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Analysis of operating costs for producing biodiesel from palm oil at pilot-scale in Colombia

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HIGHLIGHTS

- Conversion of oil to biodiesel achieved 99.4% efficiency; above required standards.
- Biodiesel production cost at the pilot scale (20.000 L/day) was US$3.75/gal.
- The feedstock, crude palm oil, represented 72.6% of the total production cost.
- The process is profitable by generating $1.08/gal (i.e., 22.4% of the total income).
- The best scenario uses crude palm oil and takes advantage of byproducts.

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ABSTRACT

The present study aims to evaluate the operating costs of biodiesel production using palm oil in a pilot-scale plant with a capacity of 20,000 L/day (850 L/batch). The production plant uses crude palm oil as a feedstock, and methanol in a molar ratio of 1:10. The process incorporated acid esterification, basic transesterification, and dry washing with absorbent powder. Production costs considered in the analysis were feedstock, supplies, labor, electricity, quality and maintenance; amounting to $3.75/gal ($0.99/L) for 2013. Feedstocks required for biodiesel production were among the highest costs, namely 72.6% of total production cost. Process efficiency to convert fatty acids to biodiesel was over 99% and generated a profit of $1.08/gal (i.e., >22% of the total income). According to sensitivity analyses, it is more economically viable for biodiesel production processes to use crude palm oil as a feedstock and take advantage of the byproducts such as glycerine and fertilizers.

1. Introduction

Climate change, variation in oil prices, declining fossil fuel reserves and the environmental consequences that originate from the widespread use of fossil-derived energy resources have encouraged society to consider other alternative energy resources to supply global energy demands. Specifically, renewable energy has been shown as a potential alternative to mitigate this crisis; however, renewable energy currently supplies only 13.3% of total global energy consumption (International Energy Agency [IEA], 2011).

Within the broad category of renewable energy, biodiesel has been established in recent years as a promising biofuel. In 2007, the world production of biodiesel was approximately 8.4 million tons (7.2 billion liters) and increased more than two fold to 20 million tons (17.1 billion liters) in 2010. Biodiesel production is projected to grow further to 150 million tons (128.4 billion liters) by 2020 (Agra CEAS Consulting, 2010). In the European Union (EU), biodiesel production in 2008 increased dramatically by 180% compared to 2007 (Lozada et al., 2010). In Colombia, biodiesel production rose from 169.4 to 503.3 thousand tons (192.5–571.9 million liters) between 2009 and 2013 (Colombia Biofuels National Federation, 2014). The above data show a significant increase in biodiesel production worldwide, most likely as a result of the implementation of different strategies and policies for the development and use of biofuels (Abdullah et al., 2009).

Biodiesel is defined as a mixture of fatty acid methyl esters [FAME], which are produced by transesterification of triglycerides

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in the presence of a catalyst and alcohol (Lee et al., 2011). Biodiesel has some important advantages compared to petroleum diesel, such as maintaining engine performance while reducing the particulate emissions by 66.7%, unburned hydrocarbons by 45.2%, and carbon monoxide by 46.7% (Schumacher et al., 2001; Graboski and McCormick, 1998). Moreover, according to Tyson (2001), biodiesel reduces net emissions of carbon dioxide by 78% over its life cycle compared to petroleum diesel fuel. Biodiesel also has some notable disadvantages, which already exists such as high freezing point (0 to −5 °C), clogging of filters, and storage problems due to its biodegradability (Berrios and Skelton, 2008).

Biodiesel can be produced from different feedstocks such as vegetable oils, animal fats and used cooking oils. With reference to vegetable oils, there exists a plethora of specific crops such as palm oil, soybean, canola/rapeseed, etc. which may serve as candidate feedstocks. Of the aforesaid, however, palm oil is one of the crops with the highest production of oil, which produces an average of 4–5 tons (4.6–5.7 thousand liters) of oil per hectare. This production yield is 10 times greater than that of soybean and 6 times as great as that of rapeseed (Basiron and Kheong, 2009). Indonesia has the largest production of palm oil, approximately 33.5 million metric tons in 2014; followed by Malaysia, with the production of palm oil that is projected to reach 21.3 million metric tons in 2014; and Colombia ranks fourth on the list with 1.1 million metric tons of palm oil in 2014, which is one of the leading producers of palm oil globally (United States Department of Agriculture [USDA], 2014).

Currently, there are several factors that impede the large-scale development of biodiesel which include the price of raw materials, production costs, lower price of fossil fuels and tax policies (Ong et al., 2012). Among these factors Haas et al. (2006) indicated that one of the most important barriers is the high cost of production compared to petroleum fuels; primarily due to the cost of raw materials/chemicals such as vegetable oils, catalyst, and alcohol. Several researchers have focused their research to quantify the effects of the above stated factors. For example, Bender (1999) analyzed 12 studies on the economic feasibility of biodiesel production using different raw materials and scales of operation. The calculated production costs, which include the cost of raw materials and subsequent conversion to biodiesel, ranged from $0.30/L ($1.14/gal) for biodiesel produced from soybean oil to $0.69/L ($2.62/gal) for biodiesel produced from rapeseed oil. Also, Jegannathan et al. (2011) evaluated the production costs of biodiesel from palm oil using a batch process and biological catalysis in a plant with capacity of 1,000 tons/year, the total cost was $8.7/gal ($2.30/L) of biodiesel and raw material costs were $588/ton.

The aim of the present study was to evaluate the economic viability of biodiesel production (from technically feasible) from crude palm oil in a pilot-scale plant in Colombia, considering that there is little information about its potential to produce biodiesel at the small to pilot scale facility. Production process uses acid/basic catalyst, biodiesel dry washing, and the use of byproducts to offset the costs of biodiesel production due to high prices incurred from the expensive crude feedstocks. A sensitivity analysis was also conducted to account for the effects of raw material costs and value-added byproducts on overall profitability.

2. Biodiesel production process

2.1. Plant capacity

Biodiesel production in Colombia has grown significantly in recent years, but most facilities have focused on developing large capacities biodiesel plants, above 100,000 L/day. Currently only about a third of the production facilities in Colombia are below this output level (Colombia Biofuels National Federation, 2014). The high capital investments required for building larger facilities often deter potential investors and impede the development of biodiesel industries. Therefore, it is important to evaluate alternatives for the production of biodiesel in a smaller scale.

This study focused on the production of biodiesel from palm oil at pilot-scale with a capacity of 20,000 L/day (5,000 ton/year), including operating costs and utilization of byproducts. Canakci and Gerpen (2001) conducted a similar study using refined soybean oil as raw material, and reported a production cost of $0.42/L ($1.58/gal) in a pilot-scale plant (190 L biodiesel/batch). The authors did not include potential gains from the use of glycerine as byproducts and did not estimate operational costs.

2.2. Feedstock and materials

2.2.1. Crude palm oil

There are different types of raw materials, such as vegetable oils, used cooking oils, animal fats, etc., which contain free fatty acids and triglycerides that can be converted into biodiesel (Janaun and Ellis, 2010). Among these feedstocks, crude palm oil is characterized by being rich in fatty acids (w/w), such as oleic acid: 42.4%, palmitic acid: 37.1%, linoleic acid: 12.5% and stearic acid: 5.4%. These acids are converted into methyl esters of fatty acids (i.e., biodiesel), by a transesterification reaction with methanol, which make palm oil an excellent raw material for industrial biodiesel production.

2.2.2. Catalyzer

During the transesterification stage of biodiesel production, potassium hydroxide is often implemented as a catalyst due to its low cost and potential to generate sodium phosphate via its neutralization with phosphoric acid. Sodium phosphate can be used to generate additional revenue because it can be sold as a fertilizer (Vicente et al., 2007; Leung et al., 2010).

2.2.3. Alcohol

Methanol was used in this stage because of its relatively lower cost, smaller required volumes, and ease of recovery of the unreacted alcohol (Haas et al., 2006).

2.2.4. Magnesium silicate

An important and different condition in the production plant discussed in this manuscript is the type of wash applied to biodiesel. Conventionally, washing water is used, which has some notable disadvantages mentioned in a later section. At this stage in the plant of interest, dry washing was implemented using magnesium silicate, commercially known as Magnesol®, which has the advantage of removing the water (Berrios and Skelton, 2008).

2.3. Process and operating conditions

It is a batch and sequential production process that allows the use of different raw materials such as palm oil, jatropha oil, rapeseed oil and used oil, individually or mixed together. Production system also allows for two types of alcohol: ethanol and methanol. Similarly, the factory allows using acidic or basic catalyst. The plant was fully manufactured and assembled in Colombia. This plant has a central system that controls all instruments, and equipment to ensure a reliable and automated operation. Finally, the plant capacity is expandable because it was designed with a modular and independent system which can be increased by installing another module of the same production conditions.