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SYSTEMS FOR BIOHYDROGEN AND BIOELECTRICITY GENERATION: A CRUCIAL COMPONENT OF BIOREFINERIES

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Abstract

Biohydrogen is a sustainable option for energy as it can be produced from organic waste through fermentation processes involving dark fermentation and photofermentation. Very often biohydrogen is included as a part of biorefinery approaches that reclaim organic wastes. The latter are an abundant source of renewable and low cost substrate that can be efficiently fermented by microorganisms. The experience shows that series systems show a better efficiency than only one stage on substrate conversion to hydrogen. The aim of this paper is to review several topics related to fermentative biohydrogen and its combination with selected bioenergy processes: (i) biohydrogen by fermentative process, (ii) bioenergy from selected processes that can be combined with dark fermentation, such as microbial fuel cells and microbial electrolysis cells, (iii) biocatalysts relevant to fermentative biohydrogen and other bioenergy processes, (iv) increased bioenergy production from wastes by series and/or sequential processes based on dark fermentation and (v) trends on improvement of biohydrogen yields. Dark fermentation (DF) and photofermentation (PF) are the emblem fermentative processes that yield H₂ from organic matter. In DF about one third (at most) of the substrate is converted to hydrogen; desirable and economic substrates are organic wastes such as sewage, domestic and municipal, agro-industrial waste, etc. The use of these substrates as well as fermentative mixed cultures in DF is feasible and desirable since it has environmental and economic advantages compared to the use of pure strains and commercial, simple substrates such as glucose, etc. DF can also be conducted in solid substrate fermentation mode when the substrate is an organic solid waste. Besides its good process performance, there are other benefits of SSF such as avoiding leachate generation and treatment, application of high loading rates leading to compact size reactors and relatively small process footprint etc. Yet, DF might show low yields of biohydrogen due to process deviations such as lactic fermentation, methanogenic, acetogenic, and sulphate-reducing consumption of hydrogen, among other causes. Overcoming and/or preventing these deviations need more research.

As DF produces fermented by-products (fatty acids and solvents), there is an opportunity for further combining with other processes that yield more bioenergy. Photoheterotrophic fermentation is one of these processes. Special types of bacteria (photosynthetic heterotrophs such as non sulphur purple bacteria) can thrive on the simple organic substances produced in DF (low molecular weight organic acids, for instance) and light, to give more hydrogen. PF can be combined with DF in series, in sequence, or co-cultivation. It is estimated that DF combined with DF can increase the H₂ yield by 50% or more, depending on the substrate, lighting regime, and microbes.

DF provides a basic process for the development of large-scale to the production of H₂ and a significant process in biorefinery approaches. In both direct and inverse cascading schemes of biorefineries, DF biohydrogen can increase the clean energy harvesting from organic wastes. Increasing H₂ production yields is a significant task in present research agenda. This can be accomplished by increasing the biohydrogen or bioenergy harvesting with combined processes, by genetic modification of the biocatalysts involved and metabolic engineering, by good process engineering practice and scale up, among other measures.

DF combined with PF and MFC and MEC appear as an alternative capable of attaining this goal. So far, two stage systems seem to be good options which allow treatment in a first step by dark fermentation of higher concentrations of feedstock without sterilization. Lab scale tests have shown a significant gain of biohydrogen or bioenergy production for several substrates. However, nutrient concentrations (i.e., N) and dark color in the first stage effluents can be problematic for PH. In practice, effluent conditioning may be required (N removal, dilution, color removal, pH adjustment) before feeding to PH in order to overcome inhibitory effects. In addition, interesting experiments with sequential and co-cultivation of DF and PF have shown good results. H₂ yields in DF can be impaired by several factors such as lactic fermentation, methanogenesis, autotrophic acetogenesis, etc. Metabolic engineering and genetic applications to biohydrogen processes can significantly contribute to the improvement of microbial metabolic capabilities and boosting biological H₂ production and overcoming deviations. Although there has been significant progress, more studies are necessary. The design of full scale reactors and ancillary equipment for DF, PH, and other bioenergies, is lagging behind. So far no cost effective approach has been developed. Scale-up and demonstration projects of DF combined with other biohydrogen and bioenergy processes are a must if we want an early integration of these processes to biorefinery setups for increasing the sustainability of biorefineries.

Key words: biohydrogen, dark fermentation, organic wastes, photofermentation, review