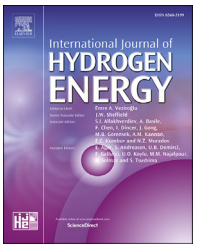
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–20

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he



Review Article

Coupling dark fermentation with biochemical or bioelectrochemical systems for enhanced bio-energy production: A review

Zumar M.A. Bundhoo

Department of Chemical & Environmental Engineering, Faculty of Engineering, University of Mauritius, Réduit, Mauritius

ARTICLE INFO

Article history:
Received 20 July 2017
Received in revised form
20 August 2017
Accepted 4 September 2017
Available online xxx

Keywords:
Dark fermentation
Anaerobic digestion
Photo fermentation
Microbial fuel cell
Microbial electrolysis cell
Bio-hydrogen

ABSTRACT

Dark fermentation (DF) is one of the most commonly studied techniques for bio-hydrogen production from biomass and waste materials. However, the relatively low H_2 yield has hampered its development on larger scale. As such, this study reviewed the potential of coupling the DF process with other biochemical techniques such as anaerobic digestion (AD) and photo fermentation (PF) or bioelectrochemical systems (BES) viz. microbial fuel cell (MFC) and microbial electrolysis cell (MEC) for maximising bio-energy production from DF effluent so as to enhance the potential of implementing the DF process on a larger scale. All the different systems reviewed assisted in enhanced bio-energy production with AD increasing the bio-energy recovery from 6.1% for single DF to 47.6% for coupled DF/AD while the two-stage DF/PF process enhanced bio-hydrogen production by 274% as opposed to single DF. Similarly, studies on integrating DF with MFC or MEC also resulted in additional bio-electricity and bio-hydrogen production respectively. Despite the obvious advantages of integrating the DF process with AD, PF, MFC or MEC, there are still some shortcomings as to the large-scale implementation of these coupled systems. These include the requirement of two or more bioreactors which represents an additional investment cost to the whole process. Other technical aspects include the use of pure H_2-producing cultures or pre-treated mixed cultures on large-scale and light requirement for PF systems that still warranty further research. Notwithstanding the shortcomings, the coupling of the DF process with at least the AD process seems the most potential two-stage system for enhanced bio-energy recovery on large scale.

Contents

E-mail address: zumar.bundhoo@gmail.com.
https://doi.org/10.1016/j.ijhydene.2017.09.050

Please cite this article in press as: Bundhoo ZMA, Coupling dark fermentation with biochemical or bioelectrochemical systems for enhanced bio-energy production: A review, International Journal of Hydrogen Energy (2017), https://doi.org/10.1016/j.ijhydene.2017.09.050

Introduction

Hydrogen has long been viewed as the "fuel of the future" owing to its clean nature [1], with several biological technologies subsequently being investigated for bio-hydrogen production. Among the different techniques studied, dark fermentation (DF) has been gaining increasing interests over the years for bio-hydrogen production from biomass and waste materials. However, the low bio-hydrogen yield from the DF process has hindered the implementation of the technology on large scale [2–4]. Consequently, several strategies have been studied in an attempt to increase the bio-hydrogen yield and bio-energy recovery from the DF process viz. metabolic engineering [5,6], the use of substrates pre-treatment technologies [7,8], reducing the H_2 partial pressure in the system [9,10], optimising process parameters such as pH and temperature and micronutrient concentrations [11–14], amongst others.

Another strategy that has been receiving much attention recently for improving bio-energy recovery is the integration of the DF process with a biochemical and/or bio-electrochemical technology. Common biochemical technologies that have been coupled with the DF process include the anaerobic digestion (AD) and photo fermentation (PF) processes while bioelectrochemical systems (BES) that have been combined with DF consist of microbial fuel cells (MFC) or microbial electrolysis cells (MEC). The aim of coupling these technologies is to assist in bio-energy (bio-methane, bio-hydrogen or bio-electricity) production following dark fermentative bio-hydrogen production, thus enhancing the net bio-energy production from the coupled technologies as opposed to standalone DF.

Currently, there exist some review articles on the integration of DF with AD [15–22] or PF [15,16,20,21,23–25] while review articles studying the combination of DF with BES [15,16,20,21] are fewer in literature. While these review articles do give an understanding of the combinations of these technologies, none of them have provided an in-depth comparison of the bio-energy production from standalone DF and when coupled with the other techniques. As such, the aim of this review article is to present a comprehensive understanding of the principles of the different technologies (DF, AD, PF, BES) while providing a comparative analysis on bio-energy recovery from standalone DF as opposed to the coupled systems. Finally, the article highlights some of the challenges of coupling two or more technologies for enhancing bio-energy recovery.

Principles of dark fermentation

DF is the acidogenic decomposition of organic matter in an oxygen-free environment and deprived from light to produce a biogas consisting of mainly bio-hydrogen and carbon-dioxide and an effluent comprising of end-product metabolites viz. acetic acid, butyric acid and ethanol, amongst others [24,26]. The bio-hydrogen yield as well as the composition of the DF effluent is highly dependent on the metabolic pathway taken by the microorganisms (pyruvate:formate lyase (Pfl) or pyruvate:ferredoxin oxidoreductase (Pfor)) [21,27]. The production of bio-hydrogen occurs through a succession of biochemical reactions [28], as illustrated in Fig. 1 [29]. Following hydrolysis of complex compounds, which may be assisted by the use of pre-treatment technologies, simpler molecules formed viz. glucose are then subjected to anaerobic degradation to produce nicotinamide adenine dinucleotide (NADH), pyruvate and adenosine triphosphate (ATP) [1,29]. The pyruvate, under the Pfl pathway, produces formate and acetyl-coenzyme A (acetyl CoA) by the action of coenzyme A (CoA-H) [1,27,29]. The formate is then oxidised to carbon dioxide and bio-hydrogen under the formate-hydrogen lyase pathway (NiFe-hydrogenase) or another pathway using a formate-dependent [FeFe] hydrogenase [1,21,29]. If the pyruvate is decomposed under the Pfor pathway, ferredoxin reductase (Fd_{red}) and acetyl CoA are produced by the action of ferredoxin oxidase (Fd_{ox}) and CoA-H [21,27,30]. The Fd_{red} is then oxidised to Fd_{ox} while simultaneously producing bio-hydrogen by a ferredoxin (Fd)-dependent hydrogenase (Fd-[FeFe]) [21,29,30]. Besides, bio-hydrogen can be produced using NADH through reduction of Fd to Fd_{red}, reduction of a hydrogenase (NADH-[FeFe]) or oxidation of the NADH by Fd-NADH-[FeFe] [1,21,29]. As for the acetyl CoA, these are converted to acetic acid, butyric acid and ethanol using NADH and are some of the components of DF effluents [1,31] while other end-products viz. propionate, butanol and lactate, amongst others may also be present [32].

Please cite this article in press as: Bundhoo ZMA, Coupling dark fermentation with biochemical or bioelectrochemical systems for enhanced bio-energy production: A review, International Journal of Hydrogen Energy (2017), https://doi.org/10.1016/j.ijhydene.2017.09.050