Waste utilization for biohydrogen production through photobiological methods

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Considering the environmental issues and challenges that humanity faces in the 21st century, there is an enormous need for change of the global energy map. Under these circumstances, new energy sources have to be considered as an option, in order to limit the greenhouse gases emissions and climate change. Hydrogen is one of the most appealing options, due to its multiple applications and zero emissions as a fuel. Especially biohydrogen production offers a possible avenue for extensive sustainable generation of hydrogen in order to empower a future hydrogen circular economy. In this review, two photobiological hydrogen producing methods are presented: Biophotolysis and Photo-fermentation. There is an extended presentation of the major steps of these methods, the key factors and effecting parameters. Furthermore, there has been a literature database analysis, regarding different substrates (carbon source), operating conditions and biohydrogen production rates and yields. In this research, the center of our attention was the utilization of wastes as carbon source, which is a decisive factor for these systems.

Light illumination is a unique characteristic of photobiological systems, as it offers the energy needed, which is stored in the form of ATP (Ghosh et al, 2016). Furthermore, pH and temperature play a significant role, because they define the metabolic pathways of the microorganisms and their enzymes (Bolatkhan et al, 2019, Hay et al, 2013). It has to be mentioned that the operation mode and the photobioreactor type are crucial factors that determine mainly the productive ability of methods as well as the ability for industrial application. In order to achieve the best performance of biophotolysis and photo-fermentation, supplementation of chemical enhancers and nutrients is necessary, while at the same time the control of substances and elements that act as inhibitors must be performed properly (Budiman and Wu, 2018). For instance, oxygen is proved to be a serious inhibitor due to the fact that enzymes (hydrogenase and nitrogenase) used during these processes are oxygen-sensitive and its presence can cause severe problems in the production process. The last implementing factor is the C/N ratio that has to be adjusted to an optimal level which will result to significant growth of bacteria whereas this will not lead to inhibitions and limitations (Wu et al, 2012).

For implementing a circular-economy approach, different kinds of wastes can be utilized as a carbon source in order to produce biohydrogen. This admirable advantage of the photo-fermentative systems can lead to sustainable systems that both utilize wastes and produce a very valuable fuel. A wide variety of industrial wastes and their potential as feedstock in photo-fermentative systems has been studied, such as sugar beet molasses, blackstrap molasses, pulp and paper mill effluents, olive mill wastewaters and brewery wastewaters. Moreover, the pretreatment that wastes need, the conditions as well as biohydrogen yields have been studied. A sample of the literature data is presented in table 1:

Table 1: Biohydrogen production through waste utilization using PNS bacteria.

Substrate	Bacterial Strain	Pretreatment method	pH	Temperature	Light intensity	Biohydrogen Production	Reference
Soy sauce wastewater	Consortium of PNSB.	Autoclaving, dilution, pH neutralization	7	30	-	2,67 L H_2 / L	Ghosh et al (2016)
Brewery wastewaters	Rhodobacter sphaeroides O.U. 001	-	-	-	116 W / m^2	2,24 L H_2 / L	Rahman et al (2016)
Dairy wastewater	Rhodobacter sphaeroides O.U. 001	Filtration, autoclaving, refiltration, dilution	7-7,2	28 ± 2	-	8,6 L H_2 / L	Ghosh et al (2016)
Sugar beet molasses	Rhodobacter capsulatus JP91	-	7	30	-	10,5 mol H_2 / mol sucrose	Trchounian et al (2017)
POME combined with paper and pulp mill effluent	R. sphaeroides NCIMB8253	-	-	30	4000 lux	4,67 ml H_2 / ml	Boodhun et al (2017)

The contribution of genetic engineering and biotechnology can lead a path to enhance the bacteria biohydrogen productivity. Precisely, a genetic modification of some bacterial strains can minimize the oxygen sensitivity of nitrogenase and hydrogenase, which is one of the main inhibitory factors to photo-fermentation and biophotolysis (Allakhverdiev et al, 2010). Another approach for improving the efficiency of these biosystems is the implementation of hybrid systems like dark-photo fermentative systems. Dark fermentation is another biological fermentative process that can produce bio-hydrogen. During this process the substrate is being converted into hydrogen while VFAs (Volatile Fatty Acids like acetate and butyrate are also being produced. These organic byproducts (VFAs) from the dark-fermentative systems can be utilized through photo-fermentation as a carbon source for further biohydrogen production (Singh et al, 2015). By implementing this approach, the variety of wastes that can be utilized is broaden, while at the same time the waste conversion efficiency and hydrogen productivity is improved. This approach is a good step for expanding circular economy models with proper waste management and sustainable biohydrogen production, which can be converted into electrical or thermal energy.

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