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Review article

Biohydrogen and Biogas – An overview on feedstocks and enhancement process

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ABSTRACT

Consumption of renewable fuels from carbon rich urban refuse is attracting core attention in the ongoing as well as upcoming research works,among which agricultural waste and municipal solid wastes (MSWs) are deliberate substrates which have issues on disposal, that can be manipulated toward the production of cleaner and versatile fuels such as biohydrogen and biogas, and also these gaseous fuels make distribution effortless, since they can be transported easily. Biohydrogen is the only carbon free fuel which ultimately oxidizes to give water as a by-product, and also it is a flexible and safe energy resource which can be utilized in all sectors globally. Biohydrogen can be converted into energy either through combustion or fuel cells to generate electricity, and further it releases explosive energy in heat engines. Biogas is a combination of two-thirds of methane (CH_4) and the rest is mostly carbon dioxide (CO_2) with traces of hydrogen sulfide which can be enriched to produce natural gas. Not only the gas but also the spent slurry can be enriched to be utilized as fertilizer for agricultural crops and hence promoting sustainable biomass production in the world. Both biogas and biohydrogen can be utilized to produce centralized or distributed power supply in rural and urban areas and are considered to be cost beneficial. In this review we focus on the insights into these two prominent gaseous fuels in order to draw more research and development toward producing a sustainable environment.

Contents

Abbreviations: AB, acetogenic bacteria; AD, anaerobic digestion; ADP, adenosine diphosphate; AFBR, anaerobic fluidized-bed reactor; ATP, adenosine triphosphate; BDS, Bio Digested Slurry; BOD, biological oxygen demand; Chl *a*, Chlorophyll *a*; Chl 700, Chlorophyll *a* P700, located in photosystem I, which absorbs light best at 700 (nm); Chl 680, Chlorophyll *a* P680, located in photosystem I, which absorbs light best at 680 (nm); CHP, Combined Heat and Power; C/N, carbon to nitrogen ration; CNG, Compressed Natural Gas; COD, chemical oxygen demand; CSTR, continuously stirred tank reactor; FD, ferridoxin; FD (ox), ferridoxin oxidized; FD (red), ferridoxin reduced; FRP, Fiber Glass Reinforced Plastic; GAC, granular activated carbon; HCNG, hydrogen and compressed natural gas; HPR, hydrogen production rates; HRT, hydraulic retention time; HSOW, high-solid organic wastes; IREDA, Indian Renewable Energy Development Agency Ltd; MEC, microbial electrolysis cell; MFC, microbial fuel cell; MS, Molecular Sieves; MSW, municipal solid waste; NAD, nicotinamide adenine dinucleotide; NADH, nicotinamide adenine dinucleotide (NAD) + hydrogen (H); NPQR, NADP/plastoquinone oxidoreductase; OFMSW, organic fraction of municipal solid wastes; OLR, organic loading rate; PAC, powder activated carbon; PBR, packed-bed reactor; PDMS, polydimethylsiloxane; PFOR, pyruvate ferredoxin flavodoxin oxidoreductase; PSI, Photo System I; PSII, Photo System II; PSA, pressure swing adsorption; PFR, Plug Flow Reactor; RDR, Rotary Drum Reactor; TS, total solids; USA, United States of America; UASB, up flow anaerobic sludge blanket; USD, United States Dollars; VFA, volatile fatty acids; VOC, Volatile Organic Compounds; VS, volatile solids.

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1. Introduction

Gaseous fuels are hydrocarbons, hydrogen and carbon monoxide mixtures present in gaseous state which forms the basis of potential heat energy or light energy that can be readily disseminated by means of pipes from the origin to the place of consumption. Gaseous fuels are in contrast to liquid fuels and solid fuels, though some gaseous fuels are liquefied for storage or transport. They have advantages over liquid and solid fuels in transportation and the dangers of spillage. Gaseous fuels are classified into two broad classes of fuel gases based on their sources, those found naturally and those manufactured from other materials. Manufactured gaseous fuels are those produced by man intervention, usually gasification. These gaseous fuels include coal gas, water gas, producer gas, syngas, wood gas, biohydrogen, uncompressed hydrogen or compressed hydrogen, biogas and blast furnace gas. Natural gas, composed primarily of methane, is the dominant source of fuel gas. Instead of being manufactured by various processes, it can be extracted from deposits in the earth. Natural gas can be combined with hydrogen (H_2) to form a mixture known as hydrogen and compressed natural gas (HCNG). This review focuses on the imminent production of manufactured gaseous fuels, biohydrogen and biogas.

2. Biohydrogen

Hydrogen has been recognized as one of the most potential and clean fuels for the sheer future, where it acts as a promising alternative to conventional fossil fuels which are fast depleting as it is being used indiscriminately and is detrimental to the surrounding environment as harmful gases are released on its combustion. Also biohydrogen is eco-friendly because it releases only water vapor and energy on combustion. Hydrogen has reached the succession in fuel evolution with promising technical and socioeconomic levels apart from its environmental benefits (does not contribute to greenhouse emissions, acid rain, ozone depletion and energy-linked environmental impacts). Also when studied, hydrogen has the highest energy content of 142 kJ/g or 61,000 Btu/lb of any known fuel. Today 40% of hydrogen is produced from natural gases, 30% from heavy oil and naphtha, 18% from coal, 4% from electrolysis and 1% from biomass. Hydrogen is used as either a direct combustion fuel for an internal combustion engine or as fuel for fuel cells. However, the largest hydrogen users are fertilizers and petroleum industries with 50% and 37% of consumption respectively. Due to the utilization of renewable energy resources, sustainability is achieved and considering the crisis of energy and environmental distress, biological hydrogen production at contiguous temperature and atmospheric pressure is receiving climbing attention in the current era [1–9]. Unlike chemical and electrochemical fuels, biological processes of producing hydrogen are catalyzed by microorganisms in an aqueous environment at optimal temperature and atmospheric pressure. The characteristics of these microorganisms widely differ from one another with respect to substrate and process conditions. Additionally, these techniques are much fitting for decentralized energy production in pilot-plant and its location where biomass and wastes are easily available, dodging energy expenditure and transport costs [10,11]. Biological systems for the production of biohydrogen are presented in Table 1.

2.1. Production methods of biohydrogen

The catalyzing chemical reaction of hydrogen production is represented in Eq. (1)

$$2H^+ + 2e^- \leftrightarrow H_2 \quad (1)$$

Table 1
Various biological systems for the production of biohydrogen.

Biosystem	Microorganism	Reference
Photobiological system (direct biophotolysis, indirect biophotolysis and photo-fermentation)	Photosynthetic bacteria	[3,12]
Dark fermentation system	Facultative and obligate bacteria	[10,13]
Hybrid system	Fermentative and photosynthetic bacteria	[14]
Hybrid system (use of bioelectrochemical assisted bioreactor)		[15]