PILOT PLANT PRODUCTION OF METHANE BY ANAEROBIC FERMENTATION OF PEAR WASTE

by

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A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

JUNE 1950

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Date thesis is presented May 12, 1950

Typed by Beverly Marquess

ACKNOWLEDGEMENT

The author wishes to express appreciation to Ernest H. Wiegand, Head of the Food Technology Department, Dr. Thomas B. Niven, Assistant Professor, Food Technology Department, and Curtis J. Wilder, Assistant Food Technologist, Food Technology Department, all of Oregon State College, for their guidance and cooperation during work on this problem. He thanks William A. Lambrecht, formerly Research Assistant, Food Technology Department, Oregon State College, for help with construction of the pilot plant, William Filz, Assistant Food Technologist, Oregon State College, for assistance in constructing special equipment, and Ethel L. Krohn, recently of the Oregon State College English Department, for reading the manuscript. Finally the author is grateful to Dr. Walter B. Bollen, Professor of Bacteriology, Oregon State College, for granting the use of a laboratory in which to perform many of the chemical analyses, for his help in interpreting data, and especially for his inspirational encouragement.

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PILOT PLANT PRODUCTION OF METHANE BY ANAEROBIC FERMENTATION OF PEAR WASTE

I

INTRODUCTION

The preparation of pears for processing in commercial canneries produces large amounts of waste, the disposal of which is becoming an increasingly acute problem. Stream pollution from dumped waste not only produces undesirable odors, but depletes the dissolved oxygen of the stream below requirements necessary to support fish and other aquatic life.

In the hope of relieving this pressing need, the following experiments were initiated and developed, not only with this in mind, but also, anticipating the ultimate, more valuable, goal of by-product utilization.

By-product utilization is an old and very profitable story in the meat industry, but, as yet, has received comparatively little attention in the food processing industries. The seasonal nature of the canning industry tends to discourage the investment of the time and money that would be required to develop an adequate disposal and/or utilization method. Then, too, the perishable nature of the material precludes any hold-over from the busy to the slack season; it must be handled immediately.

There are several ways of treating the waste in order to recover useful by-products, such as ethyl alcohol, animal feeds, and fertilizers. It would appear, however, that the adaptation and improvement of a reliable, existing method of sewage treatment offers the greatest opportunity, first, for the adequate decomposition of organic matter to make possible its disposal without nuisance or stream pollution, and second, for the production of methane to be used as a source of power.

The study of the basic principles underlying the continuous, successful production of methane from carbohydrate material may eventually yield an efficient method for satisfying the requirements of the food processor for an operating fuel.

II

REVIEW OF LITERATURE

Many investigators have concerned themselves with the study of methane. As early as 1776, Volta observed the formation of an inflammable gas in nature and rightly concluded that it arose from the decomposition of vegetable materials. It was not, however, until 1906 that the origin of methane was first clearly indicated by the fundamental and important work of Sohngen. The methane-producing bacteria commonly grow wherever organic substances are found in a suitable neutral (pH), moist, anaerobic environment such as in swamps, marshes, or water-logged soils, and in the digestive tracts of animals (especially ruminants). This property of the methane-bacteria to decompose organic, and some inorganic, matter was early adapted to the practical application of sewage treatment. It is believed, though, that the decomposition of such complex substances as proteins and carbohydrates is due to the action of a mixed micro-flora and that the substrate for the methane-bacteria is various lower alcohols and volatile acids, the relatively simple products of such crude fermentations. The early history of methane has been carefully reviewed by

Barker (2,3,6), and Stephenson (52), Kluyver and Schnellen (39), and Thayer (54). For further information in the field of anaerobic fermentation the reader is referred to the comprehensive reviews of the literature reported by Buswell, et al. (18), Harnik (29), and Lambrecht (40).

Microorganisms. Comparatively little was known about the methane bacteria before Barker's work, which commenced about 1936 (2,3). This dearth of knowledge is due to properties of this group of organisms that make the isolation and study in pure culture very difficult. The bacteria are strict anaerobes which infrequently form spores and are killed quite easily while being transferred (3,52).

Barker (3) further presented a survey of the methane-producing organisms based on the descriptions which were then scattered throughout the literature. He developed methods for obtaining highly purified cultures of four different types of methane-producing organisms which allowed the following descriptions:

> Methanosarcina methanica. Large spherical cells characteristically grouped to form cubical sarcina packets. Permanently non-motile and non-spore-forming. Ferments acetic and possibly, also, butyric acids with the production of methane. Gram variable.

Methanococcus mazei. Small spherical cells which occur singly in small groups, or in large, irregular and somewhat slimy aggregates. Immotile and non-spore-forming. Gram variable. Attacks acetic and butyric acids, but not ethyl and butyl alcohols to produce methane.

Methanobacterium sohngenii. Rod-shaped, permanently immotile cells that are non-spore-forming. The rods are characteristically joined into long threads which lie parallel to one another so as to form bundles. Ferments acetic and butyric acids but not ethyl alcohol, to form methane. Gram negative.

Methanobacterium omelianskii. Thin, frequently bent, immotile, non-spore-forming rods. Ferments ethyl alcohol to acetic acid and butyl alcohol to butyric acid with methane formation. The same organism probably also ferments butyric acid to acetic acid. Acetic acid is probably not fermented.

Four years later (1940), Barker was the first investigator to succeed in isolating in pure culture Methanobacterium omelianskii, a species of methane bacteria (7). Purity was established by microscopic examination and by testing the culture for contaminants both anaerobically and aerobically. In light of subsequent work with pure cultures, the morphological

description was changed. The organism was found to be a thin, feebly motile, Gram-variable rod. Spores are formed, that withstand exposure to air, but have relatively little resistance to heat. In 1947, Kluyver and Schnellen (39) reported the isolation of two species of methane-producing bacteria for which they proposed the names of Methanosarcina barkerii and Methanobacterium formicicum. The former was able to ferment methyl alcohol and the latter, sodium formate. These new species are able to convert a mixture of carbon dioxide and hydrogen to methane and water. This review brings the list of known species isolated in pure culture up to date.

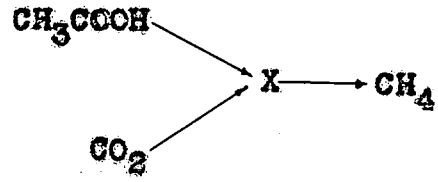
The Mechanism of the Methane Fermentation. There has been considerable evidence advanced by Barker supporting the theory first proposed by van Niel that methane is formed by the direct reduction of carbon dioxide. Three possible mechanisms for the fermentation of acetic acid have been suggested, but not proved, by past investigations: (1) Decomposition of acetic acid to hydrogen and carbon dioxide with subsequent reduction of carbon dioxide to methane (20); (2) direct reduction of carbon dioxide to methane (2); (3) Buswell and Neave's proposal of simple decarboxylation (15,20).

In criticism of the first theory, Buswell and Sollo (20) believe that the low concentration of hydrogen in the gas, resulting from the fermentation, is evidence against this mechanism. The second theory has been held in higher favor since, until recently, all the available evidence pointed to the feasibility of the direct reduction of carbon dioxide to methane. In recent years, however, the availability of radioactive carbon for experimental work has opened an entirely new method for testing this theoretical mechanism. Buswell and Sollo (20) reasoned that if the carbon atom of the carbon dioxide molecule were marked isotopically, then it should be possible to settle the question. If either of the mechanisms involving reduction of carbon dioxide were involved, then, by using labelled carbon dioxide, the resulting methane should be similarly marked. These authors used small (15 ml.) inocula from an active culture which had previously been fermenting acetic acid. To this inocula was added radioactive sodium carbonate and acetic acid. The carbon dioxide of the gas produced was absorbed and the remaining methane was oxidized to carbon dioxide and water. This carbon dioxide was precipitated as barium carbonate and the radioactivity was determined. The results showed that the specific activity

of the methane collected was only approximately 1/200th that of the carbon dioxide. It was then concluded that the methane was produced mainly from the acetic acid fed to the culture and only to a slight extent from the carbon dioxide. This experiment..."indicates that the methane is produced by some mechanism other than the reduction of carbon dioxide, and must therefore be derived from acetic acid. A simple decarboxylation seems to be the most likely mechanism, but is not definitely established. It is still possible that some preliminary condensation might take place, with subsequent decomposition of the condensation product, but this point cannot be proved by this method of attack." (20)

Barker and Stadtman (51) repeated and extended the experiments of Buswell and Sollo to obtain similar results for the fermentation of acetic acid. The results obtained for the fermentation of ethyl alcohol by a pure culture of Methanobacterium omelianskii, however, showed conclusively that the methane resulted almost entirely from carbon dioxide. These authors attempt to fit the results of tracer experiments into the carbon dioxide reduction theory by assuming that there is a common intermediate (X) in the conversion of both carbon dioxide

and acetic acid to methane in this way:



The small utilization of carbon dioxide during acetate fermentation is explained simply by assuming further that the formation of compound X from carbon dioxide is largely blocked by a product of acetate decomposition.

This third theory, that of simple decarboxylation, seems consistent with the experimental facts found. Barker and Stadtman (51) apparently base their objection to this explanation in the fact that "...it seems unlikely that useful chemical energy can be obtained by living organisms from any process, such as simple decarboxylation, that consists only of a rearrangement of the atoms within a single molecule."

Fermentation of Industrial Wastes. The canning industries have been rather slow in taking care of their own wastes. This has not been true though for a number of closely allied food processors such as a few large companies in the dairy and meat packing industries. The experimental work carried on with these wastes have been reviewed by Lambrecht (40). In recent years, other industries have followed this lead. In 1948, Singleton (50)

published results of pilot plant studies on the anaerobic digestion of wool scouring wastes. This investigator reported that the pilot plant was operated over a three-week period with a loading of 0.06 pounds (dry weight) of volatile matter per cubic foot per day with a yield of 8.6 to 14 cubic feet of gas per pound of volatile matter added. In this same year (1948) Buswell and Sollo (21) published the results of their preliminary laboratory experiments on the methane fermentation of fiber-board waste. On the basis of these laboratory results, they proposed plans for a 400,000 cubic foot fiber-board waste treatment plant.

III

OUTLINE OF PROCEDURE

The preliminary laboratory studies conducted in small carboy digestors indicated definitely that this waste, high in carbohydrate material, could be fermented to produce methane gas. Even though many of the basic conditions of the mechanism of methane production were left unsolved, the practical conditions leading to the establishment and maintenance of an active micro-flora were determined. In view of this, and considering the pressing need for a system of waste disposal, it was decided to advance directly from these preliminary laboratory studies to an operation on a pilot plant level. Aside from the generally well known requirement for strict anaerobic conditions, other factors which influenced the fermentation as indicated in the preliminary tests were: amount of sediment, agitation, and rate of feeding. Further intensive study of these factors, on a pilot plant scale, might well be made.

Designs were drawn up for the construction of a 150 gallon pilot plant incorporating those features believed necessary for the efficient fermentation of pear waste (Figure 1). Those designs were followed in the

construction of this plant, the details of which are given later, in the chapter on experimental equipment.

It was planned to put this digester into operation and to build up an active culture with the same dried pear waste used in the laboratory studies, and with the same micro-flora developed at that time and carried along in the laboratory for such a purpose. In addition it was planned to operate several continuous test runs over intervals of several months to obtain valuable data on the actual management of the pilot plant during active fermentation. These data were to include total gas production, composition of this gas, pH, and volatile acids. Additional experimental work involved the staining of slides to show the microorganisms involved, and the periodic analysis of the digested material for reducing sugars, total solids, total carbon, nitrogen, and biochemical oxygen demand (B.O.D.).

After these data were obtained, it was planned to study the effect of interrupted feeding, reduction in temperature of the fermentation from optimum to room temperature, and subsequent re-establishment of active gas production with a minimum lag period. As interruptions may occur at times in the normal operation of food processing plants, this knowledge was considered of importance in establishing the practicability of this fermentation.

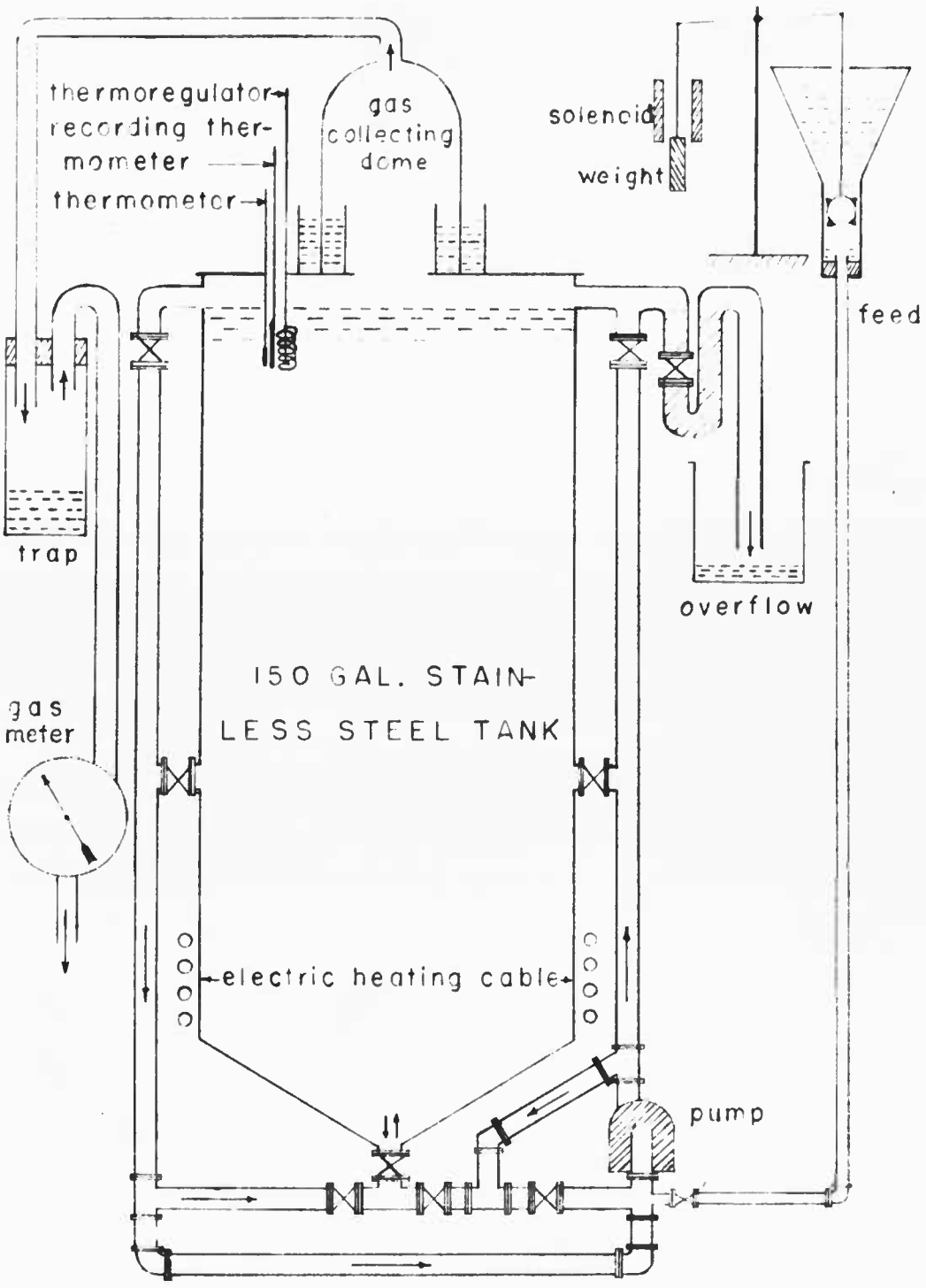


FIGURE 1. Diagrammatic Layout of the Pilot Plant for the Anaerobic Fermentation of Pear Waste.

IV

EXPERIMENTAL WORK

Materials. Dehydrated pear waste was prepared for use in the preliminary experiments by the Valley Evaporating Company, Yakima, Washington. This material was used in experiments one and two to build up an active culture during the initial stages of the pilot plant operation. Later, fresh pear waste was used. This was obtained from Reid Murdoch and Company of Salem, Oregon, and Western Oregon Packing Company, Corvallis, Oregon. This fruit waste was finely ground, packed into 30 pound tins, and placed in storage at 0° F. until needed.

The composition of the dried pear waste used is shown in Table 1. This analysis was made by the Agricultural Chemistry Department, Oregon Agricultural Experiment Station, Corvallis, Oregon, and reported by Lambrecht (40, p.16). The analysis of fresh pears was obtained from the bulletin "Proximate Composition of Fresh Fruits" (23).

Table 1

Analysis of Pear Waste

	Dried pears	Fresh pears
Moisture	2.4	83 - 85
Carbohydrate	65.0	8 - 12
Fiber	24.8	1.2 - 1.8
Protein	3.9	0.2 - 0.5
Fat	1.9	0.1 - 0.7
Ash	2.4	0.3 - 0.7

Source of Inocula. The contents of a 20 liter laboratory fermenter which had been allowed to become inactive and to stand at room temperature for two months was used as a source of inocula.

Enrichment Medium. The enrichment medium used to start the fermentation was a slight modification of that developed by Barker (3), and later improved by Heukelekian and Heinemann (34). It consisted of:

	Per cent	Grams for 600 liters of medium
NH_4Cl.....	0.1	600
K_2HPO_4.....	0.01	60
$MgCl_2$.....	0.04	240
$Na_2S\ 9H_2O$.....	0.01	60
Na_2CO_3.....	0.02	120
Yeast extract.....	0.003	18

The various components were mixed with tap water and made up to a total volume of 600 liters. The tank was filled to capacity with this medium. There was no need to adjust the pH as it was found very close to 7.0. Heukelekian and Heinemann reported that the addition of yeast extract increased the rate of growth of the methane-producing organisms in culture media. The sodium sulfide aided in maintaining anaerobic conditions by removing traces of dissolved oxygen. Evidence of this was shown by the fact that the Winkler Test for dissolved oxygen (1, p.127) gave a negative result after the medium was

prepared for inoculation. The addition of sodium carbonate acted as a source of carbon dioxide which was believed necessary to start the fermentation.

Analytical Methods. The composition of the gas was determined with an Orsat apparatus. The procedure as given in the Fisher gas analysis Manual was used for determining various components (41).

Volatile acids were determined by the method given in the Standard Methods for Examination of Water and Sewage (1, p. 218). This consisted of adding 2.5 ml. of sulfuric acid to a sample of 50 ml. of the supernatant fluid withdrawn from the well agitated contents of the fermenter. The volume of this sample was then increased to 200 ml. with distilled water, and the solution was then distilled slowly until 150 ml. of distillate was collected. The distillate was titrated with 0.1 normal sodium hydroxide, using phenolphthalein as the indicator, to the first pink coloration which disappeared on standing a short while due to absorption of carbon dioxide. Volatile acids determined in this manner are expressed as acetic acid.

Measurements of pH were made electrometrically using a Coleman pH electrometer. It should be noted here that the pH of the supernatant liquid depended to some

extent on the carbon dioxide equilibrium, and steps were taken to prevent loss of carbon dioxide while the pH was being determined. That is, the solution was cooled rapidly and the pH determined immediately.

Reducing sugars were determined by a modification of the Shaffer-Somogyi method (31).

A modification of Gunning's Kjeldahl procedure was used for the total nitrogen determination. The ammonia was distilled into boric acid solution and titrated directly with N/14 sulfuric acid.

Total carbon was determined by combustion with oxygen at 950° C. The carbon dioxide evolved by this combustion was absorbed in Ascarite towers and weighed. The samples were first measured into porcelain boats, dried at 80° C., and covered with 10 to 30 mesh Alfrax before introduction into the combustion tube.

Total solids were determined by evaporating 25 ml. samples to constant weight at 105° C.

The standard procedure was followed for the determination of B.O.D. values (1, p. 139).

Design of Experimental Pilot Plant. The initial studies leading to the design and construction of the pilot plant were set up on a laboratory scale, first with five-liter and later with twenty-liter carboys as

the digestors (40). These preliminary laboratory studies demonstrated the feasibility of this type of fermentation, but operations were not on a scale large enough to permit reliable evaluation of the cost and problems involved in handling and fermenting fresh waste material.

To permit operation on a more practical basis, the present plant was constructed. It consists of a 150 gallon stainless steel tank, approximately five feet in height by three feet in diameter, cylindrical, with a round bottom. (Figures 2, 3, and 4.) There are five outlets on the tank for circulation of the contents -- two on each side and one in the center of the bottom. A valve is connected to this bottom outlet to permit sludge withdrawal and, if necessary, drainage of the tank. The pipe for this circulation is one-inch stainless steel of the type commonly used in dairy plants, with a stainless steel centrifugal pump powered by a one-quarter-horsepower electric motor. Contact with copper was reduced to a minimum as copper is known to be toxic to the microorganisms involved in this fermentation. A few copper fittings were unavoidable but later analysis of the tank contents revealed less than 4 p.p.m. copper. The piping is so arranged as to allow the tank contents to be pumped from one side to the other, from the bottom to the mid-level,

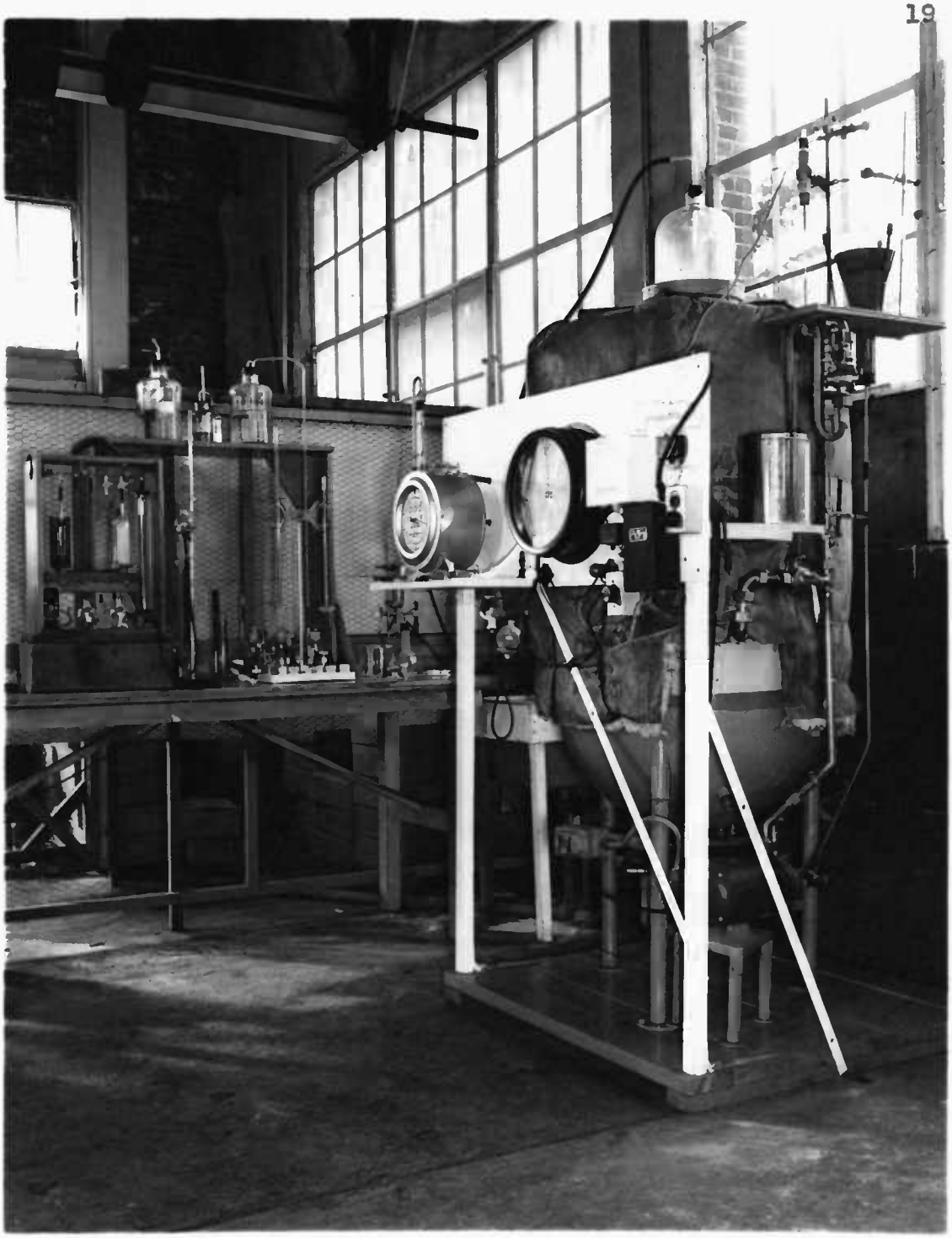


FIGURE 2. Pilot Plant used in the Anaerobic Fermentation of Pear Waste.

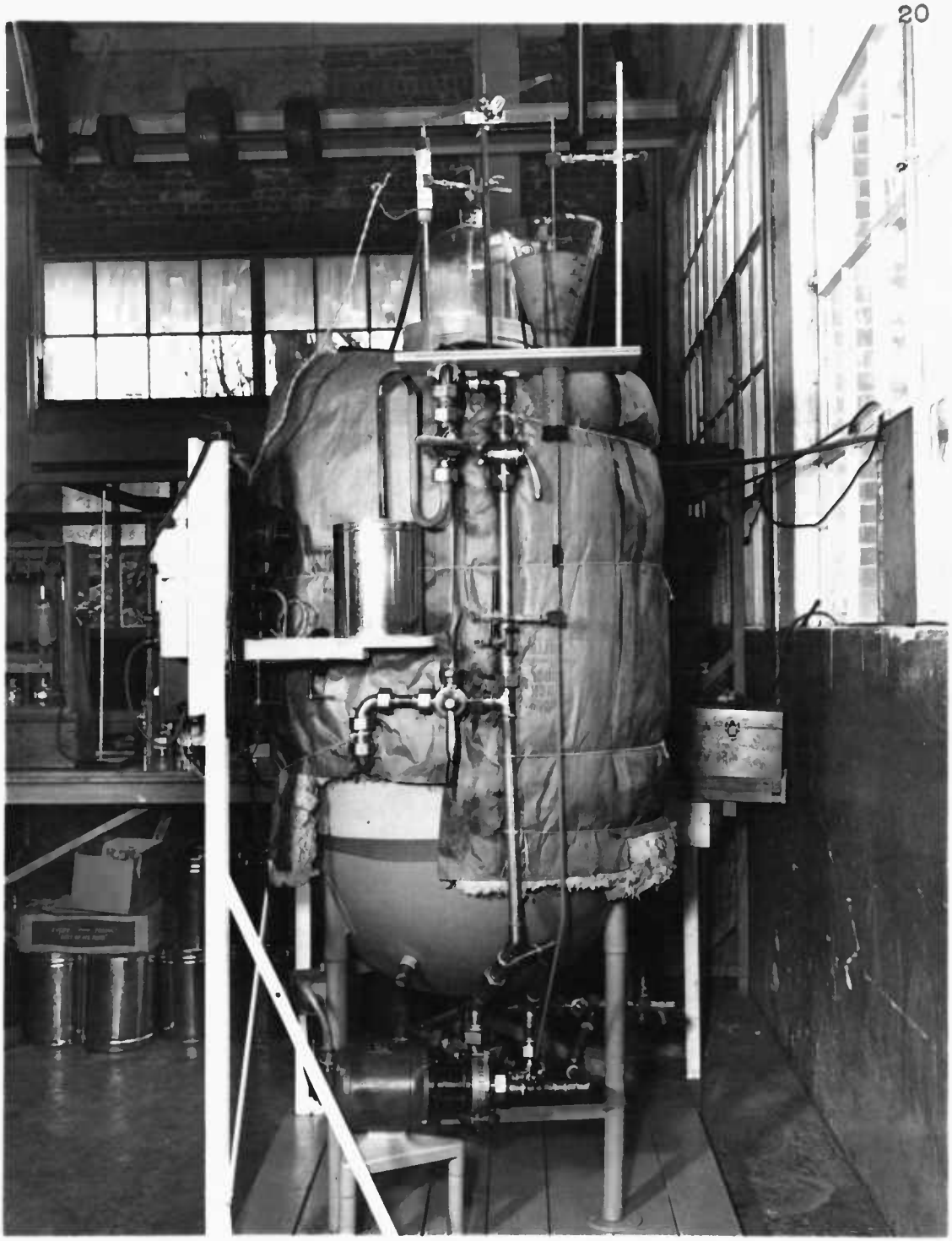


FIGURE 3. Side View of Pilot Plant.

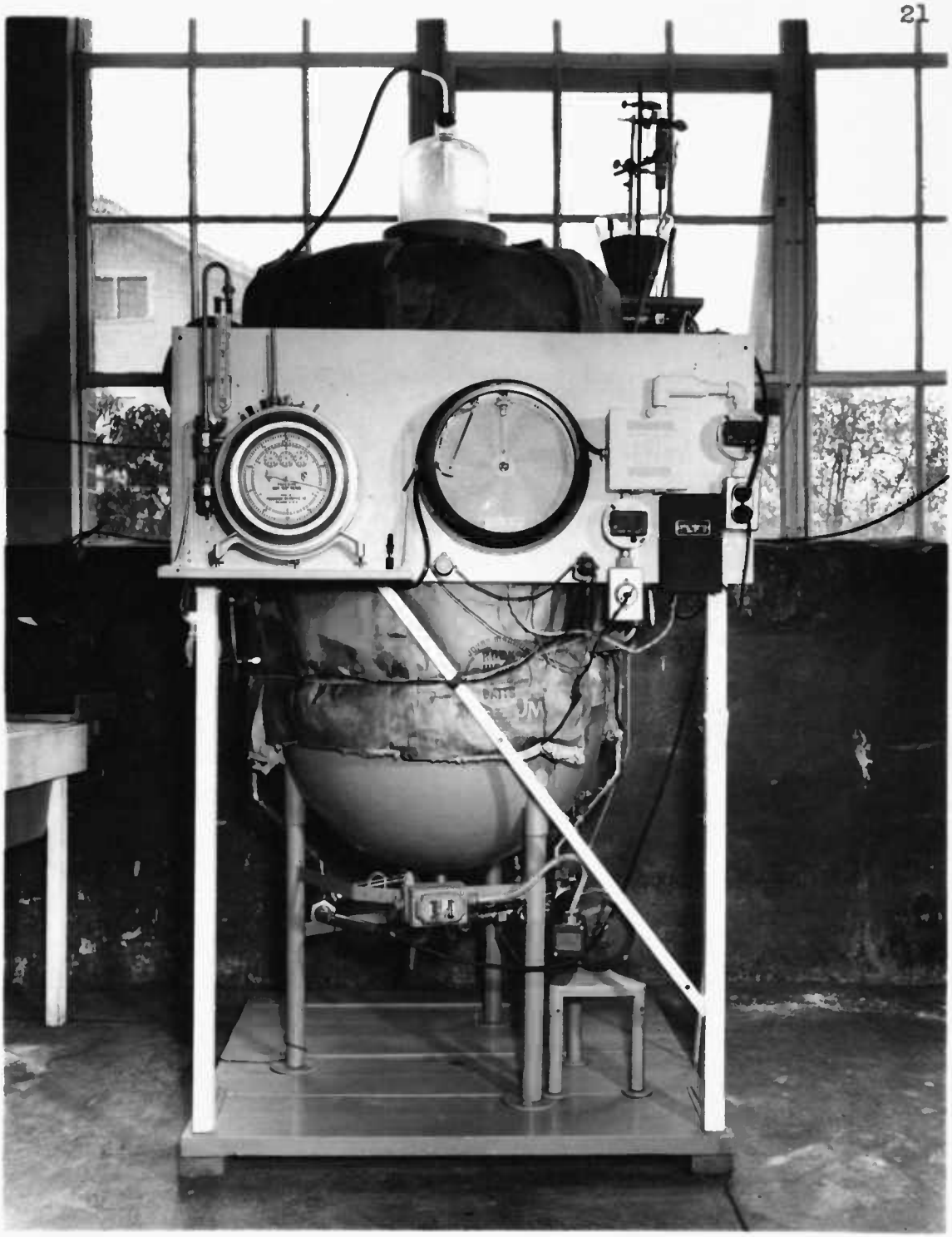


FIGURE 4. Front View of Pilot Plant Showing Control Panel.

or from the top or center to the bottom. This flexibility seemed desirable in order to determine whether circulation of the entire contents of the tank improved the efficiency of the fermentation or whether it was better to leave the sludge bed undisturbed. Attached to one of the top outlets is a trapped overflow to maintain the contents at a constant level. Sealed to the tank by means of a rubber gasket and C-clamps is a flat lid with two openings. The small opening near the edge permits the entrance of the control elements of a thermoregulator, a recording thermometer, and a visual thermometer, while the larger one in the center is surrounded by a water moat. Covering this center hole is a standard laboratory bell jar with rubber tubing attached to the top for gas draw-off. The water moat forms a seal and allows the removal of the bell jar for inspection purposes.

The tank is heated externally by the application to its lower half of approximately 100 feet of soil-heating cable. This is divided into two equal sections of 50 feet each of which one section is connected directly to a 110 volt outlet and remains heating continuously, and the other is controlled by a Micro-set thermoregulator with a sensitivity of one-half degree F. Entirely surrounding the sides and top of the tank are batts of

Johns-Manville rock wool of approximately two inches thickness. It was found that without this insulation the heat loss was too great to permit maintenance of the thermophilic temperature of 131° F. (55° C.) when these experiments were started.

The gas resulting from the fermentation collects in the bell jar, passes first through a moisture trap, and then through a "Precision" Wet Test gas meter, and finally is piped outside the building, where it is dissipated into the air. The temperature is maintained by thermostatic control, is continuously recorded, and seldom varies by more than plus or minus three degrees F.

Recently installed on the tank is an automatic feeding device that intermittently meters into the tank designated amounts of cannery waste material. We were forced to use this device by the complete lack of commercial pumps that could handle the ground waste material on the small scale required. This feeding system (as illustrated in Figure 5) consists of a plunger that moves up and down in a graduated cylinder, seating, at the end of each downward stroke, into a rubber cup which in turn connects with the feed line. This feed line enters the circulation system on the suction side of the centrifugal pump. Each time the automatic timer engages the switch,

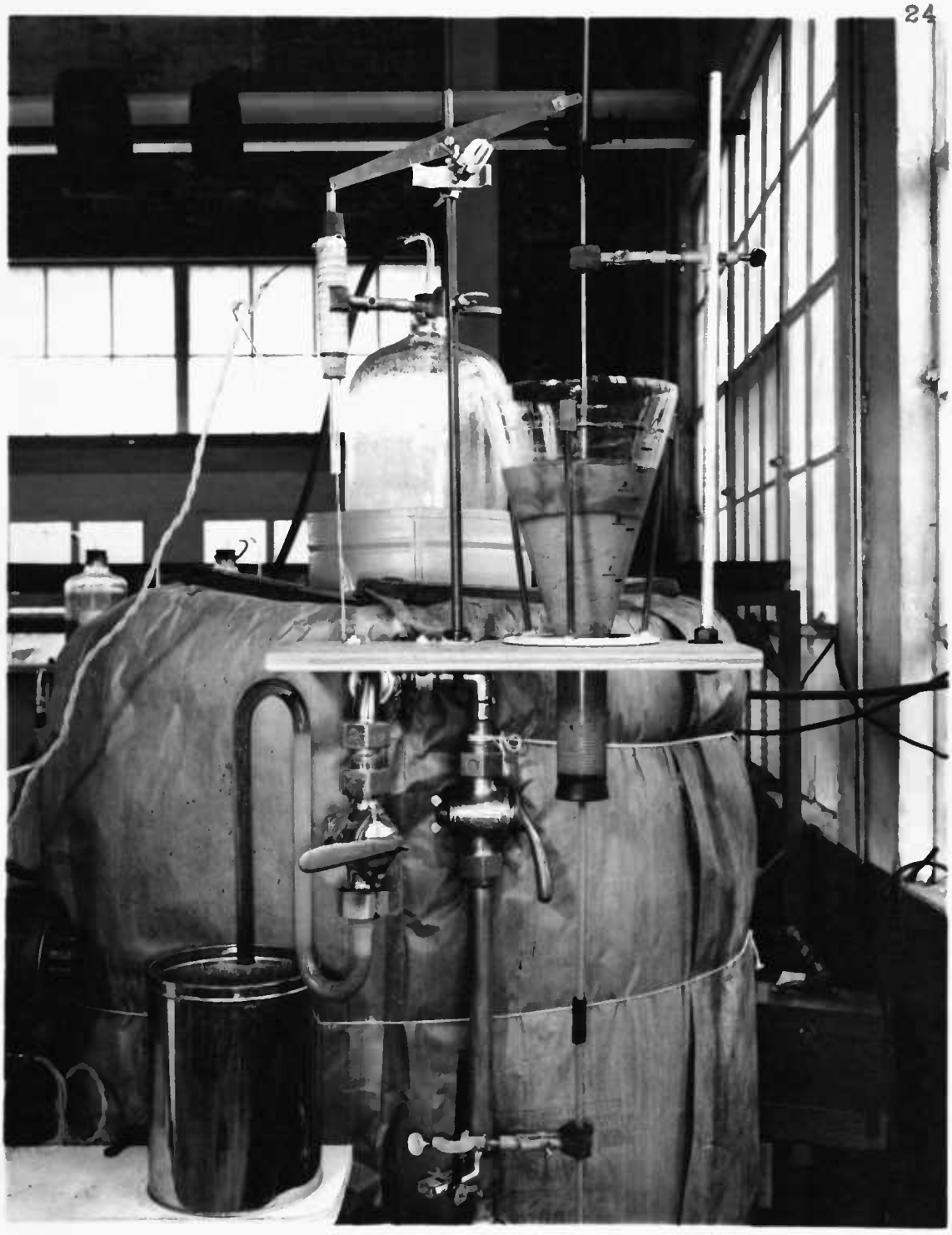


FIGURE 5. Detail View of Feeding Device, Trapped Overflow, and Gas-Collecting Dome.

turning on the circulation pump, it also activates the solenoid to release the weight that moves the plunger back to the top of its stroke. The plunger descends with the feed material and cuts off the feed at the end of its stroke by again seating into the rubber cup. This allows a definite amount of material to enter the tank with each circulation cycle. However, when this feeding system was put into actual operation, it was found somewhat unreliable, and efforts are being made to secure a positive action pump that will handle the cannery waste at the rate of feeding required. It must be noted here that this is strictly a pilot plant problem and would cause no concern on a commercial scale.

The tank contents are agitated regularly by circulation governed by a Paragon automatic timing instrument attached to the centrifugal pump. This timer can be set to turn the pump on for 0 to 12 minutes out of every one-half hour, or from 0 to 25 minutes out of every hour. In most of our experimental work the timer has been set to turn the pump on for about five minutes out of every one-half hour.

Pilot Plant Fermentation Experiments with Dried Pear Waste. The fundamental characteristics of the operations and the analytical procedures found necessary on the laboratory scale were followed in the management of the pilot plant.

The 150 gallon fermenter was filled with the enrichment medium and buffered to a pH of 7.1. Then 0.01 per cent of sodium sulfide was added to remove traces of dissolved oxygen, following which 80 pounds of the contents of a laboratory fermenter was added.

The temperature was raised to 86° F. and the feeding of dried pear waste was started. Careful control of this feeding during the early period resulted in the development of a satisfactory culture within 11 days. The pH of the tank contents was carefully maintained within a range of 6.8 to 7.4 by the frequent additions of lime. However, on the following two days this addition of lime resulted in almost complete cessation of gas production which during the next five days could not be revived (Figure 6, Table II). This seemed very unusual as the amount of lime added did not appear to be excessive.

Recent work (48) gives supporting evidence that the use of lime in methane fermentation is not good

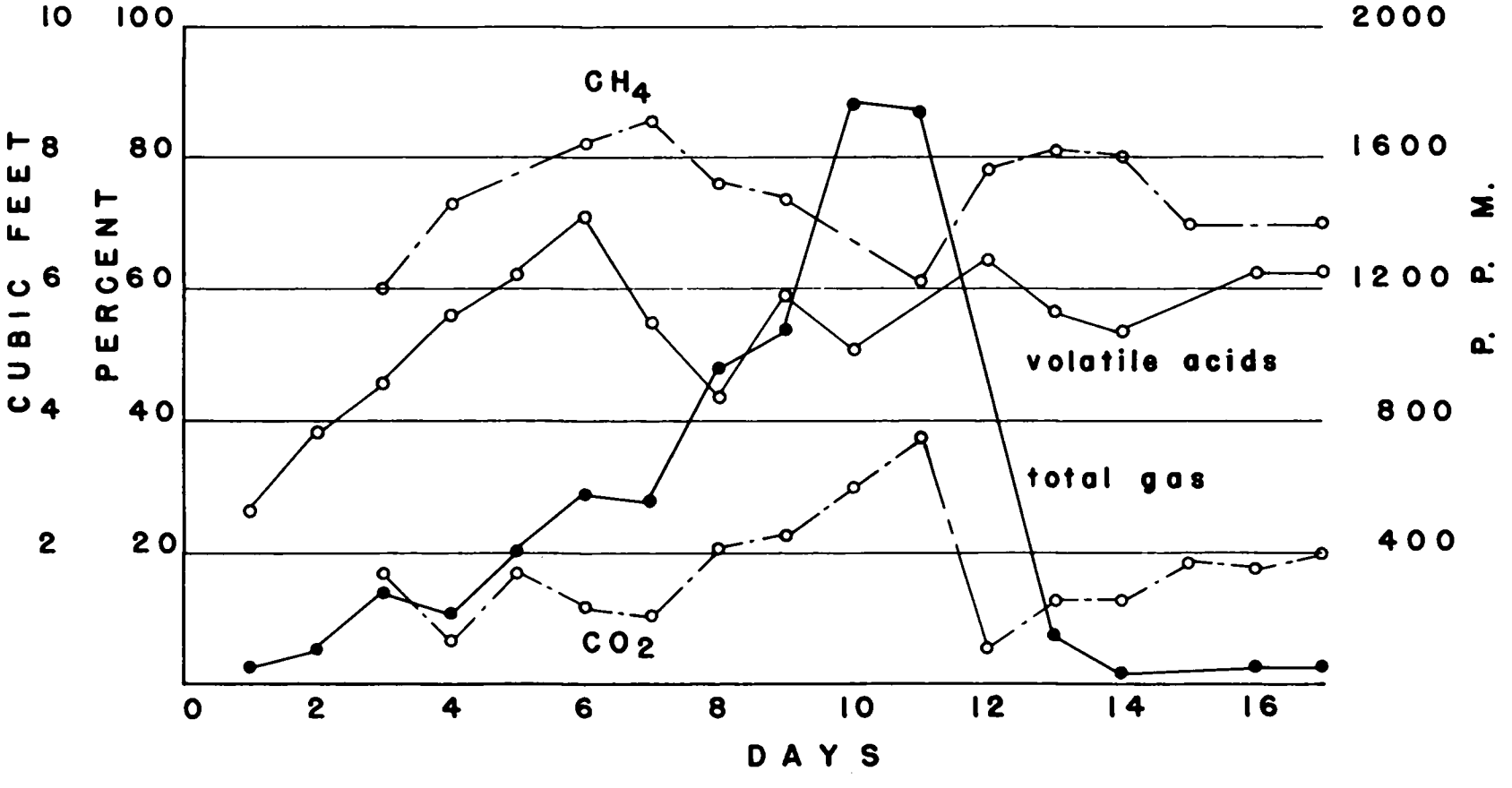


FIGURE 6. Effect of Lime in Maintaining the pH within the Range of 6.8 to 7.4.

TABLE II

Effect of Lime in Maintaining the pH Within the Range of 6.8 to 7.4.

Time in	pH		Volatile Acids	Dried Pear Waste Added	Gas Produced Daily Prod.		
days	obs.	adjusted	p.p.m.	grams	cu.ft.	CO_2 *	CH_4 *
0	---	7.6	---	---	---	---	---
1	6.1	7.1	536	600	0.26	---	---
2	6.6	7.4	772	600	0.54	---	---
3	6.3	7.5	920	---	1.40	16.2	60.2
4	6.8	7.5	1130	600	1.09	6.7	73.2
5	6.5	7.1	1253	---	2.12	18.2	78.1
6	6.8	7.1	1416	---	2.85	11.9	82.4
7	7.0	7.1	1100	600	2.79	10.9	85.3
8	6.6	6.8	880	1200	4.75	21.4	76.0
9	6.6	7.0	1181	1200	5.36	23.4	73.6
10	6.5	7.0	1021	1200	8.84	30.2	67.0
11	6.5	7.2	1158	1200	8.66	37.8	60.8
12	7.0	7.2	1287	---	4.75	6.4	78.0
13	6.6	6.8	1133	---	0.80	15.4	81.0
14	6.6	6.8	1073	---	0.23	12.9	79.5
15	6.4	6.8	1167	---	0.25	19.2	70.0
16	6.5	6.8	1253	---	0.25	17.6	71.0
17	6.6	6.8	1253	---	0.32	20.3	70.0

* Per cent by volume.

practice. Schlenz (48) states that the action of lime tends to produce a highly ionized condition causing the reaction to go strongly to the acetate, upon which the bacteria cannot work. He expressed the belief that the universal practice of resorting to the use of lime to correct a low pH does more damage than good. Buswell and Solle (21) state that..."indiscriminate addition of alkaline materials causes the production of volatile acids to increase; or, more likely, it retards their decomposition to methane and carbon dioxide, thus aggravating an already unfavorable condition instead of alleviating it." This effect of lime apparently varies with the character of the waste material and operating conditions, as the subject is still controversial.

Thus, it was finally decided to remove the entire contents of the fermenter and to start the tank anew. Detailed results of this first experiment are given in Table II and presented graphically in Figure 6.

The fermentor was once again filled with the enrichment medium as explained in experiment one and reinoculated with 85 pounds of active sludge material which had been saved for such an emergency. An active culture was built up following previous procedures, except that the addition of lime for maintaining the pH

within a specific range was eliminated. The data obtained in this experiment is shown graphically in Figure 7 and summarized in Table III. The pH was still determined as a routine procedure, but no attempt was made to maintain any specific value. Instead, the feeding of the dried pear waste was controlled as much as possible by the volatile acid concentration first suggested by Schlenz (48). The recording of the pH was continued mainly to see if there was any correlation with the volatile acid concentration. Reference to Figure 7 will show that there did not seem to be any correlation between the two.

It is usually thought by operators of city sewage digestion plants that any serious upset in the normal micro-flora of a fermentation results in a loss of gas production for a period of several weeks or even months. Results obtained in this experiment are not in accord with this view, as gas production started almost immediately and rose to over 12 cubic feet per day by the 14th day. The volatile acids, however, increased rapidly to approach 2000 p.p.m. and feeding was interrupted because of this high concentration. Previous experiments on a laboratory scale (40) corroborated Schlenz's view that 2000 p.p.m. volatile acids (expressed as acetic) should not be exceeded.

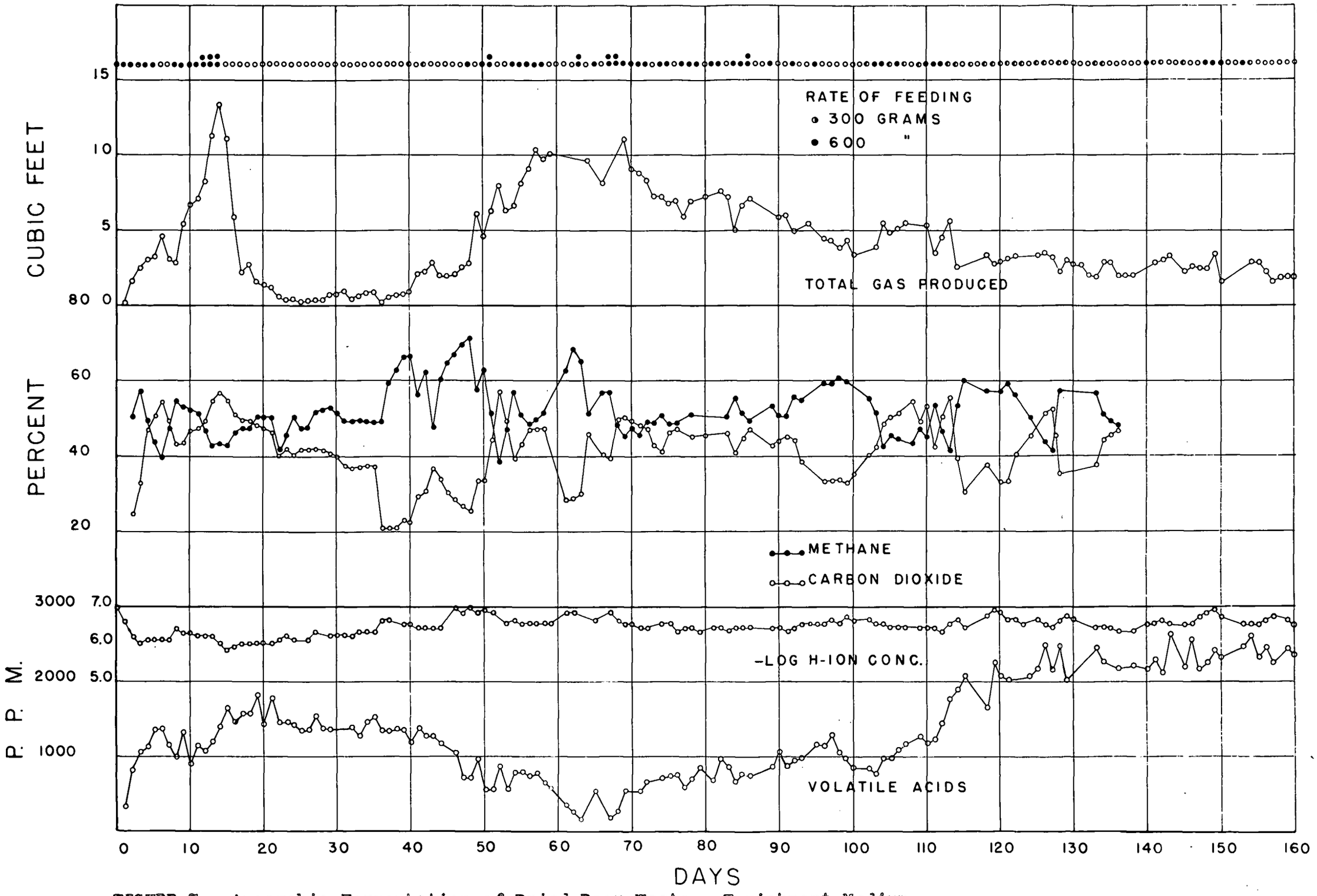


FIGURE 7. Anaerobic Fermentation of Dried Pear Waste. Enrichment Medium Initially Used. No Addition of Lime for the Maintenance of a Specific pH Range. Temperature, 86° F.

TABLE III

Anaerobic Fermentation of Dried Pear Waste. Enrichment Medium Initially Used. No Addition of Lime for the Maintenance of a Specific pH Range. Temperature, 86° F.

Time in	pH	Volatile Acids	Dried Pear Waste Added	Gas Production		
				Daily Prod.	CO_2	CH_4
Days		p.p.m.	grams	cu. ft.	%	%
0	7.0	---	600	----	----	----
1	6.6	343	600	0.10	----	----
2	6.2	815	600	1.56	24.3	50.2
3	6.0	1087	600	2.40	38.4	57.2
4	6.1	1120	600	3.05	47.3	49.2
5	6.1	1387	600	3.21	50.6	43.5
6	6.1	1384	---	4.54	54.0	39.5
7	6.1	1164	---	2.96	48.9	47.6
8	6.4	998	600	2.69	43.1	54.8
9	6.3	1327	600	5.39	48.7	52.9
10	6.3	903	600	6.66	46.5	52.0
11	6.2	1141	600	7.00	47.3	50.6
12	6.2	1090	1200	8.20	48.6	44.8
13	6.2	1201	1200	11.25	54.6	42.5
14	6.0	1384	1200	13.32	56.5	43.2
15	5.8	1650	----	11.00	54.6	42.7
16	5.9	1475	----	5.69	50.6	46.3
17	6.0	1564	----	2.10	49.5	47.2
18	6.0	1570	----	2.60	48.4	47.7
19	5.95	1614	----	1.51	48.7	51.0
20	6.0	1425	----	1.41	47.0	49.8
21	6.0	1780	----	1.13	46.0	50.0
22	6.1	1441	----	0.51	40.0	41.5
23	6.2	1441	----	0.84	41.5	45.5
24	6.05	1424	----	0.35	40.0	50.0
25	---	1339	----	0.22	41.7	47.0
26	6.1	1349	----	0.27	41.5	47.5
27	6.3	1544	----	0.37	41.0	52.5
28	---	1389	----	0.38	41.0	52.1
29	6.2	1381	----	0.61	40.3	52.8
30	6.2	----	----	0.61	39.5	51.2
31	6.2	----	----	0.69	37.3	49.0
32	6.2	1389	----	0.84	36.5	49.0
33	6.3	1278	----	0.55	37.2	49.4
34	6.3	1458	----	0.68	37.4	49.0
35	6.3	1510	----	0.73	37.2	48.3
36	6.65	1312	----	0.11	20.6	49.0

TABLE III (continued)

Time in	pH	Volatile Acids	Dried Pear Waste Added	Gas Production Daily Prod.	CO_2	CH_4
days		p.p.m.	grams	cu. ft.	%	%
37	6.6	1321	---	0.57	20.5	59.5
38	---	---	---	0.68	20.7	62.5
39	6.5	1357	---	0.64	22.4	66.0
40	6.5	1192	300	0.84	22.2	66.2
41	6.4	1381	---	2.0	29.4	56.0
42	6.4	1274	300	2.11	30.6	62.0
43	6.4	1287	---	2.79	36.8	47.6
44	6.4	1175	---	1.91	33.8	60.0
45	---	---	---	1.90	30.4	64.2
46	7.0	1029	---	2.05	28.3	66.5
47	6.8	703	---	2.46	26.4	69.4
48	7.0	707	600	2.76	25.2	71.1
49	6.8	987	---	6.08	33.2	57.3
50	6.9	532	600	4.55	33.4	62.6
51	6.8	566	1200	6.19	44.2	51.2
52	---	875	---	7.89	56.8	37.7
53	6.5	558	---	6.17	48.5	47.0
54	6.6	781	600	6.45	39.2	56.5
55	6.5	797	600	7.96	43.3	50.6
56	6.5	712	600	8.89	47.6	48.0
57	6.5	798	600	10.29	47.0	49.6
58	6.5	635	600	9.62	46.8	51.2
59	6.5	---	---	10.02	---	---
60	---	---	---	---	---	---
61	6.8	343	---	---	29.0	62.4
62	6.8	266	---	3.07	28.4	68.0
63	---	120	1200	1.41	29.6	64.5
64	---	---	---	9.64	45.7	50.5
65	6.6	515	600	8.00	40.0	56.6
66	---	---	---	---	---	---
67	6.8	189	1200	---	39.3	57.2
68	6.6	283	1200	9.81	49.5	47.8
69	6.5	515	600	10.96	50.0	44.8
70	6.5	515	600	8.96	48.5	47.4
71	6.4	515	600	8.74	48.0	45.2
72	6.4	644	600	8.83	47.2	48.6
73	---	---	---	7.1	42.6	43.6
74	6.5	704	600	7.2	41.0	50.5
75	6.5	712	600	6.74	46.0	48.0

TABLE III (continued)

Time in	pH	Volatile Acids	Dried Pear Waste Added	Gas Production Daily Prod.	CO_2	CH_4
days		p.p.m.	grams	cu. ft.	%	%
76	6.3	738	none	6.84	47.0	48.0
77	6.4	583	600	5.65	41.0	----
78	6.35	695	600	6.89	45.0	50.6
79	6.3	815	600	7.14	46.5	48.6
80	---	---	---	----	----	----
81	6.4	686	600	6.90	40.0	53.0
82	6.4	970	600	7.47	40.0	54.0
83	6.3	867	---	7.07	46.0	50.0
84	6.4	669	600	4.84	40.6	55.0
85	6.4	780	600	6.52	44.6	51.4
86	6.4	721	1200	7.00	47.0	49.0
87	---	---	---	----	----	----
88	---	---	---	----	----	----
89	6.4	867	600	----	42.5	53.5
90	6.4	1030	600	5.80	44.0	50.4
91	6.3	867	---	5.91	45.0	50.0
92	6.4	918	600	4.78	39.8	55.5
93	6.5	987	---	5.32	38.0	54.5
94	---	---	---	----	----	----
95	6.5	1140	600	Air in bell jar		
96	6.5	1115	---	4.32	32.8	59.4
97	6.6	1287	---	4.22	33.3	59.0
98	6.5	1012	---	3.63	33.8	60.5
99	6.7	978	---	4.19	32.6	58.8
100	6.6	840	600	3.26	----	----
101	---	---	---	----	----	----
102	6.6	810	300	----	40.0	55.0
103	6.5	772	600	3.74	42.0	51.3
104	6.5	970	600	5.41	48.2	42.2
105	6.4	970	300	4.69	50.3	44.7
106	6.4	1098	600	5.08	51.0	46.0
107	6.4	1150	300	5.25	54.0	42.8
108	---	---	---	----	----	----
109	6.4	1244	300	----	49.2	47.5
110	6.4	1158	600	5.17	52.8	44.6
111	6.4	1200	600	3.42	42.0	53.6
112	6.3	1432	600	4.44	50.0	46.4
113	6.5	1767	300	5.48	55.0	41.0
114	6.6	1887	300	2.86	31.4	53.8
115	---	----	---	----	----	----

TABLE III (continued)

Time in	pH	Volatile Acids	Dried Pear Waste Added	Gas Production Daily Prod.	CO_2	CH_4
days		p.p.m.	grams	cu. ft.	%	%
116	6.4	2059	300	3.44	39.2	53.0
117	6.7	1613	300	3.19	30.2	60.2
118	---	----	---	----	----	----
119	6.9	2230	300	2.60	37.4	57.6
120	6.8	2059	300	2.77	33.2	57.2
121	6.7	1973	300	2.95	32.6	59.2
122	6.6	----	300	3.08	40.5	56.0
123	---	----	---	----	----	----
124	6.5	2059	300	2.73	45.3	50.0
125	6.5	2145	300	3.21	----	----
126	6.5	2488	300	3.47	50.8	43.5
127	6.5	2119	none	3.06	52.0	41.2
128	6.6	2471	300	2.06	35.4	57.1
129	6.7	2008	300	2.80	----	----
130	---	----	---	2.58	----	----
131	---	----	---	2.56	----	----
132	---	----	---	1.90	----	----
133	6.4	2445	300	1.79	37.6	56.5
134	6.4	2256	300	2.74	44.2	51.4
135	6.4	----	none	2.66	45.6	48.8
136	6.3	2170	none	1.93	47.5	48.0
137	---	----	none	1.98	----	----
138	6.3	2200	none	1.98	----	----
139	---	----	----	----	----	----
140	6.5	2150	300	----	----	----
141	6.5	2299	300	2.83	----	----
142	6.6	2102	300	2.90	----	----
143	6.5	2684	none	3.19	----	----
144	---	----	----	----	----	----
145	6.5	2187	300	2.10	----	----
146	6.5	2530	none	2.51	----	----
147	6.7	2145	none	2.24	----	----
148	6.8	2230	600	2.36	----	----
149	6.9	2400	600	3.36	----	----
150	6.7	2282	300	1.45	----	----
151	---	----	---	2.03	----	----
152	---	----	---	2.03	----	----
153	6.5	2445	600	2.03	----	----
154	6.5	2600	300	2.89	----	----

TABLE III (continued)

Time in	pH	Volatile Acids	Dried Pear Waste Added	Gas Production Daily Prod.	CO_2	CH_4
days		P.P.M.	Grams	cu. ft.	%*	%*
155	6.5	2300	none	2.81	----	----
156	6.6	2500	none	2.13	----	----
157	6.7	2230	none	1.55	----	----
158	----	----	----	1.90	----	----
159	6.5	2420	none	1.90	----	----
160	6.5	2316	none	1.93	----	----

* Per cent by volume.

During the next 26 days the volatile acids slowly decreased, while the gas production remained practically nil. But the composition of the gas changed from approximately one-half carbon dioxide and one-half methane to approximately 25 per cent carbon dioxide and 75 per cent methane. Near the 40th day the gas production started to increase and the volatile acids to decrease rapidly so that by the 50th day conditions seemed satisfactory for a continuation of feeding. These conditions were: a pH close to 7.0; an increase in gas production; and a volatile acid concentration near 500 p.p.m. Since it was evident that a balanced micro-flora had been established, feeding was started and continued from the 50th day through the 130th day. At that time the volatile acids had again risen to over 2000 p.p.m., and the gas production had dropped to below five cubic feet per day, indicating that conditions within the fermenter were not favorable for the microorganisms to perform at maximum capacity. All attempts to bring the culture back to active gas production failed during the next 30 days. Therefore, the feeding was again stopped, the temperature of the tank was kept at 86° F., the agitation of the tank contents was continued at 5 minutes out of every 30 minutes, and the culture was allowed to "rest" for a period of one week.

Pilot Plant Fermentation Experiments with Fresh Pear Waste. After this "rest" period of one week, there was no apparent decrease in the volatile acid concentration. It was decided at this time to make a radical change in the routine management of the fermenter and to elevate the temperature into the thermophilic range in an effort to re-establish active gas production. This was done by supplementing, temporarily, the normal heating system with the use of live steam to bring the temperature of the tank contents to 131° F.

At this higher temperature, the daily gas production and the volatile acid concentration remained at a constant level until after the 20th day (Table IV, Figure 8). Immediately after the 20th day the volatile acids began to drop rapidly and the gas production to increase sharply. This indicated clearly that conditions had become favorable for the breakdown of accumulated volatile acids to methane and carbon dioxide. Apparently this condition had been induced merely by changing the temperature from 86° F. to 131° F. By the 34th day the volatile acids had fallen below 100 p.p.m. and the daily gas production had climbed to slightly over eight cubic feet. Thus, once again, an active fermentation was established and was subsequently

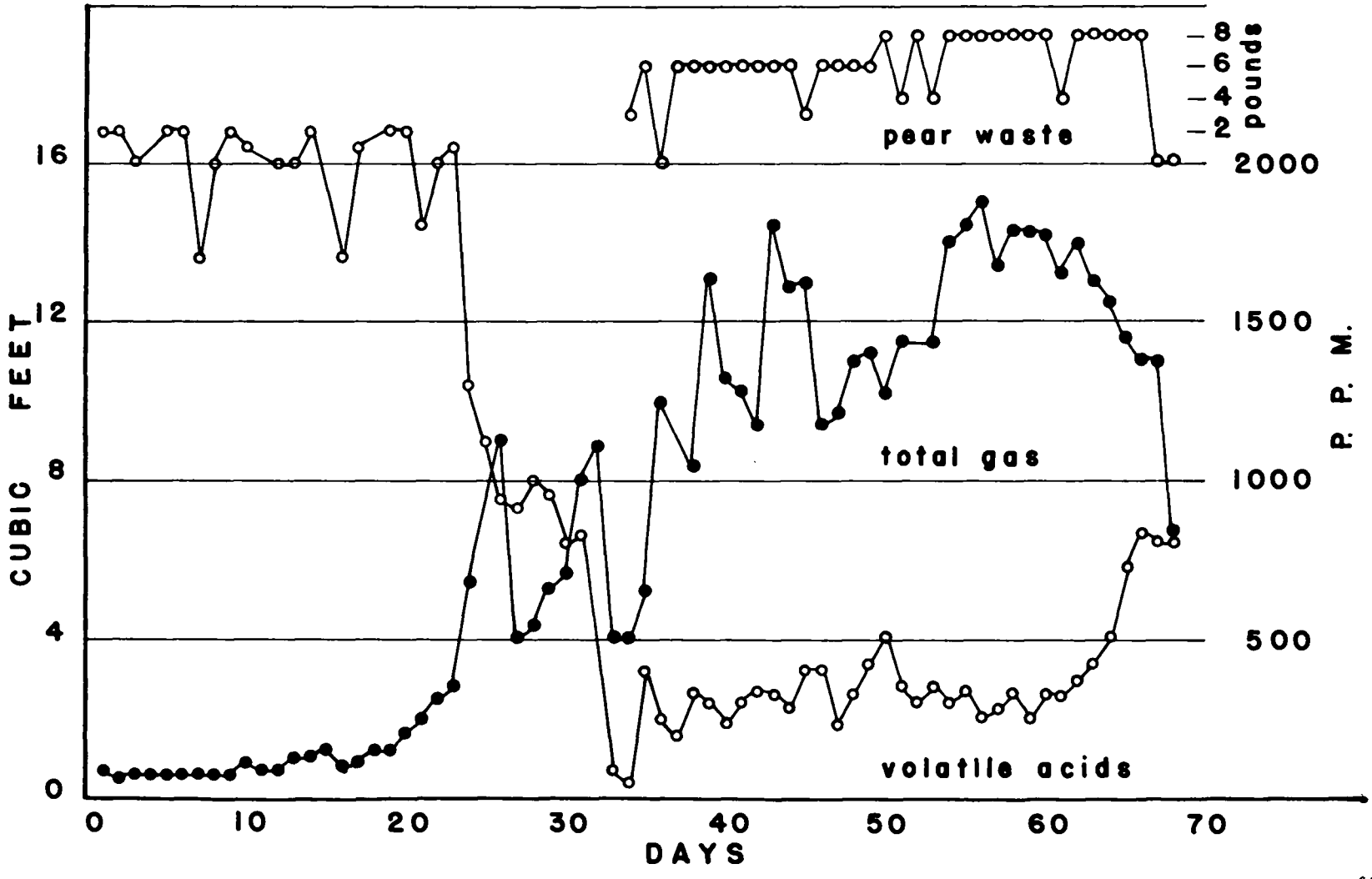


FIGURE 8. Anaerobic Fermentation of Fresh Pear Waste. Effect of Change in Temperature from 86° F. to 131° F.

TABLE IV

Anaerobic Fermentation of Fresh Pear Waste. Effect of Change in Temperature from 86° F. to 131° F.

Time in	pH	Volatile Acids	Fresh Pear Waste Added	Gas Production Daily Prod.	Gas Production CO_2	Gas Production CH_4
days		p.p.m.	pounds	cu. ft.	%	%
1		2100		0.69		
2		2100		0.48		
3		2000		0.67		
4		----		0.64		
5		2100		0.64		
6		2100		0.56		
7		1716		0.54		
8		2016		0.62		
9		2100		0.56		
10		2050		0.89		
11		----		0.66		
12		1970		0.66		
13		2010		0.98		
14		2100		1.05		
15		----		1.32		
16		1700		0.78	56.8	35.2
17		2050		0.89	55.4	40.4
18		----		1.21	----	----
19		2100		1.21	51.5	44.5
20		2145		1.66	48.0	47.2
21		1800		2.09	45.0	50.0
22	6.8	2022		2.51	----	----
23	6.8	2050		2.81	----	----
24	6.8	1287		5.43	27.8	67.2a
25	---	----		8.90	----	----
26	6.9	943		8.89	31.2	63.8a
27	6.9	910		3.92	32.1	62.9a
28	6.8	1008		4.33	----	----
29	6.9	950		5.31	----	----
30	6.9	800		5.72	----	----
31	6.8	825		8.04	----	----
32	---	----		8.93	----	----
33	6.8	68		4.26	34.8	60.2a
34	6.8	43	3	3.92	----	----
35	6.8	386	6	5.18	----	----
36	6.8	257	-	9.89	----	----
37	6.8	214	6	2.77	27.8	67.2a

TABLE IV

Time in	pH	Volatile Acids	Fresh Pear Waste Added	Gas Production Daily Prod.	Gas Production CO_2	Gas Production CH_4
days		p.p.m.	pounds	cu. ft.	%*	%*
38	6.8	343	6	8.29	----	----
39	6.8	317	6	13.12	----	----
40	6.8	240	6	10.59	----	----
41	6.8	309	6	10.29	52.3	42.7a
42	6.8	343	6	9.36	58.0	37.0a
43	6.8	326	6	14.45	47.5	47.5a
44	6.8	283	6	12.85	46.4	48.6a
45	6.8	395	3	13.08	----	----
46	6.8	403	6	9.39	43.4	51.6a
47	6.8	232	6	9.68	48.8	46.2a
48	6.75	326	6	10.90	43.0	52.0a
49	6.8	420	6	11.27	45.2	49.8a
50	6.7	498	8	10.20	43.5	51.5a
51	6.7	352	4	11.51	47.2	47.8a
52	6.75	300	8	-----	42.4	52.6a
53	6.7	366	4	11.43	43.8	51.2a
54	6.65	292	8	14.04	41.5	53.5a
55	6.7	343	8	14.37	41.0	54.0a
56	6.6	257	8	15.00	42.3	52.7a
57	6.6	274	8	13.42	43.5	51.5a
58	6.6	343	8	14.25	45.0	50.0a
59	6.5	257	8	14.24	43.5	51.5a
60	6.6	326	8	14.13	43.0	52.0a
61	6.5	326	4	13.29	44.0	51.0a
62	6.5	360	8	13.88	46.5	48.5a
63	6.4	429	8	12.97	49.5	45.5a
64	6.4	500	8	12.54	50.0	45.0a
65	6.4	729	8	11.57	50.0	45.0a
66	6.3	840	8	11.05	53.0	42.0a
67	6.3	806	none	10.94	52.8	42.2a
68	6.3	800	none	6.98	53.0	42.0a

* Per cent by volume.
a Calculated by difference assuming carbon dioxide plus methane equal to 95 per cent by volume.

maintained at efficient gas production for a period of slightly over one month before the volatile acids again began to build up enough to cause a drop in gas production. It is not clear why the methane-bacteria should become active in the face of the high concentration of volatile acid at the beginning of the experiment, yet be suppressed by a comparatively low concentration of volatile acids near the end of this experiment. At this time it unfortunately became necessary to completely shut down the fermenter and to move it to a place of storage for a period of three months. During this time the tank contents remained undisturbed at a room temperature of approximately 68° F.

Re-establishment of Active Fermentation after a Shut-down Period. This enforced interruption of experimental work afforded an opportunity to determine the length of time required to bring the pilot plant back into active production after a shut-down period. This knowledge is of very practical importance since the commercial processor often has periods of interrupted production during which time the source of waste material is cut off.

As shown in Table V, the first 33 days of which are also illustrated graphically in Figure 9, there was

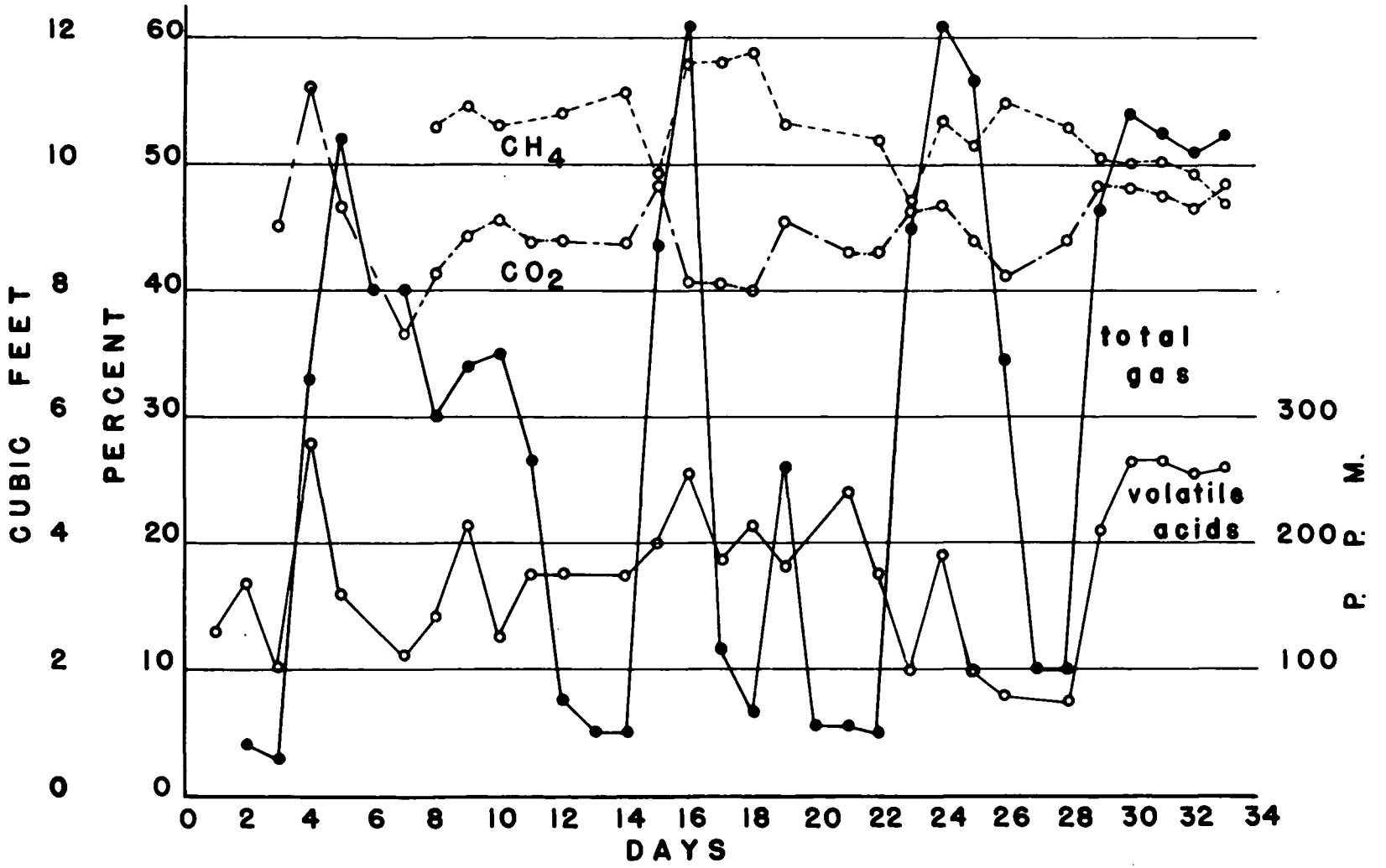


FIGURE 9. Anaerobic Fermentation of Fresh Pear Waste at 131° F.

TABLE V

Anaerobic Fermentation of Fresh Pear Waste at 131° F.

Time in	pH	Volatile Acids	Fresh Pear Waste Added	Gas Production Daily Prod.	CO_2	CH_4
days		p.p.m.	pounds	cu. ft.	%	%
0	7.0	128	-	----	40.8	----
1	7.0	130	-	----	----	----
2	7.0	172	-	0.68	----	----
3	7.0	100	6	0.54	45.0	
4	6.9	283	6	6.66	56.1	
5	7.0	165	6	10.40	46.5	
6	---	---	-	8.00	----	----
7	7.0	112	3	8.00	36.5	
8	6.8	146	3	6.03	41.4	53.0
9	6.9	215	3	6.83	44.4	54.4
10	7.0	128	3	7.01	45.6	53.0
11	7.0	172	-	5.29	43.8	
12	6.9	172	-	1.47	44.0	54.0
13	---	---	-	1.03	----	-----
14	7.0	172	6	1.03	43.7	55.8
15	6.9	197	-	8.63	48.5	49.0
16	6.7	257	-	12.18	40.6	58.0
17	6.7	188	-	2.31	40.5	58.0
18	6.9	215	3	1.33	40.0	58.8
19	6.8	189	-	5.17	45.6	53.2
20	---	---	-	1.13	----	----
21	6.7	240	-	1.13	43.0	
22	6.7	172	6	1.05	43.2	52.0
23	7.0	103	6	9.01	46.5	46.8
24	6.8	189	6	12.20	46.8	53.6
25	6.9	95	5	11.29	44.1	51.5
26	6.9	80	-	6.91	41.2	54.9
27	---	---	-	2.05	----	----
28	7.0	77	6	2.05	44.0	53.0
29	6.8	210	6	9.27	46.4	50.5
30	6.8	266	6	10.83	48.2	50.0
31	6.6	266	6	10.54	47.5	50.2
32	6.7	257	6	10.18	46.5	49.0
33	6.7	260	6	10.45	48.4	47.0
Break here of 9 days during which no feeding took place, but other conditions remained the same.						
34	7.0	137	6	----	37.8	61.0
35	6.8	223	6	7.67	49.8	48.0
36	6.7	214	6	10.76	48.6	49.5

TABLE V (continued)

Time in	pH	Volatile Acids	Fresh Pear Waste Added	Gas Production Daily Prod.	CO_2	CH_4
days		p.p.m.	pounds	cu. ft.	%*	%*
37	6.7	197	3	9.34	52.0	46.0
38	6.5	326	3	9.46	52.0	46.5
39	---	---	-	4.13	----	----
40	---	---	-	4.13	----	----
41	6.8	172	6	4.13	33.8	58.2
42	6.7	215	6	7.63	50.0	50.0
43	6.4	275	6	8.17	53.0	45.8
44	6.6	326	6	11.29	52.0	45.5
45	6.6	300	6	10.14	52.0	46.0
46	6.5	352	6	10.32	53.8	44.0
47	---	---	-	6.62	----	----
48	----	---	-	6.62	----	----
49	7.0	197	6	6.62	32.5	63.0
50	6.9	197	6	6.35	45.0	53.0
51	6.7	172	6	7.62	48.8	47.8
52	6.7	257	6	8.24	51.0	45.0
53	6.7	275	3	9.31	50.5	46.0
54	6.8	172	3	13.80	39.4	56.5
55	6.7	206	6	6.24	43.3	56.5
56	6.8	206	6	7.41	50.0	48.0
57	6.7	308	6	8.71	51.0	47.0
58	6.7	275	6	8.03	49.0	43.0
59	6.7	317	3	7.54	51.5	44.0

* Per cent by volume.

no apparent lag in re-establishing active gas production after normal operating conditions were resumed. This experiment was continued for a period of approximately two months with the same plan for collecting and tabulating data being used as was followed in the previous experiments. One fault to be noted in these data is the lack of a uniform, constant rate of feeding.

Experiments with Continuous Feeding. Results of experiments to date seem to indicate that the breakdown of pear waste is due to the action of mixed culture of microorganisms in this way: first, one group of anaerobic bacteria breaks down the carbohydrate material into various lower alcohols and volatile acids; second, the methane bacteria convert these alcohols and acids to methane and water. The exact mechanism of the production of methane is still unsolved, but the role these acids play in this mechanism is not merely academic (20, 51). Results of these, and other (13, 16, 18, 19), experiments clearly indicate that too high a concentration of these acids inhibits the action of the methane bacteria. If some means were available to prevent their accumulation above an arbitrary value of say 1000 p.p.m., then the efficiency of the methane fermentation would be improved.

One method of preventing this high concentration was thought to be the establishment of a slow, continuous, or even an intermittent, feeding system instead of batch feeding. By this method, it was hoped that a balance of feeding could be established to make possible the breakdown of the lower alcohols and volatile acids to methane, carbon dioxide, and water at the same rate at which these intermediate products were formed. Use of continuous, slow feeding was ruled out as impracticable in view of the very small amounts of pear waste necessary on a 24-hour cycle.

Therefore, considerable effort and time were expended in the attempt to design and construct a simple feeding mechanism that would introduce the waste material into the tank at a slow, intermittent rate. The use of this device (Figure 5) resulted in an improvement of the feeding system; the mechanism, however, was somewhat erratic in operation. In addition to feeding slowly and intermittently, this new system also aids in preventing localized areas of high acid concentration by introducing the raw feed into the tank through the circulation system (instead of directly into the tank), thereby resulting in the immediate mixing, buffering, and seeding of the raw material with the active culture. The data for this experiment is summarized in Table VI.

TABLE VI

Anaerobic Fermentation of Fresh Pear Waste at 131° F. Automatic, Intermittent Feeding.

Time in	pH	Volatile Acids	Fresh Pear Waste Added	Gas Production		
				Daily Prod.	CO_2	CH_4
days		p.p.m.	pounds	cu. ft.	%	%
0	6.7	292	-	----	----	----
1	6.7	343	4	4.15	52.0	47.0
2	6.5	257	4	8.91	55.8	44.5
3	6.6	214	4	8.95	45.8	50.5
4	---	---	4	6.32	----	----
5	6.7	166	4	6.32	37.8	58.6
6	Note: There was an air leak in the feed line on this date.					
7	6.7	43	4	4.85	----	----
8	6.7	257	4	5.79	45.0	50.1
9	6.7	166	4	6.91	49.2	42.2
10	6.6	43	4	5.50	44.0	51.0
11	6.6	---	4	5.60	----	----
12	6.6	69	4	6.55	----	----
13	6.6	43	7	9.95	----	----
14	6.7	52	4.5	7.69	----	----
15	6.7	103	5.5	10.62	46.6	49.0
16	6.5	103	6	8.36	49.7	49.0
17	6.6	103	5.5	9.61	52.5	47.1
18	---	---	3	9.87	----	----
19	6.6	94	7	7.20	44.0	56.0
20	6.6	103	7.5	6.60	50.6	48.0
21	6.4	352	3.5	11.98	61.3	38.6
22	6.4	352	3.5	7.39	53.3	44.4
23	6.6	257	3.5	7.21	40.2	56.0
24	6.6	154	6.0	8.79	33.9	----
	Note: Feeding system out of order; no feeding for 10 days from December 27, 1949 to January 3, 1950.					
34	---	---	11.5	----	----	----
35	6.3	368	2.5	9.89	63.2	31.2
36	6.9	223	2	8.29	40.5	56.0
37	6.7	103	2	9.38	37.2	58.0
38	6.6	86	3	4.80	38.8	57.0
39	---	---	-	4.95	----	----
40	6.6	43	5	4.95	40.5	55.4
41	6.6	43	5	5.97	47.5	49.0

TABLE VI (continued)

Time in	pH	Volatile Acids	Fresh Pear Waste Added	Gas Production Daily Prod.	CO_2	CH_4
days		p.p.m.	pounds	cu. ft.	%	%
42	6.6	43	5	6.73	44.5	49.2
43	6.6	51	4	8.00	44.5	49.3
44	6.6	43	4.5	8.10	47.0	49.4
45	6.6	103	4	6.70	49.4	47.0
46	---	---	4.5	8.90	----	----
47	6.7	60	4.5	7.08	47.4	52.0
48	6.7	130	4	6.70	48.0	51.6

* Per cent by volume.

Results of the Experiments on the Anaerobic Fermentation of Pear Waste. In the initial experiment (Table II, Figure 6) 15.9 pounds of dried pear waste (14.6 pounds dry weight) were fed over a fermentation period of 17 days with the production of 45.3 cubic feet of gas. The average methane content of this gas was 73.8 per cent by volume, which was much higher than for any of the later experiments. Because of a lack of gas collectors of sufficient size, it was impossible to obtain the true average values for the total gas produced during any of the five experiments. These values, therefore, are the averages of the daily analyses made on half-liter samples. There was a gradual increase in gas production to a maximum of 8.8 cubic feet per day on the 10th day. Thereafter, the gas production practically ceased, giving the comparatively low value of 3.1 cubic feet of gas for each pound of material fed during the fermentation period.

In the second experiment (Table III, Figure 7) 98.5 pounds of dried pear waste (90.6 pounds dry weight) were fed over the much longer period of 160 days. During this time 643.7 cubic feet of gas were produced, averaging 41.3 per cent carbon dioxide and 51.9 per cent methane. This shows a reduction of methane content, but the total gas production rose from the previous 3.1 cubic

feet of gas per pound to 7.1 cubic feet of gas for each pound of material (dry weight). There was a sharp peak in gas production near the 14th day to nearly 14 cubic feet per day, which was the maximum value recorded. Another increase in gas production to above five cubic feet per day occurred nearly the 50th day and extended through the 110th day.

The change from a mesophilic to a thermophilic temperature of fermentation and the establishment of fresh pear waste as the substrate led to a further increase in the total gas production per pound of material fed on a dry weight basis. The composition of the gas, however, remained essentially the same as for experiments with dried pear waste at 86° F.

In experiment three (Table IV, Figure 8), 208 pounds of fresh waste (35.4 pounds dry weight) produced a total of 468.7 cubic feet of gas with an average composition of 45.1 per cent carbon dioxide and 49.3 per cent methane. The total gas production for the two-month period was 13.3 cubic feet per pound of dry material, which was the highest for any of the five runs.

In experiment four (Table V, Figure 9), a total of 231 pounds fresh waste (39.3 pounds dry weight) were fed during a two-month period to produce 419.5 cubic feet

of gas. This gas averaged 45.9 per cent carbon dioxide and 51.1 per cent methane. The production of 10.7 cubic feet of gas per pound of dry material was slightly under that of the previous experiment. During the first week of this experiment, daily half-liter samples of the well-agitated tank contents were withdrawn for the following analyses, the results of which are tabulated in Table VII: pH, volatile acids, solids, ash, carbon, organic (Kjeldahl) nitrogen, reducing sugars, and B.O.D. The initial fresh pear waste analyzed 85,000 p.p.m. reducing sugar (duplicate one-gram samples averaged 85 mg. sugar).

TABLE VII

Analysis of Digested Material

Sample duplicate	Volatile Acids p.p.m.	Solids %	Ash %	Carbon p.p.m.	Nitrogen p.p.m.	Sugars p.p.m.	B.O.D. p.p.m.
1	130	1.07	0.46	2,348	334	70	775
2	170	1.15	0.44	3,385	328	25	775
3	100	1.15	0.41	3,249	335	40	645
4	283	1.30	0.46	4,040	343	50	840
5	165	1.10	0.41	3,522	320	50	900
6	112	1.01	0.38	3,058	270	40	1000
7	146	1.04	0.40	3,140	275	--	800
8	215	1.21	0.45	4,204	284	--	800
Ave.	165	1.13	0.43	3,368	311	46	842

The data in Table VII shows that the tank contents remained relatively stable during fermentation. The average five-day B.O.D. of 642 p.p.m. is due in a small part to the residual sugars and largely to other readily oxidizable fermentation by-products. The total solids (1.13 per cent) minus the ash (0.43 per cent) gives the organic solids (0.70 per cent) equivalent to 8,368 p.p.m. carbon, which would have a theoretical, ultimate B.O.D. value of approximately 9000 p.p.m. The difference between the 9000 B.O.D. value and the five-day B.O.D. value is due to resistant materials such as lignin. Lignin exerts an extremely slow B.O.D. representing an accumulative but probably undeterminable pollution effect, the significance of which is controversial and largely unknown.

The results of the last experiment (Table VI) are essentially the same as for the two previous ones (Tables IV and V). In the last experiment, 166 pounds of fresh waste (28.2 pounds dry weight) were fed during a period of 48 days to produce 275.6 cubic feet of gas. In composition, this gas averaged 46.8 per cent carbon dioxide and 49.5 per cent methane. The gas production dropped slightly to 9.8 cubic feet per pound of pear waste (dry basis).

The results of these experiments are all summarized in Table VIII.

TABLE VIII

SUMMARY OF THE ANAEROBIC FERMENTATION OF PEAR WASTE

Table	Waste Added	Dry Weight	Cu. ft. Gas Produced****	Cu. ft. per lb. dry wt.	Ave. Comp.* CO_2	CH_4
II	15.9 lbs. Dried**	14.6 lbs.	45.26	3.1	17.8	73.8
III	98.5 lbs. Dried	90.6 lbs.	643.73	7.1	41.3	51.9
IV	208 lbs. Fresh***	35.4 lbs.	468.68	13.3	45.1	49.3
V	231 lbs. Fresh	39.3 lbs.	419.53	10.7	45.9	51.1
VI	166 lbs. Fresh	28.2 lbs.	275.56	9.8	46.8	49.5

* This gas composition average is the average value of the daily samples collected, over acidified brine, from the tank for gas analysis.

** Contained eight per cent moisture.

*** Contained an average of 83 per cent moisture (23).

**** Not corrected to standard conditions.

SUMMARY AND CONCLUSION

The objectives of this study have, to a large extent, been achieved. The knowledge gained from the preliminary laboratory fermentations initiated by Harnik (29) and completed by Lambrecht (40) served as a basis for the design of a 150 gallon experimental pilot plant. This pilot plant was constructed with provision for automatic, intermittent, reversible circulation of contents; automatic temperature control; slow, intermittent feeding; continuous gas measurement; and withdrawal of digested material through a trapped overflow.

Five experimental runs, extending over about one year's time, were conducted by use of the pilot plant for the purpose of obtaining the following data: pH, volatile acids, total gas produced, composition of the gas produced, and of the digested residue.

The results obtained when the pilot plant was first put into operation agreed closely with those found on a laboratory basis. In the three preliminary fermentation runs conducted by Lambrecht the volume of gas per pound of waste (dry weight) was 6.5, 6.0, and 9.6 cubic feet, respectively. By comparison, the result of the pilot plant experiment, conducted over a period of 160 days and also utilizing dried pear waste, was 7.1 cubic

feet of gas per pound of waste. As is readily seen, the amount of gas produced on a pilot plant scale compared closely to that obtained in the laboratory.

The change in fermentation from 86 degrees Fahrenheit to 131 degrees Fahrenheit and the introduction of fresh waste as the substrate in the last three experiments caused an increase in the total gas production to 13.3, 10.7, and 9.8 cubic feet, respectively.

The composition of the digested material seemed to remain quite stable at an average of 1.13% solids, .4% ash, 3,358 p.p.m. carbon, 311 p.p.m. nitrogen, 46 p.p.m. reducing sugars, and 842 p.p.m. B.O.D.

Once the pilot plant was put into operation and an active culture built up, it was as easy to operate as the small laboratory fermentation had been. It was found that the fermentation could be interrupted for periods of several months and re-initiated with very little lag.

The micro-flora was varied, but remained quite constant as to organisms found on the stained slides. These organisms consisted of both long and short Gram-negative rods, Gram-negative cocci, and Gram-positive streptococci.

The end products of the fermentation remained fairly consistant at approximately 45% carbon dioxide

and 50% methane. This gas has a fuel value of 550 B.T.U. per cubic foot (18).

The results obtained in the above experiments with pear waste show promise of a method of disposal that will both dispense with the necessity of dumping untreated cannery wastes into streams and reduce the cost of waste disposal by providing a useful by-product.

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