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Simulation and cost estimate for biodiesel production using castor oil

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ABSTRACT

Brazilian government has established a regulation that imposes the commercialization of diesel blended with 3% of biodiesel by volume. Castor oil has being considered an option to guarantee the supply of biodiesel needed. For this reason, in this work, a continuous biodiesel plant was designed and simulated in HYSYS simulator using castor oil as feedstock. The developed process was capable of producing biodiesel at high purity using an alkali catalyst. Material and energy flows, as well as sized unit operations were used to conduct an economic assessment of the process. Total capital investment, total manufacturing cost and after annual equivalent cost were also calculated. A study of production costs was performed considering the fluctuations of the raw material prices and the glycerin purification step.

Keywords: Biodiesel; Castor oil; Ethanol; Cost estimate

1. Introduction

The probable scarcity of fossil fuels in the near future, combined with concerns over the consequences of dependency on this type of energy source, in terms of changes in the Earth's climate, has forced the world to find alternatives that are less harmful to the environment. Renewable energy sources, especially vegetable fuel, have appeared as an important alternative.

In 1975, in the midst of a world petroleum crisis, Brazil implemented a program to encourage the development of ethanol derived from sugar cane as an alternative to gasoline energy. This National Alcohol Fuel Program, called Proálcool, has resulted in the accumulation of a solid and diversified experience in the production and use of biofuels. It had been known before 1970s that it was possible to use alcohol derived from sugar cane as an automobile fuel, and this alternative had already been tested a number of times, but, until the 1970s, the low-cost availability of petroleum derivatives had served as a disincentive to developing this option. However, in 1973, the situation changed, thus prompting the Brazilian government to seek out alternatives to petroleum-based energy. One of the principal benefits of utilizing ethanol is that lead is eliminated from the fuel and carbon monoxide emissions are reduced, as are sulfur compounds, thus helping to reduce air pollution. On the other hand, Proálcool did not ultimately reduce Brazilian dependence on imported petroleum, and, since it focused exclusively on sugar cane, it neglected other alternatives that would have benefited small and medium-sized rural producers. Cassava is just one example of a product whose use could benefit an immense contingent of farmers who are excluded from agribusiness-based markets.

Another experience with vegetable fuels was the Vegetable Oil Program (Programa de Óleo Vegetal), which was implemented in the early 1980s and involved research centers and various sectors of Brazilian industry. At that time, a test was conducted, involving a fleet of heavy trucks that traveled

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1.5 million km using biodiesel made from a number of different plant sources, yielding satisfactory results.

The Brazilian National Program for Production and Use of Biodiesel (PNPD) has established the partial substitution of 3% of diesel fuel sold in Brazil since 2008, increasing to 5% in 2013. To guarantee the supply of vegetable oil needed for this substitution, biodiesel from Castor oil must be used. Biodiesel from Castor oil shows higher viscosity than the specification proposed by the National Petroleum Agency to be used pure as biodiesel, and so it can be sometimes considered not suitable. But in this case, it will be used blended with other oils or diesel, showing the properties required for this purpose.

Unlike Proálcool, PNPB utilizes direct and indirect mechanisms to stimulate the production of biodiesel and include family agriculture in the chain of production. One of the direct mechanisms is the credit line offered by the National Program for Strengthening Family Agriculture (PRONAF). Indirect mechanisms include the so-called Social Fuel Seal (Selo Combustível Social), which can be obtained by companies that meet a variety of requirements that help to encourage social inclusiveness in the production chain of biodiesel, mainly by offering tax incentives. Brazilian businesses that buy 50% of their raw material from family farmers in the northeast receive reductions in the portion of their federal taxes related to the production and sales of biodiesel.

Some vegetables have received attention from the Brazilian government, including peanut, sunflower, palm, and castor beans. The castor bean plant has received more emphasis because of its low production cost and because it is easily grown, even in Brazil's vast semi-arid regions, where frequent droughts severely limit agricultural production. Its seeds show oil contents ranging from 45 to 50%, with a productivity of 470 kg of oil per hectare (energy balance equivalent to that of alcohol–ethanol). In addition, because castor bean is not suitable for human consumption, its use as energy source does not compete with food production.

Considering the government interest in developing a program to promote the social inclusion of less economic favored areas from the northeast of Brazil, including family agriculture in the biodiesel chain of production, the aim of this work was to develop a process flowsheet and simulation, and conduct an economic analysis of this process to determine the extension of the investment needed for biodiesel production from castor oil in Brazil.

Published literature about industrial plant design simulation of biodiesel production has been scarce. Besides few studies evaluating economic aspects of biodiesel production from several vegetable oils, including canola, soybean, sunflower, rapeseed, and animal fat, have been conducted (Haas et al., 2006; West et al., 2008; Nelson et al., 1994; Noordam and Withers, 1996; Bender, 1999; Zhang et al., 2003a; Marchetti et al., 2008) no work was found considering the castor oil.

Table 1 – Properties for hypothetical molecules creation (Ndiaye et al., 2006).

Properties	Substances	
	Triricinolein	Ethyl ricinoleate
Molecular weight (g/gmol)	925.9	342.2
Critical temperature (K)	993.4	802.8
Critical pressure (bar)	3.3	9.8
Acentric factor	2.542	1.151

Table 2 – Raw materials for processing 1000 kg/h of castor oil feed.

Material	Amount (kg/h)
Ethanol	591.3
Castor oil	1000.0
NaOH	9.9
Water	1000.0

Castor oil consists mainly of esters of 12-hydroxy-9-octadecenoic acid (ricinoleic acid) and is characterized by high viscosity due to largely to hydrogen bonding of its hydroxyl groups, although this is unusual for a natural vegetable oil. Because its viscosity does not attend the Brazil's National Petroleum Agency requirements (ANP, 2008) to be used pure as a biofuel, the production of biodiesel from castor oil is intended to be used mixed with mineral oil or other oils.

2. Methods and materials

2.1. *Process simulation*

HYSYS (Hyprotec system) was used to conduct the simulation. The procedures for developing the process simulation based on use of HYSYS simulator consist on selecting the chemical components for the process, as well as a thermodynamic model. Additionally, unit operations and operating conditions, plant capacity and input conditions must be all selected and specified.

2.1.1. *Chemical components*

HYSYS library contains information for the following components used in the simulation: ethanol, glycerol, sodium hydroxide, and water. Because ricinoleic acid is the major fatty acid in castor oil, triricinolein was chosen to represent castor oil and ethyl ricinoleate to represent biodiesel. Triricinolein and ethyl ricinoleate were not available in HYSYS and two hypothetical molecules were built up to represent them using the "hypo manager" tool. Specification of a component requires input of a number of properties, such as molecular weight, acentric factor, as well the critical properties of the substance. The properties used to create the molecules of triricinolein and ethyl ricinoleate are described in Table 1.

2.1.2. *Thermodynamic model*

Owing to the presence of polar compounds such as ethanol and glycerol in the process, the non-random two liquid (NRTL) thermodynamic model was selected for use as the property package for calculation of activity coefficient of the liquid phase in the simulation. Since some binary interaction parameters were not available in the simulation databank, they were estimated using the UNIFAC vapor–liquid equilibrium and UNIFAC liquid–liquid equilibrium methods.

2.1.3. *Plant capacity, unit operations and operating conditions*

Plant capacity was specified at 1000 kg/h castor oil feed. The amounts of raw materials needed to process the defined plant capacity is shown in Table 2. The process units included reactor, distillation column, extraction column, pumps, and heat exchangers.