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The effect of economic variables over a biodiesel production plant

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ABSTRACT

Biodiesel appears as one of the possible alternative renewable fuels to substitute diesel fuel derived from petroleum.

Several researches have been done on the technical aspects of biodiesel production in an attempt to develop a better and cleaner alternative to the conventional process.

Economic studies have been carried out to have a better understanding of the high costs and benefits of different technologies in the biodiesel industry.

In this work it is studied the effect of the most important economic variables of a biodiesel production process over the general economy of a conventional plant which employs sodium methoxide as catalyst. It has been analyzed the effect of the oil price, the amount of free fatty acid, the biodiesel price, the cost of the glycerin, the effect due to the modification on the methanol price, the washing water price, and several others.

Small variations on some of the major market variables would produce significant effects over the global economy of the plant, making it non profitable in some cases.

1. Introduction

Biodiesel is defined by the ASTM as the mono alkyl esters of long chain fatty acids derived from a renewable lipid feedstock such as vegetable oil or animal fat. It is a biodegradable and renewable substitute for regular petroleum diesel fuel. Some advantages of this alternative fuel, over the regular diesel, are its lower toxicity, better combustion into CO_2, no pollutant particulates and almost none sulfur contaminants. Still, petroleum diesel is the most used fuel worldwide [1].

Biodiesel standard production consists on a process that employees a homogeneous catalyst such as sodium or potassium hydroxide [2–8] in the presence of an alcohol, being methanol the most commonly used because of its low cost, whereas ethanol could also be employed. Although high conversion can be achieved through conventional technology, it is only suitable when refined oils are employed. If a raw material with an amount of free fatty acids (FFA), over 0.1–0.5 wt.%, is used with a basic homogeneous catalyst, soaps will be produced. This will make the process less efficient, the down streaming separation more complicated and the final product more expensive, causing a decrease in the global fuel productivity [9–11]. Because of this, several studies have been carried out considering the technical aspects of different technological alternatives for biodiesel production, such as de the work done by Zhen et al. [12], Marchetti et al. [13] and Peterson and Scarrah [14] on heterogeneous catalyst, or the research done in using enzymes as catalyst by Kaieda et al. [15] Nelson et al. [16], Watanabe et al. [17], Haas et al. [18] and Sanchez and Vasudevan [19]. New approaches as using supercritical methanol, Saka and Kusdiana [20], or membrane reactors, Dubé et al. [21] are being under consideration.

The main reaction that takes place in the biodiesel process is the transesterification. In this reaction, a triglyceride interacts with an alcohol to produce fatty acids alkyl esters, normally call fatty acid methyl ester (FAME) due to the used of methanol. Glycerol is also produced. The main reaction could be summarized as follows:

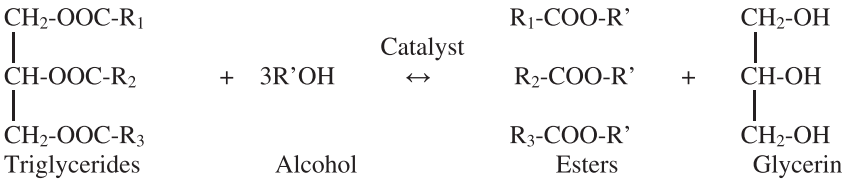

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Table 1
Summary of some economic research.

Authors/reference	Capacity	Raw material	Type of catalyst	Criterion
Nelson et al. [22]	100,000 ton/year	Beef tallow	Alkali	Total capital cost
Graboski and McCormick [23]	10 MM/year	Different raw oils	Alkali	Feedstock price[a]
Bender [24]	2, 7,5 and 12 MM l/year	Different raw oils	–	Capital equipment cost
Zhang et al. [25]	8000 ton/year	Waste cooking oil	Alkali/acid	Fix capital cost
Haas et al. [26]	37 MM l/year	Soybean	Alkali	Biodiesel price [b]
Marchetti et al. [27,28]	36,036 ton/year	Acid oil	Alkali/acid, acid, solid resin, supercritical	Net present value
West et al. [29]	8000 ton/yea	Acid oil	Alkali, acid, acidic resin, supercritical	After tax return rate
You et al. [30]	8000, 30,000 and 100,000 tons/year	Soybean oil	Alkali	Net annual profit after taxes, after taxes return rate[d]
Van Kasteren and Nisworo [31]	8000, 80,000 and 120,000 ton/year	Waste cooking oil	Supercritical	Biodiesel selling price[c]

[a] The feedstock price was the variable used to carry on a sensitivity study for the biodiesel plant.
[b] In this work there is not a comparison with other alternatives and the biodiesel price used as criteria, was the variable which variations were more significant.
[c] The biodiesel selling price of this work was not sued for comparison; it was determinate as the minimum price required to sell the biodiesel.
[d] Other economic variables were tested as well on this paper, those are the most important ones.

It is important to notice that this is a series of reactions, in which from triglycerides diglycerides are produced. Then, diglycerides are transformed into monoglycerides and finally, the latest is modified into glycerin. In every single step biodiesel is produced. Because this is an equilibrium reaction, higher amounts of alcohol are used in order to swift the reaction towards the desire product.

Despite the fact that technological viability is important, it is also relevant the economic feasibility. Different authors have also done economic analyses of several biodiesel production scenarios. Table 1 consists on a brief summary of some researches which shows the most relevant variables of the process: plant capacity, type of catalyst, and economic variable used as selection criteria. It could be seen from Table 1 that several works have been addressing the economic area of the biodiesel industry; however, all the works considered the economic data as input of the problem, the price of the raw material, the selling price of the biodiesel, etc., are considered fix for each scenario. Haas et al. [26] have done some sensitivity study on two mayor variables but to our knowledge, not much has been done addressing the effect of other economic and market variables in the global economic of a biodiesel plant. Being this information of high relevance in order to analyze the market influence on the biodiesel industry.

In this work, the influence of several market dependant variables (price of raw material, selling price of biodiesel, etc.), over the economy of a biodiesel plant, has been studied. This analysis was done over a biodiesel production plants that employees a basic homogeneous catalyst such as sodium hydroxide due to the fact that is the most common and one of the most studied processes, principally because the industrial scale plants are based on this process.

This study will provided a better understanding of the business of a biodiesel plant and how external variables (non technical ones but those related to market law and country policy's) might affect the general economic, providing a very useful tool to predict limits of economic feasibility. Even more, this work allows that producers might have an idea of the future situation due to tendencies in the studied variables and will permit them to take any decision in order to prevent, or make it less severe, the consequences of the chaotic and random behavior of international markets.

For this purpose, it was used a commercial software, Super Pro Design [32]. Data from the literature was employed as a source for the cost and prices of equipment and materials. This study could be effortlessly adapted for other biodiesel production technologies with no major modifications in the process. The mayor economic variables were set as showed elsewhere [27,28]. Nevertheless, if the catalyst or the processes are changed, it is advisable to recalculate the analysis.

2. Study case

As mentioned, biodiesel is regularly produced using a homogeneous base catalyst. The plant's flow diagram can be seen in Fig. 1.

The process goes as follow. Methanol and the base catalyst are fed together into the catalyst preparation equipment (1), where the alcoxy is produced. The outcome stream is divided in two to feed both transesterification reactors. After the first transesterification reaction (2), a decanter (3) is used to separate the glycerol phase from the oil phase. The outlet oil stream is fed into the secondary reactor (4) to achieve the desirable final conversion. The biodiesel/glycerol stream is fed into a second decanter (5) to separate the biodiesel from the glycerol phase. Both glycerol phases were fed into a neutralizer (6); then, some impurities are separated in a decanter (7). A distillation (8) is required to separate methanol, which will be recycle. In a further distillation column (9) the glycerol is separate from the remains compounds. From decanter (5), the upper stream, which is biodiesel, is washed with water for a further separation in another decanter (10). The biodiesel phase is distillated (11) in order to achieved international standards of quality.

Table 2 shows the most important economic parameters used in this work such as investment, total capital cost and plant capacity. The economic assumptions have been done according to information from the literature. In this work it has been compared the internal return rate (IRR) and the payback time. It is clear that the net present value (NPV) is more accurate for an economic decision; however, to compare and analyze the effect of modification, in for example the vegetable oil price, the IRR is more than suitable. The presented tendencies will not suffer mayor modifications if the NPV is plotted instead of the IRR.

It was carried on a research to identify how each of the following variables separately affects the global economic of a global biodiesel process.

1. Oil price (associated to its purity).
2. Biodiesel selling price.
3. Glycerol selling price.
4. Alcohol price
5. Catalyst price.
6. Shipping distance.
7. Washing water price
8. Investment in research and development.

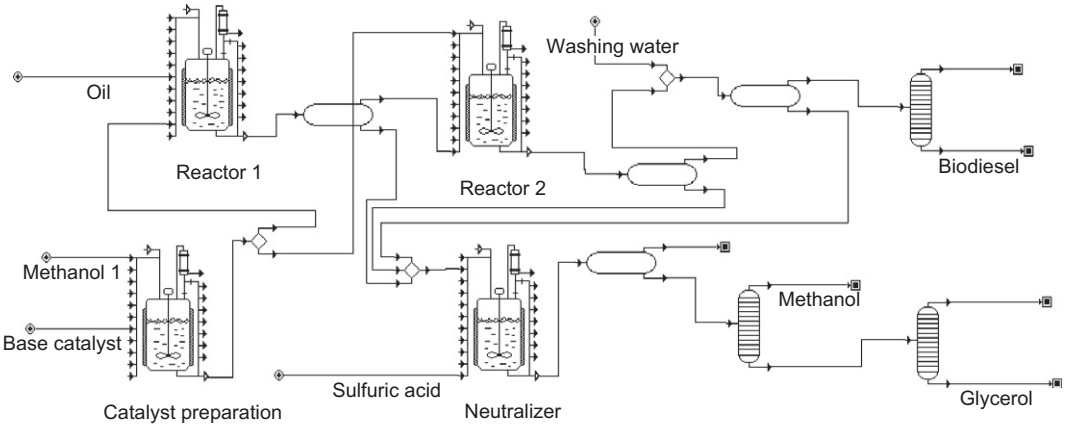

Fig. 1. Flow diagram of the process under studied.

Table 2
Technical and economic information.

Technical aspects	
Plant capacity (metric ton/year)	150,480
Project life time (year)	15
Feed streams (kg/h)	
Oil	19,000
Methanol	4750
Catalyst	400
Out coming streams (kg/h)	
Biodiesel (purity over 98%)	18,879
Glycerin (purity of 75%)	2510
Economic aspects	
Total capital investment	$ 34,868,000
Equipment purchase cost	$ 4282,000
Direct fixed capital (DFC)	$ 26,345,000
Working capital	$ 6678,000
Start up and validation cost	$ 1844,000
Total operating cost	$ 118,204,000
Labor dependant	$ 455,000
Utilities	$ 885,000
Laboratory	$ 68,000
Biodiesel unitary cost (US$/kg)	$ 0.7905

Table 3
Operations conditions and range of the variables under study.

Variable	Minimum	Standard	Maximum
Biodiesel price (US$/kg)	0.79	0.83	0.86
Glycerol price (US$/kg)	−0.10[a]	0	0.05
Alcohol price (US$/kg)	0.25	0.25	0.6
Catalyst price (US$/kg)	0.23	0.23	0.73
Shipping distance (km)	5000	15,000	20,000
Washing water price (US$/kg)	0.00033	0.00033	3.3
R&D (US$/kg of biodiesel)	0.11	0.12	0.15
Oil price (US$/kg)	350	400	450

[a] The minus means that the biodiesel plant pays the treatment company to treat the glycerol.

These variables have been chosen as the more market dependant ones. The raw materials' price, as well as the biodiesel selling price is not only ruled by the companies but by international offer and demand of biofuel, government policies and international agreements related to environmental concerns, such as the Kyoto protocol. For each of these variables, a study range has been selected in order to evaluate its influence over the IRR and the payback time. Table 3 shows these ranges.

3. Results and discussion

3.1. Changes on the selling price of biodiesel

The selling price of biodiesel is one of the most important variables that make the production process economically suitable or not. Nowadays, biodiesel price is not fixed in the market. It will depend on the local economies and the government policies towards it, such as subsidies to public transportation or higher taxes for private vehicles. Taking all this into account, the range used for this study was from 0.79 to 0.86 US$/l being a little lower than the average value in the US market [33].

Fig. 2 shows the variations of the payback time and the IRR when the biodiesel price suffers modifications.

It can be seen that as the biodiesel price increases, the IRR increases as well following a straight tendency; however, the payback time decreases but not in the same proportion as the IRR increases as showed by Haas et al. [26]. From Fig. 2 it can be noticed that a small fluctuation on the market price of biodiesel, such as a reduction of 7 cents on its selling price, will produce a reduction in the IRR of 78%. This result shows the great relevance of the selling price of the biofuel. Moreover, this price is attached to government benefits regarding the local law. Despite the absolute number showed in the figure, the tendency might not be different for other market scenarios.

3.2. Changes on the oil price

The conventional homogeneous basic technology requires refine oil. This means that the amount of FFA should be lower than 0.5% [2–5] in order to avoid soap formation and to make an easier separation and purification of the biodiesel after the reaction section. However, the mayor disadvantage of a refine oils is its price. Because of this, several other feedstock have been tested as raw materials: crude oil, soapstocks, waste oil, frying oil, cooking oil, etc., where the price is reduced as the amount of FFA increases. A price range between 350 and 450 U$S per ton has been used. This scale has been selected considering the refined vegetable oil and waste cooking oil prices according to the literature: edible oils could have a price from 478 to 650 U$S per ton depending on the oil [34], and waste cooking oil could have a price from 110 to 220 U$S per ton (where the amount of FFA is considerable higher) [25,26,35].

In Fig. 3 it could be seen the variations of the payback time as well as that of the IRR due to modifications in the oil price. As the oil price gets smaller, which could be associated with higher amounts of impurity, the IRR values gets higher. It is presented a

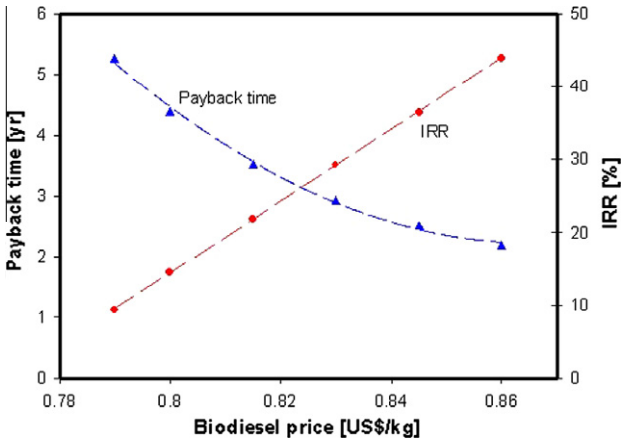

Fig. 2. Variation of the payback time as well as the IRR when the biodiesel price varies. (▲) Payback time, (●) IRR.

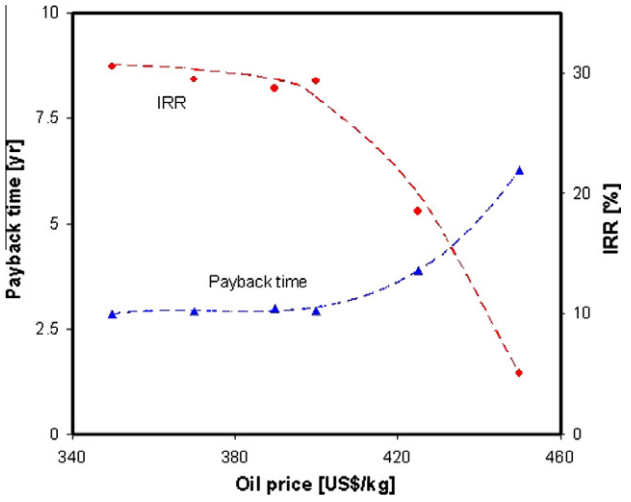

Fig. 3. Variation of the payback time as well as the IRR when an oil price varies. (▲) Payback time, (●) IRR.

transition point at around 400 US$/ton where the reduction in the price has a smaller relative effect on the IRR. This could be due to the high amount of free fatty acids present in the raw material, which will increase the soap production and therefore the final sub products' purity will be reduce. It will also make the purification process less efficient.

3.3. Changes on the glycerol price

Market price for glycerol is very variable and strongly attached to its purity and availability. Pharmaceutical grade glycerol could be sold at a price around 1380 US$/ton [30], while industry grade glycerol has a much cheaper price since it is produced in great amounts due to the biodiesel industry. The amount of glycerol produced is around 10% of the total biodiesel. Therefore, its price does have an important influence over the economy of the process. The glycerol produced by conventional homogenous technology has a purity around 75–80%, and consequently a low price.

In this section, the influence of the glycerol selling price was studied. It was considered a price that could vary from 50 US$/ton to −100 US$/ton. The minus sign on the glycerol price means that the glycerol is considered as a waste and therefore it should be pay for its treatment. This is a broad range because the high

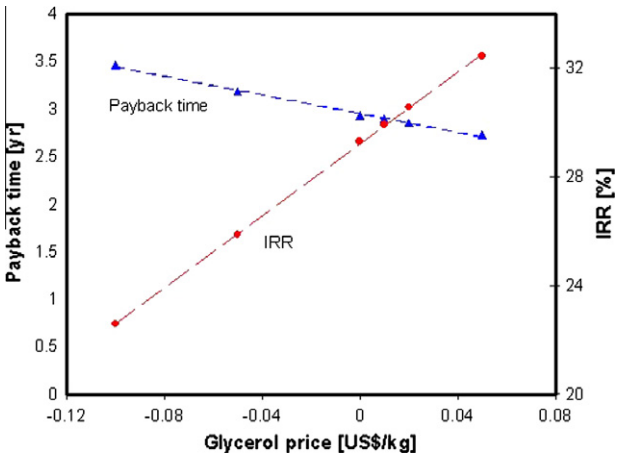

Fig. 4. Variation of the payback time as well as the IRR when the glycerol price varies. (▲) Payback time, (●) IRR.

amount of industrial grade glycerin produced by biodiesel plants has caused a considerable reduction in the glycerin price.

The influence of the glycerol price can be seen in Fig. 4. As the price gets smaller the IRR decreases as expected. It could be noticed that for the worst scenario studied the glycerol price has some influence over the general economic of the biodiesel plant but it will only produce a reduction of 30% in the IRR. Within this reduction the process will still be profitable with a lower income. One important point is that this tendency might be different for different biodiesel production technologies. For other options, the purity of the glycerol is higher and its effect might be similar but with a wider range before the process becomes unattractive for investment.

3.4. Changes on the alcohol price

The influence of the raw materials price is crucial for any economic study. The price of methanol and how it could affect the economy of a biodiesel production plant has been studied. For this research, it has been considered a range from 0.25 to 0.61 US$/kg [26].

Fig. 5 shows that the influence of the methanol price over the IRR is relevant as it was the effect of the oil price. When the price

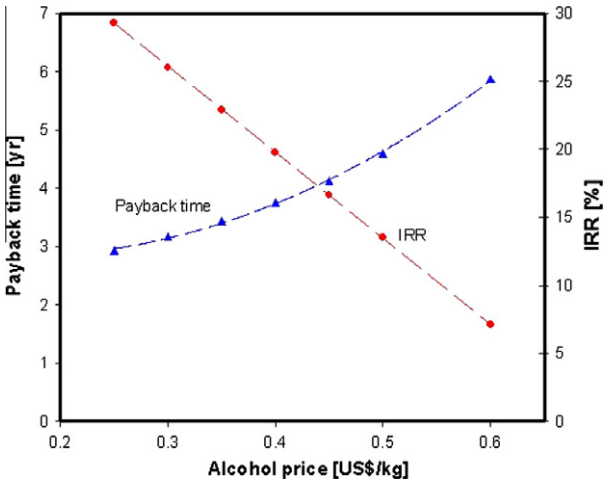

Fig. 5. Variation of the payback time as well as the IRR when the alcohol price varies. (▲ Payback time, (●) IRR.

increases from 0.25 to 0.6 US$/kg, the IRR suffers a reduction of 75%, showing its great influence on the global process, with the possibility of making the process not profitable if the price continues to raise. It can be seen, as it was the case for the oil price, that both raw materials have a very high effects over the economy of the process, as expected; and small modifications on any of them could have a very relevant impact on the profitability of the plant.

3.5. Variations on the catalysts price

The influence of the catalyst price over the global economy of a biodiesel plant has been studied. A range going from 0.23 to 0.73 US$/kg, similar to the one used by Haas et al. [26] and West et al. [29] has been employed; however, this price could be much higher, as established by You et al. [30].

The percentage of catalyst generally used is 1% w/w of the total vegetable oil [2,6,7], being this a small fraction that might not have a significant effect over the global economy compared to small variations of the biodiesel price, as showed in Fig. 2. The catalyst price is usually associated to the type of catalyst used. If sulfuric acids were employed instead of sodium methoxide, the price range will be higher because it is more expensive.

Fig. 6 shows the variations of the IRR and the payback time when different catalysts prices are studied. It can be seen that when the catalyst price increases over three times its value, the reduction on the IRR is lower than 19%. This shows that the catalyst price is not a key factor in the economic of the variables; this is due, most likely, to the fact that the amount of catalyst is very small compared to the need of vegetable oil or alcohol quantities.

3.6. Variations on the shipping distance

Biodiesel it is not generally consumed where it is produced and, therefore, shipping is required, increasing the cost of production. This could be either by boat, trucks or trains.

It has been considered the following four shipping distances, 5000, 10000, 15000 and 20000 km. In this study it could be thought that the biodiesel goes from Argentina to almost any place in the world.

Fig. 7 shows the tendency for the IRR and the payback time, becoming the IRR smaller as the distance increases associated to a higher price of shipping. A reduction in the payback time, as the shipping distance gets shorter, could be seen in Fig. 7, where it can be observed that shipping is relevant to the process. However, this variable it is also attach to the market volatility and also

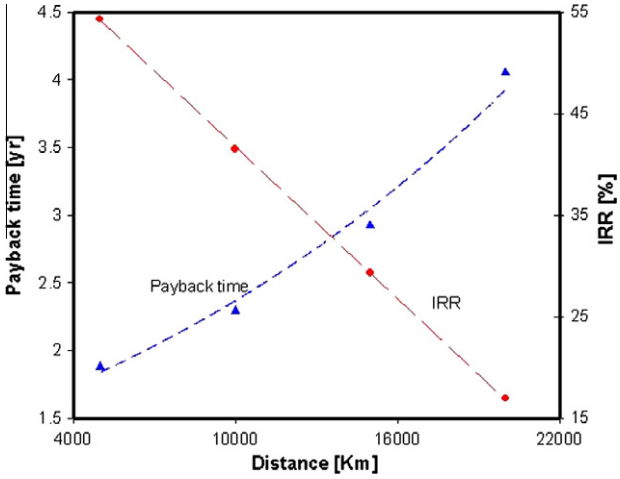

Fig. 7. Variation of the payback time as well as the IRR when the shipping distance varies. (▲) Payback time, (●) IRR.

to the petroleum industry, making it a more complicate variable to completely analyze.

3.7. Variations on the washing water price

When a homogeneous catalyst is used, both acid and basic ones, the biodiesel require purification. After the separation of the glycerol phases from the rest, the biodiesel phase is washed with water (see Fig. 1 equipment (10)). This water is then separated and the biodiesel is distillated to achieve a purity that satisfies international standards. The price of the water used in this procedure was varied and its effect over the IRR and the payback time was studied. In Fig. 8 it can be seen that it is required variations at around a thousand times bigger [26] in order to produce a significant modification on the IRR values, decreasing from 30 to around 8%. This result shows that as for the catalyst, the needs of water for washing are not big, making it not a decisive variable.

A similar result is observed on the payback time which decreases from 6 to around 3 years when the price decreases significantly.

3.8. Variations on the US$ used for research and development

The influence of the US$/kilo of biodiesel produced designated for research and development was studied. Several companies in-

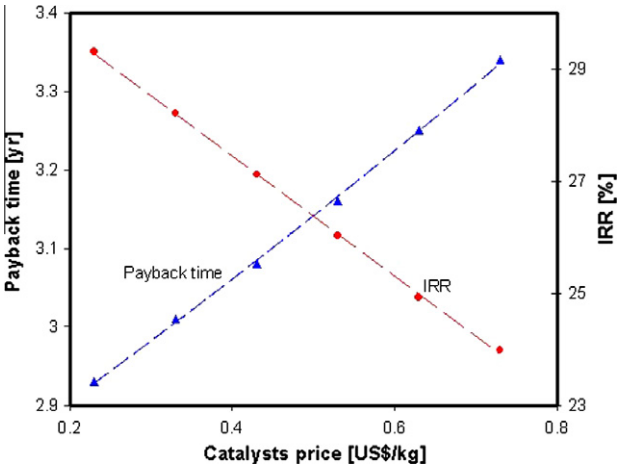

Fig. 6. Variation of the payback time as well as the IRR when the catalysts price varies. (▲) Payback time, (●) IRR.

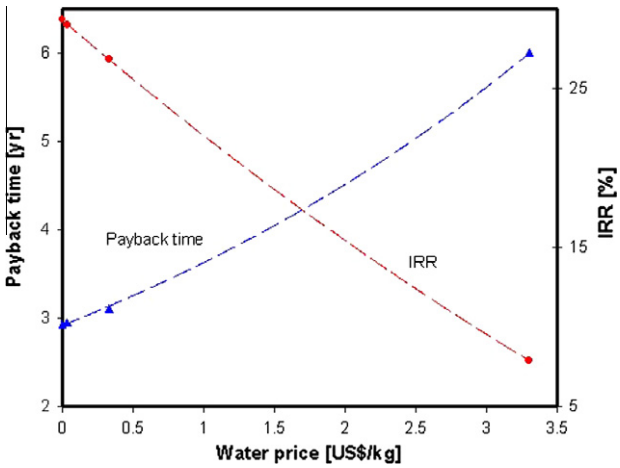

Fig. 8. Variation of the payback time as well as the IRR when the washing water price varies. (▲) Payback time, (●) IRR.

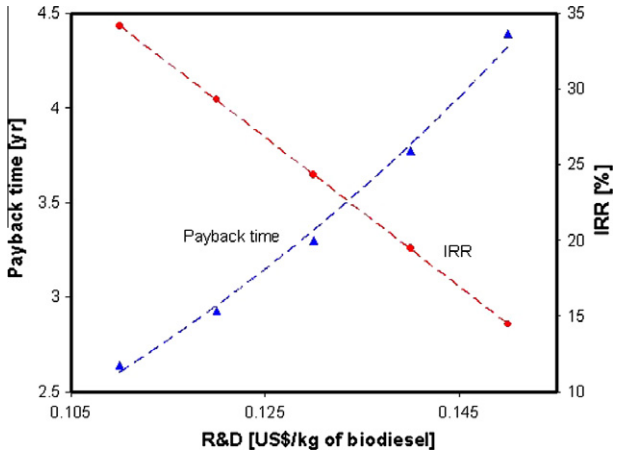

Fig. 9. Variation of the payback time as well as the IRR when the amount of US$ destiny to research and development changes. (▲) Payback time, (●) IRR.

vest money from their revenues for research and development to improve their production processes. In this section it was studied how this variable might influenced the IRR and the payback time of a biodiesel plant. It was also studied the range between 0.11 and 0.15 US$/kilo of biodiesel produced.

Fig. 9 shows that the IRR decreases more than 50% when the increase on the amount invested for research and development increases only 36%. The payback time decreases in a 60% as a consequence of the same variations on the amount given for R&D.

4. Conclusions

An economic study over a biodiesel process that uses conventional basic homogeneous catalyst has been done and how each market variable affects the internal return rate and the payback time was analyzed.

It has been found, as expected, that the entire incomes variables (selling price of glycerol as well as biodiesel) have a positive effect over the internal return rate making the payback time to be reduced as showed by Haas et al. [26]. Contrarily, the outcomes variables have the opposite effect making the process less profitable. It is important to notice that not all the outcomes variables have the same effect over the process and not all of them might produce a non profitable scenario for the ranges studied in this work. This difference is most due to the fact that for vegetable oil as well as for alcohol, the required amounts are considerable high, while for catalyst, washing water, etc., they are just small fractions, producing a relative smaller effect.

All the studies included in this work show that the payback time never tends to zero. This result is in accordance to a net investment in equipment that at least should be recovered.

It is important to notice that the variables studied are economic ones and not technological, making it possible for this study to be extrapolated easily to other technologies production process, catalyst or market scenarios. However, economic calculations are encouraged to be performed if major modifications are done to the process.

These results are of high interested since they shows tendencies of how several relevant variables modifications can affect the IRR of a biodiesel plant, it can also be seen from those tendencies what is the possible cut off values of each variable where the process will start to be in a negative financial situation. Even more, the fact that an idea of the evolution of the economic indicator as a function of several variables is showed, allows decision to be taken ahead, preventing economic crisis to strike.

Disclaimer

The authors and Plapiqui do not accept responsibility for any decision taken based on these model results. The model used on this work is for research purpose only. For specific applications please contact the authors, as well as for recommendations regarding the limitations and scope of the model.

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