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Biological Production Of Hydrogen And Methane In Two-Stage Systems: A Literature Review

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ABSTRACT

The growing demand for renewable and sustainable energy sources has fuelled the development of alternative technologies for producing clean fuels. In this context, hydrogen (H_2) and methane (CH_4) stand out for their high energy potential and are viable alternatives for replacing fossil fuels. This review aims to analyse the efficiency of two-stage systems for the combined production of hydrogen and methane compared to single-stage systems for methane production. Anaerobic digestion in two-stage systems is proving to be a promising approach, as several studies have shown positive results, emphasising the importance of anaerobic treatment in these systems.

Keywords: Anaerobic Digestion; Industrial Effluents; Renewable Energy.

INTRODUCTION

The growing demand for renewable and sustainable energy sources has stimulated the development of alternative technologies for the production of clean fuels [1]. Among these technologies, the biological production of hydrogen and methane in two-stage systems stands out as a promising approach, combining the efficiency of anaerobic digestion with the maximum utilisation of organic waste [2].

In the current scenario, hydrogen (H_2) and methane (CH_4) stand out due to their high energy potential, and are viable alternatives for replacing fossil fuels. Hydrogen is the fuel with the highest calorific value, ranging from 120 to 142 MJ/kg, while methane has a calorific value of between 50 and 55 MJ/kg [3]. Both offer a sustainable solution for generating clean, renewable energy and contribute to reducing greenhouse gas emissions.

This literature review aims to analyse the efficiency of two-stage systems for the combined production of hydrogen and methane compared to a single-stage system for methane production.

MATERIALS AND METHODS

In this review article, a structured methodology was adopted to analyse the biological production of hydrogen and methane in two-stage systems, with a focus on biological mechanisms. Initially, a search was carried out in scientific databases such as Web of Science, Scopus and Science Direct, using keywords such as: biological hydrogen production, methane, anaerobic digestion, and two-stage systems. The selection criteria included studies dealing with the production of H_2 and CH_4 in two-stage systems, and those that used industrial effluents as a substrate.

DISCUSSION

Two-stage anaerobic treatment

The two-stage system includes the separation of the acidogenic and methanogenic processes for the production of H_2 and CH_4, respectively **(Fig. 1).** According to Pohland and [4], microorganisms differ in terms of their nutritional needs, environmental conditions, among others, and these differences are seen between acid-forming and methane-forming microorganisms.

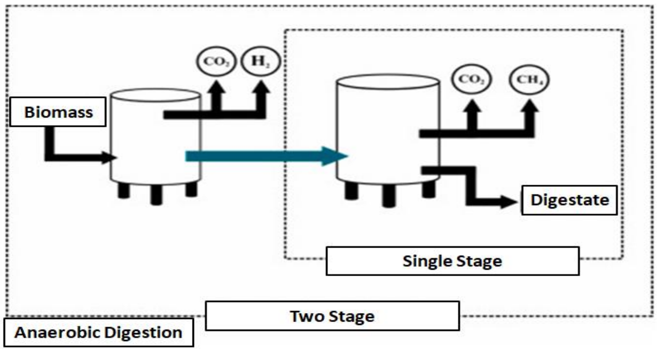

Figure 1. Anaerobic digestion in one and two stages [5]

In studies, the two-stage system has shown greater COD and SV removal efficiency when compared to single-stage systems. In the work of [6], the production of H_2 and CH_4 in two-stage systems and the production of CH4 in the single-stage system were evaluated. In the single-stage system, 69% removal of chemical oxygen demand (COD) was obtained, and in the two-stage system, 8% and 80% removal of COD was obtained in the first and second phases, respectively. However, an efficiency of 19 % was found in COD removal compared to the single stage.

Hydrogen and methane production

The biological production of H_2 and CH_4 involves the decomposition of organic substrates by anaerobic microbial communities. Generating H_2 from renewable energy sources, including biomass, represents an alternative to traditional methods. This innovative and sustainable approach efficiently utilises available resources, reducing dependence on traditional generation methods [7]. **Table 1,** shows different studies on H_2 and CH_4 production. In the study carried out by [8], with the aim of optimising the production of H_2 and CH4 from the co-digestion of food waste and sludge from Wastewater Treatment Plants (WWTP), they obtained yields of 130.1 mL H_2/gSV and 617.6 mLCH4/gSV.

The results of the study by [8] indicate that the introduction of a step aimed at H_2 production before CH_4 production in anaerobic digestion can result in good performance by methanogenic archaea.

Table 1. H_2 and CH_4 production by a two-stage system based on waste co-digestion.

Substrate	Operating Mode	H_2 yield (L H_2/g VS)	CH4 yield (L CH_4/g VS)	References
Food waste and WWTP sludge	Batch	0,130	0,617	[8]
WWTP sludge and crude glycerol	Batch	0,500	1,48	[9]
WWTP sludge	Batch	0,038	0,097	[10]
Organic waste, WWTP sludge and crude glycerol	Batch	0,260	0,377	[11]
Organic waste and crude glycerol	Batch	0,179	0,301	[12]
Sewage sludge, vinasse and poultry manure	Batch	0,027	--	[13]

In the study by [14] the production of hydrogen and methane from cassava processing effluent was investigated using two UASB reactors. The maximum hydrogen yield was 39.83 L H2/kg COD removed, with the gas comprising 36.4% H_2 and 63.6% CO_2. For methane, the maximum yield was 115.23 L CH4/kg COD removed. The study by [15] focused on the production of BioH_2 and CH_4 from the treatment of wastewater from the dairy industry. The results indicated the production of 105 mL H_2/g COD and 190 mL CH_4/g COD, highlighting the viability of the system for wastewater treatment and simultaneous generation of bioenergy, with significant economic benefits.

In the study by [16], the production of hydrogen and methane from saline wastewater containing monoethylene glycol (MEG) was optimised in an anaerobic reactor with baffles. The study concluded that mesophilic conditions of 35°C improved the biodegradability of MEG (92-98%) and the productivity of hydrogen (258 mL/g COD) and methane (140 mL/g COD), even at salinities of up to 25 g NaCl/L.

CONCLUSION

The combined production of hydrogen and methane in two-stage systems represents a promising solution to meet the growing demand for renewable and sustainable energy. The efficiency of this system maximises the use of organic waste, promoting the generation of clean fuels with high energy potential. H_2 and CH_4, with their respective calorific values, are emerging as viable alternatives to replace fossil fuels, contributing significantly to the reduction of greenhouse gas emissions and to a more sustainable future.

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