ENERGY FROM WASTES SERIES

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Methane Production from Agricultural and Domestic Wastes

P. N. Hobson
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APPLIED SCIENCE PUBLISHERS

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P. N. HOBSON, S. BOUSFIELD
and R. SUMMERS

Microbiology Department, Rowett Research Institute, Aberdeen, UK

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Methane Production from Agricultural and Domestic Wastes

ENERGY FROM WASTES SERIES

Editor

ANDREW PORTEOUS
Reader in Engineering Mechanics
The Open University
Walton Hall, Milton Keynes, UK

Foreword

This volume in the Energy from Wastes Series covers the area of methane production from agricultural and domestic wastes. Principally this involves the conversion of excreta and other organic effluents to a valuable gaseous fuel plus, in many cases, a useful sludge for fertiliser or feedstuffs.

Dr Hobson and his colleagues have written a comprehensive text on the principles of microbiological processes and the biochemistry of anaerobic digestion, embracing the design of digesters with examples of current working installations. The potential for anaerobic digestion of wastes as diverse as sewage to fruit processing effluents is also reviewed.

This work should be of interest to all who have to manage organic waste treatment and disposal, as well as to a wider readership who wish to know more about methane production by anaerobic digestion.

ANDREW PORTEOUS

Preface

The production of methane, or more exactly, a flammable 'biogas' containing methane and carbon dioxide, by microbiological methods ('anaerobic digestion') is not new. The reactions have been in industrial use for over a hundred years, but only in sewage purification processes. In some times of national stress, such as war-time, the microbiological production of gas purely for fuel has been investigated, but with the resumption of plentiful supplies of fossil fuels the investigations have faded away. The idea that fossil fuels, particularly oil, were apparently able to supply man's needs made the search for other sources of energy not worthwhile, particularly as the other energy sources were seen to be more expensive than oil. But the growing awareness in the last few years that oil supplies will not last for ever, and that while many new sources of oil remain to be exploited the oil will be costly, has led to an increased interest in the production of energy from that inexhaustible source the sun, either directly or through the agency of the converters of sunlight into energy sources—the plants and animals of the earth.

These latter materials, 'biomass', can be converted into fuels by chemical and physical processes, but microbiological processes have the advantage of being possible on any scale and taking place at low temperatures and pressures. The microbiological process most near to widespread practical use is the production of biogas, and this book surveys the present state of the process.

Whereas a few years ago there were relatively few accounts of work on the subject, in the last few years the tempo of investigation has increased and many papers in journals and at symposia are devoted to the results of investigations. To quote them all would take a much bigger book than this. Some selection has been made, some work may have been overlooked, but the references given can lead the reader deeper into the subject. This is particularly so in the consideration of the microbiology of the process where only a brief review of the bacteria and their reactions is possible.

As a whole, the book tries to describe the basis of the biological and engineering problems involved in design and running of digesters and how laboratory and pilot-plant work is now being developed into full-scale plant for commercial production of biogas from many different kinds of organic matter.

The Aberdeen work on agricultural-waste digestion has been a collaboration between the Microbiology Department of the Rowett Research Institute and, initially, the Scottish Farm Buildings Investigation Unit and, latterly, the Engineering Division, of the North of Scotland College of Agriculture. The principal workers are named in the various papers quoted which describe the work, but Mr J. Clark took part in the initial experiments and Mr I. Auld and Mr D. Clouston have done the day-to-day work on the farm-scale digesters and kept records of their performance for many years.

P. N. Hobson
S. Bousfield
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Contents

CHAPTER 1

Introduction

As the scope of man's activities has increased, so has his need for energy. The simple needs of a primitive society, whether of long ago or today, can be met by the use of human or animal energy for mechanical tasks and by the use of wood or dried plant residues or animal excreta as a source of heat energy. And the needs of quite advanced civilisations can be also met with these simple energy sources: our own great cathedrals and castles, the cities of the ancient East and the South and Central Americas were built with human or animal energy alone. But life with these energy sources was slow; a cathedral or a pyramid took years to build and generations passed as some great cities took shape.

The invention and perfecting of the steam engine was the beginning of the increased pace of life in a large part of the earth and the beginning of the demand for large supplies of 'concentrated' energy. The engine could provide in a small space the energy of dozens of men or horses, but to do this it had in turn to be supplied with a source of this energy—something that could, by burning, supply large amounts of heat to generate steam. This source of energy was sometimes wood, but more generally coal, and so was developed a civilisation based on coal as a primary energy source. It was also found that coal could be turned into another source of energy, coal gas, and the era of gas lights and gas engines began. The steam engine and later, the steam turbine, could also generate the newly discovered electricity in large amounts and electricity superseded gas as a lighting agent, and it could also be used to provide mechanical energy through electric motors.

However, although steam engines and turbines could be made very powerful, their use was limited by the large amount of the primary energy source that they required, and this limitation was particularly marked in the supply of energy for movement of people and goods. A ship could carry hundreds of tons of coal and undertake journeys of thousands of miles and days or weeks in extent. A land vehicle, such as a tractor or lorry, was limited to a ton or so and could go only a few miles without refuelling. Even a railway locomotive could go for only a short time without a refuel, although it could carry some tons of coal. And although some steam-powered models were made, a full-size aircraft driven by steam was an impossibility, largely because of the weight of fuel needed.

Then came oil for lighting and the invention of the internal combustion engine. Because the burning of the fuel was the actual driving force of the engine, this did away with the cumbersome boiler of the steam engine, and the fuel was lighter and easier to handle than coal. Thus lighter and faster land vehicles were made and powered aircraft were possible. Based on oil have developed the transport systems of the present day, and oil has replaced coal as an energy source in many static systems, such as the electricity-generating station.

However, resources of oil and natural gas are finite and although there are coal reserves to last for hundreds of years, supplies of these fossil fuels will become scarcer. These fuels came originally from plant and animal life and while the processes that made them ceased millions of years ago, plants and animals still exist and continually renew themselves. Although the processes that led to coal and oil formation are still going on to some extent as life forms die and decay, the processes cover such a time span that the reserves of coal and oil are virtually non-renewable; indeed, the geological conditions which led to the formation of vast coal and oil fields may never occur again. Even peat, which is a form of decayed vegetation probably formed over a much shorter period than the coal–oil measures is non-renewable.

Vegetation and animals were the source of the fossil fuels, but the only way in which they can now form energy sources is when used immediately, without the aeons of decay and transformation in the earth which led to the fossil fuels. Because vegetation and animal life renews itself month by month and year by year it would seem to form an inexhaustible supply of energy. But it has drawbacks. Burning is the only way of obtaining energy directly from vegetation, but only in limited circumstances will it burn, and as was said before it is bulky and unsuited to most modern energy requirements. Only after some form of conversion process will freshly dead vegetation and animals give fuels which can be used for modern energy requirements, and forecasts of shortages of fossil fuels have revitalised research into ways in which such conversions can be carried out.

While calculations of the total biomass available on earth show that there are vast amounts and that these could in theory yield a large proportion, or even all, of the energy requirements of man, in practice there are many reasons why this full potential can never be exploited. This book deals with one method of converting renewable biomass to a 'concentrated' and easily utilisable source of energy, a gas, but it does not suggest that this could be a major source of world energy, the fossil fuels and atomic power will have to be that in the near future. The authors see the process and the gas as an additive to present energy sources and a substitute for these in certain circumstances. No attempt is made to calculate the total masses of feedstock available or the gas that could be generated if all this were used. At the present stage of development such figures are purely theoretical and largely meaningless. Developmental work needs to be done with full-scale plants to solve engineering problems, but the economics will take care of themselves. As energy increases in cost and scarcity, what were once processes that were not economically viable when set against the cost of plentiful and cheap oil become economically worthwhile.

CHAPTER 2

Methods of Production of Fuels from Biomass

'Biomass' can be described as organic material, organic in the sense of being, or being obtained from, living organisms; be these macro-vegetation and macro-organisms, or micro-organisms. The biomass contains carbohydrates, proteins, lipids, nucleic acids, non-protein nitrogenous compounds, and salts, but to obtain useful energy-containing compounds these have to be converted into a limited number of compounds of carbon, hydrogen and oxygen—carbon itself, carbon monoxide, hydrogen, methane or higher gaseous or liquid paraffins and olefins and alcohols. The nitrogen and sulphur in proteins and other compounds are, so far as energy production is concerned, only a source of impurities in the fuels which can eventually lead to problems of pollution or corrosion in the use of the fuels.

There are two methods of producing fuels from biomass; one involves the use of physical or chemical processes at high temperature and/or pressure, the other involves the use of micro-organisms at low temperature and atmospheric pressure. Although in some cases a chemical process is a preliminary to a microbiological one, the chemical processes involved do not call for, at the most, temperatures and pressure beyond those of wet steam.

There are two other differences between the physical and biological processes in that whilst dry material can be used for physical processes, and is essential in some cases, the biological reactions must always be carried out on material that is at least damp or more generally very wet or in solution or suspension in water. However, although a wet feedstock carries penalties in the form of a large proportion of inert material, most biomass is wet; even apparently solid vegetable and animal structures are some 80% water. So the fact that microbiological processes need a wet feedstock makes them more generally applicable than the physical processes which need a dry feedstock.

PHYSICAL AND PHYSICO-CHEMICAL METHODS

The direct way of producing energy from biomass is by burning it in the presence of excess air and so oxidising the carbon- and hydrogen-containing compounds to carbon dioxide and water. Whilst this is quite possible with some dry materials such as woods, straws and other crop residues, and materials such as paper, made from vegetation, in general the substances are not good fuels in that their density is low and their calorific value is low compared with their volume. Such materials are used, though, particularly on sites where they are a waste from some manufacturing process and their availability and low cost outweigh their disadvantages as fuels. An example is bagasse, the sugar-cane residue, which is used as fuel in factories producing sugar from the cane.

The indirect way of producing energy from biomass is to convert it into a fuel of high calorific value which can be more readily transported or otherwise distributed. This means producing a liquid or a gaseous fuel. Methods of doing this by physical or physico-chemical processes involve either pyrolysis or hydrogenation. These methods and combustion processes will be described in other volumes in this series, but for comparison with the microbiological processes it might be mentioned that pyrolysis and hydrogenation produce mixtures of gases along with oils and carbonaceous char. To obtain full energy recovery all these products must be utilised in some way and the gases can often only be used with special burners. However, a principal drawback to these processes is the high temperatures and pressures involved. These necessitate heavy plant, unsuitable for use on a small scale, on a farm for instance.

For universal use and for the utilisation of as much as possible of the biomass available, methods which can be used on a variety of scales from small to very large are needed, and these methods are provided by biological processes.

BIOLOGICAL METHODS

Biological methods for fuel production are all based on the use of micro-organisms, with or without some additional chemical or physical process.

These methods lead to either a liquid or a gaseous fuel, and the processes being currently experimented on or developed commercially are for the production of the liquid, 'alcohol' (ethanol) or the gases methane and hydrogen.

Production of ethanol by microbiological processes is, of course, as old as mankind, as this is the production of alcoholic drinks. The production of ethanol for use as a petrol substitute is now occurring in Brazil and the substrate used is sucrose. The Brazilian climate is such that sugar cane can be grown on a large scale and production of sugar and subsequently ethanol on a scale commensurate with its use as a petrol substitute is feasible. However, the process is not straightforward, the principal difficulty being that the yeasts which produce ethanol are themselves inhibited by ethanol. Thus the fermentation can produce an aqueous liquid containing only some 10–20 % of ethanol. For use as a fuel (or indeed as a high-alcohol-content drink) the ethanol must be concentrated from this aqueous solution by distillation, and distillation is a high-energy-input process. Much effort is now being devoted to increasing the alcohol content in the fermentation and reducing the energy input to distillations or finding means other than distillation for concentrating the alcohol.

In other countries, starchy substrates such as cassava, or cellulosic materials such as domestic waste, are being examined as feedstocks for ethanol production. Here a two-stage process is needed with a preliminary chemical or enzymic hydrolysis of the polysaccharide before the resulting sugars are fermented to ethanol.

Hydrogen is a product of microbial metabolic reactions of various kinds. Hydrogen can be produced by anaerobic fermentation of sugars, as will be seen in the next chapter where its role as an intermediate in methane production is discussed. However, the conversion of the hydrogen contained in sugars to hydrogen gas is never quantitative; part of the hydrogen is contained in other products of the fermentations, various acids or ethanol, and such fermentations are not a really viable method for production of hydrogen as a fuel.

Hydrogen is also a product of photobiological reactions by some bacteria and algae. Although hydrogen production has been demonstrated in small-scale experiments, such systems are many years away from a practical proposition. There is still much work to be done on photobiological hydrogen production and besides practical difficulties there is the fact that experiments are being done in places such as California, an area of intense sunlight. Prospects for photobiological energy production would seem even less promising in a dull, cool country like Britain.

But if a gaseous fuel is to be produced, then methane has advantages over hydrogen. Methane can be burnt in conventional domestic or commercial gas fires or boilers, it can be easily piped and the heat produced by its combustion is, on a volumetric basis, some three times greater than that of hydrogen. And methane is the one gaseous fuel that has been produced microbiologically in large-scale plants for many years. Since this is so, one might ask why is there not more widespread use of microbially-produced methane, why are there not methane plants all around us, and why is the