THE PRODUCTION OF METHANE BY THE ANAEROBIC DECOMPOSITION OF GARBAGE AND WASTE MATERIALS

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Introduction

The natural gas reserves of this country are dwindling, and this resource will some day in the not too distant future have to be augmented or replaced by synthetic gaseous or other types of fuel. At the same time, waste materials of all types are ever increasing so that waste disposal is one of the largest problems facing an ecology-minded society of today.

The magnitude of the problem is shown by the fact that about 3 billion tons of solid organic wastes are generated yearly in the United States. (3)[1/]

Agricultural wastes generated total 2.5 billion tons per year, of which about 2 billion tons are manure. Total urban wastes generated including domestic, commercial, municipal, and industrial, are 400 million tons per year. Solid waste discards collected by private and municipal agencies currently total about 200 million tons per year and average about 6 lb per day per person (1). Predictions call for doubling this rate long before the end of the 20th century.

The objective of this work was to study the production of methane by the anaerobic digestion of garbage and waste materials. Other methods of utilizing waste materials have been proposed and investigated. At the U.S. Bureau of Mines Energy Research Center at Pittsburgh, Pa., garbage and waste materials have been pyrolyzed and hydrogenated to convert them to useful products (5, 2). Both of these processes, however, require special equipment, and the processes are complex. Hydrogenation, for example, is done at high pressures (2000 to 6000 psi) and high temperatures (250° to 400° C), and the waste must be reacted with a gas (hydrogen or carbon monoxide). Pyrolysis of wastes is accomplished at atmospheric pressures, but elevated temperatures of 200° to 900° C are required as are special furnaces and auxiliary equipment. Anaerobic digestion, however, would not require special high-temperature or high-pressure equipment, because it is done at atmospheric pressure and about 100° F, and would utilize conventional equipment used in the liquid waste-treatment industry today.

Description of Equipment and Test Methods

Figure 1 illustrates the glass equipment used in batch tests for the anaerobic digestion of waste materials. The procedure of testing was as follows: The side-arm flasks used as digestion vessels were first purged with helium to exclude air since the methane-forming organisms cannot survive in an oxygen atmosphere. Weighed amounts of garbage or waste material to be tested were placed in individual flasks. Measured quantities (usually 2 liters) of digester sludge from a nearby activated sludge-type sewage-treatment plant[2/] treating essentially domestic wastes were

1/ Numbers in parentheses refer to literature cited at end of paper.

2/ Pleasant Hills Sewage Treatment Plant, 1222 Cochran Mill Road, Pittsburgh, Pa., 15236 transferred to the helium-filled flasks. The flasks were then stoppered and placed in a water bath controlled at 95° to 100° F where digestion began. One of the flasks of each series of tests contained no solid wastes but only the digester sludge and served as a control for the other flasks.

The gaseous products of digestion were collected in a rubber balloon contained in a water-filled jar, which prevented contact between the gas and the water. Measurement of the water displaced as the balloon inflated gave a direct measurement of the gas produced. Gas samples were periodically removed for chromatographic analysis by deflating the balloons. The only circulation of the contents of the flasks, besides occasional manual shaking of the flasks, was the natural circulation provided by the heated liquor and passage of gas bubbles through the mixture.

Tests With Various Waste Materials and Discussion

Table 1 illustrates data from a batch test with garbage. One flask contained 2 liters of digester sewage sludge, and the other contained 2 liters of digester sludge and 25 grams (dry weight) of processed, shredded garbage. The processed garbage was obtained at Altoona, Pa., where residents separate bottles and cans from their refuse so that the destructable wastes can be shredded and ground prior to undergoing an aerobic mulching treatment.

After 24 hours of digestion, the sludge (SG-55) had produced 945 ml of gas (50% methane), while the sludge-garbage mixture (SG-56) produced 2080 ml of gas (63% methane). In a total of 336 hours of digestion, the sludge generated 2735 ml of gas (1748 ml of CH_4), and the garbage-sludge mixture generated 6620 ml of gas (4048 ml of CH_4). At the end of 336 hours, gas generation had ceased in both flasks. Assuming that the sludge would produce the same amount of gas in each flask, the difference in gas production is attributable to the garbage; or, in this test, 1.50 ft^3 of methane was produced per lb of garbage.

Table II illustrates a test with sewage sludge, cow manure, and dried grass clippings. The control (sewage sludge alone) produced only 422 ml of methane, the cow manure produced 6949 ml, and the grass clippings produced 7483 ml. Correcting for the methane produced by the control, the cow manure produced 1.11 ft^3 of methane/lb of dry waste, and the grass clippings yielded 1.20 ft^3 of methane/lb.

Other materials tested for the production of methane by anaerobic digestion, with sewage sludge as the source of the methane-producing bacteria, are listed in table III. As in previously discussed tests, the gas produced by the control (sewage sludge alone) was deducted from the gas produced by the mixture of sewage sludge-waste material, and the total methane produced by the waste material is listed in cu ft/lb (dry weight) of solid waste material.

Numerous coals were tested for methane production by anaerobic digestion, but only two results are listed: LVB coal produced 1.04 ft^3 methane/lb coal; the HVAB coal produced 0.44 ft^3 methane/lb coal. Since this symposium is concerned with fuels from nonfossil sources, the coals are mentioned merely to show that they too are amenable to bacteriological degradation.

The garbage char of test SG-38 (table III) was the residue from pyrolysis at 500° C of a processed garbage. Processed garbage is a raw garbage that has been shredded after the removal of glass and metal materials. The fresh garbage of test SG-41 was a hand-picked, blended mixture of the following: apple, orange, silicone rubber, waxed milk carton, potato, newspaper, onion, aluminum foil, eggshell, lemon, and plum. As noted, both of these garbages produced about 1.3 ft^3 of methane/lb of waste. The processed garbages (SG-43 and SG-44) were the best methane producers generating 3 to 4 ft^3/lb of garbage. Other materials tested were shredded brown paper hand towels, shredded newspaper, wood excelsior, and cow manure. Apparently, any organic material is susceptible to some degree of degradation by anaerobic digestion, which makes the process attractive for the disposal of urban solid wastes since they are a conglomeration of discarded materials.

Process Improvements Needed

Although the methods used in our tests gave results that were comparable and reproducible, it is felt that digestion would have been more complete and higher yields of methane could have been obtained if changes in test operation were made to more nearly simulate conventional sewage treatment practice. For example, continuous circulation of the solid-liquid mixture would provide better contact between the methane-producing organisms and materials on which they feed. This would also provide more consistent temperature control. Likewise, periodic feed of waste material and withdrawal of digested solids would aid digestion by providing the proper balance between organisms and food material.

One of the drawbacks of this system is the length of time required to obtain complete digestion. As shown by the data in tables I and II, digestion times of 300 to 900 hours may be required. In today's sewage treatment practice, a 1-month minimum detention time is usually required for providing well-digested sludge. Any methods of reducing these long digestion times would add greatly to the attractiveness of the process.

Combined Sewage-Garbage Treatment

To operate a combined sewage-garbage treatment plant, tin cans, glass, and undigestable solids would have to be removed from the garbage. The digestable garbage should then be shredded or otherwise comminuted before addition to the sewage system. The ideal location for addition of the comminuted garbage would be at the sewage treatment plant. However, it could just as easily be added anywhere along the sewage collection system, and the sewers would transport it to the treatment plant. In large cities there could be numerous garbage collection centers strategically located to reduce haulage costs. A disadvantage of this type of system could be that the additional water added to the garbage to render it transportable might tend to overload the treatment plant. Wherever the garbage or waste is added in the system, when it gets to the treatment plant it would undergo conventional treatment.

The block diagram of figure 2 is an illustration of an activated sludge plant. The solids removed by the primary sedimentation step (generally about 50% of the total solids) are pumped to the anaerobic digesters, which are maintained at about 95° to 100° F. In figure 2, the garbage is shown as being added before the inlet to the treatment plant; it could also be added to the raw sludge from the primary sedimentation step, thus subjecting all the garbage to anaerobic digestion rather than only 50% of the garbage solids. Pumps provide recirculation of the digester contents. As the solids become digested, they settle to the bottoms of the digestion tanks. The supernatant liquor, which includes excess water and nonsettling solids, is drained to the secondary treatment system where it undergoes aerobic digestion, final clarification, and chlorine treatment before being released to the receiving stream.

Digested solids from the digestion tank bottoms are drained to sand-drying beds or vacuum-filter presses for drying. The dry digested solids, which have been reduced in mass at least 50%, are useful as low-grade fertilizers and soil conditioners. As practically sterile digested solids, they are much more acceptable aesthetically and much less offensive than the original raw garbage.

The gaseous products of digestion consist essentially of methane (about 65%) and carbon dioxide (about 35%). Many sewage treatment plants today utilize the 650-Btu gases that they generate in their digesters to operate internal-combustion engines to drive blowers, pumps, and other plant auxiliary equipment. One such plant[3/] treating about 2 million gallons per day, produced 606,300 ft^3 of methane during a recent 1-month period. This amount of methane was produced from about 80 tons of solids contained in the raw sludge pumped to the digesters, or 3.8 ft^3 of methane was produced/lb of sewage solids.

If all the solid waste discards that are collected annually in this country by collection agencies (200 million tons) were subjected to treatment by anaerobic digestion, potentially some 1.2 trillion ft^3 of methane would be produced based on yields obtained in our batch tests. Likewise, if all the animal wastes (manure--2 billion tons) were also to receive this treatment, an additional 4.4 trillion ft^3 of methane could be produced annually. These amounts together are about one-fourth the annual U.S. consumption of natural gas (4). The value of gas from this potential source would amount to millions of dollars, and this is a renewable energy source that is today being wasted.

Conclusions

The urban and agricultural solid wastes being generated in the United States are a potential source of more than 5 trillion ft^3 of methane per year--about one-fourth our annual consumption. Methane could be produced from these wastes by the process of anaerobic digestion, the same process utilized in the operation of household septic tanks. The digestion process would not require exotic or expensive equipment since it would take place at 95° to 100° F and at atmospheric pressure. In addition to a gaseous product consisting of 65% to 70% methane and 30% to 35% carbon dioxide, a solid product remains (reduced more than 50% in mass from the original waste) that is useful as a fertilizer or soil conditioner. One of the biggest advantages of this scheme is that waste materials are a renewable energy source that will not diminish like our fossil fuels but will continue to increase.

Literature Cited

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3/ Work cited in footnote 2.

Table I. **Gas Production** by Anaerobic Digestion of Garbage and Sewage Sludge

	Digestion time, hr	Gas produced, ml Total	Gas produced, ml CH_4	Gas analysis, % CH_4	Gas analysis, % CO_2	Gas analysis, % N_2
SG-55	24	945	473	50.0	39.1	10.9
2 liters digester sewage sludge	72	1690	974	67.2	23.6	9.2
	264	2495	1570	74.0	19.7	6.3
	336	2735	1748	----	----	----
SG-56	24	2080	1310	63.0	35.1	1.9
2 liters digester sewage sludge + 25 grams processed garbage	72	4375	3017	74.4	24.0	1.6
	264	6230	3724	82.7	16.9	0.4
	336	6620	4048	----	----	---

Methane produced by sludge-garbage mixture (SG-56) 4048 ml
Minus methane **produced** by sludge (SG-55) - 1748 ml

Methane produced from garbage: 2300 ml

$$\frac{2300 \text{ ml } CH_4}{25 \text{ g garbage}} = 1.50 \text{ ft}^3 \; CH_4/\text{lb garbage}$$

Table II. Gas Production by Anaerobic Digestion of Bovine Waste, Grass Clippings, and Sewage Sludge

	Digestion time, hr	Gas produced, ml Total	Gas produced, ml CH_4	Gas analysis, % CH_4	Gas analysis, % CO_2	Gas analysis, % N_2
SG-60	82	1175	227	19.3	14.8	65.9
2 liters digester sewage sludge	286	1425	336	43.5	13.8	42.7
	310	1625	422	----	----	----
	Gas production ceased					
SG-61	46	1930	867	44.9	34.2	20.9
2 liters digester sewage sludge + 100 g cow manure	82	2870	1480	64.2	27.0	8.8
	160	4035	2248	65.9	27.4	6.7
	286	5095	2966	67.7	27.0	5.3
	502	7475	4592	68.3	28.1	1.7
	957	10700	6949	73.1	25.2	1.7

$$\frac{6949 \text{ ml } CH_4}{100 \text{ g manure}} = 1.11 \text{ ft}^3 \; CH_4\text{/lb manure}$$

	Digestion time, hr	Gas produced, ml Total	Gas produced, ml CH_4	Gas analysis, % CH_4	Gas analysis, % CO_2	Gas analysis, % N_2
SG-62	82	1395	239	17.1	29.6	53.3
2 liters digester sewage sludge + 100 g dried grass clippings	160	3220	1093	46.8	37.1	16.1
	238	4605	2072	70.7	25.3	4.0
	286	5550	2778	74.7	23.3	2.0
	502	8940	5409	77.6	22.4	0
	957	12190	7905	76.8	19.4	3.8

$$\frac{7483 \text{ ml } CH_4}{100 \text{ g grass}} = 1.20 \text{ ft}^3 \; CH_4\text{/lb grass clippings}$$

Table III. - Methane Yields from Waste Materials and Coals by Anaerobic Digestion

Test No.	Material	Dry wt, g	Duration of test, hr	Gas production, ml Total1/	Gas production, ml Methane	Ft^3 methane produced/lb waste material
SG-19	LVB coal minus 325 mesh	100	1330	7600	6460	1.04
SG-20	HVAB coal minus 325 mesh	100	1330	4015	2770	0.44
SG-38	Garbage char...	100	840	9850	8195	1.31
SG-41	Fresh garbage..	50	360	8980	4215	1.35
SG-43	Processed garbage......	50	864	18735	12571	4.03
SG-44	Processed garbage......	25	864	7895	5282	3.39
SG-47	Shredded brown paper towels	25	816	865	692	0.44
SG-49	Shredded news-papers......	25	734	1500	Gas not analyzed	0.67 2/
SG-50	Wood excelsior	25	734	770	Gas not analyzed	0.34 2/
SG-58	Cow manure.....	100	234	7800	4402	0.71

1/ Deduction from total production has been made for gas produced by control.

2/ Estimated.

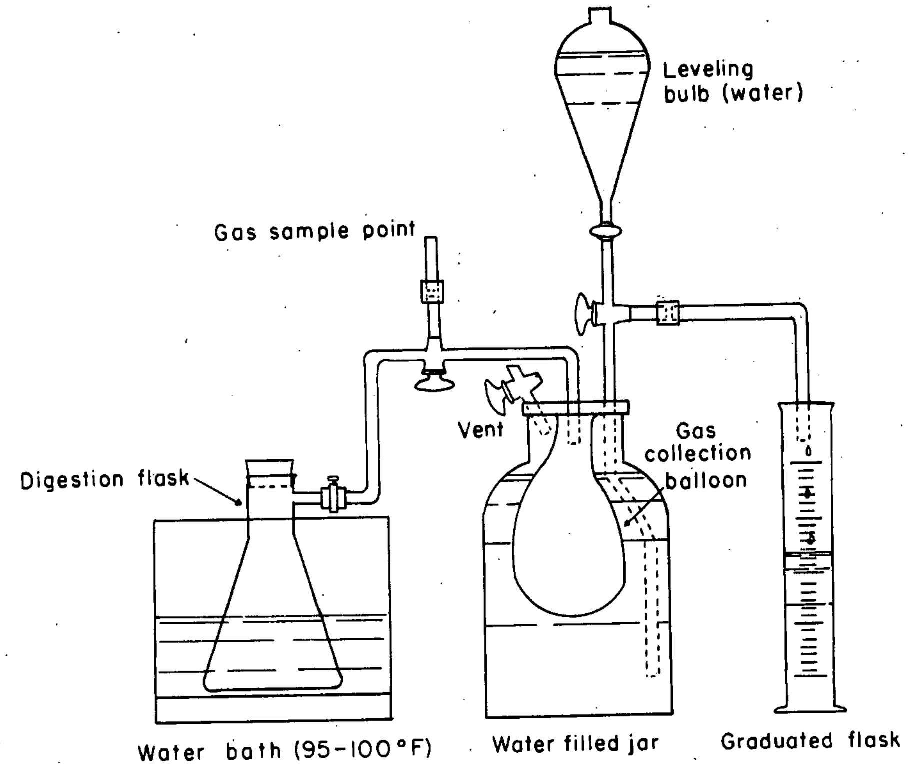

Figure 1. Apparatus for Production-Collection of Gases from Anaerobic Digestion of Wastes.

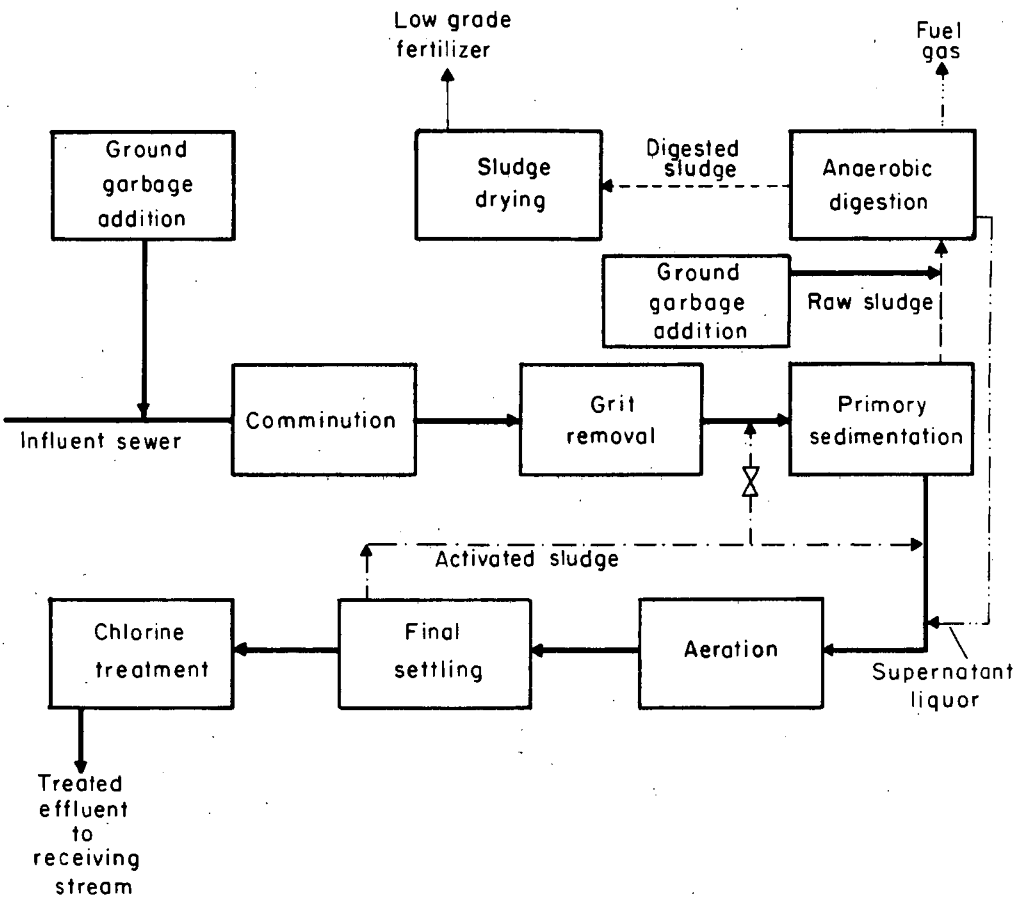

Figure 2. Flow Diagram of Garbage-Sewage Treatment Process.