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2nd International Conference on Engineering, Natural and Social Sciences

April 4-6, 2023 : Konya, Turkey

https://www.icensos.com/

Life Cycle Assessment (LCA) of the Effect of Magnetite Addition on Biohydrogen Production

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***Abstract* –** In this study, the effect of magnetite addition on biohydrogen (bio-H_2) production from apple processing plant wastes by dark fermentation (DF) was investigated under anaerobic and batch reactor operating conditions. Within the scope of the study, optimum ratio and magnetite concentration were determined as S/I: 2 gVS/gVS (substrat/inoculum: gram volatile solid/ gram volatile solid) and 100 mg/L, respectively. Results showed that magnetite nanoparticles supported the bio-H_2 production. Moreover, life cycle assessment (LCA) analysis of 1 m^3 bio-H_2 production from apple pulp by DF process was performed. At this stage, the effects were revealed using the Recipe method in SimaPro 9.1.1.1 software. In the production of bio-H_2 by the DF process, lower effects were obtained in all effect categories compared to the production of H_2 from fossil sources.

Keywords – Apple Pulp Waste, Biohydrogen, Dark Fermentation, Life Cycle Assessment, Magnetite Nanoparticles.

I. INTRODUCTION

LCA is the determination of the environmental effects of a product from raw material supply to waste disposal by following a scientific method [1]. There are different types of LCA, such as “cradle to grave”, “cradle to door”, “cradle to cradle” and “door to door”, which express which stages of the life cycle of a product or service [2]. When the analysis is made by considering all the life cycles of a product or service, from raw material supply (cradle) to waste disposal (grave), this situation is “cradle to grave”; When the analysis is made to cover all the processes from raw material supply (cradle) to the transmission stage (door) to the factory, this situation is called "cradle to door". A “cradle to grave” LCA is referred to as “cradle to cradle” if waste disposal, which is the last stage of the cycle, results in recycling. With commercially available programs or some models developed by researchers, it is possible to reveal the environmental effects of a production by following different paths and compare them with similar processes. With LCA, it may be possible to propose an alternative process instead of the part of a production process that creates the most environmental burden. However, it is also possible to minimize the environmental load of the production chain with different production scenarios. In this context, LCA of bio-H_2 production will be made in the DF process with SimaPRO software. Moreover, the environmental impacts of hydrogen production from fossil resources and DF processes with and without magnetite will also be compared. In this

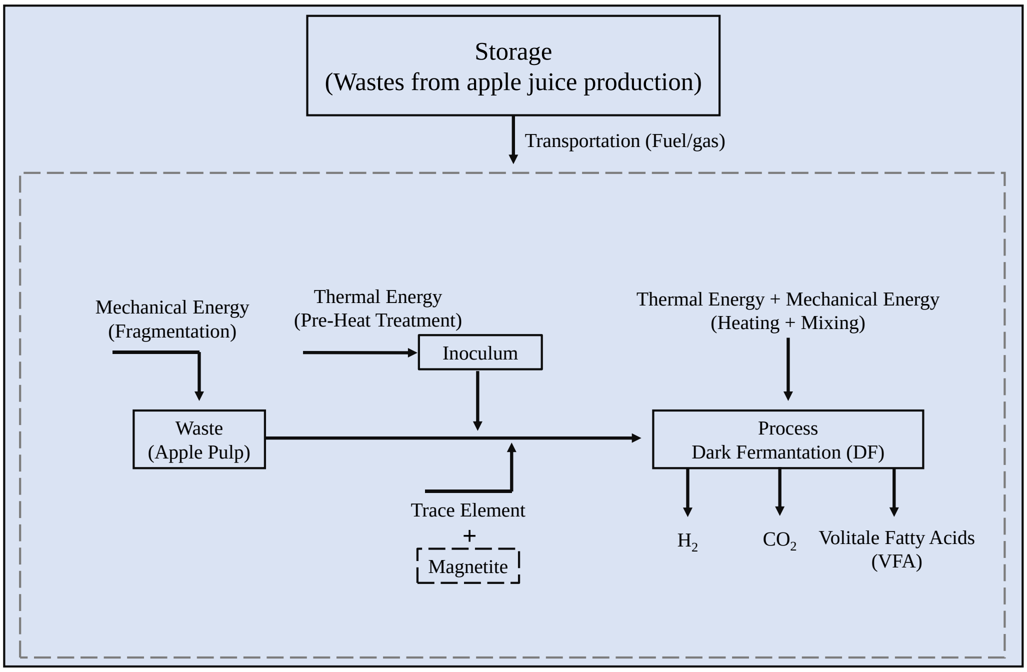

Figure 1. System boundaries of LCA

way, pre-feasibility will be made to understand whether bio-H_2 production is environmentally sustainable, the effects of magnetite use and whether magnetite use should be recommended to real-scale plants to improve bio-H_2 production efficiency. In this way, it will be possible to have an idea about the carbon footprint of the use of magnetite in the production of bio-H_2 in the DF process.

II. Materials and Method

Today, in the production of industrial products, besides the cost and technical performance evaluation, design is made by considering the environmental problems that may occur with raw material and energy consumption [3]. There are many software that use the LCA method. According to the database they contain, the most appropriate data in the databases is selected, product set, life cycle and substrate/inoculum scenarios are created. In the impact assessment phase, there are many methods based on mathematical calculations. In the study, LCA of magnetite added and non-magnetite (control) reactors set and compared in terms of hydrogen production from fossil fuels and environmental performances (effects on air, water, and soil) via SimaPRO software. Local (Niğde) and/or country-based (Turkey) data was used when entering inventories into SimaPro software. Thus, the environmental performance of the biohydrogen to be produced under the conditions of Türkiye was revealed.

In this study, system boundaries determined with the "cradle-to-door" approach (Figure 1). Therefore, this means that all stages up to production are considered, however, the use of the product was not taken into account [1]. The system boundary determined to include four main steps (Figure 1): 1) Preparation of waste material (apple pulp) and anaerobic sludge; pretreatment of anaerobic sludge for inhibition of methanogens and grinding of waste material if necessary 2) magnetite supply, 3) addition of trace elements and addition of mineral additives if needed, 4) DF process. If the need for transportation arises, the emissions resulting from the combustion of fuel in the internal combustion engines of the vehicles to be used were also considered.

S/I ratios (2 gVS/gVS) [4] and magnetite nanoparticles concentrations (100 mg/L) [5] of batch reactors in which LCA analyzes were carried out were determined with reference to previous studies.

III. Results

In recent years, hydrogen has attracted a lot of attention as an energy carrier in the transition process to a low carbon economy. In this context, generating electricity from hydrogen instead of using traditional methods from fossil sources is of great importance in reducing carbon emissions. For this purpose, much research is carried out on the development of hydrogen technologies. However, the environmental impacts that occur depending on the technology and raw materials (water, coal, natural gas, biomass, etc.) used in hydrogen production are changing [6]. H_2 production is carried out by many methods such as reformation, coal gasification, thermochemical methods, electrolysis of water and biological methods [7]. These methods have some advantages and disadvantages in themselves (Table 1).

Table 1. Advantages and disadvantages of different H_2 production technologies [7].

Methods	Advantages	Disadvantages
Reformation	High efficiency	CO_2 and CO emissions
Gasification	Use of low budget substrate	Use of fossil-based substrates
Prolysis	Carbon neutral	CO_2 emission
Electrolysis	Use of low budget substrate	Tar formation
Biological methods	No emissions	Substrate dependent cost

The results in Figure 2 and Figure 3 show that H_2 produced by three different processes (A: H_2 produced with fossil fuels, B: bio-H_2 produced in reactors without magnetite added, C: bio-H_2 produced in reactors with magnetite added) obtained from the evaluation.

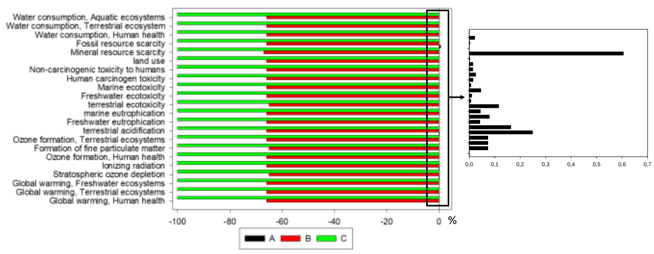

Figure 2. Medium-term impact categories (Recipe Method)

When the literature is examined, it is emphasized that the production of bio-H_2 with the DF process has the lowest environmental impact compared to other production processes [8]. Similarly, the lowest effect in the medium term was obtained as negative 100% in bio-H_2 produced with the use of magnetite (Figure 2). In the reactors where magnetite was not added in the second row, negative 66% was obtained. However, it is seen that the highest environmental impact in the DF process is due to the electricity used. Because electricity is used during the pre-treatments (breaking and heating treatments applied to the substrate and the graft) and the operation of the reactors. The electricity used during the production of biohydrogen with DF in the study was observed as a negative effect in total, taking into account the gains obtained in the process.

According to the recipe method, the medium-term effects given in Figure 3 are long-term; human health, ecosystem and resources are grouped into three categories. The medium-term effects are similarly the lowest in bio-H_2 production with magnetite.

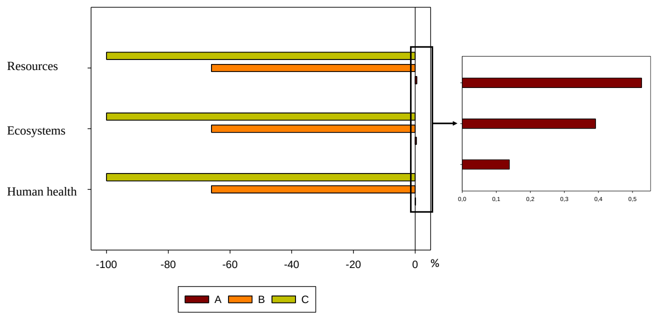

Figure 3. Long-term impact categories (Recipe Method)

Obtaining negative carbon emissions of hydrogen production by biological methods is promising both for contributing to the negative carbon policy of the world and for our country's carbon-neutral target for 2053. However, the biggest obstacle to the application of biohydrogen production on an industrial scale is low conversion efficiencies. With this study, a bio-H_2 increase of 46% was obtained with the addition of magnetite. Additional studies are needed to increase the bio-H_2 yield per unit substrate.

IV. DISCUSSION

In this study, different concentrations of magnetite were added to batch reactors using apple pulp waste and the effect of this addition on H_2 production by the DF process was investigated. Within the scope of the study, 1 m^3 of H_2 production was compared with the production of H_2 from fossil fuels in the SimaPro database under DF reactor conditions that did not use magnetite and added magnetite in the LCA made with SimaPro 9.1.1.1 software and Recipe method. According to the analysis, the lowest effect in the medium and long term was obtained as negative 100% in bio-H_2 produced with the use of magnetite. In the reactors where magnetite was not added in the second row, negative 66% was obtained. The electricity consumed during the DF process (breaking and heating treatments applied to the substrate and graft) and the operation of the reactors constitute the most important environmental impact. The electricity used during the production of bio-H_2 with DF in the study was observed as a negative effect in total, taking into account the gains obtained in the process (avoided co-products). Low yields and production rates are the most important problems in the large-scale use and commercialization of hydrogen production processes from biomass.

V. CONCLUSION

This study has shown that magnetite can be used as an environmentally friendly and yield-enhancing catalyst and can increase the efficiency of hydrogen production systems by using biomass resources. However, there is a need for more comprehensive studies targeting higher increases in efficiency, including cost accounting.

ACKNOWLEDGMENT

The authors would like to thank the following for funding and supporting the study: The Scientific and Technological Research Council of Turkey (TUBITAK, project number: 121Y452).

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