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Microbial electrosynthesis of solvents and alcoholic biofuels from nutrient waste: A review

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A B S T R A C T

Using renewable resources to produce chemicals and fuels is increasing. Organic materials from wastes and carbon dioxide are renewable and serve as alternative sources for the production of biofuels and biochemicals. This review provides a survey of solvents and alcohols production from organic matter by microbial electrosynthesis (MES) as a new emerging technology. Using electricity-assisted system in anaerobic microorganisms metabolism (biocatalysts) showed improvement in solvent production compared to conventional fermentation methods. Electrotrophs, the kind of microbial strains which can accept electron from cathode to reduce organic carbon source materials to valuable biochemicals is of interest nowadays. Glucose, glycerol, and other organic compounds could be converted into high value added bio-solvents, such as ethanol, butanol, acetone, and propanediol. This review addresses electricity-driven microbial synthesis of chemicals especially solvents and alcohols by reduction of multi-carbon substrates considering the characteristics and advantages of MES.

Contents

1. Introduction 941
   1.1. Environmental benefits and evolution of MES 941
2. Bio-platform chemicals production in microbial electrolysis cell (MEC) 942
3. Microorganisms 942
   3.1. Microorganisms and electric charges 942
   3.2. Media and *Clostridia* species 944
4. Bioreactor and process concept 945
   4.1. Cathode and anode compartments 946
   4.2. pH effect 946
   4.3. Electrodes and applied potential 946
   4.4. Membrane 947
5. Mechanistic study 948
   5.1. Electron mediators 949

Abbreviations: ABE, acetone-butanol-ethanol; emf, electromotive force; E-BCs, electrobiocommodities; HVAP, high value-added product; MES, microbial electrosynthesis; MEC, microbial electrolysis cell; MFC, microbial fuel cell; EF, electro-fermentation; WW, waste water; PEMs, polymer electrolyte membranes.

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2213-3437/

6. Conventional biological process vs MES 950
7. Techno-economic reports 950
8. Scale-up considerations and constraints 950
9. Current and future development 951
10. Conclusion 952
Acknowledgement 952
References 952

1. Introduction

Nowadays, bio-fuel production from biomass or waste material is being performed around the world in the laboratories or pilot plants. Because of the abundance of organics in wastewater, it is considered as one of the most important alternatives to fossil derived and crude oil derivatives. Despite the production and use of renewable energy (hydro, wind, etc.), large quantities of oil (heavy oils, gasoline, diesel, natural gas, etc.) is still consumed. The use of renewable energy, combined with bioenergy, allows us to be more independent in energy matters and fight climate change. Among bioenergy, bio-alcohols as high value added products from agro-industrial waste as organic carbon source can be generated by fermentation of waste during electrolysis.

Electrobiocommodities (E-BCs) are organic compounds or fuels produced by carbon dioxide using electrical energy [1]. Microbial reduction leads to more specific compound production and lowering the energy required [2]. Chemolithoautotrophs are microorganisms which gains energy by oxidizing inorganic compounds [3]. Photoautotroph obtains energy from light and produces renewable source of energy using inorganic matter. The microorganism that derives electrons directly from cathode are called electrotrophs which can accept electrons to reduce substrates [4]. In this category, acetogenic bacteria could produce bio-organic compounds, such as acetate and ethanol by use of gas substrates, such as CO_2, CO, H_2, and N_2 [5]. On the other hand, heterotrophic microorganisms utilize organic compound as carbon source by electrofermentation (using electron from the cathode as co-reducing equivalent) which is focused in the present review. In recent years, microbial electrosynthesis of different products, such as hydrogen, hydrocarbons, and alcohols has been explored and some aspects of MES have been reviewed. In this regard, dynamic model, optimization and process control, operational parameters in MES processes, advances and future perspectives, basic principles, biocatalysts role in MECs, hydrogen production, wastewater treatment and energy recovery have been reviewed [6–13].

This paper reviews the microorganisms, substrates and products, electron transfer mechanism, processing conditions, and system configurations regarding MES, focusing on solvent (non-acidic) production.

1.1. Environmental benefits and evolution of MES

Apart from biochemicals production, MES, can also be used for wastewater treatment and pollutant removal. MEC encompasses several new applications, such as microbial electrodialysis cell, microbial saline-wastewater electrolysis cell, microbial electrolysis desalination and chemical-production cell, and microbial reverse-electrodialysis electrolysis cell [7]. Wastewater is the source of environment pollutants, but at the same time it can be used as renewable resource of water, electricity production in microbial fuel cells (MFCs) and producing commodity biochemicals and bioremediation (removal of pollutants). Resource recovery and reuse can be achieved by integrated MES processes and waste biorefineries. In addition, by variety of reactions potentials in MESs, selective products could be achieved from waste streams [14]. Variety of biomass can be used in solvent fermentation, such as CO_2, syngas, amino acids, cellulose, apple pomace, wastewater sludge from palm oil processing, date-palm fruit spoilage, milk dust powder etc. [15]. Since MES does not required large amount of water for processing biomaterials to biofuels, it can reduce detrimental environmental impact of large quantities of biomass production [2].

The traditional fermentation method for using non-food biomass such as, cellulose and hemicellulose in agricultural products and wastes have been developed at laboratory scale for butanol production. Utilizing agricultural waste material by hydrolyzing the hemicelluloses can extend the amount of raw material for acetone and butanol (AB) production [16]. Domestic, agricultural, and industrial wastewaters which contain organic matter must be treated before discharge to environment. Microbial electrolysis cell is one of the promising technology for production of chemicals containing energy from wastes and it has improved over the past few years. If this technology is to achieve practical application for wastewater treatment will face numerous challenges such as, elaborating the degradation of complex compounds, and controlling microbial reactions in the bioreactors. [17]. For instance, Ellis et al. [18] performed a study on acetone, butanol, and ethanol (ABE) production using *Clostridium saccharoperbutylacetonicum* N1-4 using wastewater algae biomass. They performed batch fermentation with 10% algae as feedstock. Likewise, They produced 2.74 g/L and 9.74 g/L of total ABE using pretreated algae and by adding xylanase, cellulose xylanase and cellulose enzymes to fermentation system, respectively. Logan and Rabaey [19] reported that although the complex structure of various wastes resources needs a diverse microbial community to degrade the organic materials, several companies currently are in a process of industrializing MECs for treatment of wastewaters and production of biochemical, caustic and hydrogen peroxide solutions.

Various types of waste can be used as feedstocks for producing value-added products, such as acetate, non-fermentable organics (butyric acid, lactic acid, etc.), fermentable organics (glucose, galactose, mannose, xylose, pure glycerol, biodiesel by-product glycerol), high-strength wastewater (industrial and food processing wastewater, winery wastewater, etc.), lignocellulosic biorefinery by-products, and fermentation effluent (cellulose fermentation, corn stover, lignocellulose fermentation, crude glycerol fermentation, etc.) [20].

Several studies agree that the biobutanol is a biofuel with little or no impact on the food supply because it can be produced from cellulose and wood residues. In fact, when biobutanol is produced from organic plant matter, it has a neutral CO_2 balance [21,22]. The main advantages of using organic matter (e.g. wastewater) compared to CO_2 are lower electron consumption, easier biocatalyst growth, and using current infrastructure for bioproduction [23]. The quality and stability of bioproducts are closely related to the type of biomass used for synthesis. In such a process (MES), bacteria catalyze reduction reactions of organic molecules (at the cathode) or carbon dioxide. These reactions are related to bacterial respiratory metabolism.