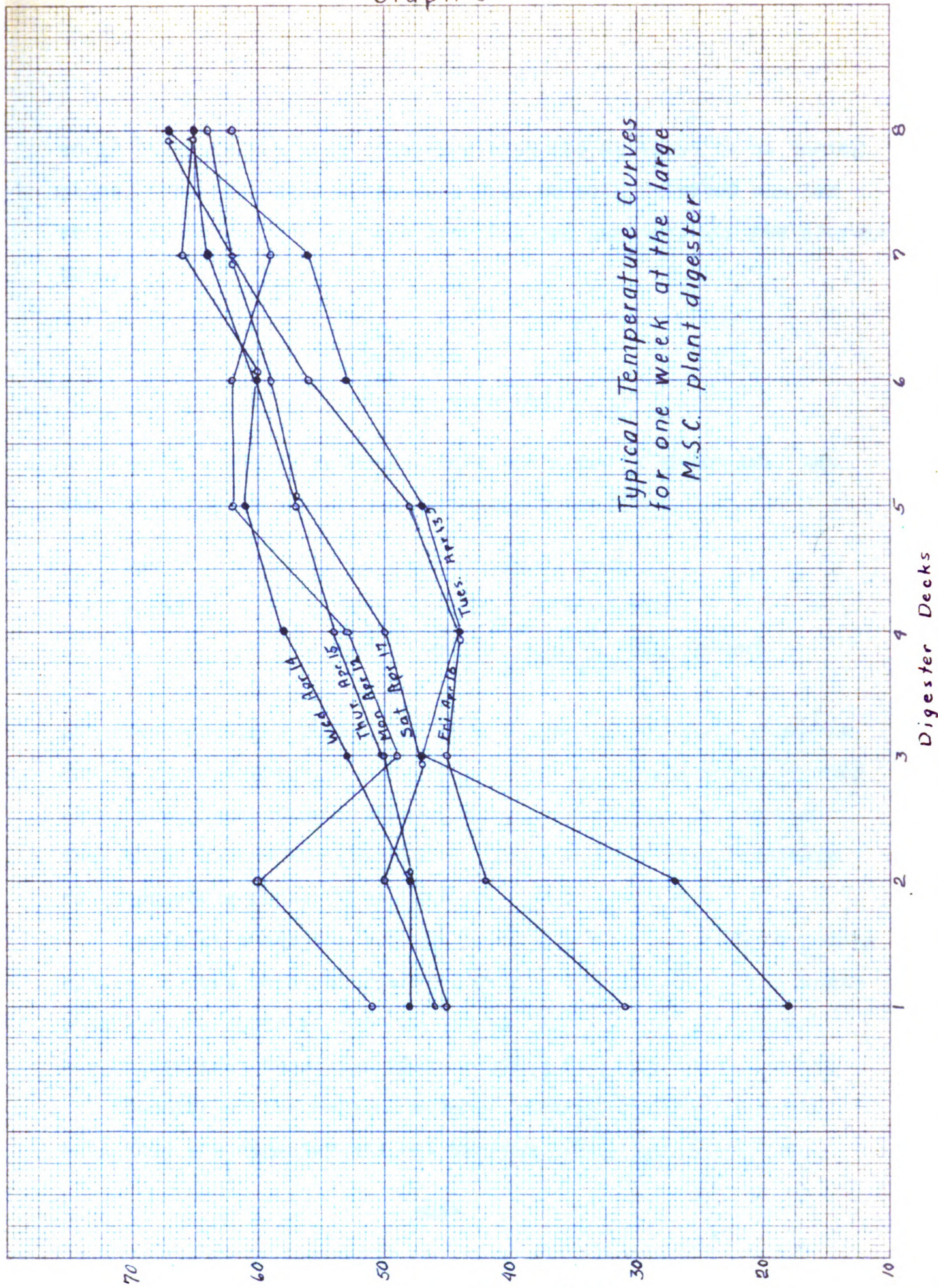
It is possible that temperature rate might be more significant than just isolated temperature readings. Temperature rate could be calculated by use of a recording thermometer. Possibly sharp rises or falls in temperature could be computed as degrees rise or fall per hour, and in this form be used as a clue to the digestive process. This possibility might well be investigated in future research.

FINAL TEST RUN

A final test run was made using several of the tests investigated earlier. The run was made at a time when the digester was running at about twice the capacity as when previous runs were made. The compost did not appear to be well digested and had a strong odor. These tests were run to see if they

Graph 9

Typical Temperature Curves
for one week at the large
M.S.C. plant digester



would indicate the poor digestion that was believed to be taking place. The following tests were made on well selected samples from each feed, plus samples from the raw garbage, and the storage tank.

pH
Moisture
Ash
Oxygen consumed

Results of ash determinations are shown on graph 10. Ash was determined by using the following procedures:

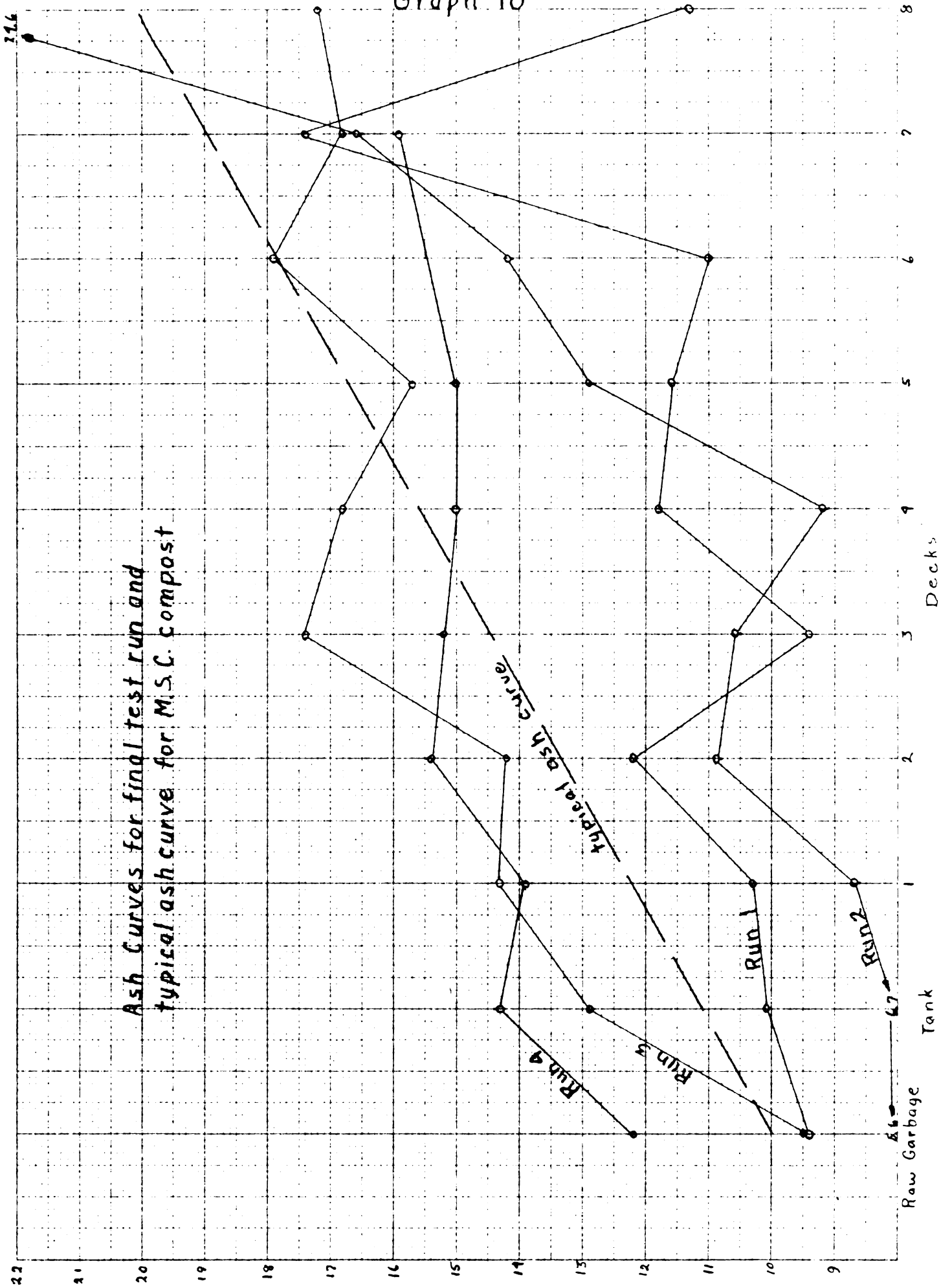
Run	Type of Sample Used
1 and 2	dried, mixed, whole samples
3	dried, ground samples
4	dried, ground samples which passed a number 40 sieve

Ash determinations show a variance in results which is probably due to unrepresentative sampling, and which necessitates further study along this line. Even with this variance, one can see that there is not the characteristic buildup of ash percentage as in previous runs. This indicates poor digestion.

Graph 11 shows the results of moisture and pH determinations. Typical curves were obtained for both. This clearly shows their inability to indicate poor operating conditions and confirms our belief that these two tests could not serve as yardsticks.

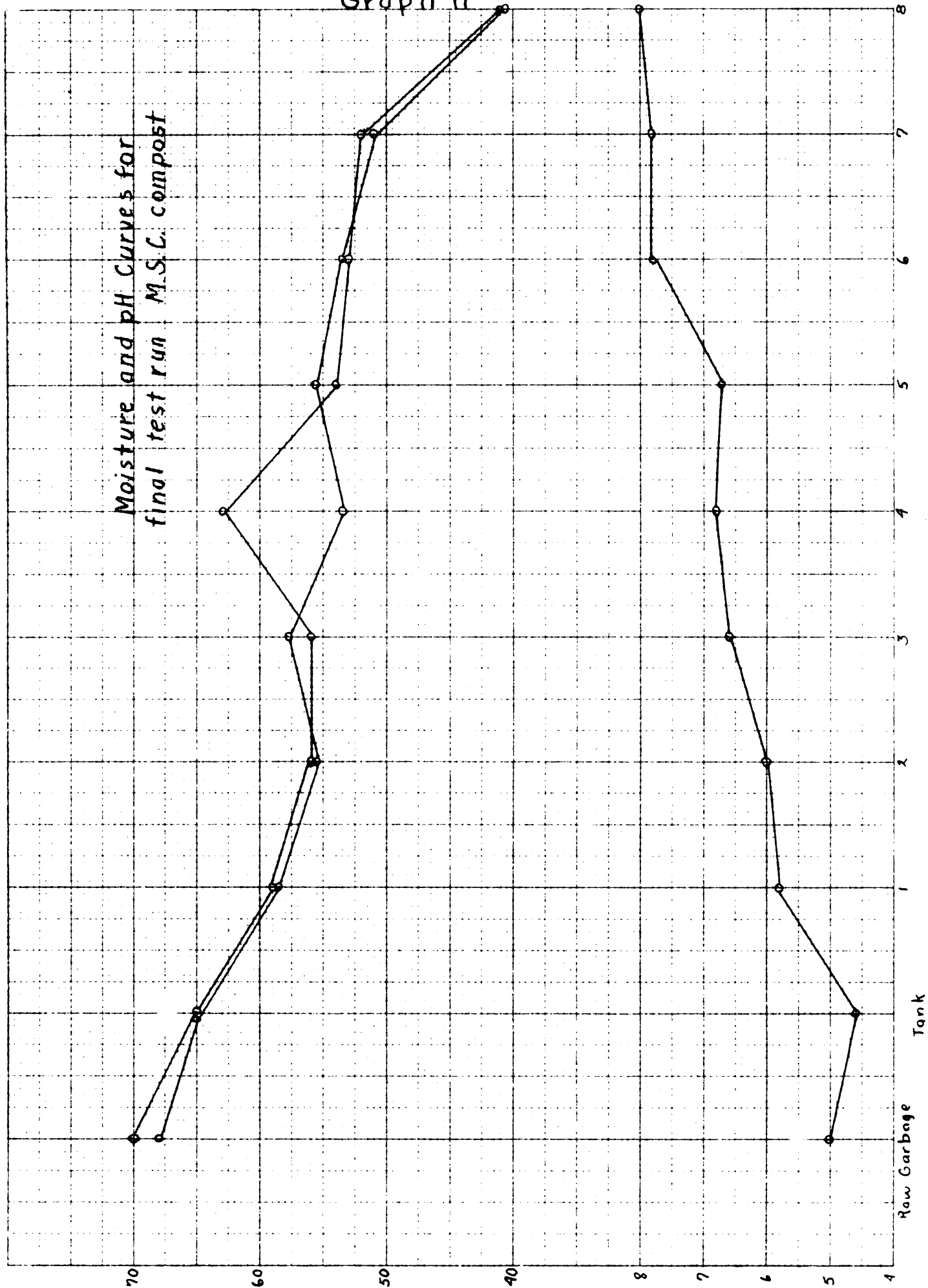
Results of the oxygen consumed test (graph 12) show very well that the digester was not working properly. The dotted

Graph 10



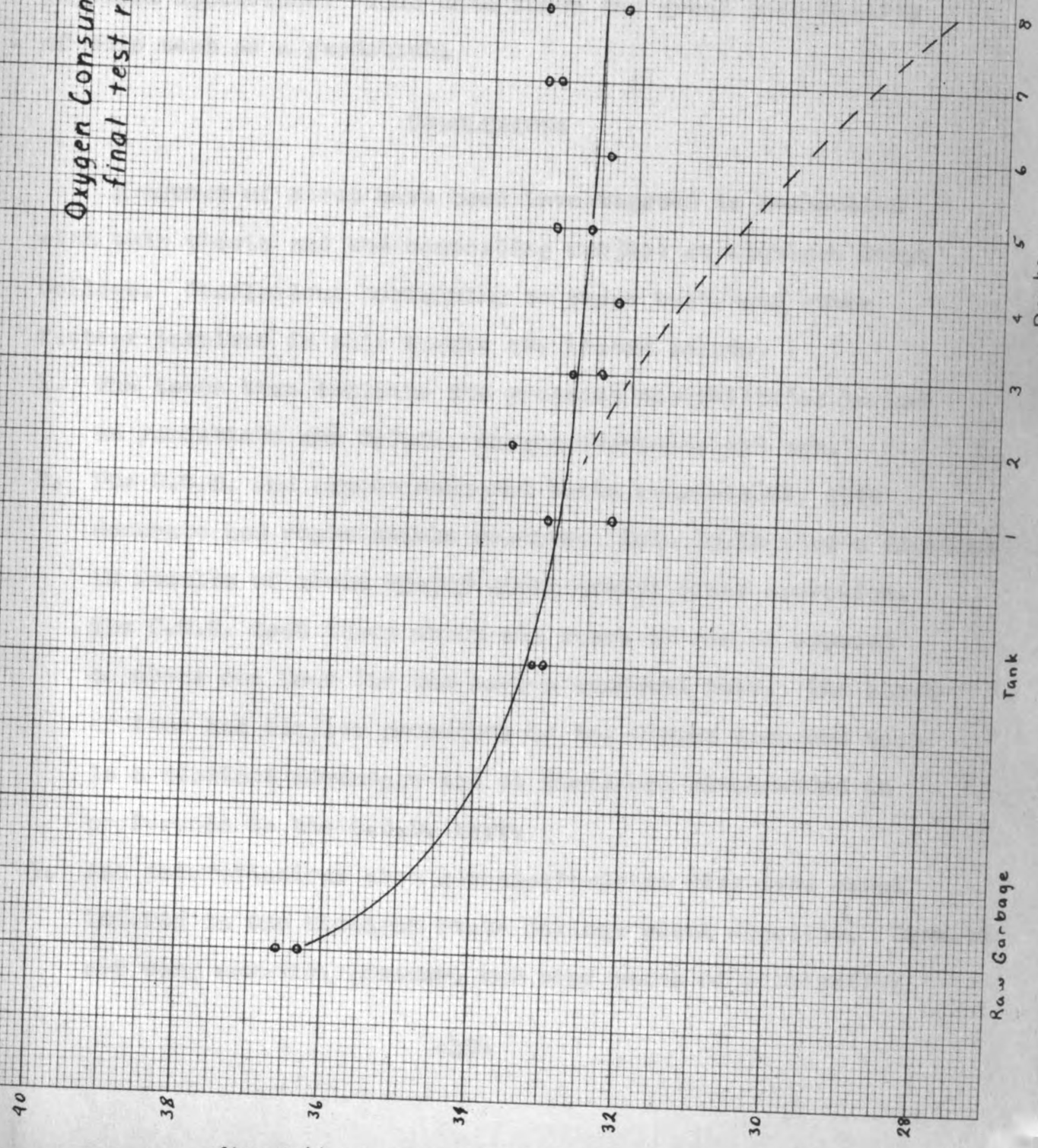
Graph 11

Moisture and pH Curves for
final test run M.S.C. compost



Graph 12

Oxygen Consumed Curve for
final test run M.S.C. compost



line on graph 12 shows a typical reduction when the plant was operating well. Intentional manipulations of air flow and overload of the digester apparently caused a slow up in the composting action as shown by the results and substantiated by physical appearance. This data shows the great potentiality of this test as a yardstick.

CONCLUSIONS

A number of tests have been investigated in connection with this thesis and the composting project at Michigan State College. Conclusions pertaining to these tests and other factors involved in this thesis are listed below.

1. The tests that indicate the greatest possibilities in use as yardsticks are C.O.D., oxygen consumed, and ash.
2. The C.O.D. and oxygen consumed tests consistently give accurate and reproducible results. Both tests show a decrease in results of about 25-30% under normal plant operation. The C.O.D. test takes about six hours to run as opposed to about one hour for the oxygen consumed test. The shorter time and simpler procedure of the oxygen consumed test is a distinct advantage and is therefore recommended in preference to the C.O.D. test.
3. Ash determinations show a characteristic rise from about 10%-20% in the Michigan State College plant digester. Results are very erratic, however, and some means of eliminating

these wide fluctuations is needed before this test can be used as a yardstick. These fluctuations are probably due to unrepresentative sampling.

4. Chlorine demand did not seem applicable as a yardstick because of the poor penetrability characteristics of chlorine. Higher demands were experienced on raw garbage than on finished compost due to this phenomenon.
5. Iodine demand and B.O.D. could not be used as yardsticks because of starch interference. The large quantities of starch in raw garbage make accurate determinations of these tests impossible by the standard starch iodine titration method. Methods other than starch iodine titration are used in connection with this type of test, but they involve very expensive equipment which was not available for this research.
6. The relative stability test, although a test of the nature of the material, is not a quantitative test and could not be used as a scientific yardstick.
7. Temperature, moisture, and pH were investigated in this thesis. These three tests seem important as indicators of normal plant operation, but cannot apply as yardsticks in Michigan State College composting studies because they are to be used as variables in experimentation.
8. Odor and appearance have a definite place in judging the condition of composting material. They are not quantitative

tests and could not be used as scientific variations.

2. The greatest problem in compost testing is the heterogeneous nature of the material. Because of this problem, any known or modified test will give varying results. Some tests are affected more than others, but all show the effects of unrepresentative sampling. The problem of attaining representative samples is of prime importance and should be investigated in future research.

DISPOSITION

1. Personal correspondence.
2. Transactions of the Third Annual Conference on Sanitary Engineering, University of Kansas publication, The Bulletin of Engineering and Architecture, No. 29.
3. New Zealand Engineering, Vol. 6, Nos. 11-12 (Nov.-Dec., 1951).
4. Reclamation of Municipal Refuse by Composting, Technical Bulletin, No. 2, Series 37, June, 1953, Sanitary Engineering Research Projects, University of California.
5. Personal correspondence.
6. Standard Methods for the examination of water and sewage, 7th ed.
7. Leininger and Stone, Elementary Quantitative Analysis.

C. 2

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