

USE OF RESTRICTED AIR SUPPLY FOR TEMPERATURE CONTROL IN THE AEROBIC DECOMPOSITION OF SOLID ORGANIC WASTES

> Thesis for the Degree of M. S. MICHIGAN STATE UNIVERSITY John B. Zondorak 1956



This is to certify that the

thesis entitled

Use of Restricted Air Supply for Temperature Control in The Aerobic Decomposition of Solid Organic Wastes

presented by

John B. Zondorak

has been accepted towards fulfillment of the requirements for

degree in Sanitary Engineering Masters

Drank R. Theraw Major professor

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Date____November 28, 1956

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John B. Zondorak

AN ABSTRACT

Submitted to the College 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

1956

Approved_____

JOHN B. ZONDORAK

A study was made on the control of temperature for an aerobically decomposing mass of solid organic matter by restricting the supply of air.

Preliminary work indicated that a discontinuance of air flow during the decomposition process resulted in a decrease in temperature. Conversely, addition of air caused the temperature to rise. A unit operating on this principle of controlled air supply was constructed.

A cylindrical batch-type digester with 4 gallon working capacity and no stirring mechanism was used. Forced air at room temperature was applied through a plastic diffuser plate to the unit when a solenoid air valve was energized by a thermostat set for 45° C. In this way air was supplied to the solid organic material in the unit when the temperature was below 45° C and not above this level.

The solid organic matter consisted of fresh food which was proportioned in such a manner as to represent a typical garbage. The sample was shredded, mixed with oven dried end product from previous runs, and stored for 48 hours at room temperature before each of three experiments was started. One experiment did not have a storage period.

Physical and chemical tests for evaluating changes which resulted during each run were made for initial and final samples.

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A series of experiments were conducted in the manner described above and the results have been reported. The experiments were successful with respect to control of temperature by limiting the supply of air available to the material undergoing decomposition. It is considered that this success established the validity of the principle employed.

Moisture content increased during experiments with both moist and dry air resulting in partial anaerobic conditions and foul odors.

An initial air supply ranged from 17.0 to 35.9 cu ft per lb of volatile solids per day was reduced to about onethird after a temperature of 45° C was reached. Volatile matter was reduced 36 to 46 per cent and nitrogen loss was 11.1 to 54.6 per cent. The greatest volatile solids reduction and nitrogen loss was at 17.0 cu ft of air per lb of volatile solids per day.

After initial heating all experiments required about 10 days time at 45° C for stabilization of the material. The material then cooled to within 10° C of room temperature in 2 days. Initial heating to 45° C required about 24 hours in experiments with food stored 2 days at room temperature after grinding. In the run made with freshly ground material 3 days time was required for initial heating.

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SECTION I

INTRODUCTION

The aerobic decomposition of organic matter can be accomplished successfully only by providing an environment favorable for efficient biological activity. The control of these environmental conditions is of paramount importance if the decomposition process is to attain a satisfactory degree of stabilization. Several of the factors which constitute a favorable environment have been established and a limited amount of progress made towards their regulation.

Knowledge concerning the effect of oxygen supply upon a mass of solid organic matter undergoing decomposition by biological activity is lacking in the field of sanitary science. Such physical factors as temperature, moisture, and air supply upon a mixed population of aerobic and facultative aerobic organisms govern the decomposition process. This author has found no reports upon the control of one of these factors by varying another and the effects of this control upon the decomposition process.

The purpose of this work has been to investigate the control of temperature during decomposition of a synthetic garbage by limiting the air supply. The effect of this limited air supply upon nitrogen loss, ordor and rate of decomposition has been carefully noted.

SECTION II

LITERATURE REVIEW

The aerobic and anaerobic decomposition of organic wastes occur in nature continuously. The degree of stabilization and type of by-products depend upon the type of organic matter present and the environmental conditions existing. If aerobic decomposition is to exist, such factors as air supply, temperature, and moisture must be made favorable to the organisms. Efficient biological activity and "breakdown" of the complex organic compounds then results.

Waksman [6] in his studies on the aerobic decomposition of manure and vegetable residues stated:

The temperature of the organic matter is one of the most important factors in the controlling the rapidity of the decomposition and the conservation of nitrogen.

The most rapid decomposition of horse manure sets in at 65° C, followed by that at 50° C. After the first stages of rapid decomposition the process was found to proceed more rapidly at 50° C.

Whenever decomposition was delayed either because of too high or too low temperature, losses of the volatile forms of nitrogen occurred.

This study was made in earthen-ware pots which were maintained at constant temperature by incubation and aerated by mixing when samples were removed. The relative degrees of decomposition were measured by correlating on a dry weight basis the amounts of material in the process remaining and lost.

In a report on a study of the composting of garbage and other solid organic wastes at Michigan State University[5], studies were made on the effect of temperature and moisture upon the oxygen uptake of the composting mass. The data collected in these studies seemed to indicate that the maximum oxygen uptake was at a moisture content of 40-45 per cent for the first 27 hours in the laboratory digesters. From this time on, the maximum oxygen uptake was at a moisture content of approximately 56 per cent. At the conclusion of the experiments the material in the digesters containing a moisture content of 56 per cent appeared to be well composted material. The material with a moisture of 40-53 per cent was only partially composted. Material containing a moisture content of less than 40 per cent was very dry and very little if any composting had taken place. Material with a moisture content above 60 per cent was anaerobic and in very bad condition.

Studies on the optimum temperature, utilizing a moisture content of approximately 55-60 per cent, were made within the range of $25-45^{\circ}$ C. The greatest oxygen uptake measurements were recorded at 45° C with a rate of 420×10^{-4} moles per 100 gm of dry weight per hour at standard temperature and pressure. Converting this value to cu ft of air at 20 psi and 45° C yields approximately 0.166 cu ft of air per hour per 100 gm dry weight or 18.1 cu ft per 1b of dry weight per day.

Ludwig [4] in a thesis for a Master's degree (1952), made a similar study on the effect of various temperatures

upon the aerobic digestion of garbage. This paper indicated that the optimum temperature for the most rapid aerobic digestion and stablization of the garbage samples, under the conditions stated, was 45°C. The maximum rates of oxygen uptake occurred at this temperature along with the greatest volatile matter reductions. A synthetic garbage composed of meat, potatoes, carrots, celery, and apples, containing a moisture content of 85 per cent, was employed. The maximum oxygen uptake rate was 0.129 cu ft of air at 45 °C per 100 gm of dry weight per hour or 13.7 cu ft per 1b of dry weight per day. The results of Ludwig and Michigan State University concerning the oxygen uptake rates did not disagree markedly and good agreement was found regarding the temperature at which the oxygen uptake rates were maximum. Differences may have been due to the variance in moisture contents and to the types of material tested.

Laboratory, batch-type mechanical composters to determine criteria for high rate composting of solid organic wastes were employed by Wiley and Pearce [7] in 1955. Physical and chemical tests for indicating the degree of decomposition were outlined and the results reported. The units were of an 11-gallon working capacity with a stirring mechanism and with insulation. Low pressure air, 10 psi, was used for aeration with provisions for regulating air rate. The raw material was a mixture of garbage and refuse with the non-compostable items removed. The end of a run was reached when the temperature of the material returned to within $10^{\circ}F$

of room temperature. Average moisture of the composting material used in these experiments was 54.5 per cent.

In general, losses in volatile solids varied between 17 and 53 per cent with an average of 30 per cent. This result indicated that nearly one third of the organic matter was decomposed. Varying the rate of aeration produced marked differences in the course of decomposition. Low aeration, 4.0-6.4 cu ft per day per lb volatile solids in the initial charge, resulted in a late peak temperature (seventh day) and unfinished compost by the ninth day. Medium aeration 9-29 cu ft per day per lb volatile solids, resulted in a peak temperature on the fourth day with a slow decline until the ninth day when the digestion was considered complete. Higher aeration values than those mentioned caused reheating of the compost after it was considered complete. It was concluded that low aeration provided either insufficient oxygen or insufficient sweeping out of waste gasses, resulting in a prolonged period of composting. Medium aeration values, in the range of 10-30 cu ft per day per 1b volatile solids, resulted in a relatively stable climb to peak temperatures $(140^{\circ}F)$. and a slow decline to room temperature with the inability to reheat. High aeration resulted in rapid cooling and dehydrated compost, with seeming completion of the process in a very short period, but with reheating upon subsequent mixing. Results of a series of tests indicated that optimum aerobic decomposition of organic material occurred when the moisture content was maintained within the limits of 55-69 per cent.

The activated sludge process of sewage treatment involves oxidation of the adsorbed organic matter by the aid of bacteria during aeration of the mixed liquor containing sewage and activated sludge [1]. Therefore, this process is biological utilizing forced air. Bloodgood [8] determined the oxygen utilization rate of normal activated sludge processes to range from 14 to 20 mg of oxygen per gram of suspended solids per hour. This figure agrees with more recent data presented by Wuhrmann [9] of 11 to 20 mg of oxygen per gram of suspended solids per hour. Standard aeration equipment used today in activated sludge plants has an approximate oxygen transfer efficiency of 5 per cent. Assuming that all of the oxygen supplied is utilized 26 cu ft of air is required per 1b of suspended solids per day. With an efficiency transfer of 5 per cent of the oxygen supplied it is necessary to supply 520 cu ft of air per lb of suspended solids per day.

The data presented by Michigan State University [5] for the maximum oxygen uptake measurements of 420×10^{-4} moles per 100 gm of dry weight or 13.5 mg of oxygen per gm of dry weight agrees with that of Wuhrmann [9]. This comparison of activated sludge and composting seems valid because oxygen supplied to the organisms is dissolved in water in both cases.

SECTION III

THEORETICAL CONSIDERATIONS

(A) Energy and Living Cell

Only two sources of energy for living cells are known to exist, light and chemical energy. Light can be eliminated from this study as a source of energy because the nature of the work did not permit its utilization. Heat, electricity and mechanical energy can also be ignored because the bacterial organisms involved lack appropriate "transformers." Heat, in the form of a rise in temperature, may cause increased growth and metabolic activity of a cell, but affect the process only in so far as the chemical changes (which supply the essential energy) are speeded up by a rise in temperature. A starving cell, for instance, derives no benefit from a rise in temperature.

It follows that the energy liberated in one cell is of no value to any other cell; neighboring cells, even those closely linked in one tissue, have no direct energy exchange system. The chemical energy necessary for growth must be liberated within the cell, therefore, the only foods of value to the organism are those which can diffuse through the surrounding moisture layer. Complex proteins, fats and carbohydrates like starch and cellulose, are not directly available

to the organism, but must first be broken down or hyrolyzed to appropriate soluble, and diffusible compounds. The work of breaking down food to a usable form is carried on by a class of exo-cellular enzymes or hydrolases which are secreted into the medium by the organisms. The reactions catalysed by these exo-cellular enzymes involve only relatively small energy changes, while reactions brought about by the endoenzymesinside the cell, where the energy liberated is of real value to the organism and involve large energy changes.

The value of a compound as a food or energy source also depends on the degree of oxidation which it undergoes; the more complete the oxidation the greater the energy made available. Glucose may be taken as an example, and the energy liberated with varying degrees of oxidation compared:

(a) Complete aerobic oxidation

 $C_{6}H_2O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 674$ Cals. (Kilo cals.) (b) Partial aerobic oxidation

oxalic acid $2C_6H_{12}O_6 + 9O_2 \rightarrow 6C_2H_2O_4 + 6H_2O + 493$ Cals. (c) Anaerobic oxidation

 $\begin{array}{c} \text{lactic acid} \\ \text{C}_{2}\text{H}_{12}\text{O}_{6} \rightarrow 2 \text{ C}_{3}\text{H}_{6}\text{O}_{3} + 22.5 \text{ Cals.} \\ \text{ethyl alcohol} \\ \text{C}_{6}\text{H}_{12}\text{O}_{6} \rightarrow 2\text{C}_{2}\text{H}_{5} \text{ OH} + 2\text{CO}_{2} + 22 \text{ Cals.} \\ \text{acetic acid} \\ \text{C}_{6}\text{H}_{12}\text{O}_{6} \rightarrow 3 \text{ CH}_{3}\text{COOH} + 15 \text{ Cals.} \end{array}$

It follows that with less complete oxidation more of a given substance must be broken down to supply the needs of an organism.

From the above mentioned considerations (which are generally true due to the heterogeneous organic matter and organisms present in the synthetic garbage) it can be stated that an increase in temperature of a biological active mass of organic matter can be expected if an adequate supply of oxygen is available and aerobic conditions prevail. This statement should hold true in spite of the cooling effect of evaporation because biological activity is an exothermic reaction.

(B) Influence of Temperature Upon Reaction Rates

The majority of known chemical reactions are increased in rate by increase in temperature. In biological systems this increase in rate is limited because at higher temperatures the enzymes begin to be denatured. We, therefore, find an increase of reaction rate up to a certain "optimum" temperature, and then generally a rapid decrease is noted due to enzyme destruction or denaturation.

The effect of temperature upon a homogeneous chemical reaction can be expressed by its effect upon the velocity constant, K, of the reaction.¹ The simplest case is that of a monomolecular or "first order reaction." Thus if we start with (a) molecules of a substance and (x) of these molecules

¹The derivation and values concerning the velocity constant K are taken from Kenneth V. Thimann, <u>The Life Of Bacteria</u>, The Maxmillan Company, New York, 1955, pp. 148.

have reacted after time (t), the rate then depends upon the remaining molecules which have not reacted, i.e., the rate of change of (x) with time depends on (a-z), or: $\frac{dx}{dt} = K$ (a-x)

by integration
$$\frac{1}{K} \int \frac{dx}{dx} = \int^{t} dt$$

 $K = \frac{1}{t} \ln \frac{a}{a-x}$ equation (1)

The value of K increases with an increase in temperature as illustrated by the following equation:

$$\log \frac{K_2}{K_1} = \frac{T_2 - T_1}{T_2 \times T_1} \text{ equation (2)}$$

The velocity constant, therefore, is a measure of the activity of the biological reaction. In equation (1) it can be seen that if the value of K increases (x) (the molecules which have reacted after a time (t)) must also increase.

Figure 1 shows the values and variations of K with temperature for various chemical reactions, and for the growth of some bacteria. The effect on growth is also illustrated by the data of Barber (1908) on B.coli (Figure 2). In this graph the time plotted is the actual time required for an organism to divide once, i.e., the "generation time." This time is infinitely great both at low temperatures and when the temperature is so high that the bacteria are destroyed faster than they can grow.

DECOMPOS	SITION	COAGU	LATION
$N_2 O_{5} N_2 O_4 + \frac{1}{2} O_2$,9H ₂ 0 ₂ →H ₂ 0+ ¹ ₂ 0 ₂	Of milk by Rennet	Of Hemoglobin by Heat
Temp.Kx10 ³ °C 0 0.05 10 20 1.17 25 2.03 30 35 8,08 40 45 29.9 50 55 90.0	Kx10 ³ 1.06 3.08 5.16 7.90 13.4 17.3	Temp. v °C 25 1 30 1.69 35 3.15 40 5.40 50 60 62.6 65.6 67.6 70.4	K 0.009 0.019 0.044 0.074 0.15
HYDROI	YSIS	GR	OWTH
Of Propyl Acetate by KOH	Of sucrose by Invertase	Of Lac	tobacillus
Temp. K _a oc 0 1.03 10 2.15 20 4.23 30 8.10 40 14.95 50	K x 10 ⁵ 18 120 163 216 302	Temp. oc 15 25 30 35 40 45	к.434 0.084 0.184 0.365 0.62 0.84

.

Fig. 1. EXAMPLES OF VELOCITY CONSTANTS FOR VARIOUS CHEMICAL REACTIONS AND FOR THE GROWTH OF SOME BACTERIA



Fig.2. THE GENERATION TIME OF B.coli AS A FUNCTION OF TEMPERATURE (Data of m. A. Barber, from <u>The Life of Bacteria</u> by Thimann, Kenneth V., (1955). By courteay of The Maxmillan Company, page 151.)

It was shown above that increase in temperature increases the rate of all the reactions involved in growth, i.e., temperature accelerates not only those reactions which constitute normal metabolism, but also those reactions, like enzyme inactivation and protein denaturation, which are damaging to the cell. Therefore, the <u>optimum</u> temperature for growth must be defined loosely as that temperature above which the damaging reactions just produce a discernible effect. Correspondingly, the <u>maximum</u> temperature is that at which the rates of damaging reactions become just equal to those of the metabolic processes so that no growth takes place.

(C) The Effect of Forced Air on Moisture Content

Saturated air contains a given amount of water vapor at a specific temperature and pressure. Therefore, when dry air flows through a moist mass it becomes saturated, and in doing removes the vapor of saturation.

In mixtures of perfect gases, the partial pressures of the components may vary without limit. A vapor, however, cannot exist in a mixture at a pressure higher than the saturation pressure for the vapor at mixture temperature.

This fact is useful for obtaining a measure of the relative quantity of vapor present in a gaseous mixture. If the vapor has a partial pressure equal to the saturation pressure, the mixture is said to be saturated. The humidity ratio M_s is defined as the mass of vapor associated with 1 lb of dry air to form a mixture of $1 + M_s$ lb. The specific volumes

of the air and water vapor may be expressed by the perfect gas law:

The mass of moisture associated with 1 lb of air is the mass contained in a volume equal to the specific volume of air (since in mixtures all components occupy the same volume). T_a and T_s are of course equal.²

$$M_{s} = \frac{v_{a}}{v_{s}} = \frac{R_{a} P_{s}}{R_{s} P_{a}} = \frac{53.3P_{s}}{85.7P_{a}} = 0.622 \frac{P_{s}}{P_{a}}$$

Equation (3)

The experiments described here were conducted at approximately atmospheric pressure, 14.7 psi at a temperature of $114^{\circ}F$. If the relative humidity was assumed to be 100 per

²Charles L. Brown, <u>Basic Thermodynamics</u>, McGraw-Hill Book Co., 1951, p. 204.

cent in the unit when the temperature reached $114^{\circ}F$, then, from vapor pressure tables [3] the corresponding saturation pressure for the vapor was 71.88 mm of mercury or 1.39 psia. Therefore, the humidity ratio for saturated air at $114^{\circ}F$ was:

$$P_{sat.} = 1.39psia = P_s$$

 $P_a = 14.7 - 1.39 = 13.31 psia$ equation (3)
 $M_s = 0.622 \frac{1.39}{13.31} = 0.065 lb/lb dry air$

From the above it can be seen that for every pound of dry air (14 cu ft) which entered the unit 0.065 lb of vapor could be carried out the exhaust if the humidity in the unit was 100 per cent.

(D) The Effect of Evaporative Cooling

The cooling effect of evaporation was a significant factor in the experiments performed. The heat of vaporization is the quantity of heat required to change one gram of liquid to vapor without change of temperature. From the tables of the properties of saturated steam (3), 571 calories of heat are required to vaporize one gram of liquid water or 1028.4 B.T.U. are required per pound at 45° C. Therefore, it can be seen that forced air effected the rate of cooling of the decomposing mass of organic material by removing the vapor, thereby causing a loss of heat in the mass by the process of vaporization.

SECTION IV

EXPERIMENTAL EQUIPMENT AND PROCEDURE

(A) Principle of Operations

When organisms utilize oxygen and organic food as a source of energy heat is produced and a corresponding rise in temperature ensues. This exothermic production of heat was the subject of the study reported here. In the devise used a reduction of the oxygen supply to the organisms was used to reduce the rate of heat production to cause an attendant cooling. In this way the rate of air supply was used to control temperature of the digestion unit.

The operation was similar to a furnace utilizing natural gas as a fuel. The furnace utilizes the gas as a source of heat energy by combining it with oxygen in an exothermic reaction-thus producing heat. When either the gas or the oxygen ceases to be supplied to the furnace heat energy is no longer produced and a reduction in temperature will result (the rate of reduction being dependent upon the degree of insulation). With a thermostat the temperature of a room can be controlled by regulating the injection of fuel when the room is heated above or drops below a designated limit. The above analogy applies directly to the experimental unit employed in this study as the identical operation was utilized.

(B) Description and Function of Equipment

The type of unit employed to study the effect of restricted air supply upon temperature of solid organic waste was a laboratory batch-type digester without mechanical stirring as shown in Figure 3. It consisted of a cylindrical drum 8.5 inches in diameter and 21 inches in depth. The working capacity was approximately 4.0 gallons or 16 lb of solid organic waste. A temperature sensing element for continous recording was placed in the unit as shown in Figure 3.

The drum was covered with 1-1/2 inches of fiber glass to prevent excessive heat losses and because the maintenance of a constant temperature would have been difficult without insulation.

Air supplied to the digester was controlled by a solenoid valve as shown in Figure 4. Forced air was allowed to enter the unit containing the solid organic waste when the solenoid valve was energized from the thermostat set for 45° C, therefore, the solenoid was energized until the unit reached this temperature as shown in Figure 5. In this way air was supplied to the material up to 45° C. Above 45° C the air supply was cut off by the thermostat as shown in Figure 6. The temperature therefore remained at 45° C throughout the decomposition process after the initial heating. The 45° C temperature was selected because the work of Waksman [6], Ludwig [4], and Michigan State University [5] suggested that this was the temperature at which the most aerobic decomposition and maximum oxygen uptake of solid organic wastes occurred.



Figure 3. DETAIL OF DIGESTOR UNIT







Figure 5. DIAGRAM OF ELECTRICAL CIRCUIT WITH TEMPERATURE BELOW 45°C.



Figure 6. DIAGRAM OF ELECTRIC CIACUIT AS AS TEMPERATURE IN UNIT EXCEED. 45°C CLOSING AIR SUPPLY Low pressure air, 5 psi. was supplied to the false bottom of the digester as shown in Figure 3. The forced air entered the organic matter through the plastic diffuser plate composed of 1/64 inch diameter orifices spaced 1/4 inch on centers. This design of the diffuser plate resulted in uniform dispersion of forced air throughout the decomposing mass without "channeling." The rate of forced air supplied to the sample of organic matter was the single variable studied in this investigation. Aeration rates were varied depending upon the results obtained during each test, and the rates used in this study varied between 17.0-35.9 cu ft per 1b of volatile solids per day.

When the solenoid valve was energized the air passed through a flask containing calcium chloride and a Daigger continuous gas flow recorder and then entered the digester. The calcium chloride removed any moisture which may have been present from the air source, and the gas recorder indicated the time and rate of air flow. The gas recorder served to indicate whether or not the solenoid valve was energized and permitted computations of the amount of air fed to the unit. be made.

(C) Raw Materials

The solid organic matter used for aerobic decomposition was composed of fresh food from the Food Stores at Michigan State University. The specific constituents of food used were representative of Mallison's [5] data for a typical sample

Food Constituent	Per Cent on Wet Weight Basis	Wet Weight
Meat (ground beef)	12.8	1.50
Bread	10.5	1.25
Green Vegetables	26.2	3.25
Coffee grinds	11.1	1.50
Fruit	21.8	3.00
Potatoes	17.3	2.00
Paper	negligible	12.5

of garbage from East Lansing, Michigan as follows:

Decomposed matter from previous run (oven dried 103°C)

3.00

Total weight of sample- 15.5

The main variation of the above constituents from those reported by Mallison was the reduction in the per cent of paper and miscellaneous constituents. The moisture of the synthetic garbage was 75 per cent. Wiley and Pearce [7], Michigan State University [5] and the University of California [2] have suggested that for this type of organic matter a moisture content of approximately 60 per cent would be desirable for aerobic decomposition. Such moisture content was obtained by adding approximately 24 per cent of oven dried compost; that is, 24 per cent of the total wet weight of fresh food used or 19.3 per cent of the 15.5 lb sample. Each experiment contained identical amounts of the specific constituents. This procedure permitted a valid comparison of the end results of different experiments. The fresh food was thoroughly mixed and chopped manually before grinding. An Enterprise Engine Company vertical mill grinder with 3/8 inch screen openings was employed for the shredding. The food and the oven dried compost were put through the grinder twice. The ground material was collected in a bucket and inverted onto a screen where it was allowed to set for about 48 hours to drain. This procedure produced a sample of organic matter with a moisture content of about 60 per cent.

(D) Procedure

The thoroughly mixed and shredded sample containing approximately 12.5 lb of food constituents and 3 lb of dried compost was placed in the digester unit. The sample occupied a volume of about 2.6 gallons with a moisture content of about 60 per cent. Samples for initial analysis were takenfrom the original weight.

Air was supplied to the unit until it reached a temperature of approximately 45° C at which time the thermostat opened the electrical circuit, closed the solenoid valve, and ceased to supply air to the unit. The reverse occurred when the unit cooled below 45° C. The rate of air supplied during each run was constant. Aeration rates ranged from 4 to 8 cu ft per hour or 17.0-35.9 cu ft per day per 1b of volatile solids.

Usually, 24 hours of aeration were required to raise the temperature of the sample organic matter in the unit to

 45° C. Once the temperature reached 45° C in the unit, it remained there (within $\pm 3^{\circ}$ C) for 9 to 11 days. The unit then cooled to within 5° to 10° C of room temperature at which time the experiment was stopped.³ Samples for analysis were taken and the remaining material dried at 103° C for 48 hours to be readied for use as seed for moisture control in the next run.

(E) Sampling and Testing Procedure

Preliminary studies on sampling techniques indicated . that variable results were obtained if samples removed from the decomposing mass were taken from one level in the unit. Samples were, therefore, collected only at the beginning and end of a run. Initial samples were obtained by spreading the entire mass of organic material on a large surface and extracting small segments of a whole sample from various parts of the mass. That is, if a 20 gm sample was to be collected, then, about ten 2 gm random samplings were made to comprise the whole 20 gm sample. Samples were collected from the entire end product in a similar manner except that the material was first mixed thoroughly by hand. This procedure minimized the errors which would have resulted from variations in moisture and type of material due to the fact that the material in the unit was not stirred or disturbed during the experiment. Also, this allowed a closed system during the entire run.

 $^{^{3}}A$ series of air and temperature charts are included in the appendix.

Moisture was determined gravimetrically by drying in an oven at 102°-105°C for about 48 hours. Drying periods of 24 hours were sufficient for 15 gm samples, but when larger samples were used 48 hours was employed. Some of the more readily volatilized compounds such as ammonia, volatile acids, and carboydrates were probably reported as moisture. The moisture was reported as the per cent of wet weight.

Total volatile and fixed solids (ash) were determined by igniting the approximately 6 grams of total dry solids remaining from the moisture tests. Ignition was in an electric muffle furnace for 3 hours. The per cent volatile and fixed solids were reported on a dry weight basis. Carbon dioxide and volatile minerals may have been reported as volatile solids, although volatile solids represent primarily organic matter in the solid organic matter considered.

The determination of total nitrogen by Kjeldahl required the development of a different technique from that mentioned in <u>Standard Methods</u>, tenth edition, because of the sample of the organic matter used. The procedure employed was developed with the aid of D. Erwin J. Benne of Michigan State University and is outlined below:

- Weigh out 1-4 gm of sample and place into a 800 ml Kjeldahl flask.
- 2. Add 1-2 gm of $CuSO_{\perp}$
- 3. Add 4-5 gm of K_2SO_4
- 4. Add 25-30 ml of H_2 SO₄ 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).
- 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 zine (to decrease bumping). Add sufficient NaOH to make solution alkaline (about 40 to 60Ml). It is most important that the solution is alkaline at this point.
- 9. Distill off about 150 ml into a measured quantity of standard acid (the amount of standard acid depends upon the amount of nitrogen present and the normality of the acid).
- 10. Titrate with NaOH using methyl red as an indicator. In the experiments performed here an automatic Beckman titration meter was used.

The calculation is as follows:

- % N <u>1.4X N. acid</u> x ml acid used by NH₃ gm of sample*
- ml of acid used by NH_3 ml of acid used $\frac{\text{N base}}{\text{N acid}} \times \text{ml base}$
- * Gm of sample is on a dry weight basis.

Samples of approximately 5 gm were collected at the beginning and end of a run, diluted in distilled water, and mixed thoroughly before the pH was measured with a Beckman meter.

SECTION V

EXPERIMENTAL RESULTS

Experiment 1.

This experiment was made to demonstrate whether temperature control of aerobically digesting material with a restricted air supply was feasible. The air valve was set to supply 6 cu ft of air per hour with the thermostat adjusted to open the electric circuit when the temperature in the unit reached 45° C. The amount and type of organic matter supplied to the unit was the same in this and each subsequent experiment; namely, 12.5 lb of fresh food and 3 lb of the oven dried end product from a previous run as described in Section IV.

Saturated air was provided in this run by bubbling air through a flask of water installed in the inlet air line. The flow diagram of Figure 4 applied to this run except for the provision for moist air.

The initial temperature of the organic material was 25° C when saturated air at a rate of 6 cu ft per hour was fed to the unit. Within 24 hours the temperature rose to approximately 30° C. The air supply was then discontinued for 2 days but no further increase in temperature resulted. Therefore, the air was again supplied to the unit at the previous rate. Within 24 hours a level of 45° C was reached, thereby causing the thermostat to close the air supply line. In approximately

30 minutes the material cooled about 2°C and the air supply came on again. This air feed rate continued for approximately two days with the air remaining on about 15 minutes and off for about 30 minutes. Gradually, the interval between off and on times decreased. After the third day the air was on and off every two or three minutes for a period of approximately seven days after which time the period of air flow began to increase. At the end of nine days the material began to cool and reached a room temperature within two days. The experiment was then concluded.

This experiment proved that temperature could be controlled by restricting the air supply.

Tables 1 through 5 contain the individual results of the four experiments of the study with a summary in Table 6. For this first experiment the initial dry weight of 3350 gm was reduced by 32 per cent to 2292 gm and the volatile matter of 2830 gm was reduced by 36 per cent to 1820 gm. These weight reductions were in line with those reported by Wiley and Pearce [7] and by Michigan State University [5]. The water loss was 331 gm or a 6.7 per cent reduction with initial moisture of 60 per cent and final moisture of 67 per cent. The dry weight reduction of 32 per cent and water loss by only 6.7 per cent accounts for the increase in per cent moisture from 60 to 67 per cent. The small water loss was probably due to the use of saturated air thereby decreasing the amount of water vapor which could be carried away by the air. The

Experiment No.	1	2	3	4
Air Rate (cu ft per hr.)	6	6	8	4
Air Rate (cu ft per lb of volatile solids per day)	23.1	29.5	35.9	17.0
Condition of Air Entering Unit	Saturated	Dry	Dry	Dry
Thermostat S et (temperature)	45°C	45 ⁰ С	45°C	45°C
Days Unit Remained at 45 ⁰ C	11	10	10	9
pH (initial) (final)	6.8 8.6	6.8 8.2	6.4 9.0	6.1 9.2

TABLE 1. Experimental Conditions for Runs 1 through 4.

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TABLE 2. Moisture Levels, Runs 1 through 4.

	In	itial	Fi	nal		
Experiment Number	Per Cent	Total Weight Gram s	Per Cent	Total Weight Grams	Loss Per Cent	
1	60	4985	67	4654	6.7	
2	62	4202	64	2920	30.3	
3 `	62	4584	67	3625	20.8	
4	60	4278	68	3490	18.3	

	Int	itial	Ff	inal			
Experiment Number	Per Cent	Total Weight Grams	Per Cent	Total Weight Grams	Loss Per Cent		
1	40	3350	33	2292	32		
2	38	2580	36	1650	36		
3	38	2740	33	1785	35		
4	40	2852	32	1640	42		

TABLE 3. Dry Weight, Runs 1 through 4.

TABLE 4. Volatile Matter and Ash, Runs 1 through 4.

<u> </u>		Initial			Final _				
Experi-	Pon	Total Weight Gra	ms	Per	Total Weight Gr	Loss			
Number	Cent	Vol.Matter	Ash	Cent	Vol.Matter	Ash	Cent		
1	84.3	2830	520	79.5	1820	472	36		
2	86.0	2210	370	82.0	1350	300	38		
3	88.5	2420	320	82.5	1470	315	39		
4	89.8	2560	292	85.0	1390	250	46		

<u></u>	In	itial	Fi	nal	
Experiment Number	Per Cent	Total Weight Grams	Per Cent	Total Weight Grams	Loss Per Cent
1	4.05	135	5.30	120	11.1
2	4.02	112	5.80	96	14.3
3	3.40	93	3.70	63	32.8
4	3.03	91	2.60	41	54.6

TABLE 5. Total Nitrogen, Runs 1 through 4.

TABLE	6.	Summary	of	Runs	1	through	4.

Experiment Number	Dry Weight Loss Per Cent	Volatile Matter Loss Per Cent	Water Loss Per Cent	Nitrogen Per Cent	Air Rate cu ft/hr
1	32	36	.6.7	11.1	6
2	36	38	30.3	14.3	6
3	35	39	20.8	32.8	8
4	42	46	18.3	54.6	4

initial total nitrogen was 135 gm or 4.05 per cent and the final 120 gm or 5.30 per cent. This is equivalent to a nitrogen loss of 11.1 per cent. The initial and final pH was 6.8 and 8.6 respectively.

A very strong putrid odor characterized the end product. The excessive moisture was attributed to the use of saturated air. This suggested that dry air might alleviate this condition and dry air was used in the three subsequent experiments.

Experiment 2.

Dry air was fed to the solid organic matter in this run at a rate of 6 cu ft per hour. The use of dry air resulted in a loss of 1280 gm of water or a reduction of 30.3 per cent. The initial and final dry weights were 2580 and 1650 gm with a reduction of 36 per cent. A volatile matter reduction of 38 per cent was the result of initial and final volatile matter weights of 2210 and 1350 gm respectively. The nitrogen level increased from 4.00 per cent to 5.80 per cent although over-all nitrogen loss was 17.8 per cent as compared to the previous run with a 11.1 per cent loss. The initial ph was the same as the first experiment, 6.8, and the final 8.2.

The material undergoing decomposition remained at a level of 45° C for approximately 10 days before cooling. About one day was required to reach a temperature of 45° C at the beginning of the run. The rapid increase in temperature as

compared to the first run was attributed to a two day storage period at room temperature as explained in Section IV.

A less putrid odor was noticed in the end product than for the first run although a strong ammonia odor was noticeable. The bottom and top of the finished material had a one inch layer of bluish white actinomycetes with a very musty odor. A sample of this growth, which was tested, showed a moisture of 10 per cent and a total per cent nitrogen of 4.86. The final moisture of the end product was 64 per cent. Therefore, the use of dry air did not reduce the final per cent moisture materially although the total moisture loss was high. This fact indicated that more water was produced and that the decomposition process probably more effective.

Experiment 3.

A higher rate of dry air, 8 cu ft per hour, was utilized in this run in an attempt to produce an end product with a lower moisture content and less putrid odor. The organic material heated to a temperature of 45° C in about 24 hours and remained within 2°C of this temperature for 10 days before cooling. This rapid temperature rise was again attributed to the two day storage period previous to placing the organic material in the unit.

The initial moisture in this run was 62 per cent and the final 67 per cent with a total loss of 959 gm of water or a reduction of 20.8 per cent. The initial volatile matter of 2420 gm was reduced to 1470 gm for a total loss of 39 per cent.

This was greater than the two previous experiments and indicated that a higher degree of stabilization had occurred in this run. In this experiment an initial nitrogen content of 93 gm was reduced to 63 gm for a total nitrogen loss of 32.8 per cent.

Theappearance and odor of the end product were similar to experiment 2 except for an even stronger ammonia odor. Actinomycetes growth at the top and bottom was largely absent due to high moisture content of the end product. This experiment showed that a higher rate of air did not decrease the moisture level during the decomposition process and did not increase the rate of stabilization.

Experiment 4.

Per cent moisture increased from 60 to 68; the highest final moisture recorded in these experiments. The water loss from 4278 gm to 3490 gm, a reduction of 18.3 per cent, was approximately that of the previous experiment. The initial and final volatile matter of 2560 gm and 1390 gm was a reduction of 46 per cent. The nitrogen loss of 54.6 per cent was the result of reducing the initial weight of total nitrogen from 91 gm to 41 gm. These high values indicated that the stabilization process proceeded at an igher rate in this run than in any of the preceeding experiments.

The odor of the end product was foul and the appearance of the material was similar to very moist humus. When the lid was taken off of the unit at the end of the run the

ammonia odor was overwhelming. From this general condition of the material and odors emanating from the unit during the process, it was concluded that at least partially anaerobic conditions prevailed in this run.

In general good relationships were noted between initial and final total and volatile solids. However, a variation of between 3 to 15 per cent in initial and final ash was noted. This variation must be attributed to sampling errors and the fact that when obtaining the dry weight of a sample to be used for ash determination, exactly identical periods of time were not employed for drying the material.

SECTION VI

DISCUSSION OF RESULTS

These studies demonstrate that the temperature of a decomposing mass of solid organic matter can be controlled by restricting the supply of air. The fact that a level of 45°C was reached by supplying air at lower temperatures and that it was possible to maintain this temperature by restricting the air supply indicated that certain organisms utilized oxygen in their metabolism and produced heat. Aerobic organisms were therefore undoubtedly present. Probably a mixture of facultative aerobes and anaerobes also existed.

The putrid odor of the end products suggests that anaerobic decomposition took place. In general, odors produced were typical of the end products of anaerobic decomposition of protein. The strong odor of ammonia also suggests that anaerobic "break down" was occurring during the degradation of amino acids which was favored by the anaerobic conditions.

The experiments which utilized dry air produced the highest reduction in volatile matter, and no difficulty was encountered in raising the temperature to 45° C initially--as was the case when saturated air was used. The use of saturated air throughout the entire first experiment may have prevented the growth of aerobic or facultative anaerobic organisms at the beginning of the run. However, it is more probable that

temperature lag was due to omitting the two day aging process at room temperature which was utilized for experiments 2 through 4. Because aerobic organisms produce a greater quantity of heat during their metabolism than anaerobes a sizeable population of aerobes were undoubtedly present in order to raise the temperature to 45° C at the beginning of the experiment.

Experiment 4 supplied the least amount of air to the solid organic matter and produced the highest degree of volatile matter reduction, 46 per cent. This high loss of volatile matter was accompanied by a 54.6 per cent loss of total nitrogen and very putrid odors which indicated that decomposition had taken place at a high rate. If all this ammonia is considered to have been in the form of protein, then a 51 per cent reduction took place. This 51 per cent value was obtained by multiplying the per cent nitrogen in the initial and final samples by a factor of 6.4, since protein is commonly about 16 per cent nitrogen. The fact that this large per cent of ammonia was lost to the atmosphere suggests that very little, if any, of this free ammonia was oxidized to the nitrite or nitrate form. Anaerobic conditions definitely accompanied this run but in spite of these conditions a higher volatile matter reduction was observed in this experiment than in any other.

Experiments 2 and 3 appear to have undergone a lower degree of decomposition as shown by the reduction of volatile

matter. These two experiments were conducted at higher rates of air supply indicating that anaerobic conditions tend to result in more rapid decomposition. Further investigations will be necessary in order to establish the relationship between anaerobic decomposition and rate of stabilization.

The rates of air were 4, 6, and 8 cu ft per hour or 17.0, 29.5, and 35.9 cu ft per 1b of volatile solids per day. Actually, these rates existed only when the temperature was below 45° C. Due to the fact that the air was on one-third of the time after the initial heating, the above air flows should be divided by three. Therefore, the rates of air discussed in Section II in connection with the studies made by Wiley and Pearce [7], Michigan State University [5], Ludwig [4] and an activated sludge process correlate closely to those used before and after, but not luring the heating process.

In Section III it was shown that at 100 per cent humidity and 45°C 0.065 lb of water vapor could be carried out through the exhaust for every 14 cu ft of dry air which entered the unit. Applying these figures to experiment 4 approximately 2.2 lb of water could have been lost during the entire experiment. Only 1.7 lb of moisture was lost in the run probably due to condensation on the lid of the unit which was not insulated.

SECTION VII

CONCLUSIONS

A study was made to investigate the control of temperature for solid organic material undergoing aerobic decomposition by limiting the supply of air. A six gallon capacity unit with a plastic air diffuser was constructed for the study using a thermostat and solenoid air valve to control air flow. Raw material used was fresh food mixed with oven dried end product from previous runs. Inlet air was at room temperature. Conclusions pertaining to four runs and to other factors involved in this thesis are listed below:

1. A satisfactory method was devised for controlling the temperature of an aerobically decomposing mass of solid organic material at 45° C by restricting the supply of air.

2. Once the temperature reached a level of 45°C and the "on and off" process of air flow started, flow rates were reduced to one-third of the initial level. This rate of air flow continued for approximately 10 days.

3. The end products of the experiments were putrid in all cases indicating that partially anaerobic conditions existed.

4. Experiment 4 produced the greatest reduction in volatile solids and total nitrogen loss. These losses of 46

and 54.6 per cent respectively occurred at an initial air rate of 4 cu ft per hour or 17.0 cu ft per 1b of volatile solids per day. Experiments 1', 2, and 3 with higher initial air rates showed lower reductions in volatile solids and in total nitrogen as follows:

Experiment Number	Initial Air Rates (cu ft per hr) cu ft per lb of Volatile S olids per Day	Reduction of Volatile Solids (per cent)	Total Nitrogen Loss (per cent)
1	23.1 (saturated)	36	11.1
2	29.5 (dry)	38	14.3
3	35.9 (dry)	39	32.8
• 4	17.0 (dry)	46	54.6

The above table also shows that increased nitrogen loss accompanied a high reduction in volatile solids.

5. Because of the moist condition of the end products the optimum moisture for aerobic decomposition was probably exceeded. Moisture contents were as follows:

Experiment Number	Initial Moisture (per cent)	Final Moisture (per cent)
1	60	67
2	62	64
3	60	68
4	60	68

6. The use of dry air in experiments 2, 3, and 4 resulted in a greater loss of water, volatile solids and total nitrogen than when using saturated air in experiment 1.

7. Material stored for 2 days at room temperature after grinding heated to 45° C in 24 hours. For one run in which no initial storage period was allowed three days initial heating was required.

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APPENDICES



TYPICAL AIR FLOW AND TEMPERITURE CHART: 20 HOURS AFTER START OF EXPERIMENT



TYPICAL AIR AND TAMPERATURE CHARTS DURING APPROXIMATELY 10 DAY PERIOD AT 45°C TEMPERATURE LEVEL

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