ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XVIII [2020] | Fascicule 1 [February]

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665

[1.]James G. SPEIGHT, [2.]Ljiljana RADOVANOVIĆ

BIOGAS – A SUBSTITUTE FOR NATURAL GAS

[1.]CD&W Inc., Laramie, Wyoming, USA
[2.]University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, SERBIA

Abstract: Biogas is a combustible mixture of gases and consists mainly of methane (CH4) and carbon dioxide (CO2) and is formed from the anaerobic bacterial decomposition of organic compounds, i.e. without oxygen. The gases formed are the waste products of the respiration of these decomposer microorganisms and the composition of the gases depends on the substance that is being decomposed. If the material consists of mainly carbohydrates, such as glucose and other simple sugars and high-molecular compounds (polymers) such as cellulose and hemicellulose, the methane production is low. However, if the fat content is high, the methane production is likewise high. This paper presents an overview of biogas in terms of production, composition, and use.
Keywords: biogas, origin, composition, cleaning, applications, the future

1. INTRODUCTION

As the need for the replacement of fossil fuels as energy sources continues to grow, gases products from other sources (such as biomass) will continue to grow in importance. In fact, biomass will play an increasingly important role in the future global energy infrastructure for the generation of power and heat, but also in the production of gaseous and liquid products for the production of fuels and chemicals and fuels. Biomass is a source of alternative energy insofar as it can be used for fuel substitution and is (unlike the fossil fuels sources) a non-depleted resource which can be renewed and o annual basis.

The dominant biomass conversion technologies will be anaerobic digestion, gas from landfills, pyrolysis gas, and gasification of biomass, with gasification processes likely to supersede anaerobic digestion for the production of gases as intermediates for high-efficient power production or for the synthesis of chemicals and fuels.

Isolation of the gas produced from the organic waste in a landfill will also be of extremely high interest. Furthermore, in the discussion on the production of gases from biomass (other forms of organic feedstocks, such as organic waste are also included here), it is important to understand that the composition of the produced gas is very dependent on the type of gasification process and especially the gasification temperature and the predominance of the various reactions [1-5].

2. BIOGAS

Biogas is a combustible mixture of gases and consists mainly of methane (CH_4) and carbon dioxide (CO_2) and is formed from the anaerobic bacterial decomposition of organic compounds, i.e. without oxygen. The gases formed are the waste products of the respiration of these decomposer microorganisms and the composition of the gases depends on the substance that is being decomposed. If the material consists of mainly carbohydrates, such as glucose and other simple sugars and high-molecular compounds (polymers) such as cellulose and hemicellulose, the methane production is low. However, if the fat content is high, the methane production is likewise high.

Methane – a colorless and odorless gas with a boiling point of -162°C (-260°F) and it burns with a blue flame – is the major combustible constituents of biogas. Methane is also the main constituent (77 to 90%) of natural gas. Chemically, methane belongs to the alkane series of hydrocarbons and is the simplest possible member of this series (C_nH_{2n+2}) form of these.

At normal temperature and pressure, methane has a density of on the order of 0.66 to 0.72 g/L in the gas phase or 0.42 g/L in the liquid phase. Due to carbon dioxide being somewhat higher density, biogas has a slightly higher density than methane and is on the order of 1.15 g/liter. If biogas is mixed with 10 to 20% air, there is the high probability of an explosion – explosive air is the name often applied to such a mixture.

3. ORIGIN

Biogas originates from the metabolic activities of bacteria in the process of biodegradation of organic material under anaerobic conditions (conditions without air and sometime referred to as fermentation). Thus, the natural generation of biogas is an important part of the biogeochemical carbon cycle, which is a pathway by which a chemical substance moves through the biosphere and lithosphere, atmosphere, and hydrosphere of the Earth. In addition to natural systems, biogas is produced in different anthropogenic environments such as landfills, waste water treatment plants (WWTP), and biowaste digesters during anaerobic degradation of organic material.

Biogas is typically produced by anaerobic digestion (also called anaerobic fermentation) of various feedstocks (Table 1, Table 2), although other processes are known, which involves the activities of three different bacterial communities. In the biogeochemical cycle, methanogens (methane-producing bacteria) are the final link in a chain of micro-organisms which degrade organic material and return the decomposition products to the environment. It is in this process that biogas is generated and the constituents of biogas – methane, hydrogen, and carbon monoxide – can be combusted or oxidized with oxygen and it is this energy release which allows biogas to be used as a fuel. Biogas can be used as a low-cost fuel in any country for any heating purpose, such as cooking, and it can also be utilized in modern waste management facilities where it can be used to run any type of heat engine, to generate either mechanical or electrical power [6-8].

Table 1. Composition of Various Biogas Samples

Component	Source		
	Household waste	Wastewater treatment plant sludge	Agricultural waste
Methane, % v/v	50 - 60	60 - 75	60 - 75
Carbon dioxide, % v/v	38 - 34	33 - 19	33 - 19
Nitrogen, % v/	5 - 0	1 - 0	1 - 0
Oxygen, % v/v	0 - 1	< 0.5	< 0.5
Water, % v/v	6	6	6
Hydrogen sulfide, mg/m³	100 - 900	1000 - 4000	3000 - 10 000
Ammonia, mg/m³	-	-	50 - 100
Aromatics mg/m³	0 - 200	-	-
Properties:			
Density*	0.93		0.85
Wobbe index**	6.9		8.1

*Natural gas: 0.57; **Natural gas: 14.9

Table 2. Simplified Illustration of the Generation of Biogas

Substrate	Stage 1 products	Stage 2 products	Stage 3 products*
Organic waste	Carbon dioxide		Carbon dioxide
	Acetic acid		Methane
	Propionic acid	Carbon dioxide	Carbon dioxide
		Acetic acid	Methane
		Carbon dioxide	Carbon dioxide
	Butyric acid	Acetic acid	Methane
		Carbon dioxide	Carbon dioxide
		Acetic acid	Methane
Stage 1 catalyst: fermentive bacteria			
Stage 2 catalyst: acetogenic bacteria			
Stage 3 catalyst: methanogenic bacteria			
* Hydrogen is also produced in minor quantities in each stage			

The process of biogas-production depends on various parameters [9-11]. For example, changes in ambient temperature can have a negative effect on bacterial activity. The microbes that produce biogas microbes consist of a large group of complex and differently acting microbe species, notably the methane-producing bacteria. The whole biogas-process can be divided into four steps: hydrolysis, acidification, acetogenesis, and methane formation. As a result of these four steps, biogas typically from different digestible sources contains constituents that can range considerably – up to 70% v/v methane and as much as 45% v/v carbon dioxide when the methane contact is lower.

Depending on the source, biogas can also contain, e.g., nitrogen, hydrogen sulfide, halogenated compounds and organic silicon compounds.

4. COMPOSITION

The composition of biogas is highly variable, especially when compared to the composition of natural gas (Table 3). For example, biogas from sewage digesters usually contains from 55 to 65% v/v methane, 35 to 45% v/v carbon dioxide, and <1% nitrogen whereas biogas from organic waste digesters usually contains from 60 to 70% methane, 30 to 40% carbon dioxide and <1% v/v nitrogen, while in biogas from landfills typically from 45 to 55% v/v methane, 30 to 40% v/v carbon dioxide, and 5 to 15% v/v nitrogen. Besides the main components, biogas also contains hydrogen sulfide and other sulfide compounds, aromatic compounds, and halogenated compounds, and siloxane derivatives. The latter compounds (i.e. halogenated compounds, and siloxane derivatives) are more common in landfill biogas than in biogas from the anaerobic digestion of manure (unless the livestock have been on a very mysterious diet).

Table 3. Ranges of Composition of Biogas Compared to Landfill Gas (also a biogas) and Natural Gas

	Anaerobic digester gas	Landfill gas	Natural gas
Density	1.1	1.3	0.82
Relative density (air = 1.0)	0.9	1.1	0.63
Wobbe index	27	18	55
Methane number*	>135	>130	73
Methane, % v/v	60-70	35-65	85-92
Heavy hydrocarbons	0	0	9
Hydrogen, % v/v	0	0-3	-
Carbon dioxide, % v/v	30-40	15-40	0.2-1.5
Nitrogen, % v/v	-	5-40	0.3-1.0
Oxygen, % v/v	-	0-5	-
Hydrogen sulphide, ppm v/v	0-4000	0-100	1.1-5.9
Ammonia, ppm v/v	100	5	-
Total chlorine, ppm v/v	0-5	20-200	-

*A measure of the gas resistance to knocking in an internal combustion engine; see Malenshek, M., and Olen, D.B. 2009. Methane Number Testing of Alternative Gaseous Fuels. Fuel, 88: 650-656.

Although the amounts of trace compounds are low compared to methane, they can have environmental impacts such as stratospheric ozone depletion, the greenhouse effect and/or the reduction in local air quality. In addition, some compounds cause engine damage leading to engine failure if the gas is used as an energy source. Many volatile organic compounds (VOCs) with high vapor pressure and low solubility, which can occur in biogas from some sources, are harmful to the environment and/or to human health. For example, aromatic derivatives, heterocyclic compounds, ketone derivatives, aliphatic derivatives, terpene derivatives, alcohol derivatives, and halogenated aliphatic derivatives, for example, occur in particular in landfill gas [12-16]. Also, many toxic volatile organic compounds are formed from household waste which includes cleaning compounds, plastics, synthetic textiles, coatings, pesticide derivatives, and pharmaceutical derivatives, [17].

The predominant sulfur compound in biogases is hydrogen sulfide (H2S) but other sulfur compounds such as sulfide derivatives (-S-, including hydrogen sulfide, disulfide derivatives (-S-S-), and thiol derivatives (-SH, also called mercaptans) can also occur in biogas. In the presence of water, sulfur compounds can cause corrosion to compressors, gas storage tanks and engines and, thus, these compounds need to be removed before biogas can be utilized as energy. Under anaerobic conditions hydrogen sulfide and other sulfide compounds originate along several different pathways [18]. For example, methanethiol (CH_3SH) and dimethyl sulfide (DMS, CH_3SCH_3) are formed by the degradation of sulfur-containing amino acids such as cysteine ($HO_2CCH(NH_2)CH_2SH$) that may be present in manure.

5. CLEANING

Biogas cleaning, which is the first step in the biogas upgrading process, has gained increased attention due to the recognition that as conventional fossil fuel sources of gas are being depleted the sources of biogas – the various forms of biomass – offer an unlimited supply of feedstocks for the production of the gas. It is therefore important to have an optimized upgrading process in terms yielding high methane content in the upgraded gas [11,19-21]. It is also very important to minimize, or if possible avoid, emissions of methane during the upgrading process, since methane has a greenhouse gas effect that is twenty three times greater than the greenhouse gas effect of carbon dioxide.

Biogas can be cleaned in a conventional gas processing facility with the recognition that the main difference in the composition between biogas and natural gas relates to the carbon dioxide content. Carbon dioxide is one of the main components of biogas, while natural gas contains lower amounts carbon dioxide. In addition, natural gas also contains higher levels of hydrocarbons other than methane. These differences result in a lower energy content of biogas per unit volume compared to natural gas and by separating carbon dioxide from the biogas in an upgrading process, the energy content of upgraded biogas becomes comparable to natural gas.

Biogas from anaerobic digestion and landfills consists primarily of methane (CH_4) carbon dioxide (CO_2) (Table 3). Trace components that are often present in biogas are water vapor, hydrogen sulfide, siloxanes, hydrocarbons, ammonia, oxygen, carbon monoxide and nitrogen. The end result is that the biogas for use must be very clean to reach pipeline quality and must be of the correct composition for the gas distribution network to accept – any carbon dioxide, water, and hydrogen sulfide.

In order to transfer biogas into biomethane, two major steps are performed:

(i) a cleaning process to remove the trace components and

(ii) an upgrading process to adjust the calorific value (Table 4).

Upgrading is generally performed in order to meet the standards for use as vehicle fuel or for injection in the natural gas grid. Different methods for biogas cleaning and upgrading are used. They differ in functioning, the necessary quality conditions of the incoming gas, the efficiency and their operational bottlenecks. Condensation methods (demisters, cyclone separators or moisture traps) and drying methods (adsorption or absorption) are used to remove water in combination with foam and dust.

6. APPLICATIONS AND THE FUTURE

Biogas is considered to be a renewable resource because its production-and-use cycle is continuous, and it generates no net carbon dioxide. The gas is copious and is available from sources such as landfills, wastewater treatment facilities, and animal and agricultural waste. If fully consumed, the yield from existing organic waste streams could satisfy about 20% v/v of current natural gas use.

Biogas is currently applied as a heating and electricity fuel but is expected to find more advanced applications as a vehicular fuel gradually. The developing technology should not be viewed as a competition to the already existing conventional energy sources but rather a compliment to what is already existing and a sustainable environmental management scheme for the future. Additionally, to improve the awareness of a sustainable fuel, more demonstration plants should be set up.

In future investigations, analyses of synchronized process of co-digestion with substrates are needed to be executed and also researchers need to concentrate on multi stage anaerobic co-digestion with reduced cost through the selection of appropriate expertise. Purification of biogas is the major task behind the fixation of cost level, which should be analyzed in detail with methods like cryogenic upgradation and In situ methane enrichment. Further, the developing methods for upgrading and refinement of the produced biogas will receive major attention due to rapid increment in the price of fossil fuels.

Biogas production in the agricultural sector is a very fast growing market in Europe and finds increased interest in many parts of the world. In the next few decades, bioenergy will be the most significant renewable energy source, because it offers an economical attractive alternative to fossil fuels. The success of biogas production will come from the availability at low costs and the broad variety of usable forms of biogas for the production of heat, steam, electricity, and hydrogen and for the utilization as a vehicle fuel. Many sources, such as crops, grasses, leaves, manure, fruit, and vegetable wastes or algae can be use, and the process can be applied in small and large scales. This allows the production of biogas at any place in the world.

Finally, in order to improve the economic benefit of biogas production, the future trend will go to integrated concepts of different conversion processes, where biogas production will still be a significant part.

Note:

This paper is based on the paper presented at IIZS 2019 – The 9th International Conference on Industrial Engineering and Environmental Protection, organized by Technical Faculty “Mihajlo Pupin” Zrenjanin, University of Novi Sad, in Zrenjanin, SERBIA, in 03–04 October, 2019.

References

[1] Speight, J.G. 2013a. The Chemistry and Technology of Coal 3rd Edition. CRC-Taylor and Francis Group, Boca Raton, Florida.

[2] Speight, J.G. 2013b. Coal-Fired Power Generation Handbook. Scrivener Publishing, Beverly, Massachusetts.
[3] Speight, J.G. 2014a. The Chemistry and Technology of Petroleum 4th Edition. CRC-Taylor and Francis Group, Boca Raton, Florida.
[4] Speight, J.G. 2014b. Gasification of Unconventional Feedstocks. Gulf Professional.
[5] Luque, R., and Speight, J.G. (Editors). 2015. Gasification for Synthetic Fuel Production: Fundamentals, Processes, and Applications. Woodhead Publishing, Elsevier, Cambridge, United Kingdom.
[6] Bove R., and Lunghi P. 2005. Electric Power Generation from Biogas Using Traditional and Innovative Technologies. Energy Conversion & Management; 47, 1391- 1401, 2005.
[7] Budzianowski W. 2011. Sustainable Biogas Energy in Poland: Prospects and Challenges. Renewable and Sustainable Energy Reviews, 2011.
[8] Niemczewska, J. 2012. Characteristics of Utilization of Biogas Technology. Nafta-Gaz, LXVIII(5): 293-297.
[9] Weiland, P. 2010. Biogas Production: Current State and Perspectives. Appl. Microbiol. Biotechnol., 85(4): 849-60.
[10] Nasir, I.M., Mohd, Ghazi. T.I. and Omar, R. 2012. Anaerobic Digestion Technology in Livestock Manure Treatment for Biogas Production: A Review. Eng. Life Sci., 12(3): 258-69.
[11] Speight, J.G. 2019b. Biogas: Production and Properties. Nova Science publishers, New York.
[12] Allen, M. R., Braithwaite, A. & Hills, C. C. 1997. Trace Organic Compounds in Landfill Gas at Seven U.K. Waste Disposal Sites. Environ. Sci. Technol. 31: 1054-1061.
[13] Spiegel, R. J., Preston, J. L. & Trocciola J. C. 1997. Test results for fuel-cell operation on landfill gas. Energy 22: 777-786.
[14] Eklund, B., Anderson, E. P., Walker, B. L. & Burrows, D. B. 1998. Characterization of landfill gas composition at the fresh kills municipal solid-waste landfill. Environ. Sci. Technol. 32: 2233-2237.
[15] Shin, H-C., Park, J-W ., Park, K. & Song, H-C. 2002. Removal characteristics of trace compounds of landfill gas by activated carbon adsorption. Environ. Pollut. 119: 227-236.
[16] Jaffrin, A., Bentounes, N., Joan, A. M. & Makhlouf, S. 2003. Landfill Biogas for Heating Greenhouses and Providing Carbon Dioxide Supplement for Plant Growth. Biosyst. Eng. 86: 113-123.
[17] Reinhart, D. R 1993. A review of recent studies on the sources of hazardous compounds emitted from solid waste landfills: A U.S. experience. Waste Manage. Res. 11: 257-268.
[18] Wilber, C., and Murray, C. 1990. Odor Source Evaluation. Biocycle, 31(3): 68-72.
[19] Mokhatab, S., Poe, W.A., and Speight, J.G. 2006. Handbook of Natural Gas Transmission and Processing. Elsevier, Amsterdam, Netherlands.
[20] Persson M., Wellinger A. 2006. Biogas Upgrading and Utilization, IEA Bioenergy. International Energy Agency, London, United Kingdom.
[21] Speight, J.G. 2019a. Natural Gas: A Basic Handbook 2nd Edition. GPC Books, Elsevier, Gulf Publishing Company, Elsevier, Cambridge, Massachusetts.

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665

Faculty of Engineering Hunedoara,
5, Revolutiei, 331128, Hunedoara, ROMANIA
http://annals.fih.upt.ro