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Life cycle assessment of biodiesel produced by the methylic-alkaline and ethylic-enzymatic routes

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ABSTRACT

A comparative environmental impact analysis of the soybean biodiesel production by two different technologies was done in this study. The production routes evaluated were the alkali-catalyzed (catalyst: sodium hydroxide) methylic transesterification and the enzyme-catalyzed (catalyst: lipase) ethylic transesterification. In an early work, simulations of the biodiesel production processes with the software Aspen HYSYS, from AspenTech Inc., were carried out. Now, a life cycle assessment (LCA) of the entire biodiesel production chain is done. The inventories related to each production subsystem were developed based on the mass and energy balances obtained from the simulations and on literature information. The results clearly indicated the best environmental performance of ethanol over methanol and of the enzymatic technology over the traditional alkaline technology, but also demonstrated some bottlenecks that should be attacked in a seek for more sustainable solutions.

1. Introduction

Biodiesel is a biodegradable fuel consisting of a mixture of fatty acids alkyl esters, which can be produced from raw materials such as vegetable oils, animal fats and residual oils [18]. Homogeneous alkaline transesterification is the most common biodiesel production process of industrial scale [34,35,37]. Reaction occurs between the oil and short chain alcohols, such as methanol and ethanol with an alkaline catalyst, such as NaOH [9,11,10,19].

However, in a search for more economical and sustainable solutions, there is an evident tendency in the scientific literature the study processes that use heterogeneous catalysts [8,16]. Specially, and already with industrial application, stands out the enzymatic catalysis, where lipases are used as catalysts in transesterification [21,36]. This process seems to have certain economic [36] and environmental [13] advantages over other emerging technologies, such as the supercritical route [17]. The greatest obstacle to the definitive implementation of the enzymatic technology at industrial level is probably the high catalyst cost [36].

In Brazil, about 75% of the feedstock's used for biodiesel production is soybean. Soybean is also the most used feedstock for biodiesel production in the world and, because of that, many authors have considered soy production in the life cycle assessments of the biodiesel production chain [2,3,25].

Although the most used alcohol for biodiesel production is methanol, due to its non-renewable origin, production with ethanol appears as a particularly interesting alternative in an environmental point of view. It is even more interesting to Brazil, which has one of the biggest and well established ethanol industries of the world [12]. The Brazilian ethanol industry has also great interdependence with the industries of United States and Europe, the two major methylic biodiesel producers of the world [7]. An efficient integration of both industries is an interesting, if not essential, path to the definitive establishment of a green fuels culture.

Life Cycle Assessment (LCA) is an environmental management tool used to analyze and evaluate the environmental impacts of a product, along its entire life cycle, i.e., since its formation until its complete disappearance in the nature [29,32]. This type of analysis is complex and generally limited by data availability and generalizations [14,20]. In this context, it is necessary to understand LCA as an evolution tool that measures potential environmental impacts, not real impacts [4]. Thus, the objective of LCA is not to define solutions, but rather to provide the necessary basis for decision-making towards more sustainable scenarios [28,29,32].

The life cycle assessment carried out in this study was conducted in accordance with ISO 14.040 and had the objective to compare the environmental performance of soybean biodiesel obtained by two different routes: the methylic-alkaline

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(traditional) production route, and the ethylic-enzymatic route. This work is a direct continuation of our paper "Biodiesel production by the methylic-alkaline and ethylic-enzymatic routes: discussion of some environmental aspects" [5].

In the former work, biodiesel synthesis was simulated in the software Aspen HYSYS, from AspenTech Inc., and a subsequent analysis was carried out in terms of the 12 Principles of Green Chemistry [1] and calculation of some sustainability metrics [31].

2. Methodology

In this work, biodiesel was considered as an energy source for compression ignition (diesel cycle) engines. In order to quantify the energy to be used, a reference flux was determined to indicate the quantity of product needed to meet this objective based on the calorific value of soybean biodiesel (39.9 MJ/kg), since it does not show significant variation as a function of the chosen alcohol.

2.1. Definition of the production systems

Biodiesel production was divided in four main subsystems: soybean oil production (SOP), anhydrous ethanol production (ETP) or methanol production (MEP), caustic soda (sodium hydroxide) production (CSP) and biodiesel synthesis (BIS). A scheme of the production system and its main subsystems can be viewed in Fig. 1. In this work, we consider a LCA approach of the type "cradle to gate", where impacts associated with biodiesel production are listed from resource extraction to the end of the production chain, with inclusion of the product distribution stage.

The life cycle assessment does not include the environmental loads related to lipases, since it is believed that the impacts of biological catalysts are insignificant and because it is possible to reuse it for several cycles [13,24]. Plant and equipment construction were also not considered in the analysis, since the useful life of these assets is considerably large, resulting in low relevant environmental impacts when compared to daily environmental impacts of the production process.

In addition to these main subsystems, there are intermediate subsystems, which provide the necessary support structure for production. These are: the production of diesel, which is used to transport materials and to generate thermal energy; the production of fuel oil, also used in the production of thermal energy; electricity generation; production of fertilizers, pesticides and limestone, necessary for the agricultural stages; and the transport subsystem, which includes the analysis of the environmental load attributed to the transport stages between the production subsystems.

For big countries like Brazil, production decentralization is a very interesting strategy, since the reduction of the distances between producers and consumers would minimize transport costs [15]. Therefore, in this work we considered that the biodiesel production units could be installed in two different places: the States of Goiás (GO) and Rio Grande do Sul (RS). These places require different distribution systems with different environmental performances.

2.2. Environmental impact evaluation

The environmental impact factors evaluated were non-renewable energy usage (NEU), liquid effluents generation (LEG), solid waste generation (SWG), the greenhouse effect potential (GEP), the potential of ozone layer depletion (OLD), the potential of ozone photochemical formation (OPF) and the acidification potential (ACP). It was also evaluated the CO_2 balance and the petroleum, natural gas, coal and water consumption in each production system. Once all the factors have been calculated for each system, an overall impact indicator was calculated, as a way to quantitatively base the choice for the more sustainable technology and place. The impact indicator was calculated as a sum of the products between each factor and its normalized relevance factor [33,23]. The relevance factor is calculated as the ratio between the biggest value of the impact factor among the production systems and the annual value of the factor in Brazil.

The criterion adopted by Vianna [33] and Marzullo [23] was used in the calculation of the LEG factor. The necessary amount of water added to the effluents was calculated to promote dilution of these effluents until critical limits determined by the "Regulation on requirements for the discharge of wastewater into surface waters" (Abwasserverordnung – Abw) of 1997 adopted in the BASF method [27]. These are 75 mg/L for COD (chemical oxygen demand) and 15 mg/L for BOD (biochemical oxygen demand).

The energy-mass ratios indicated in Table 1 were used to calculate the required amount of non-renewable energy (NEU). These can be directly obtained from the inventories of each subsystem,

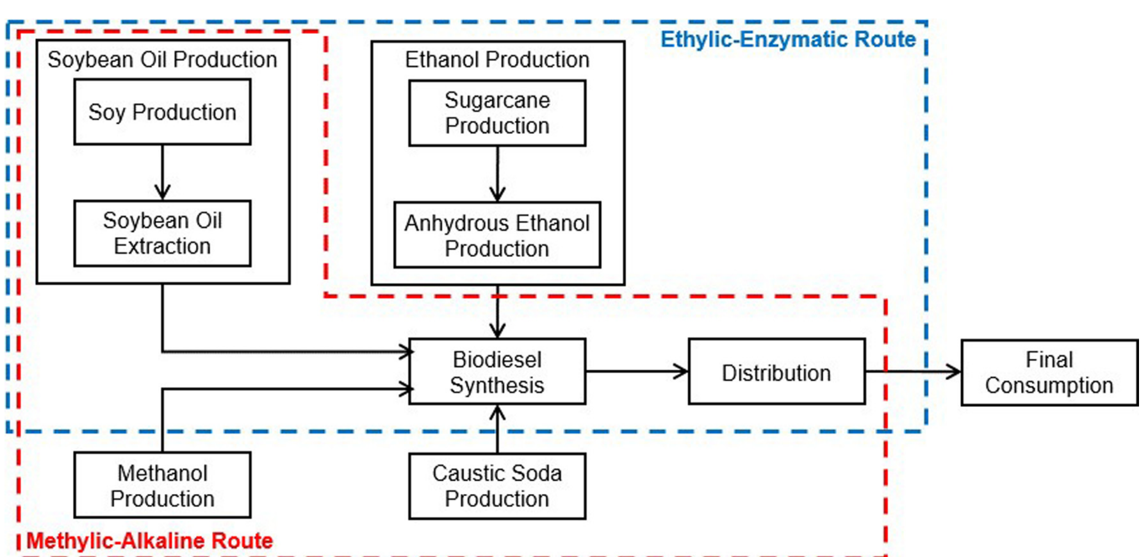

Fig. 1. Main production subsystems.