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Biogas E

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Biogas Energy

Springer

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Dedicated to

Aunties Neelu, Sophia, and Rubi
–Tasneem Abbasi

Papa (Abid Hussain Saheb),
Ammi (Tasneem Fatima Sahiba),
and my beloved wife Rabab
–S.M. Tauseef

Didi (Nilofer Changi),
Aapa (Sophia Kapasi), and Rubi behn
–S.A. Abbasi

Foreword

For most of the twentieth century "biogas" was perceived as a poor man's fuel. India and China led the initiative of the developing countries in extracting biogas from animal manure to meet the much needed source of energy for farmers in villages. To developed countries, however, biogas was too lean and too inconvenient a fuel compared to the then abundantly available and cheaper petroleum-based fuels. Hence they either released the biogas that got generated in to atmosphere during manure management or from sanitary landfills, or flared it off when there was a danger of it forming a flammable cloud upon release.

For a short while developed countries did look at biogas as a potential fuel during 1973 and 1979 when "oil shocks" crisis hit them. But when the crisis passed off and oil prices dipped through the 1980s, the biogas again went out of contention in the developed world just as other non-conventional energy sources did.

The perceptions saw a sea change at the beginning of twenty-first century in the wake of an imminent threat to the existence of life on the planet earth due to global warming.

The world has realized that methane – which is the major component of "biogas" – is the second biggest contributor to global warming, next only to carbon dioxide. It is a fact that each molecule of methane potentially causes several times more global warming compared to a molecule of carbon dioxide, it is also a fact that the same methane, if captured and used as fuel, provides one of the cleanest sources of energy. This has brought methane capture to the forefront of global R&D thrust.

Interestingly, the status of biogas has also changed from a "poor man's fuel" to a "global priority" in such a short time that a large part of the world was not adequately prepared for it. I also understand there are hardly any dedicated books related to this emerging important clean fuel source. Hence I feel that the work presented in this book would be a trail-blazer and contribute to the R&D efforts in biogas generation and use.

Professor S.A. Abbasi has been associated with R&D on biogas since the 1970s and has pioneered the use of aquatic weeds in biogas generation, reporting research findings regularly since 1979. He has produced this book jointly with his two junior associates who also have substantial exposure in this area. I congratulate Springer for their foresight in commissioning this book and wish it critical, as well as commercial, success.

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Prof. J.A.K. Tareen
Vice Chancellor

Preface

Like carbon dioxide, methane is also generated in nature through a number of different routes and plays a crucial role in keeping the earth warm enough to be habitable. But during the last two centuries, and more so in the last few decades, anthropogenic activities have been contributing more *extra* methane to the earth's atmosphere than is good for the health of the Earth.

Each methane molecule contributes about 25 times as much to global warming as a molecule of carbon dioxide but methane has one major attribute which carbon dioxide does not have – methane can be used as a fuel. These twin aspects makes it doubly gainful to "capture" anthropogenic methane.

In developing countries, especially India and China, the importance of capturing methane that is generated from animal manure was recognized from the early twentieth century and major programmes were launched to popularize the "biogas digesters" that made this methane capture possible. Then the advent of several "high-rate" digesters during the late 1960s and early 1970s dramatically enhanced the reach of anaerobic digestion to wastewaters which were, till then, considered to be too "dilute" to be profitably handled by anaerobic digestion. Now a third, and perhaps the most important, phase of the evolution of biogas technology is underway wherein treatment of municipal solid waste, crop waste, and other forms of "high-solids" biowaste is being increasingly brought under its preview.

We deem it a privilege to have been asked by Springer to articulate this book at a time when there is a great resurgence of interest in methane capture – hence biogas technology – all over the world.

TA and SAA thank the Department of Biotechnology, Government of India for support in the form of an R&D project. SMT thanks the Council of Scientific and Industrial Research (CSIR), New Delhi, for Senior Research Fellowship. We also thank Ms M. Premaltha, Senior Research Fellow, for her help in locating and organizing on lot of material that has gone in the making of this book. Above all we thank Professor J.A.K. Tareen, Vice Chancellor, Pondicherry University, for his perceptive *Foreword* and the all-important moral support.

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Chapter 1
Biogas and Biogas Energy: An Introduction

Abstract "Biogas" is the name popularly used to denote the flammable mixture of gases that are generated when organic material undergoes anaerobic decomposition. The mixture contains 40–70% (usually 55–65%) methane, carbon dioxide, and traces of other gases. "Biogas" has good calorific value and can be directly used as fuel or indirectly used to generate electricity.

In this chapter a general introduction to "biogas" is provided, and steps involved in its formation are described. The factors which influence the sustainability and efficiency of anaerobic digestion – hence biogas production – are also briefly discussed.

1.1 What is Biogas?

When organic matter – such as food, plant debris, animal manure, sewage sludge, biodegradable portions of municipal solid waste, etc. – undergoes decomposition in the absence of free oxygen, it normally generates a gas which consists of 40–70% methane, the rest being mostly carbon dioxide with traces of other gases. If ignited, this gas burns cleanly (i.e., gives off no soot or foul smell) similar to liquefied petroleum gas (LPG) or compressed natural gas (CNG). This gas is commonly called "biogas" which is an inexact and imprecise term because the gas which is produced by aerobic decomposition (carbon dioxide) is also "biogas" in the sense that it is also a result of biodegradation just as the other biogas is. But the word "biogas" has come to be used exclusively to denote the combustible CH_4–CO_2 mixture (besides traces of other gases) that is generated by the anaerobic decomposition of organic matter. Biogas has good calorific value, though lesser than LPG and CNG (Table 1.1).

It must be mentioned that a mixture of CH_4 and CO_2 is not the only gas possible by anaerobic degradation of organic matter. Of the two, methane is produced only if methanogenic bacteria are involved in the anaerobic decomposition. Under different conditions, and with other species of anaerobic micro-organisms, gases such as hydrogen

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Table 1.1 Comparison of the calorific values of various fuels (MNRE 2011)

Fuel	Calorific value (approximate)
Natural gas	8,600 kcal m^{-3}
Liquefied petroleum gas	10,800 kcal kg^{-1}
Kerosene	10,300 kcal kg^{-1}
Diesel	10,700 kcal kg^{-1}
Biogas	5,000 kcal m^{-3}

and hydrogen sulphide may be generated instead of methane. But methanogenic bacteria occur very commonly in nature and in most instances anaerobic digestion does result in the generation of the predominantly CH_4–CO_2 mixture which is widely referred as "biogas."

Since the early years of the twentieth century, developing countries, notably China and India, had recognized the value of obtaining biogas from animal dung as a source of energy for the rural poor. From 1950s onwards these countries have made particularly strong efforts to popularize the use of "biogas plants." But till the start of the 1970s, developed countries had paid little attention towards utilizing the biogas that was generated in the course of anaerobic treatment carried out by them of sewage sludge, animal manure, high-strength wastes, etc., because in developed countries at that time energy from fossil fuel and other conventional sources was abundant as well as cheap. Quite often the biogas generated from anaerobic digesters was simply flared off! Also, wastewater treatment was predominantly based on aerobic processes which consume a great deal of energy but do not generate any. This situation began to change slowly after the "oil shocks" of 1969 and 1973. More attempts were made than before to shift to anaerobic processes as far as possible as also to use the methane that was generated. As detailed later, several "high-rate" anaerobic reactors were developed to circumvent the major short-coming – the slowness – of conventional anaerobic digesters, in an endeavour to treat larger quantities of wastewaters with anaerobic processes.

1.2 How is Biogas Generated?

Anaerobic digestion involves bacterial fermentation of organic wastes in the absence of free oxygen. The fermentation leads to the breakdown of complex biodegradable organics in a four-stage process (Fig. 1.1):

1. Large protein macromolecules, fats, and carbohydrate polymers (such as cellulose and starch) are broken down through hydrolysis to amino acids, long-chain fatty acids, and sugars.
2. These products are then fermented during acidogenesis to form volatile fatty acids, principally lactic, propionic, butyric, and valeric acid.
3. In acetogenesis, bacteria consume these fermentation products and generate acetic acid, carbon dioxide, and hydrogen.

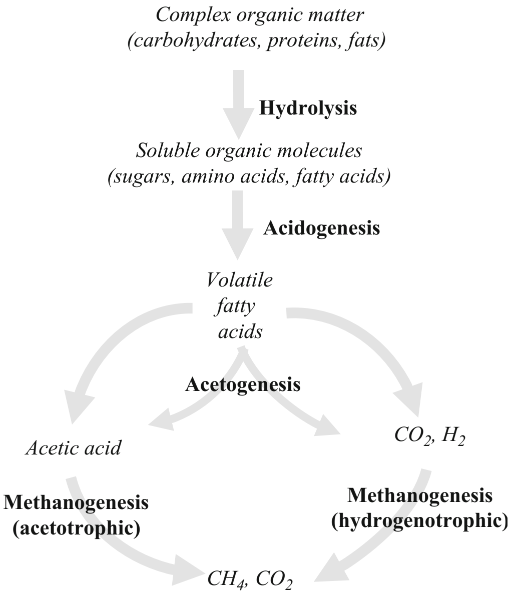

Fig. 1.1 The steps involved in anaerobic digestion (adopted from Rapport et al. 2008)

4. Methanogenic organisms consume the acetate, hydrogen, and some of the carbon dioxide to produce methane. Three biochemical pathways are used by methanogens to achieve this: (a) acetotrophic pathway ($4CH_3COOH \rightarrow 4CO_2 + 4CH_4$), (b) hydrogenotrophic pathway ($CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$), and (c) methylotrophic pathway ($4CH_3OH + 6H_2 \rightarrow 3CH_4 + 2H_2O$).

Methylated substrates other than methanol can also be converted. Acetotrophic pathway is the primary one; hence, theoretical yield calculations are often made using this pathway.

Theoretically, biogas should contain equal volumes (50–50) of methane and carbon dioxide. However, acetogenesis typically produces some hydrogen, and for every four moles of hydrogen consumed by hydrogenotrophic methanogens a mole of carbon dioxide is converted to methane. Fats and proteins can yield larger amounts of hydrogen leading to higher typical methane content for these substrates. In certain conditions, these molecules can also get converted to products other than methane. Therefore, the overall biogas yield and methane content varies for different substrates, biological consortia and digester conditions. The methane content of biogas can range from 40–70% (by volume) but more often than not it is in 55–65% range.

Wherever biogas is generated – be it from organic matter decomposing under anaerobic conditions in the open, or in captive anaerobic digesters, or in the guts of large ruminant animals, or by termites and some other smaller organisms – these four steps are principally involved. If the process is properly controlled in reactors so that it proceeds optimally as per these stages, the principal end product, the biogas, contains 40–70% (by volume) of methane gas, the rest being carbon dioxide

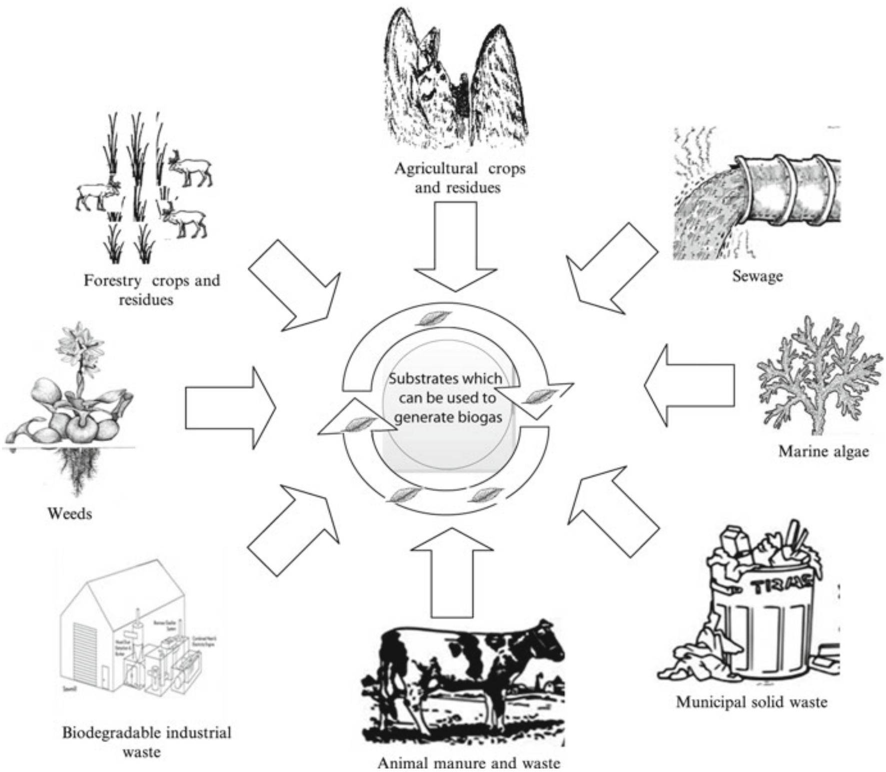

Fig. 1.2 Examples of substrates which can be anaerobically digested to generate biogas

and traces of ammonia, hydrogen sulphide, and hydrogen. This "biogas," which is a convenient and clean fuel, can either be used directly with or without the removal of carbon dioxide or can be converted into electricity with the help of suitable generators. A wide variety of substrates can be used to generate biogas (Fig. 1.2).

Three physiological groups of bacteria are involved in the anaerobic conversion of organic materials. As illustrated in Fig. 1.1, the first group of hydrolysing and fermenting bacteria convert complex organic materials such as carbohydrates, proteins and lipids to fatty acids, alcohols, carbon dioxide, ammonia, and hydrogen. The second group of hydrogen-producing acetogenic bacteria convert the product of the first group into hydrogen, carbon dioxide, and acetic acid. The third group, in turn, consists of two physiologically different groups of methane-forming bacteria, one converting hydrogen and carbon dioxide to methane, and the other forming methane from decarboxylation of acetate (Balch et al. 1979; Boone and Bryant 1980; Bryant et al. 1967; Mah et al. 1977; McInerney et al. 1979; Mosey 1983; Hansson 1981; Nagar and Tietjen 1978; Abbasi and Abbasi 2011). The reactions and the bacteria generally involved in the anaerobic processes are presented in Table 1.2.