



Mass transfer modeling and maximization of hydrogen rhythmic production from genetically modified microalgae biomass



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ABSTRACT

A transient mathematical model for managing microalgae derived hydrogen production as a source of renewable energy is developed for a well stirred photobioreactor. The model allows for the determination of microalgae and hydrogen mass fractions produced by the photobioreactor with respect to time. A Michaelis–Menten type expression is proposed for modeling the rate of hydrogen production, which introduces a mathematical expression to calculate the resulting effect on H₂ production rate after genetically modifying the microalgae species. The so called indirect biophotolysis process was used. Therefore, a singular opportunity was identified to optimize the aerobic (t_1), to anaerobic (t_2), stages time ratio of the cycle for maximum H₂ production rate, i.e., the process rhythm. A system thermodynamic optimization is conducted through the complete model equations to find accurately the optimal system operating rhythm for maximum hydrogen production rate, and how wild and genetically modified species compare to each other. The maxima found are sharp, showing up to a ~60% variation in hydrogen production rate for $t_{2,opt} \pm 1$ day, which highlights the importance of system operation in optimal rhythm. Therefore, the model is expected to be useful for design, control and optimization of hydrogen production as a source of renewable energy.

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1. Introduction

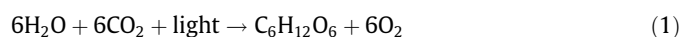
Microalgae derived hydrogen has been considered one possible environmentally correct alternative to supply a so called hydrogen economy. However, H₂ production has been demonstrated only at the laboratory scale, and the yield of H₂ is still low for commercial application. Therefore, the optimization of design and operating parameters for maximum H₂ production is a possible direction to address the issue of increasing hydrogen production rate.

A fully optimized system to produce hydrogen as a clean fuel, in an economically viable way, is still a dream. However, no matter how far from reach that goal is, many efforts are being conducted to achieve it. The first challenge is the production, which needs to depict a favorable cost-benefit relation. Next challenges are storage and distribution. Biological production of hydrogen technologies provide a wide range of approaches to generate hydrogen, including direct or indirect biophotolysis, photo or dark fermentations (or a process combining both) and hybrid biological hydrogen

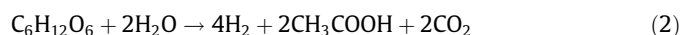
production by electrochemical processes [1–3]. Several microorganisms are able to produce biofuels like hydrogen, but recent studies have targeted cyanobacteria and green microalgae [1,4–8].

The indirect biophotolysis is a biological process to produce hydrogen. In this approach, hydrogen is produced from water using a system of microalgae photosynthesis to convert solar energy into chemical energy in the form of hydrogen through several steps: (i) biomass production by photosynthesis, (ii) biomass concentration, (iii) dark aerobic fermentation produces 4 mols of hydrogen/mol of glucose in the algal cells, together with 2 mols of acetate, and (iv) conversion of 2 mols of acetate into hydrogen [1]. The process is divided in three reactions, two of which depend on the light and the other is light independent. These reactions are written as follows [9]:

(stage 1 – aerobic)



(stage 2 – anaerobic)



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