Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Power Sources 141 (2005) 19–23
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Short communication

Hydrogen photosynthesis by *Rhodobacter capsulatus* and its coupling to a PEM fuel cell

Deliang He[a,1], Yann Bultel[a,*], Jean-Pierre Magnin[a], Claude Roux[a], John C. Willison[b]

[a] *Labora toire d'Electrochimie et de Physico-Chimie des Matériaux et des Interfaces, UMR 5631 CNRS-INPG-UJF, ENSEEG, BP 75, 38402 Saint Martin d'Hères, France*
[b] *Laboratoire de Biochimie et Biophysique des Systèmes Intégrés, DRDC/BBSI, CEA-Grenoble, 38054 Grenoble Cedex 9, France*

Received 25 March 2004; received in revised form 3 September 2004; accepted 3 September 2004

Abstract

Four different mutant strains of *Rhodobacter capsulatus* (IR1, IR3, IR4 and JP91), a photosynthetic purple non-sulfur bacterium, were tested for their ability to produce hydrogen in a 3 L volume photobioreactor coupled to a small PEM fuel cell. The four mutants, together with the wild-type strain, B10, were grown at 30 °C under illumination with 30 mmol L^{-1} DL-lactate and 5 mmol L^{-1} L-glutamate as carbon and nitrogen source, respectively. Bacterial growth was measured by monitoring the increase in absorbance at 660 nm, and hydrogen yield, and substrate conversion efficiency were measured under the same conditions. The hydrogen production capability of the five strains was then compared and shown to be in the order: IR3 > JP91 > IR4 > B10 > IR1. The most preferment strain, IR3, showed a substrate conversion efficiency of 84.8% and a hydrogen yield of 3.9 L L^{-1} of culture. The biogas produced by these photobioreactor cultures was successfully used as feed for a small PEM fuel cell system, with the mutant IR3 showing the most sustained hydrogen and current production. The maximum current was similar to that obtained using pure hydrogen produced by a small electrolysis cell (High-Tec Inc.).

Keywords: Photoproduction; Hydrogen; *Rhodobacter capsulatus*; Lactate; PEM fuel cell

1. Introduction

Hydrogen is a clean and efficient fuel, considered as a potential and more sustainable energy substitute for fossil fuels. It has been predicted that the contribution of hydrogen to global energy consumption will increase dramatically, to approximately 50%, by the end of the 21st century due to the development of efficient end-use technologies, possibly becoming the main final energy carrier. Also, it is undoubted that hydrogen will play a strategic role in the pursuit of a low-emission energy source for environmental demand [1,2].

To this end, it will be necessary for hydrogen to be produced renewably and on a large scale. The global hydrogen production system, initially fossil-fuel based, is shifting progressively toward renewable sources. The following technologies for the conversion of secondary and primary fuels into hydrogen are being investigated extensively: electrolysis, coal gasification, steam methane reforming of natural gas, partial oxidation of fuel oil, solar thermal cracking, biomass gasification and photobiological synthesis [1–5]. Biological hydrogen production stands out as an environmentally harmless process carried out under mild operating conditions with renewable resources. Currently, much research on hydrogen production is carried out with laboratory-scale or pilot-scale

* Corresponding author. Tel.: +33 476 82 65 80; fax: +33 476 82 67 77.
E-mail address: yann.bultel@lepmi.inpg.fr (Y. Bultel).
[1] Present address: College of Chemistry and Chemical Engineering, Hunan University, Changsha 410082, China.

0378-7753/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.jpowsour.2004.09.002

reactors using photosynthetic microorganisms [3–11]. Phototrophic purple non-sulfur bacteria, such as *Rhodobacter capsulatus*, are commonly utilized for hydrogen production from various carbon sources [12–20]. However, the production rate and the yield vary greatly depending on the carbon source used and the experimental, physiological conditions, such as light intensity or pH [15,21]. On the other hand, several studies have shown that mutant strains can be isolated and show improved hydrogen producing capabilities compared to the wild-type [22,23].

Four different mutants of *R. capsulatus* (IR1, IR3, IR4 and JP91), isolated in previous studies, as well as the wild-type strain, B10, were checked for photohydrogen production in a large culture volume (3 L) with 30 mmol L^{-1} DL-lactate provided as the carbon source and 5 mmol L^{-1} L-glutamate as the nitrogen source. The growth characteristics of these five strains were determined by monitoring the absorbance of the cultures at 660 nm and calculating the cell dry weight. The cultures were incubated at 30 °C and illuminated by two 120 W incandescent lamps placed at a distance of 1 m. The hydrogen yield and substrate conversion efficiency of each strain were measured and used to compare the hydrogen production capabilities of these four mutants and the wild-type B10.

We also checked the practicability of coupling the photohydrogen produced these bacterial cultures to the operation of a fuel cell. It is well known that fuel cells have significant potential to become an important element of the portfolio of options to meet ever-increasing demands for energy services while responding to more stringent reliability and power quality standards, mounting environmental constraints, cost-effectiveness pressures and other challenges that energy systems will face in the future [24]. In the present work, a small polymer electrolyte membrane fuel cell (PEMFC) was selected for further evaluation. Hydrogen was applied without purification and generated an efficient current response, indicating the potential of this system for future applications.

2. Experimental

Five strains of *R. capsulatus*, B10 (wild-type), IR1, IR3, IR4 and JP91, were tested in this study. The preparation of these mutants has been described before [22,23]. Precultures were grown photosynthetically at 30–32 °C in a mineral salts (RCV) medium supplemented with 30 mmol L^{-1} DL-malate and 7.5 mmol L^{-1} $(NH_4)_2SO_4$ as described previously [22,23]. The culture for absorbance measurements and the photohydrogen production contained 30 mmol L^{-1} DL-lactate as carbon source and 5 mmol L^{-1} L-glutamate as nitrogen source. The medium was autoclaved (120 min, 120 °C, 1.2 bar) before use. Rubber-stoppered glass bottles of 10 mL volume were used for cell growth of different strains of *R. capsulatus*. A water-jacketed glass reactor of 3.5 L liquid volume was used for hydrogen production. The volume of culture was 3 L. The schematic figure of the experimental setup is shown in Fig. 1. The temperature of the photobioreactor was controlled at 30 °C in a glass-sided water bath. Illumination was provided by two 120 W incandescent lamps placed at a distance of 1 m. To initiate growth of the culture, 20–30 mL pre-culture was inoculated into the bioreactor.

The flow rates of photohydrogen produced by the photobioreactor were measured with a mass flow controller coupled to a digital multi-meter, which was connected via RS232C to a compatible PC. The yields of biogas were determined by integrating the curves of flow rates against time. The bacterial cell concentration was determined spectrophotometrically, it was found that an absorbance at 660 nm of 1.0 is equivalent to a cell density of 0.45 g dry weight L^{-1} culture under our experimental conditions.

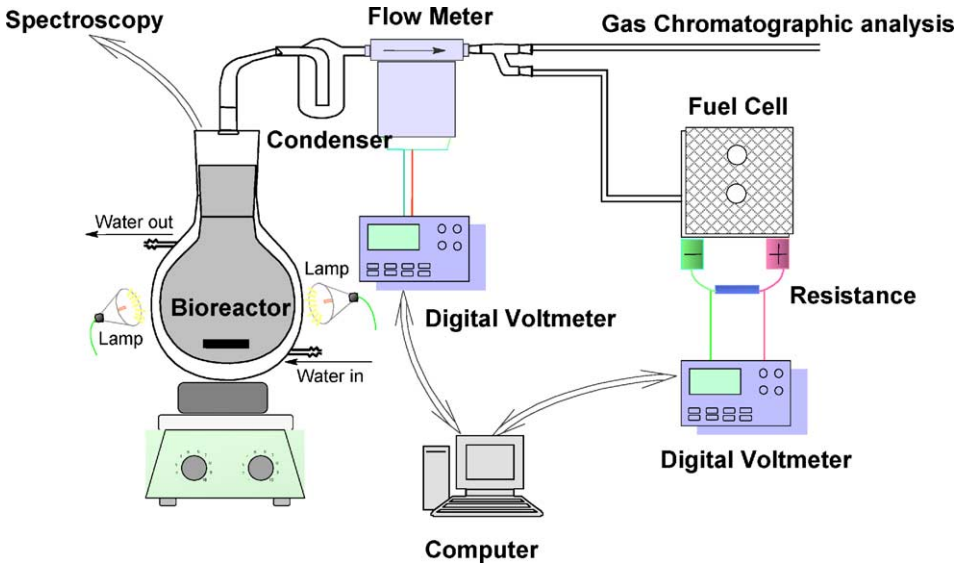

Fig. 1. Schematic diagram of the photohydrogen production and application system by *R. capsulatus*.