Methane Production from Waste Organic Matter

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PREFACE

The last 100 years has seen huge strides in technology development as well as a rapid depletion of nonrenewable energy sources. We are now at a crossroads in history for energy utilization as well as for food production for the world's increasing population. The process of anaerobic digestion is an artificially contrived system to copy natural biological processes for the recycling of organic materials. Energy is produced in the form of methane, but the residue is considered valuable in that it contains nutrients suitable for soil fertilization as well as other materials such as protein, which may be used as animal feed.

For the biological system to operate satisfactorily, the engineering parameters must be adequate to provide the appropriate environment, and for the process to be of use, the economics must be favorable. Considerations of Biology, Engineering, Economics, Process Controls and Applications are considered in the following 12 chapters, and attempts are made to bring together worldwide existing knowledge of a process that may help to meet National Energy shortfalls or even produce a total alternative energy system for some countries. The benefits for waste disposal, pollution and disease control are also discussed to highlight the method as a recycling system with more than one function.

The potential for the process is clear. All that remains is for the practical exploitation of anaerobic digestion to offset in part an approaching energy crisis, which will be of far greater impact than those caused by recent energy production price rises. We hope that the appropriate use of anaerobic digestion will be made soon and that the points raised in this book will in some way aid those concerned in implementing decisions to use the process.

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July 1978

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Dr. Stafford received his B.Sc. degree in 1967 from the University of Salford, United Kingdom and obtained his Ph.D. in 1970 from the University of Wales. His prime areas of research include the microbiology of industrial effluent treatment, waste recycling, and methane generation.

Dr. Stafford has co-authored a book on industrial effluent treatment, and has written many papers in the field of waste recycling, including a review on the microbiology of the activated sludge process for CRC Press. He is currently involved in a study for the United Kingdom Department of Energy on the potential of methane production from Biomass.

Dennis L. Hawkes, B.Sc., Ph.D., C. Eng., M. Inst. E., is a Senior Lecturer in the Department of Mechanical and Production Engineering at The Polytechnic of Wales.

He spent 14 years in the aircraft industry before becoming a lecturer, first in the University of Malawi, Central Africa, and finally in Wales, where he joined the Polytechnic staff in 1972.

Mr. Hawkes' interest in Anaerobic Digestion Technology began in 1973 and has since taken him to Europe and the United States to discuss recent trends.

He directs the Polytechnic Anaerobic Digester Research and Development Unit at The Polytechnic with Mr. Horton. He is also actively engaged in research and consultation work in his field. He has contributed to a number of publications on the subject.

Rex Horton, Ph.D., F.I.E.D., is a Senior Lecturer in the Department of Mechanical and Production Engineering at The Polytechnic of Wales, where he is responsible for the teaching of engineering design.

He has spent more than 20 years as a specialist in this field. His experience and training have been acquired by the traditional British method of progressing through the industral system, from workshop apprentice to eventual Chief Designer status, while obtaining professional qualifications en route by part-time study. After extensive experience in industry he joined the academic staff of The Polytechnic of Wales in 1968.

His current research interest is centered around digester technology. Now he directs the Polytechnic Anaerobic Digester Research and Development Unit with Mr. Hawkes. He is co-author of a number of papers on this topic.

TABLE OF CONTENTS

Chapter 1

WHAT IS A DIGESTER?

I. INTRODUCTION

Digesters vary widely with regard to complexity and layout. No simple design can ever be considered as ideal, since many factors affect their arrangement and construction, and these need to be considered for an optimum to be arrived at for each particular set of circumstances and environmental conditions. There are, however, some essential differences in digester principles, and for convenience, digester types have been loosely categorized into four sections: batch, continuous, high rate, and others. This order generally follows a pattern of ascending sophistication, the simpler designs usually falling into the description of a batch digester and the more complicated heated and stirred, two-stage layouts at the other end of the spectrum.

Within the various sections, this order has also been maintained, but inevitably some overlapping is unavoidable. Another difficulty is that considerable interest is being generated in the area of digester application. Consequently, there are probably more varying designs being patented and published during this decade than in any other.

II. TYPES OF DIGESTERS

A. Batch Digesters

The waste to be treated is placed in the digester, a quantity of seed material or biomass is then usually added, and the vessel is sealed and left until digestion is completed. Excreta from some warm-blooded animals invariably contain methanogenic bacteria since these are naturally present in their intestines. Other types of organic waste — such as straw, leaves, agricultural residues, and wastes from breweries, distilleries, paper and pulp mills, and textiles and food manufacturing industries — can also be digested, but inoculation with the contents of a working digester will greatly accelerate the start of the process. Without it, digestion could take many months. Start-up without seeding can be speeded up by allowing the digester contents to decompose semiaerobically for 2 to 4 weeks depending on the volume and nature of the waste. The digester is then closed and sealed to achieve an anaerobic environment, and under these conditions, gas production should start in 3 to 4 days.[1] When gas production tapers off or ceases, digestion is assumed to be complete, so the contents are then removed from the tank, pit, trench, or bag, and preparations are undertaken to repeat the cycle.

The simplest arrangement of this batch-loading principle is the vertical drum type as shown in Figure 1. Waste is placed into the outer drum and then seeded with digester contents. The inner drum is pushed down in the waste with gas taps open to exclude any air, and when the digester begins to work, the inner drum is forced upwards by digester gas thereby giving visual indication of gas generation. The disadvantages of this simplicity are obvious. The amount of usable gas is relatively small, and the first drum of gas should be vented to atmosphere since it usually contains air, which forms an explosive mixture with methane at ratios of 1:4 to 1:14 if ignited. Also, initial gas yields could be high in carbon dioxide.[1] Feeding in this arrangement is accomplished by removing the inner drum, then removing some of the contents and replacing with fresh waste, a time-consuming, messy, and inefficient operation. However, the system is useful for preliminary experimentation and for obtaining methanogenic bacteria for a particular waste.

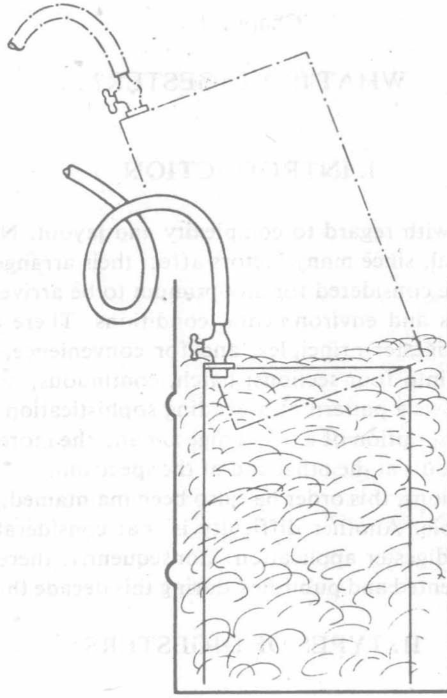

FIGURE 1. Vertical drum type.

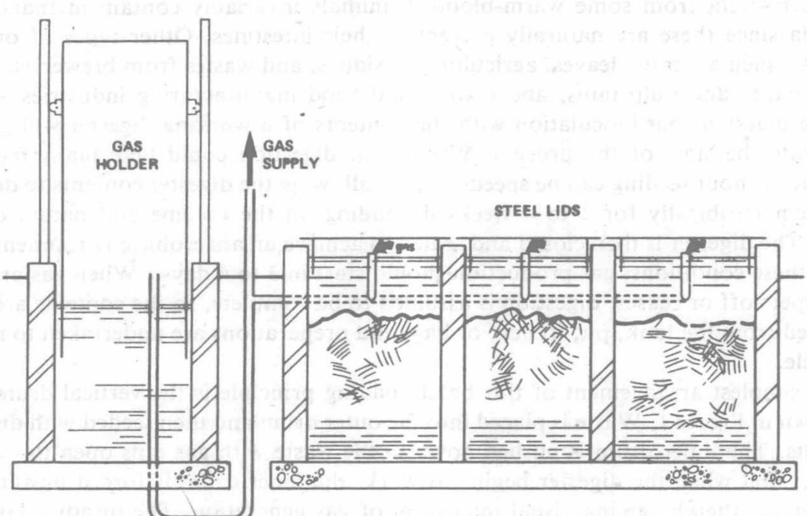

FIGURE 2. Diagram of Tollemache plant. (With permission from Sampson, S., Methane, Wadebridge Ecological Centre, Cornwall, U.K., 1975, 27.)

Many hundreds of digesters were installed in Europe during World War II. These simple arrangements were said to supply sufficient gas to supplement the needs of small farm. The diagram in Figure 2 shows such a plant.[2]. A series of pits was con-

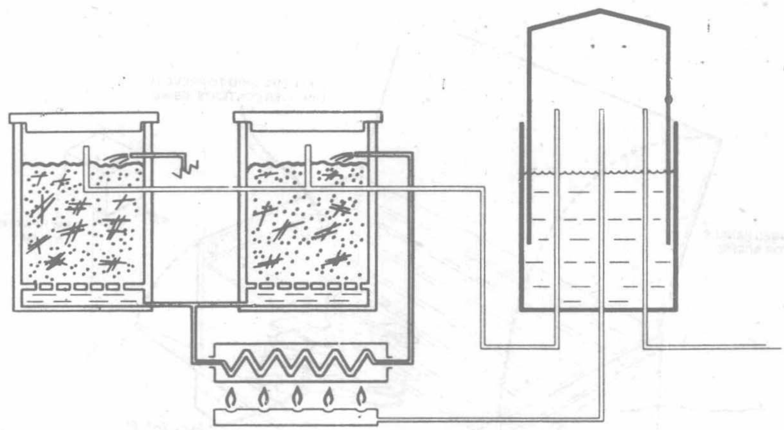

FIGURE 3. Flow diagram of the labor intensive Ducellier and Isman process which was a batch system with high T.S. animal waste concentrations.

structed as shown. The waste material, dung, straw, vegetable tops, and cuttings were shoveled or forked in and then seeded with anaerobic bacteria. The charge was then trampled down and water hosed in to seal the contents. In this unheated version, retention times were long, especially in winter. A similar design by Ducellier and Isman is shown in Figure 3. This was first developed in North Africa in 1937 and formed the basis for many of the wartime French plants. An advantage of this type of system is that the charge does not require to be watered down to the appropriate "thick creamy consistency", as specified for the continuous and high-rate digester. Stable manure, for example, was delivered in its natural condition, and apart from the topping up and inoculating process, which could take about 10% of the total capacity, no other treatment was required. However, it was clearly a very labor-intensive operation, and unloading especially must have been strenuous and unpleasant, taking place every 2 to 3 months.

It has long been known that decomposing garbage produces methane, together with other gases. Until very recently, this fact had been considered a liability associated with sanitary landfill applications. However, it now appears practical to utilize what is, in effect, a batch-filled anaerobic digester. The number of sites available for exploitation by this method is large enough to make the process economically viable. There could be 13,000 to 20,000 waste disposal sites existing in the U.S.,[4] and while most of them would be unsuitable fo methane recovery, it has been estimated that many hundreds have potential for commercial methane recovery.[5] At least one company is in business extracting gas from such sites.[6] Gas extracted from such landfills may be utilized in four ways:

1. Utilization of low calorific value gas for generation of steam or electricity by incorporating suitable gas engines
2. Supplying partially cleaned gas of low calorific value to industrial customers (both of these applications could be subject to state utility commission jurisdiction, and the cost of laying and maintaining pipelines and associated equipment could prove costly and troublesome)
3. Purifying the biogas to standard fuel and injecting into a nearby utility company pipeline to be used by the entire distribution area under normal natural gas usage conditions
4. Converting the landfill biogas to methanol or to liquified natural gas on site

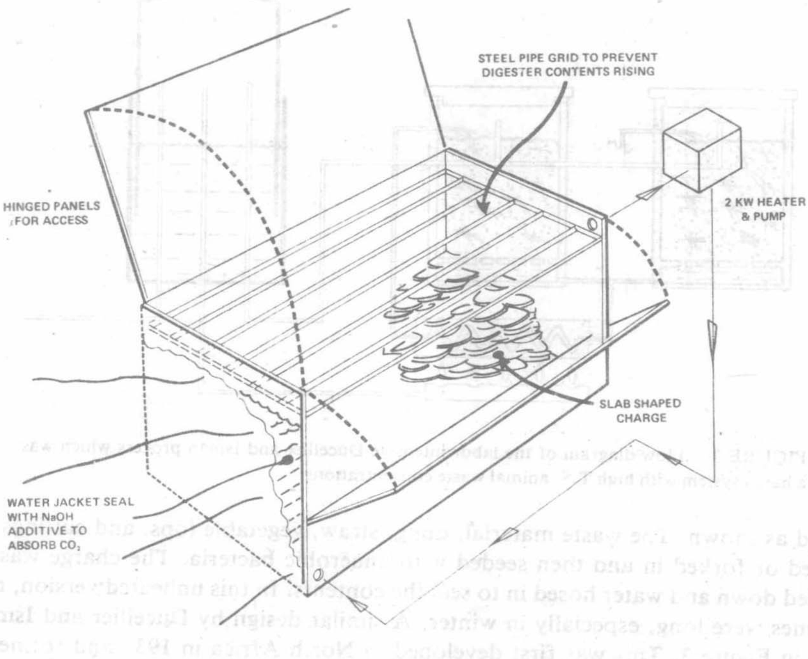

FIGURE 4. Isman-type French farm digester.

The third alternative is considered to offer more advantages as a viable proposition.[5]

The technology of this extraction procedure, however, is not easy since embedding a 150-mm diameter pipe into the bottom of landfill well and sucking out the gas presents many problems. If the landfill is pumped to extract gas at a faster rate than it is being generated, the resulting partial vacuum could bring air into the essential anaerobic environment. Conversely, pumping the gas out at a rate slower than the natural generation rate could mean that the pressure inside the well is sufficient to cause leakage of gas from unexpected points in the tip. The technology of the withdrawal process requires considerable expertise from a range of various disciplines.[7]

Gas generation figures have been estimated to be around 30 to 90 m^3/t of municipal refuse, and typical methane content is 50.2% with carbon dioxide, say, 48% with 0.86% nitrogen, 0.19% hydrogen, 0.12% oxygen, and 0.45% other hydrocarbons. Actual methane extraction from the Palos Verdes fill in Los Angeles, which receives 3600 t/day of solid waste (5 days/week), is reported to be about 8.3 m^3/t.[7]

Although gas is generated for long periods (up to 50 years in some cases),[7] it is believed that, under what can be described as average conditions, most of this will be given off in the first 15 years. Clearly, factors such as type and consistency of waste, temperature, pressure, air etc. will all contribute to this time, but the most significant feature is percentage moisture content. Below about 25% water by weight, gas production is virtually zero.[4]

The French Institute of Research in Applied Chemistry is carrying out laboratory and full-scale studies on animal waste and straw.[8] The laboratory equipment consists of glass columns 2 m long × 200 mm in diameter which are packed with this combined waste. Animal urine is heated and passed through the columns, maintaining a temperature of 35°C.

Isman's long experience in designing plants for this application is being used in the full-scale trials, being undertaken on a farm. The digester is essentially as shown in Figure 4.

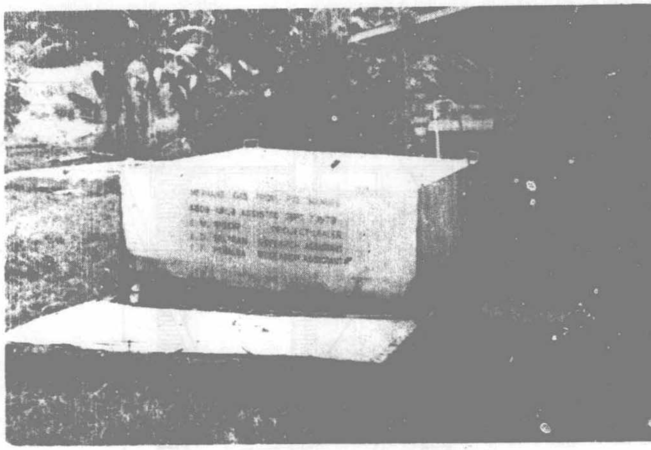

PLATE 1. Philippines digester of the type shown in Figure 9. (Courtesy of Professor E. M. Rigor, University of the Philippines at Los Banos College of Agriculture.)

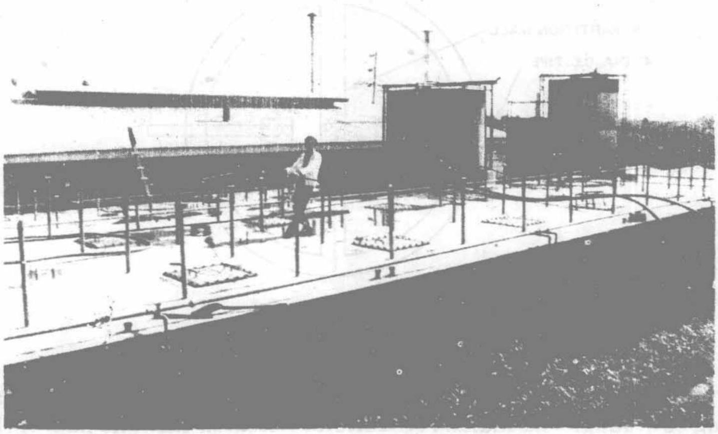

PLATE 2. Batch-fed digesters with floating gas holder at Maya Farms, Philippines. (Courtesy of F. D. Maramba, Liberty Flour Mills Inc., Manila.)

B. Continually Fed Digesters

As the name suggests, this category of fermenting reactor requires the feed as influent to be deposited into the vessel at regular intervals. The rate of feeding should, in theory, be continuous for maximum efficiency, but for practical reasons, the digesters are usually fed intermittently, probably the most common period being once a day.

For equilibrium conditions it follows that the digester must also be emptied by a similar amount. On the simpler designs, which rely on gravity feed, this is automatically catered for, but in the more sophisticated types, influent and effluent rates are determined by pumps and associated equipment. Plate 1 shows an experimental digester working at the University of the Philippines Los Banos, and Plate 2 shows a much larger unit at Maya Farms, Phillipines.

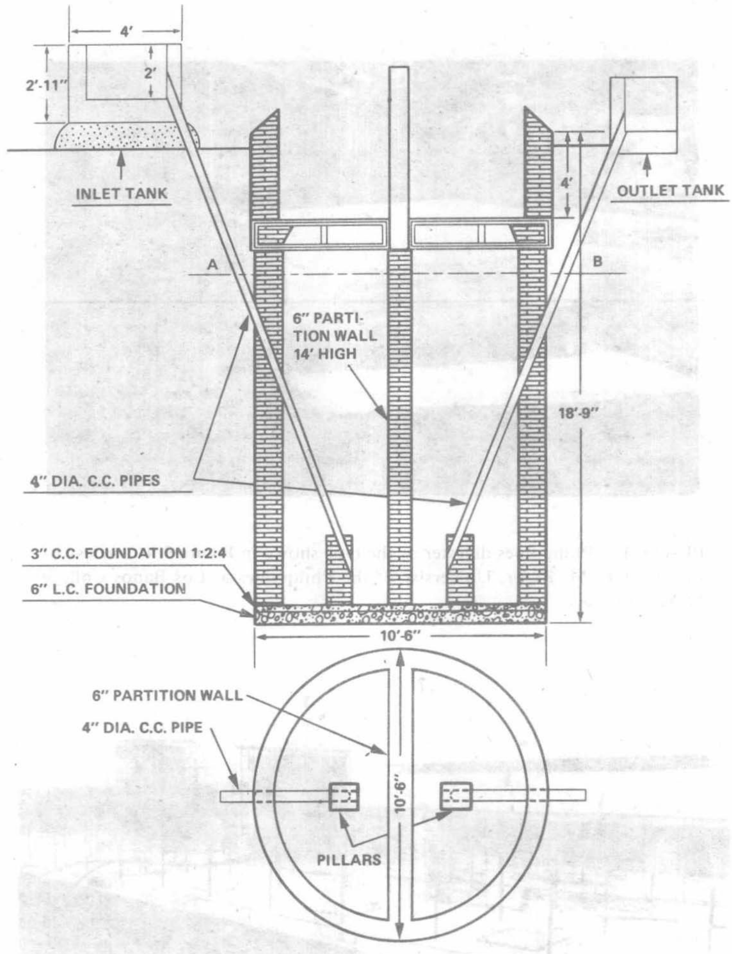

FIGURE 5. Digester (India).

Possibly the most widely publicized plants of this type are those developed in India for digesting cow dung. The Indian Agricultural Research Institute had worked in this field in the 1930s producing a design in 1939. The arrangement generally accepted as being typical of its kind is that developed by the Gobar Gas Institute under the direction of Ram Bux Singh (Figure 5).[10] These plants have been constructed since the mid-1950s in increasing numbers and by 1973 the Khadi and Village Industries Commission had set up over 6000 plants. By 1975 the number had reached 12,000, with a target of installations of 100,000 units. This organization gives assistance by scrutinizing proposals, surveying sites, and supervising construction work. It also allots grants and arranges bank loans.[11]

The design is a vertical displacement type, where the cattle dung is mixed with water in a 4:5 proportion and introduced down the inlet pipe (usually at daily intervals) into the digester. This, in turn, displaces an equal amount of contents into the drying bed. Sizes and construction vary, but usually the fermenter is a brick-lined cylindrical pit between 3.5 and 6 m deep with diameters varying between 1.6 m and 6 m. A small family unit would be about 1.6 m in diameter and 3.6 m deep and would be suitable for accepting the waste from, say, five cows, or 40 to 50 kilos of dung per day. The

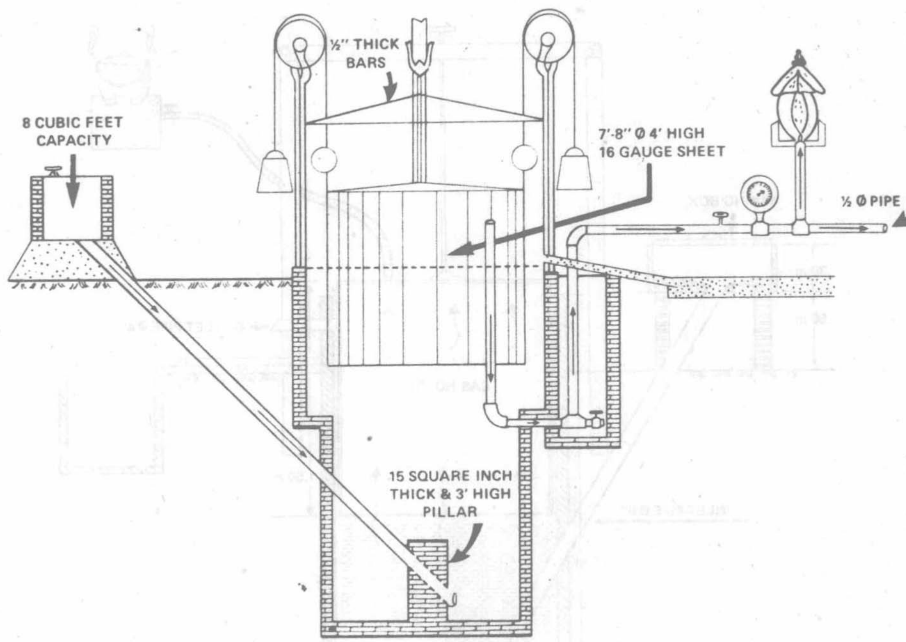

FIGURE 6. Digester (Pakistan).

output could be in the order of 3 m^3 of biogas per day of about 55% methane, which is sufficient to cater for the simple needs of a family in that particular part of the world. The floating metal gas holder usually has the capacity to store 50 to 100% of the daily gas production, and a retention time of 50 days is considered normal.

This very simple concept has variations, and Figures 6 to 9 show adaptations for different countries,[1] while Figures 10 and 11 are an attempt to render this design suitable for colder climates.

China is reported to have tens of thousands of digesters operating, but it is thought that most of these are small and similar in outline to the Korean type (Figure 8). The basic similarity between this arrangement and the Indian design again reinforces the conclusion that this very basic concept is well suited to third-world applications.

In Korea, the number of working digesters is said to be around 25,000, and these are usually of around 5 to 6 m^3 capacity. Korean winters are far more severe than in India; consequently, the operating temperatures in these simple, uninsulated designs will be low. Gas production would also be very low and could even cease altogether under the worst conditions of perhaps −15°C. Attempts are being made to improve gas generation during the 5-month winter period when it is most needed. Insulating the digester with rice hull or rice hull cover has maintained the temperature at 8°C with an outside January air temperature of −12°C. Erecting a 1-m high vinyl sheet cover over the top of the digester under similar conditions recorded nearly 15°C, and in these circumstances gas has been produced.

The Korean Office of Rural Development has produced some interesting results showing the effect of temperature on gas production, and some of these are shown in Figure 12. As can be seen, increasing the temperature from 5 to 15°C boosts gas production ten times. They have also shown the advantage of sunken digesters. Figure 13 shows that at 5-m depth, the ground temperature was almost 15°C compared with −12°C aboveground.[1]