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LCA studies comparing alkaline and immobilized enzyme catalyst processes for biodiesel production under Brazilian conditions



Igor Alberto Peñarrubia Fernandez^{a,b,*}, De-Hua Liu^{a,b}, Jinsong Zhao^a

^a Department of Chemical Engineering, Tsinghua University, Beijing, 100084, PR China

^b China–Brazil Center for Climate Change and Energy Technology, Tsinghua University, Beijing, 100084, PR China

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ABSTRACT

Brazil is a leader in the production of biodiesel, and some challenges still exist in improving the energy usage and feedstocks alternatives for the transesterification process. In this paper, an industrial scale simulation was conducted to show a comparison of the traditional alkali-catalyzed process using catalysis sodium hydroxide with an enzyme-catalyzed process novel developed by the research team of one of the authors. LCA methodology was used to evaluate the potential multiple effects on the environment in Brazilian scenarios. In this regard, three basic cases were carried out: Case 1, where 1 t of soybean biodiesel was produced from the alkali-catalyzed process; Case 2 and 3, where 1 t of biodiesel, using the enzyme-catalyzed process, was produced from soybean oil and waste cooking oil respectively. The results reveal that considerable contribution can be made to the environment in Case 3 when waste cooking oil (WCO) is considered as a nearly environment-burden-free resource. Additionally, as illustrated in Case 2, not only the feedstock but also the technologic process can generate great influence on the environment when producing biodiesel in a large-scale plant. The efficiency of electric and thermal energy usage should be appropriately considered to diminish these impacts as much as possible. Likewise, chemicals and waste disposal also need to be well managed.

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1. Introduction

A recent global warming research indicates that by 2050 a reduction of 40–70% in greenhouse gas (GHG) emissions is necessary to maintain the temperature rise below 2 °C (IPCC, 2014). In 2014, however, renewable energy shared only 13% of the world's energy supply. The transportation sector alone is responsible for nearly 22% of global GHG due to the increasing demand for vehicles (IEA, 2014). Consequently, biodiesel, as a renewable biofuel, has become a most written topic. Nowadays, policies worldwide are proposed to support the production of biodiesel, in the form of subsidies and tax exemptions (Gerald et al., 2014). An example of the pioneers establishing this support is Brazil, the second-biggest producer for both biodiesel and fuel ethanol production, being only behind the United States in both categories (REN21, 2015). Since 2008, Brazil has almost tripled its biodiesel production (ABIOVE, 2015) (Table 1).

In March 2016, about 52 biodiesel plants were authorized by the National Agency of Petroleum, Natural Gas and Biofuels (ANP, 2016) for operation in the country, corresponding to a total capacity of 20.310,11 m³/day.

Biodiesel can be produced by various resources such as virgin vegetable oil, animal fat and waste cooking oil (WCO). In Brazil, 70% of the biodiesel production is made from virgin soybean oil. The percentage varies from region to region (1–North, 2–Northeast, 3–Central-West, 4–Southeast, 5–South) as depicted in (Fig. 1) (ANP, 2016). Beef tallow plays an important role in region 2, 4 and 5. Other feedstocks such as cottonseed oil, WCO, palm oil, pig and chicken fat have not been widely used nowadays, accounting for less than 10%.

The high costs and limited availability of biodiesel feedstock are critical issues, since they can exacerbate the competition for food and land in the near future (Cremonez et al., 2015). For this reason, WCO, currently a waste resource, can be an effective solution to reduce the cost and the adverse impacts on the environment (Morais et al., 2010; Ortner et al., 2016).

Transesterification is the most common way to produce biodiesel by reacting triglycerides with alcohol in the presence of chemical, biocatalyst or non-catalyst (Raman et al., 2011). Nowadays researchers are still struggling to develop new advances

* Corresponding author at: Department of Chemical Engineering, Tsinghua University, Beijing, 100084, PR China.

E-mail addresses: penarrubia.igor@gmail.com (I.A. Peñarrubia Fernandez), dhliu@mail.tsinghua.edu.cn (D.-H. Liu), jinsongzhao@mail.tsinghua.edu.cn (J. Zhao).

Table 1
Annual Brazilian Production of Biodiesel.

Year	Annual production (10.000 t)	Growth rate
2007 and before	No statistics	Na (%)
2008	105.9	
2009	145.9	37.8
2010	216.4	48.4
2011	242.4	12.0
2012	246.6	1.7
2013	264.6	7.3
2014	310.2	17.2

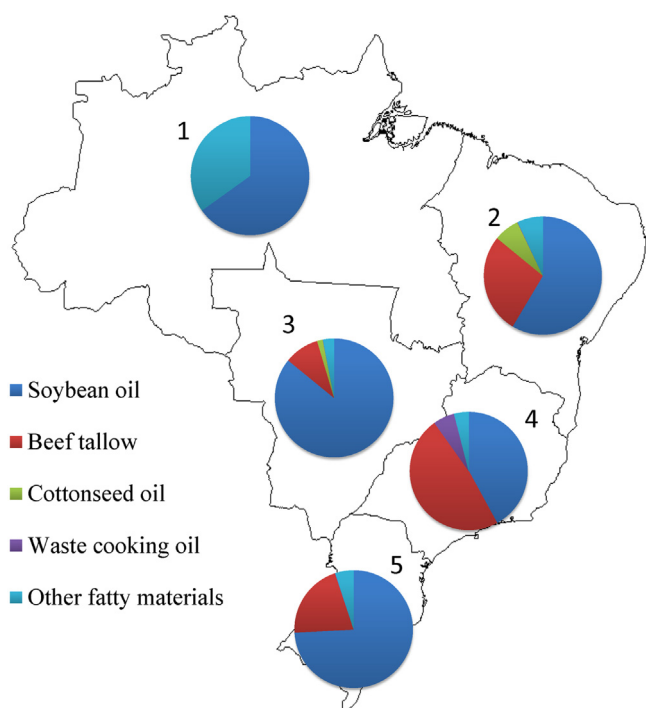


Fig. 1. Raw materials employed for biodiesel production in Brazil.

for transesterification routes, improving additives stability and defining standards for processes effluents. Examples of several studies can be found in literature about the main transesterification routes for biodiesel production using different catalysts: alkaline (Georgogianni et al., 2007; Marchetti et al., 2007; Zhang et al., 2003), acid (Gerpen, 2005; Haas et al., 2003) and enzyme catalyzed (Al-Zuhair, 2007; Guldhe et al., 2015; Li et al., 2014).

Among all, the alkaline and acid catalyzed processes are the most commercialized ones, almost being used for all biodiesel plants in Brazil (EPE, 2015). However, the main disadvantages of these routes when compared to enzyme-catalyzed processes are the environmental effects, such as waste disposal and water required for washing, soap formation and purification (Banerjee and Chakraborty, 2009; Georgogianni et al., 2007; Tan et al., 2010) (Table 2).

As a consequence, enzyme catalyzed routes have been considered as a promising technique due to its mild process conditions, feedstock flexibility, easier purification and low waste emissions (Tan et al., 2010). Searching for improvements of the transesterification processes, in an industrial scale, should be considered as a great impact factor when concerning environmental influence. Peters et al. (2015), for example, have shown that among different types of oil feedstock, the energy requirements are highly related to the process, and so are the environmental impacts. An immobilized enzyme-catalyzed process was proposed by the research team of

Table 2
Chemical and biological transesterification: advantages and disadvantages.

Transesterification Route	
Chemical Alkaline/Acid-catalyzed	Biological Enzyme-catalyzed
Advantages	Advantages
Higher reaction rate	Better purity for products and co-products
Cheaper catalyst	Mild operation conditions
	Alcohol usage close to stoichiometric value
	Easier catalyst recovery
	Absence of soaps and others wastes
Disadvantages	Disadvantages
Higher energy consumption for purification of the products	Simpler production plant
Formation of soaps (harder separation of the end products, FAME and glycerol)	
Humidity control, due its influence on ester hydrolysis	
	High cost of the catalyst
	Loss of enzyme activity
	Longer residence time

one of the authors in his previous works (Du et al., 2004; Lv et al., 2010), with higher recycling features and flexibility in feedstock.

By using the new technology, the enzyme can be reused more than 100 times, almost double the times of that used in other lab-scale designs, making it affordable and applicable in industrial plants. Currently, a similar version of this technology has been implemented and used in a plant of 50,000 t/year capacity, located in Hunan, China, with a variety of feedstock materials from virgin vegetable oil to WCO.

Further optimization and viability of its economic benefits were discussed and compared with other studies by Zheng (2010). By applying this new technology to Brazil, great contribution can be gained considering its low cost and feasible options for feedstock. However, the evaluation of its impacts on the environment should be executed based on the database from Brazil before being applied.

LCA is widely used as a key methodology for evaluating the multiple impacts on resource use, climate change and ecological well-being. Comparison and measurement of the real benefits for biodiesel usage and potential contributions on reducing GHG emissions have been summarized by Horne et al. (2009). Harding et al. (2008) and Sajid et al. (2016) conducted an impact analysis for comparing an alkaline catalyzed process to an enzyme-catalyzed process for rapeseed oil and non-edible Jatropha oil respectively, where environmental advantages for the latter was found due to avoided use of a chemical catalyst and neutralizing acid. Rocha et al. (2014) carried out an extensive literature review, evaluating and comparing the main environmental life cycle impacts and energy balance of ethanol from sugarcane and biodiesel from soybean and palm oil, in Brazilian conditions. A process based on cradle-to-gate attribution LCA method was applied, reaching the conclusion that biofuel production systems with higher agricultural yields and extensive use of co-products in its life cycle present better environmental results.

Since few published literatures focus on the large-scale enzyme-catalyzed process in Brazil, it is imperative to carry out the simulation and LCA study to make a comprehensive assessment of the prospect for applying this new technology. Thus, the purpose of this study is to compare the traditional alkali-catalyzed process using catalysis by sodium hydroxide with the optimized enzyme-catalyzed process developed by our research team. Based on the feedstock available in Brazil, virgin soybean oil and waste cooking oil (WCO) were selected for the simulation and analysis. Three basic cases were included in this paper: Case 1, where 1 t of soybean biodiesel was produced from the alkali-catalyzed process; Case 2

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