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Evaluation and simultaneous optimization of bio-hydrogen production using 3^2 factorial design and the desirability function☆

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Abstract

Various mixtures incorporating a simulated organic fraction of municipal solid wastes and blood from a poultry slaughterhouse were used as substrate in a dark fermentation process for the production of hydrogen. The individual and interactive effects of hydraulic retention time (HRT), solid content in the feed (%TS) and proportion of residues (%Blood) on bio-hydrogen production were studied in this work. A central composite design and response surface methodology were employed to determine the optimum conditions for the hydrogen production process. Experimental results were approximated to a second-order model with the principal effects of the three factors considered being statistically significant ($P < 0.05$). The production of hydrogen obtained from the experimental point at conditions close to best operability was 0.97 L Lr^{-1} day^{-1}. Moreover, a desirability function was employed in order to optimize the process when a second, methanogenic, phase is coupled with it. In this last case, the optimum conditions lead to a reduction in the production of hydrogen when the optimization process involves the maximization of intermediary products.

Keywords: Dark fermentation; Hydrogen; Waste treatment; Factorial design; Optimization; Desirability function

1. Introduction

Hydrogen has a higher gravimetric energy density than any other known fuel and is compatible with electrochemical and combustion processes for energy conversion without producing the carbon-based emissions that contribute to environmental pollution and climate change [1]. There are several methods of producing this clean fuel. Among them, biological techniques are a promising option. When combined with the treatment of wastes, they are able to solve two problems: the reduction of pollution from uncontrolled degradation of waste and the generation of a clean alternative fuel [2].

Hydrogen production through dark fermentation has advantages over other processes because of its ability to produce hydrogen continuously from a number of renewable feed-stocks without any input of external energy [3]. The major criteria for the selection of waste materials to be used in bio-hydrogen production are the availability, cost, carbohydrate content and biodegradability. Major waste materials, which can be used for hydrogen gas production, can be agricultural and food industry wastes, carbohydrate-rich industrial wastewaters and waste sludge from wastewater treatment plants [4].

Among agricultural wastes used as substrate for the production of hydrogen are wheat straw [5] and rice slurry [6]. Successful results have also been obtained from the use of food-processing wastewater [7–9] and the organic fraction of municipal solid wastes [2,10–15] as substrates, under mesophilic and thermophilic conditions. Furthermore, waste sludge has proved to be a suitable substrate for obtaining hydrogen by the use of dark fermentation [11,16]. A complete treatment of the waste is obtained by the coupling of a methanogenic phase in a two-phase configuration for the simultaneous production of hydrogen and methane allowing the stabilization of the biosolid [2,15,17].

Some of the major drawbacks of the dark fermentation process are the need for pre-treatment to obtain an H_2-producing inoculum, and the continuous addition of alkalinity to maintain pH in the desired range, since a low pH can inhibit hydrogen-producing microorganisms. The pH value should be above 4.0,

Abbreviations: $\sum$Ac, acids concentration; Alk, volume of alkaline added; COD, chemical oxygen demand; HRT, hydraulic retention time; NH_4^+, ammonium concentration; PH_2, hydrogen production; RSM, response surface methodology; TS, total solids; VFA, volatile fatty acids; VS, volatile solids

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