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# Evaluation of production costs of biodiesel from jatropha curcas oil with two zirconia based catalysts

CRUZ-NETRO, Liz Del Carmen*†, MENDOZA-HERNÁNDEZ, Ana Viriginia, CRUZ-NETRO, Zahira Gabriela y PADILLA-TORRES, Sergio Antonio

*Universidad Politécnica de Altamira. Nuevo Libramiento Altamira Km. 3, Santa Amalia, 89602 Altamira, Tamps.*

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**Abstract**

This paper presents the results of the cost evaluation for the production of biodiesel from jatropha curcas oil and methanol using heterogeneous types of zirconium base catalysts, in order to establish the most economically viable catalyst. The comparative tables of the production costs for both catalysts were made considering the capacity of recovery and reuse of the same catalysts as the operational costs considering a capacity of 2000L per lot on a batch process. Costs are for laboratory conditions (retail purchase). The basic catalyst ZrO2-Na is the best alternative to get 98% after using up to four cycles of the transformation process without losing its catalytic property, costing approximately $2,601,872.24 which corresponds to a cost of $1,300.94 per liter. By making the performance comparison by the catalyst considering its number of reusable cycles, the cost of biodiesel with the basic catalyst reduces up to 40% in the fourth cycle obtaining a total cost of production per liter of $791.75.

**biodiesel, jatropha curcas oil, production cost, catalyst, circonia**

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* Correspondence to Author (email: liz.cruz@upalt.edu.mx)
† Researcher contributing first author.

## Introduction

In this last century, the main environmental problem worldwide has been global warming with the large accumulation of pollutants and the excessive exploitation of the planet's natural resources. This has generated serious consequences such as the extinction of flora and fauna, terrible natural disasters, the evident perceived sensation of diverse climatic changes and contamination by crude or refined oil accidentally or deliberately generated. It is estimated that 3,800 million liters enter the oceans every year as a result of human activities, of these, only 8% is due to natural sources; at least 22% at intentional operational discharges from ships, 12% from ship spills and another 36% from wastewater discharges [1].

Therefore it is important to create awareness, replace the main sources of energy and proceed to a positive change in our excessive habits. The reason for the investigations to replace oil as the main energy resource is because the world reserves sooner or later will be exhausted [2]. Diesel or diesel, the main derivative of petroleum, is used as a domestic fuel and in diesel engines. An additional reason to replace diesel with biodiesel is that the latter does not contain sulfur, so it does not generate SO2 (sulfur dioxide), a gas that contributes significantly to environmental pollution [3].

## Theoretical framework

In order to improve the competitiveness of biofuels, new technologies and raw materials capable of reducing the cost of the production process are investigated; so they call the attention seeds not suitable for human consumption as alternatives for obtaining oil [4].

The plant Jatropha curcas L. is a shrub resistant to drought belonging to the Euphorbiaceae family, its toxic characteristics and adaptation to arid lands, besides its low cost by not competing with food, make this an attractive raw material for production of biodiesel [4].

Biodiesel from jatropha curcas oil or other non-consumable plant oils has economic, as well as energetic and environmental advantages; generally it does not require major modifications for its use in common diesel engines, it allows the producer to become independent of the oil-producing countries. It has a great power of lubrication and minimizes the wear of the engine; reduction of polluting emissions of carbon monoxide (CO), hydrocarbons (HC), sulfur dioxide (SO2), polycyclic aromatic hydrocarbons (PAH), and particulate matter (PM), visible smoke particles; it is not considered a contaminant for surface water sources or underground aquifers, it is degraded 4 to 5 times faster than fossil diesel and can be used as a solvent to clean fossil diesel spills; generates positive effects for health, since it reduces carcinogenic compounds; in addition, global warming decreases through the reduction of CO2 (carbon dioxide) in the environment [3-4].

The competitiveness of biodeisel depends on the costs of raw materials and the type of catalyst. Recent, various investigations evaluated the economic viability of the production of biodiesel with waste vegetable oil in a homogenous acid process, resulting in a low total manufacturing cost compared to alkaline transesterification with pure vegetable oil. In supercritical conditions (high pressure and temperature) the economic viability is very high due to the high cost of equipment when needing a reactor capable of withstanding high pressures.

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Choosing between a homogeneous and heterogeneous catalysis is very important, since it affects the cost associated with the separation and purification method. With a homogeneous catalysis, the process requires an extensive separation process to remove the catalyst and purify the final product increasing costs of production; With a heterogeneous catalysis the separation process is reduced but often require high temperatures and / or long reaction times. A sensitivity analysis indicated that plant size and raw material are the most important parameters of the economic viability of biodiesel production [5].

**Methodology**

This study includes the comparison between the catalysts $ZrO_2$-Na and $ZrO_2$-$SO_4$ during the transesterification process with jatropha curcas oil and methanol. The precursors for the preparation of the catalysts are zirconium butoxide, tert-butyl alcohol, demineralized water for both catalators; Sulfuric acid for the acid catalyst and sodium hydroxide for the basic catalyst. The number of cycles to which the catalyst is subjected after recovery and reuse in the process was also considered.

The acid catalyst can be reused in the transesterification process about 3 times and in the case of a basic catalyst it achieves a total reuse of approximately 4 cycles.

In the production of biodiesel, the catalyst is mixed with the jatropha oil with methanol at a rate higher than 1200 rpm and 75 ° C at two hours of reaction [6-7]. The next step is to recover the catalyst by washing with hexane and ethanol, filter and put in the oven at 120ºC for 1 hour [8-9].

**Cost analysis**

According to the data presented by the company Petróleos Mexicanos (PEMEX), the average consumption of diesel in Mexico is 333 thousand barrels per day, equivalent to 53 million liters, of which in Tamaulipas, through the Storage and Distribution Terminal (TAR), indicates that this state is supplied with an average of 46 million liters-diesel [10]. Due to climate change, one of them has been chosen to make transformations in fuels, biodiesel because it is a source of clean, renewable, economically viable energy and contributes to the environment, which entails reducing environmental damage little by little. in this way improve the quality of life for future generations. The following analysis has been made in order to compare two types of biodiesel, one with acid catalyst and another with basic catalyst.

**Estimation of costs**

**Fixed costs**

Costs have been considered for a laborartory process, for which an industrial agitation reactor with a 2000 L capacity has been taken as a base.

Considering shifts of 8 hours per day (hours allowed in a working day by Mexican laws), the cost of the personnel was calculated with three rotating daily shifts of 8h, working 3 days time required for the preparation of the catalysts and an initial batch with a engineer in charge and two operators per team for the production of biodiesel. Personnel costs are calculated based on the Secretary of Labor and Social Prevention considering the legal minimum wage in force in 2017 [11], for operating officer of $ 105.77 pesos per shift and for an industrial engineer $ 11,000.00 pesos per month including contributions legal for each one. Table 1 shows the total labor cost per initial batch.

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| Workforce | Salary per batch |
|---|---|
| 2 operators | 951.93 |
| 1 engineer | 3,535.71 |
| **Total** | **4,487.64** |

**Table 1** Labor costs per initial batch of 2000 L of biodiesel

According to the tariff of CFE (National Commission of Electricity) 2017 [12] the price will be of $ 195.03 pesos per kilowatt / hour, elaborating the energy calculations for the elaboration of a batch of biodiesel with a reactor with industrial agitator that generates 15.75 Kw7 per lot would have a total cost of $ 3071.73 pesos per lot. For water consumption according to the Municipal Commission for Drinking Water and Sewerage of Altamira (COMAPA) [13], the industrial rate for a range of 0-20 m3 valid for 2017 will be $ 427.09 pesos per month, considering to obtain the cost per lot the previous price, the approximate water cost will be $ 42.70 pesos per lot.

## Cost of raw material

Using prices obtained by different suppliers at the laboratory level, for the production of biodiesel based on a reactor with a capacity of 2000 L, the following costs were obtained; In Table 2 are shown for biodiesel with basic catalyst and for biodiesel with acid catalyst shown in table 4.

| **Biodiesel with basic catalyst 2000 L** | | | |
|---|---|---|---|
| **Reagents** | **Amount per reagent (L)** | **Unit cost ($ / L)** | **cost ($)** |
| **Zirconium butoxide** | 294.81 | 2,604.00 | 767,694.10 |
| **Terbutyl Alcohol** | 925.93 | 609.00 | 563,888.89 |
| **DM water.** | 111.11 | 9.47 | 1,052.63 |
| **Sodium hydroxide (kg)** | 44.44 | 624.00 | 27,733.33 |
| **Methanol** | 2,242.78 | 190.25 | 426,688.47 |
| **Jatropha curcas oil** | 2,037.04 | 400.00 | 814,814.81 |
| | **Total cost for 2000L** | | **2,601,872.24** |

**Table 2** Raw material costs for a 2000 L biodiesel batch

Making a quick comparison of prices we could choose to choose the most economical, in this case biodiesel with basic catalyst (table 2) with a cost of $ 2,601,872.24 pesos per lot, however, before opting to choose any of the above, a detailed comparison analysis taking into account that the catalyst can be recovered by a simple treatment and reused by means of the transesterification process obtaining in this way for the basic biodiesel a maximum yield of 4 times and in the case of acid biodiesel can be reused until 3 times its catalyst, because in both cases the catalyst is deactivated by poisoning by-products.

| Biodiesel with acid catalyst 2000 L | | | |
|---|---|---|---|
| \| | **Amount per reagent (l / Lot)** | **Unit cost ($ / L)** | **Cost ($)** |
| **Zirconium butoxide** | 303.24 | 2,604.00 | 789,628.22 |
| **Terbutyl Alcohol** | 952.38 | 609.00 | 580,000.00 |
| **DM water.** | 114.29 | 9.47 | 1,082.71 |
| **Sulfuric acid** | 19.05 | 770.00 | 14,666.67 |
| **Methanol** | 2,306.86 | 400.00 | 922,742.86 |
| **Jatropha curcas oil** | 2,095.24 | 190.25 | 398,619.05 |
| | **Total cost for 2000L** | | **2,706,739.50** |

**Table 3** Raw material costs for a 2000 L batch of biodiesel with acid catalyst

Considering as batch 1 the capacity of 2000 L, table 5 shows the comparison of costs for basic biodiesel, maximizing up to 4 times the reuse of the catalyst with 8000 L, against the assumption that in order to obtain the same quantity it would have to add new catalyst for each batch.

| BASIC BIODIESEL | Cost | |
|---|---|---|
| | **Batch 1 (2000L)** | **Batch 4 (8000L)** |
| **Without maximizing utility of the catalyst** | $ 2,601,872.24 | $ 10,407,488.96 |
| **Maximizing catalyst utility 4 times** | $ 2,601,872.24 | $ 6,326,360.00 |
| **Cost per liter of biodiesel** | **$ 1,300.94** | **$ 790.80** |

**Table 4** Cost comparison maximizing the performance of the basic catalyst up to 4 times (8000 L)

Table 4 shows that the higher the amount per initial batch, the cost per liter of biodiesel is decreasing because only for the first batch generates the cost of the catalyst because it is used 4 times more, in this case having a reactor with a capacity of 2000 L with a cost of $ 2,601,872.24 pesos per lot (lot 1), and using the same catalyst on four occasions generates a total yield for 8000 L at a cost of $ 6,326,360.00 pesos per lot (lot 4), thus obtaining the decrease in the cost of biodiesel basic from $ 1300.94 to $ 790.80 pesos per liter generating 39% less of the total cost for 4 lots.

In the same way, for biodiesel with acid catalyst the comparison has been made in the yield of its catalyst (acid) up to 3 times with the same quantity of 2000 L, consequently the maximum yield of the obtained catalyst will be 6000 L.

In the table 5 you get the cost of acid biodiesel with the maximum yield of the catalyst 3 times from $ 1,353.37 to $ 1,082.21 pesos per liter of biodiesel reducing up to 20% of the total cost.

| BIODIESEL ACID | Costo | |
|---|---|---|
| | **Batch 1 (2000 L)** | **Batch 3 (6000 L)** |
| **Without maximizing utility of the catalyst** | $ 2,706,739.50 | $ 8,120,218.49 |
| **Maximizing catalyst utility 3 times** | $ 2,706,739.50 | $ 6,493,276.83 |
| **Total cost per liter of biodiesel** | **$ 1,353.37** | **$ 1,082.21** |

**Table 5** Cost comparison maximizing the performance of the acid catalyst up to 3 times (6000 L)

Analyzing tables 4 and 5 it can be concluded that it will be better to use the basic catalyst, because with its higher yield (4 times) we can reduce the cost of biodiesel to almost 40%, therefore to a greater amount of the first batch greater is the decrease in the cost per liter of biodiesel which generates greater utility ensuring the feasibility of biodiesel.

### Total cost of production per batch

In order to obtain the costs per lot, the fixed costs, labor and cost per lot have been considered because this research was elaborated at the laboratory level. Table 6 shows the total costs for the production of biodiesel with basic catalyst, obtaining a production cost per liter of $ 791.75 pesos per liter.

| Costs per batch (8000 L) | Biodiesel básico |
|---|---|
| Raw material | $ 6,326,360.00 |
| Fixed costs | $ 3,114.38 |
| Workforce | $ 4,487.64 |
| Total cost of the lot | $ 6,333,962.02 |
| Production cost 1L | **$ 791.75** |

**Table 6** Cost of production per liter for biodiesel with basic catalyst

In the same way table 8 has been generated where the production costs of biodiesel with acid catalyst are broken down.

| Costs per batch (6000 L) | Biodiesel ácido |
|---|---|
| Raw material | $ 6,493,276.83 |
| Fixed costs | $ 3,114.38 |
| Workforce | $ 4,487.64 |
| Total cost of the lot | $ 6,500,878.85 |
| Production cost 1L | **$ 1,083.48** |

**Table 7** Production cost per liter for biodiesel with acid catalyst

Analyzing tables 6 and 7, it can be seen that the biodiesel with the highest production cost will be that of the acid catalyst with a production cost of $ 1,083.48 pesos per liter, so the most economically viable would be to produce biodiesel with a basic catalyst with a total production cost of 791.75 pesos per liter.

### Results

As can be seen in this analysis of production costs of biodiesel with two types of zirconia base catalysts, one basic and one acid, in the costs of raw material per batch of 2000 L (2 and 3) the biodiesel with acid catalyst is more expensive with total cost of $ 2,706,739.50 per lot. On the contrary, the most economical is the basic catalyst with a total cost of $ 2,601,872.24 per lot. However, considering the tables of cost comparison with the maximum reuse of the catalysts (4 and 5), it is obtained that the biodiesel of basic catalyst generates a cost of $ 790.80 pesos per liter due to the reuse of its catalyst on 4 occasions.

Acid catalyst biodiesel generates a cost per liter of $ 1,082.21 pesos since its maximum reuse is 3 times. Therefore, the comparison analysis of costs per batch or per liter generated in the tables (2-5) confirms that the best option to make biodiesel is with a basic catalyst because it generates less costs, generating costs of Total production approximate to $ 791.75 pesos per liter.

### Conclusions

Undoubtedly, climate change has forced us to create awareness about what we are doing to our planet and for this reason we seek to generate new energy sources trying to reduce the ecological damage that traditional fuels have caused. Biodiesel has emerged as a good alternative for the replacement of diesel.

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In this article focused on the comparison of costs of biodiesel based on jatropha curcas oil with two types of catalysts, one acid and one basic, which results in biodiesel with basic catalyst is the most affordable option due to its high reuse decreasing thus the costs for its production. As future work, its viability will have to be analyzed for implementation at an industrial level, through a cost-benefit study, looking to consider the base oil biodiesel of jatropha curcas with heterogeneous basic catalyst as an alternative to conventional diesel

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