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Ecological analysis of hydrogen production via biogas steam reforming from cassava flour processing wastewater

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A B S T R A C T

The use of bioenergy has turned into a good alternative for reducing the emission of pollutant gases. In Brazil, this sort of energy has increased in usage during the last years. Biohydrogen, produced from cassava, appears as an alternative fuel to fossil fuels and, also, becomes economically competitive, since this is a low cost carbon source. The repertoire of results about the ecological impact from the production of bioenergy from cassava wastewater is very limited because, in general, this commodity is more common in underdeveloped countries. This paper evaluates and quantifies the environmental impact of electricity production in a cassava wastewater treatment plant. The ecological efficiency methodology developed by Cardu and Baica [Regarding a new variant methodology to estimate globally the ecologic impact of thermopower plants. Energy conversion and management 40, no. 14 (1999): 1569–1575] is used as a benchmark in this study. The methodology mainly assesses the emissions of equivalent carbon dioxide (CO_2, SOx, CH_4 and particulate matter), pollutant indicators and ecological effects of a cassava wastewater plant utilizing biohydrogen as energetic carrier. As a result some environmental parameters, such as equivalent carbon dioxide emissions, pollutant indicator and ecological efficiency are evaluated due to the fact that they are important to electricity production. In this way, the environmental parameters was calculated to evaluate how interesting is the process from the environmental feasibility point of view. The average values of the environmental parameters among different biogas compositions was calculated, the average pollution indicator was 10.11 $kgCO_2e/kgH_2$ with an average ecological efficiency of 93.37%. As a conclusion, bioenergy production using biohydrogen from cassava wastewater treatment plant can be justified by the determination of environmental parameters, allowing innovation for producing energy from a cassava wastewater treatment plant, and adding important findings to the energy industry.

1. Introduction

The development of sustainable technologies for the production of bioenergy has become an attractive alternative for the energy sector regarding reduction of pollutant emissions. The need to change the energy matrix, due to several factors, has provided great incentive for the insertion of this form of energy generation in Brazil and many countries around the world.

Recently, there have been several significant advances in the research related to the treatment of effluents (He et al., 2013; Kothari et al., 2013; Wang et al., 2012). This treatment offers several advantages considering environmental and social aspects. Studies that demonstrate a procedure which allows the design of new configurations to maximize energy production and recover as many nutrients as possible in a wastewater treatment plant were undertaken by Khiewwijit et al. (2015).

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Nomenclature

c	Dimensional Coefficient
C	Carbon
CH_4	Methane, kg_{CH4}/kg_{Biogas}
CO	Carbon Monoxide
CO_2	Carbon Dioxide, kg_{CO2}/kg_{Biogas}
CO_{2e}	Equivalent Carbon Dioxide, kg_{CO2e}/kg_{Biogas}
h	Specific Enthalpy, kJ/kg
H	Hydrogen
H_2	Molecular Hydrogen, kg_{H2}/kg_{Biogas}
H_2O	Water
K	Dimensional Coefficient
l	Liter
m	Mass flow, kg/h
M	Molecular weight, g/mol
MP	Particulate matter
n	Dimensionless Coefficient
NOx	Nitrous oxide, kg_{NOx}/kg_{Biogas}
O	Oxygen
P	Pressure, kPa
s	Specific entropy, kJ/kg°C
T	Temperature, °C

Greek character

ε	Ecological Efficiency, %
η	Energetic Efficiency, %
π_p	Pollution Indicator, kg_{CO2e}/kg_{H2}, kg_{CO2e}/MJ
ρ	Specific Mass, kg/m^3

Subscript

Biogas Ref	Biogas used in the reform process

Abbreviation

FH	Fired Heater
HT	High Temperature
LT	Low Temperature
LHV	Lower Heat Value, kJ/kg
PEM	Proton Exchange Membrane
PSA	Pressure Swing Absorption
PSRK	Predictive Soave Redlich Kwong

Cassava wastewater is a byproduct of the cassava processing plant, an effluent with high potential for biohydrogen production. Some studies demonstrate that the biogas, from cassava wastewater, reduces the carbon footprint of the cassava starch industry (Hansupalak et al., 2016). Its potential for energy production has gained strength in the last years (Anyanwu et al., 2015; Chaleomrum et al., 2014; De Sena Aquino et al., 2015; Intanoo et al., 2014; Tosungnoen et al., 2014).

Another study that consider economic and environmental aspects of a wastewater treatment plant, where the biogas produced was used for the generation of electric power and heat, was performed by Venkatesh and Elmi (2013). A methodology of thermoeconomic analysis to evaluate technical and economical feasibility of a municipal wastewater treatment plant was proposed by Abusoglu et al. (2012). Paula et al. (2015) developed the simultaneous treatment of urban effluents by using algae and energy recovery of residual biomass from algae. A study to determine the cost of the environmental impact, considering aspects of exergetic accounting was conducted by Seckin and Bayulken (2013). Optimization of the energy efficiency of a municipal effluent treatment station was obtained by Rojas and Zhelev (2012). Costs associated to the products generated in a small wastewater treatment plant by applying the optimization method based on a functional diagram was obtained by Lamas et al. (2009).

Most of the production of cassava (*Manihot esculenta Crantz*) in Brazil is intended for the production of cassava flour, which accounts about 60% of the production (Bianchi and Cereda, 1999). It is considered the main by product from cassava, consumed primarily in all Brazilian territory, but mainly in the North and Northeast regions. There are several companies in Brazil that produce cassava flour, located mainly in the States of Mato Grosso do Sul, Santa Catarina, Paraná, and São Paulo.

An issue faced by the industrial cassava-processing is the cassava wastewater toxicity. Cassava wastewater exhibits high polluting effects due to the increased BOD level and for containing hydrocyanic acid (extremely poisonous), which makes this residue different from others of the agroindustry (Fioretto, 1994). Therefore, the production of these derivatives generates pollution, harming mainly the populations living around the companies (Inoue, 2008).

In Brazil, the cassava-processing effluents are usually not treated, causing serious environmental problems. According to Patino (2001), the problem of this waste disposal is increasing because of the concentration of industries in specific regions of the country, causing environmental changes, such as the odor and the death of fish and livestock, as well as a sharp deterioration of the quality of the water in the outskirts of the plants. In this regard, among all the effluents from the production of manioc starch, is the one that presents the greatest potential of pollution due to its high concentration of organic materials and their release in the streams, generally without the necessary water treatment.

Among several hydrogen production processes, the steam reforming process, using natural gas, is widely used in chemical industries, and it is responsible for 50% of the hydrogen produced in the world (Boyano et al., 2012). The biogas from cassava wastewater is a good alternative raw material to steam reforming technology, because the biogas is very similar to the natural gas and has included additional benefits. This biogas has interesting advantages, such as: it is a renewable resource, reduces emissions by preventing methane release in the atmosphere, reduces landfill waste, produces nutrient-rich fertilizer as by-product and also can decrease the quantity of cyanide of wastes from cassava flour industry.

The purpose of this study is to evaluate and quantify the average values of the environmental parameters of hydrogen production via steam reforming of biogas obtained from cassava wastewater with different biogas compositions. Initially, a computer program, Hysys Software version 8.0, was used to simulate a hydrogen production plant using biogas obtained from the cassava wastewater. This simulation allowed the establishment of a bunch of thermodynamic properties of all streams involved in the process. Subsequently, the ecological efficiency calculation method was applied to determine the equivalent of carbon dioxide emissions, the indicator of the pollution and ecological efficiency of the proposed system. Finally, the results of the study are discussed and compared with other systems that produce hydrogen from biogas.