# PARAMETRIC ALGORITHM FOR THE STUDY OF TECHNICAL AND ECONOMIC FEASIBILITY OF BIODIESEL PRODUCTION PLANTS AT SMALL AND MEDIUM SCALE IN COLOMBIA

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# DEDICATION

This work is dedicated to my family, because they are the strong in my life and my support to continue with my passion which is the mechanical engineering. Also this work is dedicated to my friend Steven Pinto because his support during all our friendship.

## ACKNOWLEDGMENT

I want to acknowledge principally to my family for their support in this project, to God because he is my guide in all my projects, to my classmates during my career because they contributed a lot every day in my learning and in special I want to say thank for the teachings to my professors Dionisio Malagón, Carlos Narváez, Rodrigo López, Carlos Camacho, Jair Ladino and Elver Carvajal because they have been fundamental pieces in the construction of my profession.

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# OBJECTIVES

## GENERAL OBJECTIVE

Develop a computational tool, conceived in order to determine the technic and economic feasibility of Biodiesel facilities and their implementation at small and medium scale to be used in further analyses in the Colombian context.

## SPECIFIC OBJECTIVES

- Develop or select a suitable methodology to perform a parameterized algorithm for feasibility analysis of Biodiesel production plant at small and medium scale.

- Develop and implement computationally an algorithm for feasibility study of Biodiesel production plants for small and medium scale and validate it with data from specialized literature.

- Identify relevant indicators and values about the prospective of Biodiesel production and demand in Colombia based on regional studies in order to get a regional reference for further feasibility studies using the developed algorithm.

# INTRODUCTION

In Colombia The Mines, Energy, Environment and Sustainable Development Ministries by administrative act and after consultation with the Intersectional Commission of Biofuels, decide to set percentages of biofuels over 10% as base on the mandatory mixtures since January 1 of 2013 [1], where for departments of Boyacá, Casanare, Cundinamarca, Meta, Guaviare, Vaupes and Amazonas, the mixture of biodiesel has to be 7% (B7). However, on the North of Santander, Vichada, Arauca and Guania, there is not a mandatory mixture for the use of biodiesel because of the low wealth of sources to produce biodiesel. The rest of the country is regulated under the B10 mixture according to Fedebiocombustibles [2]. Based on the mandatory mixture, for biodiesel production there is a global trend focus on the approach of waste cooking oil in substitution of the palm oil with the aim of not affect the human feedstock to obtain biodiesel [3]. It represents an opportunity to analyze if implement in a new biodiesel production plant is technical and economically feasible, considering the oil represents the greatest percentage in the breakdown cost analysis for biodiesel production [4].

For the analysis is necessary to make a technic and economic study involving the most relevant aspects and variables associated with the biodiesel production, starting from the definition of the biodiesel production process. As a way to reach that aim, the principal object of this project is to develop an algorithm at technical and economical level to determine the feasibility of the implementation of a biodiesel plant at small or medium scale in order to establish expressions that can be used by beginner investors in the Biodiesel market, based on the process to obtain biodiesel from waste cooking oil. Technically speaking, any raw material based on vegetable oil could be used. However, the evaluation of biodiesel production is performed based on the process carried out with waste feedstock as raw material at laboratory scale developed at Santo Tomas University, in order to continue with the research made by López et. al [5] about the technic feasibility for biodiesel production process from waste cooking oil by transesterification, where the economic analysis is a complement for a global study applied for industry. The study requires collect information about equipment, production and operation costs and raw materials used for biodiesel production by transesterification from waste cooking oil.

The algorithm applied in a computational tool by a macro in Excel ® estimates the capacity of the plant and the size of equipment as output that represent the technical feasibility. The biodiesel production cost, capital investment cost and internal rate of return were outputs to define the economic viability. The results pretend represent the starting point of future projects about the feasibility of biodiesel plant at small and medium scale in Colombia context, starting from the quantity of waste cooking oil collected per month for biodiesel production as the unique input in the computational tool.

The project is focused on collect information about economic and technic feasibility analysis with the aim to develop a suitable, not necessary the optimal, methodology and production process for analysis at small and medium scale facilities. The obtained results in the computational tool show internal rate of return (IRR) between 8% to 19,3% in a period of 15 years and total capital investment cost in a range of $2.800.000 to $7.000.000 USD considering small plant between 1.000 ton/year to 10.000 ton/year capacity [6] respectively. For medium plant capacity (up to 10.000 ton/year to 50.000 ton/year [6]) the IRR is 20% and 23% in a period of 15 years respectively, with capital investment cost up to $7.078.356 USD and $196.187.000 USD.

# 1 THEORETICAL BACKGROUND

## 1.1 INTRODUCTION OF BIODIESEL PRODUCTION BY TRANSESTERIFICATION AND USE

According to ASTM (American Society of Testing Materials) the biodiesel is defined as mono alkyl esters of long chain fatty acids which are derived from renewable lipid feedstock [6]. Chemically, biodiesel production is represented by the equation:

$$\begin{array}{c} CH_2-OOC-R_1 \\ | \\ CH-OOC-R_2 \\ | \\ CH_2-OOC-R_3 \\ Triglycerides \end{array} + \begin{array}{c} 3R'OH \\ \\ Alcohol \end{array} \xleftrightarrow[catalyst]{} \begin{array}{c} R_1-COO-R' \\ R_2-COO-R' \\ R_3-COO-R' \\ Esters \end{array} + \begin{array}{c} CH_2-OH \\ | \\ CH-OH \\ | \\ CH_2-OH \\ Glycerin \end{array}$$

*Equation 1. Transesterification reaction for biodiesel production*

Source: [6]

A chain of triglycerides as vegetable oil reacts with three moles of alcohol, usually methanol, in presence of a catalyst to obtain long chain of methyl ester called biodiesel and a co-product glycerin, this reaction is called transesterification [6]. In the production of biodiesel is necessary to use a catalyst for the time reaction decrease [6].

In order to determine which is the appropriated catalyst, Rio et al [7] show results about the yield and purity in biodiesel production at 60°C and one hour at atmospheric pressure, for three homogeneous catalysts, which have a homogeneous behavior in the mixture with the reagents: $CH_3ONa$, NaOH, KOH and four heterogeneous catalysts supported on aluminia, which form a heterogeneous mixture with the reagents: $Na_2CO_3$-$Al_2O_3$, KOH-$Al_2O_3$, $K_2CO_3$-$Al_2O_3$, NaOH-$Al_2O_3$; the results show homogeneous catalyst has the highest percentage of yield and purity of the biodiesel with 96% and 88% respectively, over the obtained results using heterogeneous catalysts, especially catalysts with potassium in its structure. Also, due to low prices, quantity for reaction and processing facility, homogeneous catalysts are the conventional selected raw material in many industries for biodiesel production [7].

Producing biodiesel is a very useful alternative to reduce the environmental negative impacts generated for the carbon dioxide ($CO_2$) emissions, and pollution of the fossil fuel used by different transport and industrial machines, according to UPME [8]. Focus on this idea, many governmental bodies could be interested in invest in new biodiesel production plant. Considering many countries, according to Duffey [9], Colombia has high potential of raw material such as soybean oil, palm oil, waste cooking oil, and represents a very strong source to invest in biodiesel production plants, becomes in one of the most important producers countries with more than 330.760.00 liters produced per year.

### 1.1.1 Pretreatment for Biodiesel Production from Waste Cooking Oil

Commonly, some feedstock has high percentage on free fatty acids (FFA) in its composition, for example waste cooking oil, the percentage reach more than 3%, and it is a disadvantage because it reduces the yield in the reaction for biodiesel production, and the quality of the biofuel because transesterification reaction with oil generates saponification in the final product, which is the formation of a phase FFA in the composition of the final product [10]. Alptekin et. al [11] have development a pretreatment of the waste cooking oil for biodiesel production in order to reach good yield and quality. This process consists on a first filtration of the WCO to eliminate all solids greater than 2mm; then start a esterification reaction to evacuate free fatty acids from the waste cooking oil by dosing 1% percentage of acid catalyst over the total mass of WCO, in a storage tank with the oil at 60°C for 20 minutes and then separate the two obtained phases: the upper phase is water and free fatty acids, and the lower phase is the treated waste cooking oil. Alptekin et. al [11] recommend sulfuric acid for the esterification because its characteristics; the two phases are separated using a centrifuge equipment. Then the process of transesterification can continue normally as is shown in *section 1.2.*

## 1.2 BIODIESEL PRODUCTION PROCESS BY TRANSESTERIFICATION USING WASTE COOKING OIL

There are some technologies to obtain biodiesel depending of the used catalyst for the reaction and the different raw materials such as soybean [12], peanut [13], palm [14] waste cooking oil (WCO) [15] and fat from animals [16]. Some of the different technologies to obtain biodiesel from WCO are exposed by West et.al [17]; they designed four different process: transesterification by homogeneous acid and alkali catalyst, transesterification by heterogeneous catalyst and the last one transesterification by supercritical process where is not necessary to employ any catalyst because of the critical condition of the process (250°C and 70 bar) [18].

One of the most used technologies is the process to obtain biodiesel from waste cooking oil, by transesterification with homogeneous catalyst. According to Zang [19], that technology is the most economically and technically feasible, because the cost of waste cooking oil is low, and the transesterification process does not require high temperatures and pressure; for the reaction is necessary a temperature of 60°C at atmospheric pressure [20], compared with the supercritical technology according to Marchetti [18].

In order to obtain biodiesel (methyl ester) by transesterification process is necessary make a reaction between vegetable oil, in this case the selected raw material is waste cooking oil (WCO), and methanol by using a homogeneous catalyst potassium hydroxide (KOH) for this study case [5]. Methanol is the most used alcohol because of its low cost and physical and chemical advantage because of the short chain of the hydrocarbon which allows the formation of easy and fast bonds for the transesterification reaction [21]. As first step is necessary make a pretreatment (*section 1.1.1)* of the WCO to reduce free fatty acids presented to secure a good reaction between the methanol and the oil, this process is called esterification [17]. For that aim consider to make a mixture of the three principal raw materials (WCO, methanol and KOH as catalyst), followed of a phase separation between the crude biodiesel and the co-product glycerol obtained from the mixture [5].

To improve the retention of biodiesel impurities is necessary a neutralization stage by dossing water to the crude biodiesel. To reach the ASTM standards for biodiesel at commercial scale, is necessary use a method to purify the final methyl ester and eliminate the presence of water in the final product (0,5% of water is acceptable) [22]. In the other hand is possible to sell the obtained glycerol by making a rectification for purity of the co-product near to 95% – 99% [23] For ASTM standard of biodiesel is necessary to reach density of 870-900 $kg/m^3$, kinematic viscosity of 1,9-6,0 $mm^2/s$, and flash point greater than 130°C [23]. In complement, another important process is drying the biodiesel in the very last stage of production, to eliminate water which can produces negative impacts on diesel engines [22].

The optimum condition for biodiesel production is using a methoxide-oil (mixture between methanol, catalyst and oil) ratio of 6:1, at 60°C with a time of 1 hour for the reaction to obtain a biodiesel yield of 88%. This is the result of experimental study made by Eman et.al [22] at different condition to select the most appropriate production parameters for the process and is a base for the selection of the equipment for biodiesel production plant. When the reaction occurs the mixture obtained has two phases, de layer on the top refers to crude biodiesel (880 $kg/m^3$), and the other layer is the glycerol (1050 $kg/m^3$). That is why is necessary to implement centrifuge equipment to separate the product and the co-product.

To neutralization of crude biodiesel and remove presented soap, water washing treatment at 60°C complements biodiesel purification before drying biodiesel. Drying can be done by flash or thin-film evaporation [24]. The purification of biodiesel could be done by wet washing or only by dry washing, however, for WCO is better to use wet washing method in order to eliminate all the impurities, methanol rests and water on the final product and then make a drying to eliminate the wet [24].

The wet process consists on washing the crude biodiesel in order to eliminate impurities and adjust the pH to reach neutral grade, and then use a flash drum unit to dry the excess water in the biodiesel; the dry washing process consists on eliminate the excess water and some impurities only by extracting wet of the crude biodiesel by using a potential drying unit, this process is commonly used when the process is made from virgin oil as raw materials and pH adjustment is no required [24].

Table 1 shows the advantages and disadvantage between the two methods for purification. As can be seen, the both method are very interesting to implement in the same process in order to guarantee the quality of the product by washing and drying.

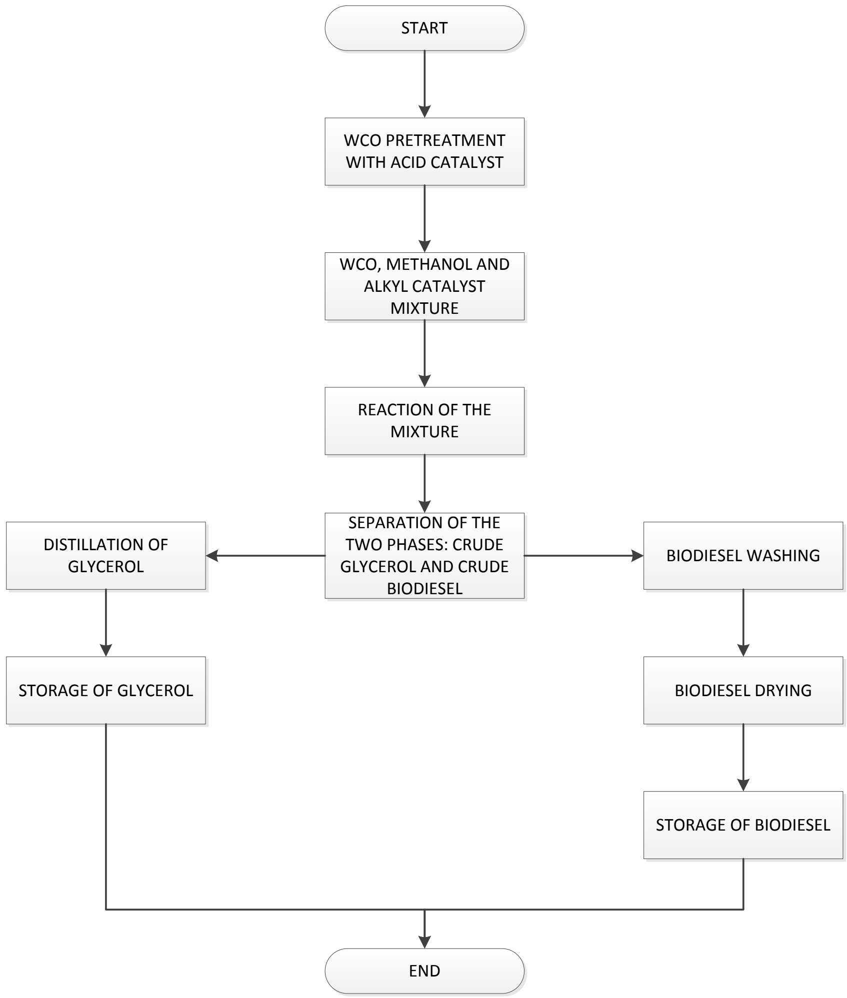
**Table 1. Advantage and disadvantage of wet washing and dry washing method for biodiesel purification**

| Purification method | Advantage | Disadvantage |
| --- | --- | --- |
| Wet washing | • Very simple and effective method of purifying biodiesel<br>• Successful removal of residual soluble compounds and soap<br>• Possible very high biodiesel purity (99%)<br>• Possible use of aqueous solution acids<br>• Can be combined with an organic solvent for removing the hydrophobic compounds<br>• Little lower running costs than dry washing | • Requires a large amount of water<br>• Possible formation of free fatty acids by hydrolysis of esters in the presence of water<br>• Drying of washed product is required to remove the trace amount of water increasing energy cost<br>• Possible stable emulsion formation in the presence of soaps that can cause loss of biodiesel yield<br>• It is a time-consuming process because of multiple washings, water/biodiesel separations |
| Dry washing | • Much easier and less effort than wet washing<br>• Drastic reduction of waste water<br>• Decreases the total time of production<br>• No risk of water in the fuel<br>• Both magnesium silicate and ion exchange resin are very effective at removing soap<br>• Allows for continuous operation<br>• Requires less space than wet washing | • Purifies biodiesel might not fulfill the standard specifications<br>• Ion exchange resins do not remove methanol<br>• Need extra equipment (columns and pumps)<br>• Little higher running costs than wet washing |

Source: [24]

According to the overall process, in a mass balance, for 1 ton of fresh vegetable oil, is possible to obtain 1 ton of biodiesel and 0,11 tons of glycerol [4], however considering the yield for biodiesel production under the condition of 60°C using WCO, for 1 ton is possible to obtain 0,88 ton of biodiesel [10]. Figure 1 shows flow sheet for biodiesel production process.

**Figure 1. Biodiesel production process flow sheet**




Source: The author.

## 1.3 THE CO-PRODUCT GLYCEROL

As can be seen in the transesterification reaction of the *equation 1* a co-product, the glycerol or glycerine, is obtained. In order to use the co-product, many of the biodiesel production plants make glycerol distillation with the aim to sell it for pharmaceutical proposes with purity greater than 95% according to Nobrega et. al [25]. The glycerol from biodiesel production has different grade of purity depending of the treatment after separation of the glycerol and the crude biodiesel; crude glycerol can has a composition of of 84,7% of glycerol, 12,1% water, 0,46% of methanol and the rest 2,74% of impurities according to the study by Hájek and Skopal [26]. Table 2 shows three grades of purity of glycerol obtained where the crude glycerol is the directly obtained after separation of the mixture biodiesel-glycerol without treatment. Technical grade glycerin is the obtained by distillation in one step (using only one distillation column), and finally the bi-distilled glycerol is obtained from double distillation and represents the highest purity [25].

**Table 2. Grades of purity and selling prices of glycerol from Biodiesel production**

| Grade of glycerol | Purity (%) | Selling price at 2012 in U.S.A. (USD$/ton) |
|---|---|---|
| Crude Glycerol | 80,71 | 300 |
| Technical Grade Glycerol | 81,90 | 480 |
| Bi-Distilled Glycerol | >99,7 | 1.600 |

Source: [25]

The use of the distillation columns to obtain glycerol with high purity represents high costs for feasibility because of the operating costs for the use of high pressure and temperatures and high equipment costs according to Apostolakou et. al [27]. The selection of equipment for distillation requires special chemical knowledge beyond the reach in this study such as simulation using HYSYS software to estimate the number of trays of the columns, and the knowledge to use the expressions for select distillation systems considering the behavior for the crude glycerol in each temperature for distillation [28]. It represents an opportunity for future research for technical and economic analysis for biodiesel production plants using distillation columns at small and medium scale in the Colombian context, and compares its results with biodiesel production without distillation of the glycerol. However, with the propose of make a complete technic and economic study, dimension of distillation column can be defined based on the design of the plant made by Apostolakou et. al [27] for 50.000 tons per year of biodiesel production; They use a distillation column of 23 stages and 10,8 meters of height and 0,6 meters of the diameter of the plates for glycerol refining. This dimension can be used for different capacities of plant by varying the diameter of the plates, because the composition of glycerol must be the same in all of the sizes. Treybal [29] has defined some consideration for the design of distillation column, where for optimum behavior in distillation the material flow must be 0,015 $m^3/s$ per one meter of diameter of the plates; this relation is fundamental in order to select the diameter of the column depending of the flow rate of the fluid in the process. The simulation of the plant made by Apostolakou et. al [27] express a distillation of the glycerol of technical grade 85% approximated.

Alexandre et al. [30] have defined different uses for crude glycerol such as production of chemical products, fuel additives methanol production, animal feed, research and fuel cell among others. A research made in Panama, the production of soap from distilled glycerol and crude glycerol as raw material was compared from its qualities; this study shows that using crude glycerol from biodiesel, the quality of soap is very similar to commercial soaps and could be used for selling [31].

In the Colombian context there are studies about the use of crude glycerol. One of them is the production of 1,3-propanediol using glycerol derived from biodiesel production without purification [32], in this way crude glycerol is harnessed for chemical factories in their industrial production such as detergents, textiles and polymers.

## 1.4 EQUIPMENT FOR BIODIESEL PRODUCTION

According to biodiesel production process, identification of the machinery is a fundamental part for technic and economic analysis. Based on the plant of Skarlis et. al [33] with a capacity of 10.000 ton/year (small plant) and the plant design by Apostolakou et. al [27] with a capacity of 50.000 ton/year (medium plant), and according to the collected literature, table 3 shows three principal stages for biodiesel production with the corresponding equipment to help with the definition of the process plant,

**Table 3. Principal Equipment for biodiesel production plant for each stage**

| Stage | Equipment |
|---|---|
| Working Supply Capacity | Waste cooking oil storage tank<br>Methanol storage tank<br>Crude Glycerol storage tank<br>Biodiesel storage tank with filter in the discharge |
| Transesterification Process | Pretreatment Tank<br>Centrifuge # 1<br>Mixer<br>Reactor # 1<br>Reactor # 2<br>Centrifuge # 2<br>Centrifuge # 3 |
| Purification Process | pH adjustment and mixer tank<br>Flash drum for dryer<br>Distillation column |

Source: The author.

## 1.5 ECONOMIC VARIABLES OF BIODIESEL PRODUCTION

Different alternatives to obtain biodiesel were analyzed, in order to select the most attractive process which use low raw material cost, low operating cost and the highest internal rate of return (IRR) and net present value (NPV), to define a production model technical and economically feasible for Colombian context, considering equipment and operation condition which can be used in Colombia.

The authors Marchetti [34] and Errazu [35] have developed many studies about economic indicators for four processes to obtain biodiesel with different operating condition. The processes were simulated for the studies, and the investment and operating cost were determined in order to estimate the IRR, NPV, total operating costs and return over investment. Table 4 shows the results of the economic indicators for each process for a plant capacity of 36.000 tons/year evaluated at 15 years using waste cooking oil as raw material.

**Table 4. Economic indicators of four biodiesel production processes from WCO**

| | Homogeneous process with preesterification | Transesterification with homogeneous acid catalyst process | Transesterification with heterogeneous solid catalyst process | Supercritical process |
|---|---|---|---|---|
| Total operating costs ($USD/year) | $18.109.000 | $18.359.000 | $18.896.000 | $35.514.000 |
| Net present value (NPV) ($USD) | $1.797.000 | -$1.275.000 | $7.789.243 | -$2.575.271 |
| Internal rate of return (IRR) | 11,17% | 6,95% | 31,95% | 1,80% |

Source: [34], [35]

As can be seen, the biodiesel production process by transesterification with heterogeneous solid catalyst process has the most attractive IRR and NPV. However, the homogeneous process with preesterification offers a good IRR and NPV too, and as can be seen in *section 1,2* this technology is the most technically feasible process for produce biodiesel to reach ASTM standards, considering the yield of the oil and time of reaction, that is the reason why that process represents a good alternative to develop a parametric algorithm for techno economic analysis for biodiesel production plant; in that way that process becomes to be the most popular process used for biodiesel from waste cooking oil [34].

Focus on feasibility studies of Biodiesel production, Marchetti [6] and Haas et.al [36] developed studies about the effect of economic variables over the economy of a biodiesel production plant. The relevant variables have been established as: the price of oil, biodiesel selling, glycerol selling, alcohol, catalyst type, water washing,

shipping distance and investment in research and development. Each one affects the global economic of a biodiesel process. Their effect over the biodiesel economy is studied based on economic criteria: net present value (NPV) and mainly internal rate of return (IRR). The sell price of biodiesel depends of the local economy and politics, and is one of the most important factors for an economically sustainable production [6].
The analysis for the variables in the production and their effect in the IRR is showed:

a. Oil price: to producing biodiesel using oil as raw material, there are many alternatives such as crude oil, refine oil and waste and cooking oil. A conventional process uses virgin oil which has a maximum percentage of FFA of 0,5%. However, for an economic analysis, the use of virgin oil increments the biodiesel production price. That is the reason why using WCO is a good alternative for the production employing pretreatment of the WCO to reduce the 3% of FFA and reach 0,5%.
b. Biodiesel selling price: this is a very important variable, because it defines if a biodiesel production is economically suitable or not. The selling price of biodiesel depends of the local politics and the economy of the location. Many authors such as Hass et al [36] have determined the important influence of the biodiesel selling prices in the IRR and the payback time. For example, for a selling price about $0.84US/liter, the IRR is 35%, and for selling price of $0.80US/liter, the IRR is 15%, in the 2011.
c. Glycerol selling price: the co-product obtained from the biodiesel production, the glycerol, has industrial and pharmaceutical application. The industry grade is cheaper than pharmaceutical glycerol because its purity is lower. Approximately 11% of the biodiesel production corresponds to the producing of glycerol. The IRR decreases when the glycerol price is reduced.
d. Alcohol price: The alcohol price in the case of transesterification, methanol, affects the feasibility in a biodiesel invest in the same way of the oil price, because the both are raw materials. For example, according to the literature a change from 0,3 $US/kg on the methanol price to 0,4 $US/kg decreases the IRR from 27% to 20% approximately [37].
e. Catalysts price: according to You et al. [12], the percentage of any catalyst commonly used for biodiesel production is 1% w/w, it means a variation on the catalyst price does not affect significantly the profitability of the plant. The influence on the IRR and the payback time is very low, compared with the rest of the raw materials for the production.
f. Shipping distance: the payback time of invest in a new biodiesel production plant, has a directly proportional relation with the cost of the shipping distance on the distribution of the biodiesel. According that shipping is relevant to the process, the time, cost of drivers and the logistics for distribution, represents important influence on the economic feasibility [38]. Long distances represent high shipping costs, affecting the costs of biodiesel production

g. Washing water price: in order to satisfices the international standards is necessary to wash the biodiesel which is produced after the reaction and the produce of glycerol to achieve its purity, where for one liter of biodiesel is necessary use two liters of water for washing [33]. However, the required water for each production does not represent high costs, and that is the reason why water washing cost is not a decisive variable for biodiesel feasibility [4].

In order to study the feasibility of biodiesel production plant is necessary to determine the size of the plant which it could be classified in large, medium and small scale production sizes. According to Skarlis et.al [33], the authors define large scale plants with a capacity greater than 50.000 tons per year, and are very competitive exporting oriented. In contrast, medium scale plant has a capacity above 10.000 tons per year to 50.000 tons per year, and in spite of the fact that they have higher operating cost than large facilities, they are more suitable for enhance local development; small size is defined for a production capacity lower than 10.000 tons per year.

In table 5 capital investment cost analysis for a biodiesel production plant at small scale is presented roughly. As can be seen, the equipment acquisition represents the highest investment cost.

**Table 5. Capital investment cost percentage analysis for 4.000 ton/year**

| ITEM | PERCENTAGE |
|---|---|
| Equipment | 52% |
| Building and Services | 15% |
| Working Capital | 16% |
| Land | 3% |
| Other Costs | 14% |

Source: [4]

Table 6 shows the biodiesel production cost analysis for the same small scale plant. Raw material and utilities represent the highest cost distribution for production; the percentage, 86% over the total production cost, is a principal factor to select the raw materials for the production plant; it represents the importance of use waste cooking oil in order to reduce the biodiesel production costs.

**Table 6. Biodiesel production cost analysis for 4.000 ton/year**

| ITEM | PERCENTAGE |
|---|---|
| Raw Materials and Utilities | 86% |
| Labour and Mantenaince and Operation Costs | 5% |
| Depreciation | 5% |
| Other Costs | 4% |

Source: [4]

As can be seen, the capital investment cost and the biodiesel production cost are economics parameters to make the financial analysis using IRR. For Marchetti [6], the study of biodiesel production plant is based on assumptions of the operating time, biodiesel selling price and the annual tax rate for other costs where the apropiate IRR range must 16% to 24% for biodiesel production plant at small and medium scale, respectively. The influence of each variable for investment and production cost are important information in order to generate a parametric algorithm with the appropriated methodology and expressions that produce the IRR and NPV as economical decision for invest in a new biodiesel production plant in the applied in the Colombian context by using raw materials costs, industrial services costs and biodiesel selling prices in Colombia.

## 1.6 BIODIESEL PRODUCTION IN COLOMBIA

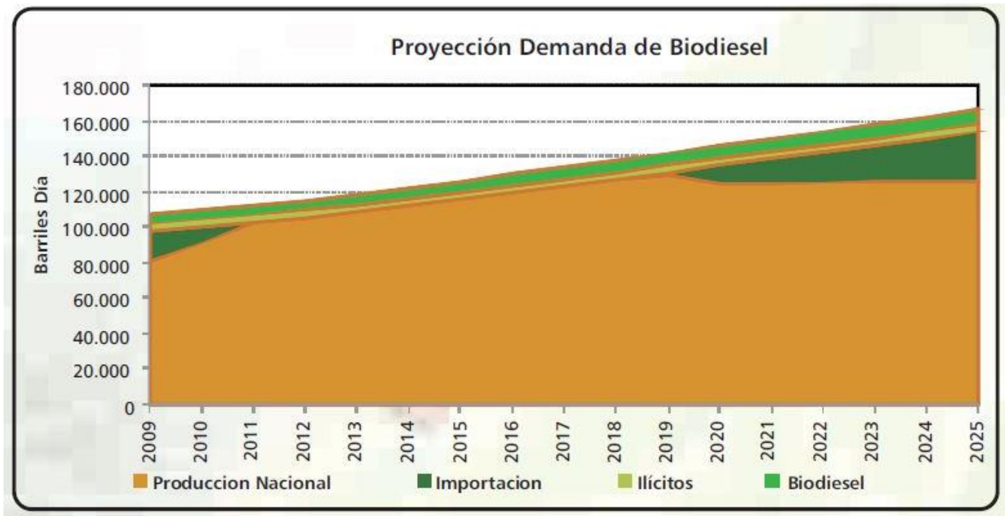
In the Colombian context Table 7 shows nine Biodiesel production plants with the capacity per year and the region. The sizes are at small, medium and large scale in order to supply the demand expect showed in figure 2.

**Table 7. Biodiesel production plants in Colombia**

| Region | Factory | Capacity (ton/year) | Planted area (ha) | Date of operation start |
|---|---|---|---|---|
| **Codazzi** | Oleoflores | 60.000 | 19.204 | Jan/08 |
| **Santa Marta** | Biocombustibles Sostenibles del Caribe<br>Odin Energy | 100.000<br>36.000 | 32.007 | Mar/09 |
| **Barranquilla** | Romil de la Costa | 10.000 | - | - |
| **Gálapa** | Biodiesel de la Costa | 10.000 | - | - |
| **Facatativá** | BioD | 115.000 | 36.809 | Feb/09 |
| **Barrancabermeja** | Ecodiesel de Colombia | 115.000 | 36.809 | Jun/08 |
| **Meta** | Aceites Manuelita | 120.000 | 38.409 | Jul/09 |
| **Meta** | Biocastilla | 15.000 | - | - |
| **TOTAL** | | **581.000** | **163.238** | |

Source: [2]

**Figure 2. Demand expect for biodiesel in Colombian context**




Source: [8]

According to Ministry of Mines and Energy in Colombia in accordance with the Resolution 90342 of March 31/2014, the actual Biodiesel price ($ COP/gal) is $9.600, it means $1,30 USD per liter, in average. This value is actualized in the web source www.fedebiocombustibles.com [39] according to the changes on the dollar price.

## 2 EXPRESSIONS FOR BIODIESEL PRODUCTION COSTS ANALYSIS

The economic analysis integrates an important part of this study to reach the general objective about generates a parametric algorithm for technic and economic analysis for biodiesel production plants at small and medium scale. For that aim, is necessary to calculate the cost and determine the dimension for each equipment for the biodiesel production, as is established by the expression of Apostolakou et. al [27], and determine the total capital investment cost. Table 8 shows expressions established for the capacity and cost of equipment for biodiesel production plant by transesterification. The capacity of each reactor tanks in volume (V) in $m^3$ is determined with the equation 2.

$$\boldsymbol{V = \frac{\tau_R Q}{0.8}}$$

*Equation 2. Capacity for reactors*

Source: [27]

Where, $\tau_R$ is the residence time of the product in hours and Q ($m^3$/h) is the flow rate for the process determined by the simulation made for production of biodiesel using HYSYS by Apostolakou et. al [27]. The bare module (BM) in table 8 refers to direct and indirect costs for equipment such as valves and piping connections.

**Table 8. Bare module for equipment**

| EQUIPMENT | BARE MODULE | COST EXPRESSION |
|---|---|---|
| Transesterification Reactors | 2,8 | $C_R^0 = 15000V^{0.55}$<br>*Equation 3. Transesterification reactor cost* |
| Centrifuges | 1,3 | $C_{FF}^0 = 28100Q^{0.574}$<br>*Equation 4. Centrifuge cost* |
| Mixing Tanks | 2,8 | $C_V^0 = 12080V^{0.525}$<br>*Equation 5. Mixing tank cost* |
| Flush Drum | 2,8 | $C_D^0 = 6500V^{0.62}$<br>*Equation 6. Flash drum cost* |
| Distillation Columns | - | $C_T^0 = 4555H_C^{0.81}D_C^{1.05}$<br>*Equation 7. Distillation column cost*<br>$D_c$ = Column diameter in meters<br>$D_C = \sqrt{\frac{4A}{0.88\pi}}$ |

| | | |
|---|---|---|
| | | *Equation 8. Column diameter*<br>A is the net are of the column.<br>$H_c$ is the column height determined by the equation 9.<br>$H_c = 1.2(TS)(N-1)$<br>*Equation 9. Column height*<br>Where, TS is the tray spacing in meters and N the number of real trays. |
| Storage tanks | 1,2 | $C_{ST}^0 = 250000 + 94.2V$<br>*Equation 10. Storage tank cost for volume between 2.000 m³ to 50.000 m³*<br>$C_{ST}^0 = 65000 + 158.7V$<br>*Equation 11. Storage tank for volume lower than 2.000 m³* |
| Total Installed equipment cost | 1,2 | $T.I = \sum Cost\ of\ Equipment$<br>*Equation 12. Total installed equipment cost* |
| Total Equipment Cost | 2 | $T.E.C = 2\ (T.I)$<br>*Equation 13. Total equipment cost* |

Source: [27]

In order to use the expressions for equipment costs and translate it in present values Peters [40] has defined the appropriate equation.

$$Present\ Cost = Original\ Cost\left(\frac{Index\ value\ at\ present\ time}{Index\ value\ at\ time\ original\ cost\ was\ obtained}\right)$$

*Equation 14. Present Cost for equipment*

Source: [40]

The index value is taken from the CEPCI (Chemical Engineering Plant Cost Index) which varies each year. Table 9 shows index value for plants according to the 2007 and 2014 year, in order to use the costs for the equipment established by Apostolakou et. al [27] at 2007 and translate them to the present year.

**Table 9. Index value according to CEPCI for the 2007 and 2014**

| | **2007** | **2014** |
|---|---|---|
| **Equipment** | 602,8 | 687,9 |
| **Heat exchangers and tanks** | 556,9 | 621,6 |
| **Process machinery** | 586,1 | 656,0 |
| **Pipe, valves and fittings** | 724,9 | 875 |

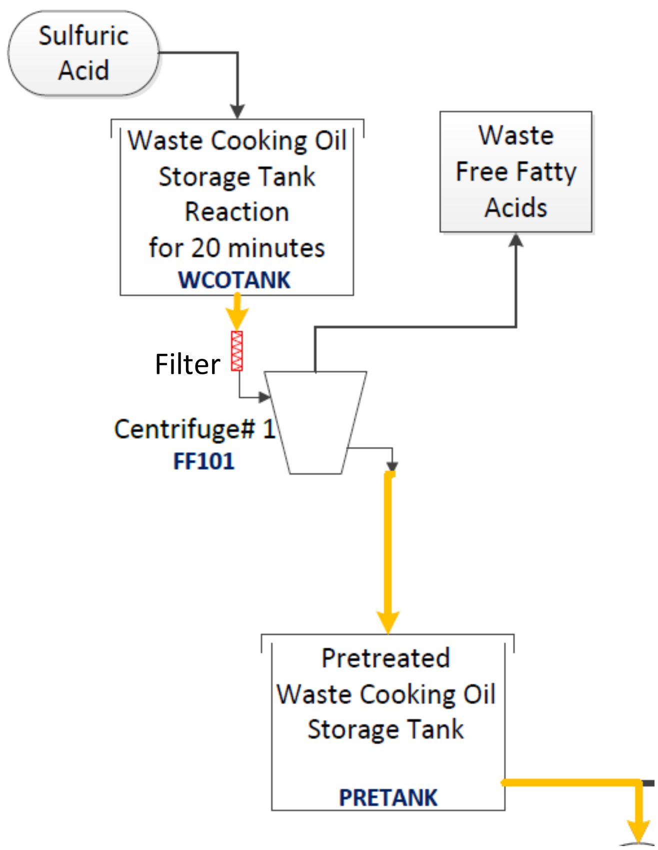
Source: [41]

Using the expressions for equipment cost is the first step to obtain total capital investment cost.

## 3 DEFINITION OF BIODIESEL PRODUCTION PLANT AT SMALL AND MEDIUM SCALE

As first product of this study, the stages for the production are represented according to the collected information and the designed plants by Skarlis et. al [33] and Apostolakou et. al [27], where is showed the pretreatment process, reaction of the raw material, phases separation, glycerol distillation, biodiesel washing and drying for storage. The final diagram represents the plant for capacities between 10.000 to 50.000 tons per year; it means small and medium scale.

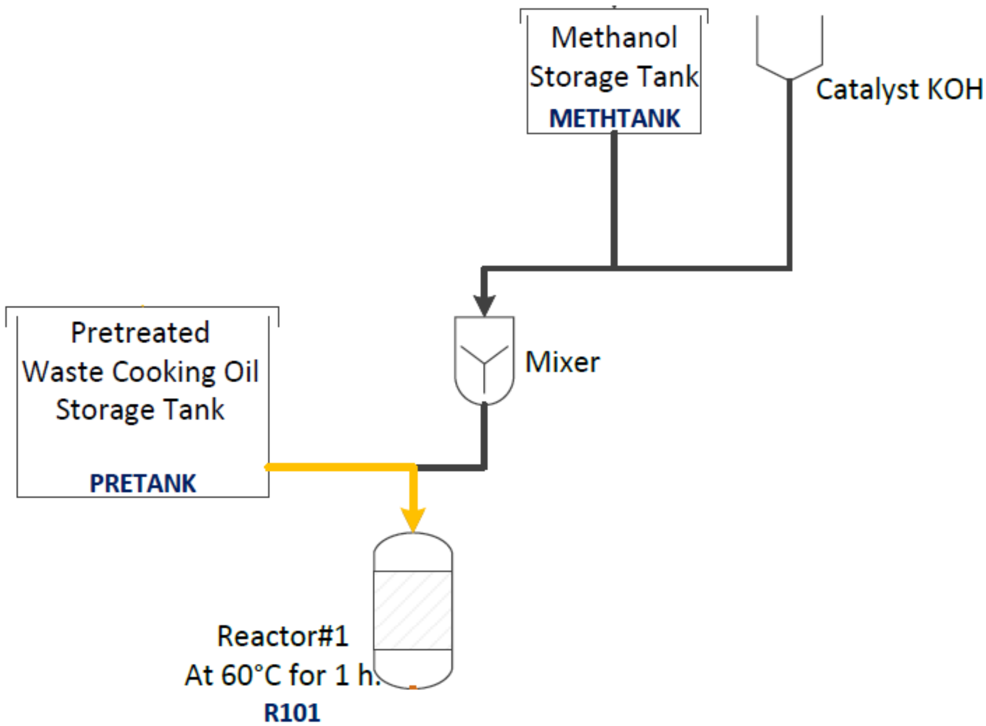
**Figure 3. Process diagram: pretreatment stage**




Source: The author.

Figure 3 shows the pretreatment stage, according to *section 1.1.1,* where the WCO is storage in the *WCOTANK* and 1% of sulfuric acid is dosing to obtain the free fatty acids in the upper phase; the product is discharged passing by a filter to be centrifuged to separate the two phases: WCO oil and free fatty acids. The WCO is storage in the *PRETANK* at 60°C at atmosphere pressure during 20 minutes [11].

**Figure 4. Process diagram: mixing and reaction stage**

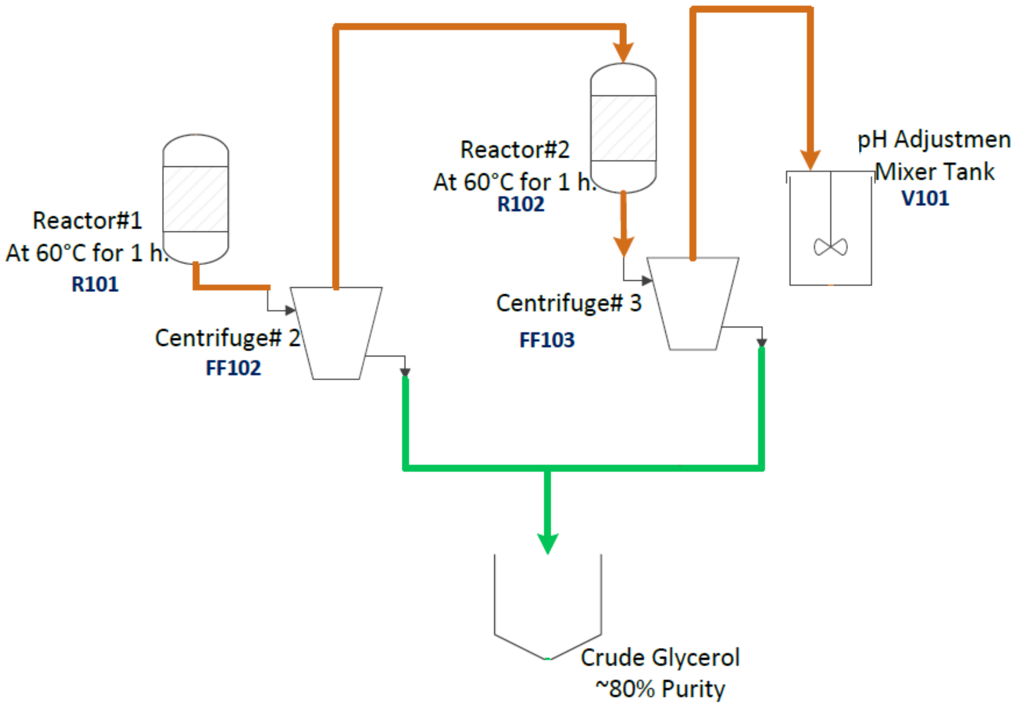



Source: The author.

Then the methanol storage tank *METHTANK* dosing methanol to the be mixing with the catalyst (KOH), then the methoxide and the oil in the *PRETANK* are discharged to the first reactor R101 for the transesterification at 60°C for 1 hour according to Rio et al [7] to obtain 88% of yield for biodiesel production. *Figure 4.*

The next stage consists in the phase separation of crude glycerol and biodiesel (figure 5). The glycerol phase is in the bottom of the obtained heterogeneous mixture from the reactors and is discharged to crude glycerol storage; the crude biodiesel is discharged to the pH adjustment and mixer tank V101.

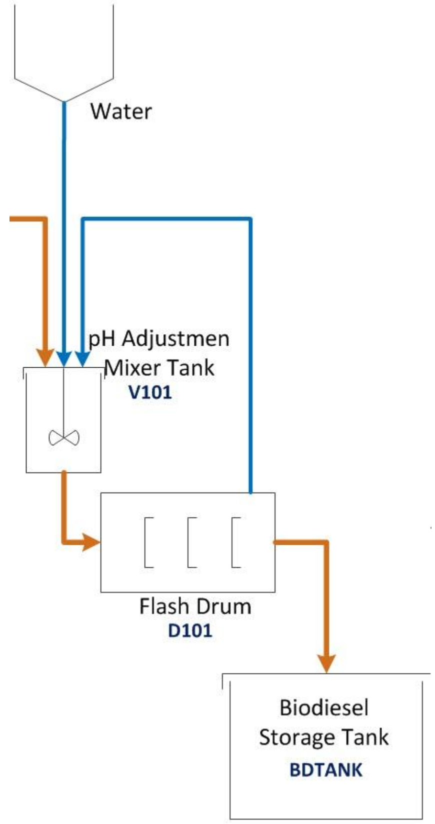
**Figure 5. Process diagram: glycerol and biodiesel separation**




Source: The author.

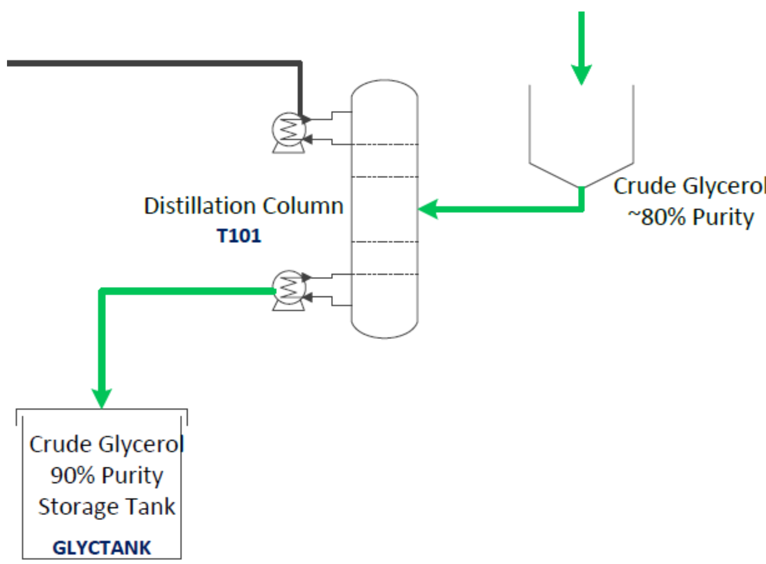
With the crude biodiesel in the *V101* equipment the washing and drying of the biodiesel stage starts for the final biodiesel product storage as can be seen in figure 6. The washing is made using 2 tons of water for 1 ton of biodiesel in the mixer tank and the drying is made by using a flash drum [24], where the evaporated water of the biodiesel is recirculated to the water tank.

**Figure 6. Process diagram: biodiesel pH adjustment, washing and drying process**




Source: The author.

**Figure 7. Process diagram: glycerol purification and storage**

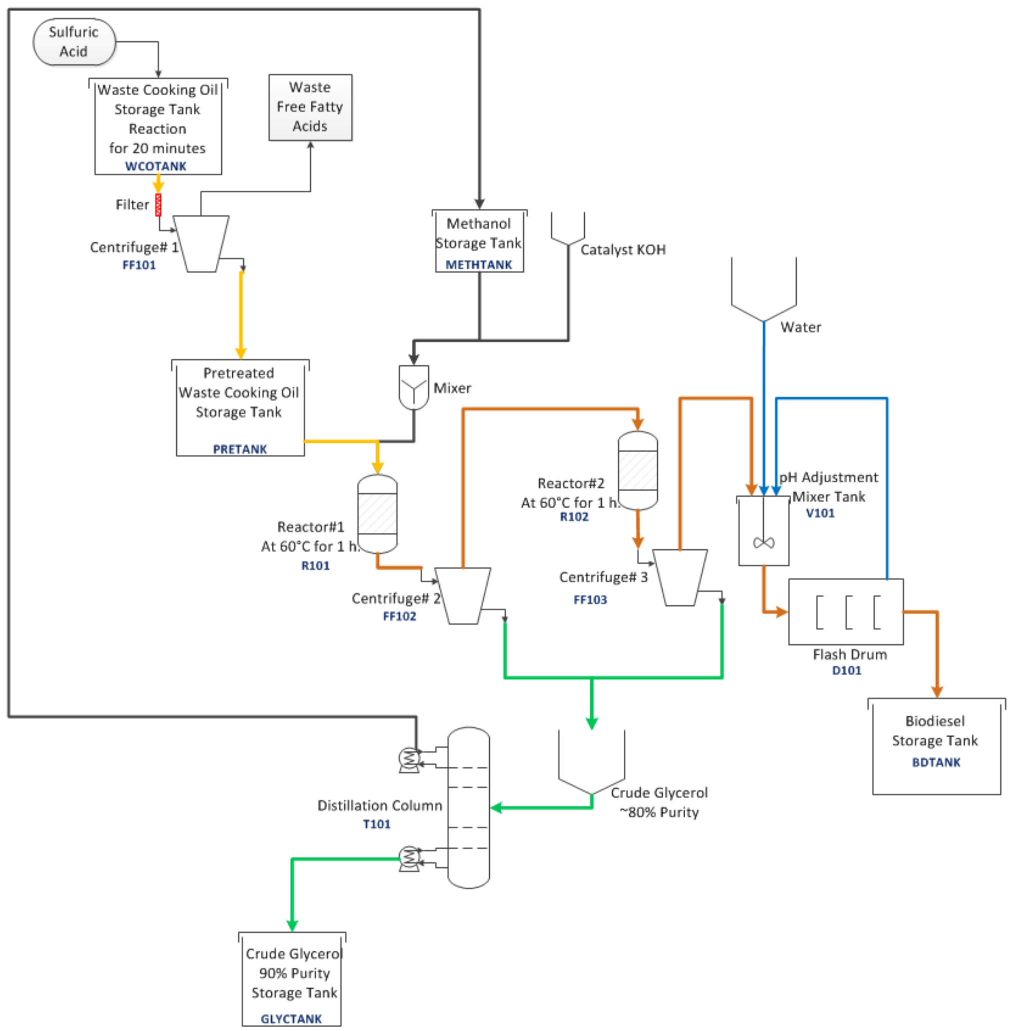



Source: The author.

Finally, figure 7 represents the glycerol purification to obtain technic glycerol for selling. The glycerol is distillated using a column distillation of 23 stages according to the equipment selection by Apostolakou [27] where for the biggest plant capacity (50.000 tons/year) the appropriated column has 23 stages, 0,6 m of diameter and 10,8 m oh high. The methanol obtained in the reboilers is approached by returning the alcohol to the *METHTANK.* The last step is to storage the distilled technic glycerol in the *GLYCTANK.*

All the stages integrate the overall biodiesel production process represented in the figure 8, and can be applied for small and medium scale according to the definition of biodiesel, and the required condition expressed in the theoretical background *section1.*

**Figure 8. Biodiesel production process at small and medium scale in continuous process**




Source: The author.

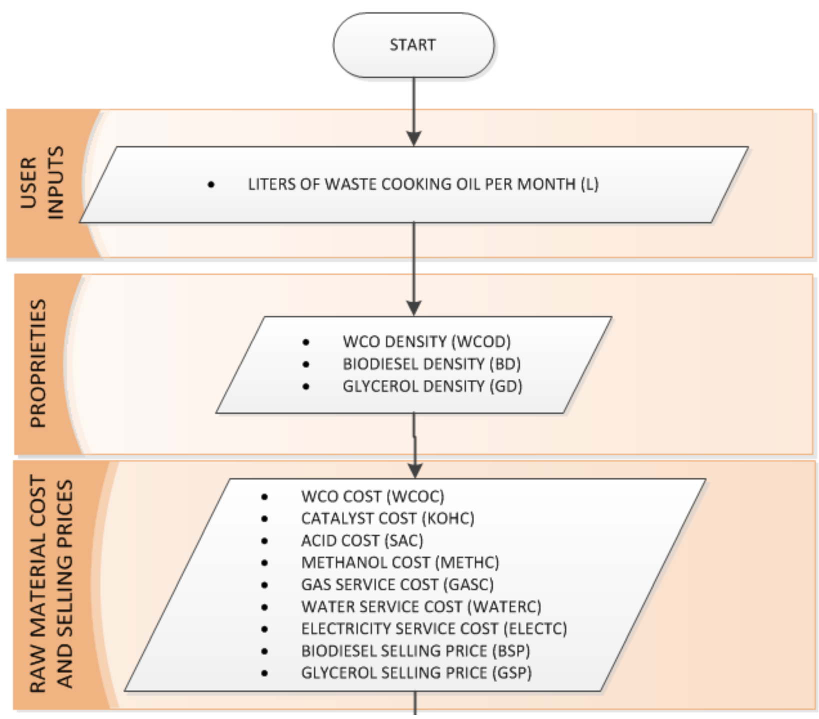
# 4 DESIGN OF PARAMETRIC ALGORITHM

Considering the collected information about estimation costs for Biodiesel production plants, the algorithm developed starts with the data of quantity of waste cooking oil a business man interested in investment project for Biodiesel production can collect for continuous flow process in the plant per month. That is the reason why the algorithm for feasibility analysis ask as an input for the waste cooking oil volume, it means the volume for the storage of this raw material for 4 weeks. The next figures show the development of the algorithm for economic and technic feasibility analysis which integrating the overall algorithm flow sheet in the *Annex A*.

## 4.1 DATA INFORMATION

The algorithm requires input in order to determine outputs. For that aim, the initial point is specifying data as information to employ in different expressions to determine the necessary results. The data reading consist on three groups: user inputs, proprieties of the materials to determine quantities and raw material cost and selling prices as fixe data of the expressions. Figure 9 shows the data information with the name of the variable in parenthesis to be used in the next expressions.

**Figure 9. Parametric algorithm: data information**



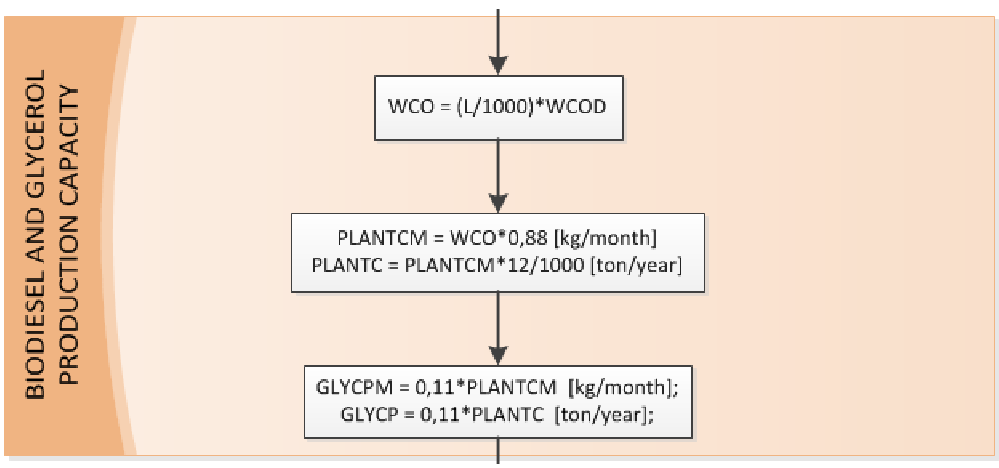

Source: The author.

The value for each data is based on the theoretical background, *section 1,* for the proprieties data and considering actual costs in Colombia for raw material and industrial services; the prices of services are established by the Acueducto (sewer, water and toilet of Bogotá, Colombia company) [42] and EPM [43] for the water and electricity service respectively. Actually the price for water is \$3.345,09 COP/$m^3$, and the price of electricity is \$464,86 COP/kWh. For natural gas the prices is \$74,59 COP/kWh. The price for waste cooking oil selling is \$10.000 COP for 20 liters, information taken from Biogras S.A.S [44], a company for recycling waste cooking oil. The liters of WCO are the unique input selected by the user according to his interests and capacity to buy liters of WCO for one month.

## 4.2 BIODIESEL AND GLYCEROL PRODUCTION CAPACITY

Based on the mass balance and the yield in biodiesel production (88%), figure 10 shows the expression in the flow sheet for biodiesel and glycerol production capacity.

**Figure 10. Parametric algorithm: Biodiesel and glycerol production capacity**




Source: The author.

**Table 10. Variable designation for biodiesel and glycerol production capacity**

| VARIABLE NAME | VARIABLE DESIGNATION | UNIT |
|---|---|---|
| Quantity of waste cooking oil to storage | WCO | kg |
| Monthly biodiesel production capacity | PLANTCM | kg/month |
| Annual biodiesel production capacity | PLANTC | ton/year |
| Monthly glycerol production capacity | GLYCPM | kg/month |
| Annual glycerol production capacity | CLYCP | ton/year |

Source: The author.

## 4.3 RAW MATERIAL QUANTITIES AND COST

According to mass proportion evaluated for raw material by Skarlis et. al [4] and the pretreatment process by Alptekin et. al [11], the quantities for each raw material (methanol, potassium hydroxide, sulfuric acid and water) are estimate. The electricity and gas consumption for industrial services required for the equipment and temperature condition (60°C), are calculated using the equations 15 and 16, based on the study made by Saville [45] where the consumption of gas for biodiesel production is 440 kWh for each ton of oil employed, and for electricity consumption, the relation is 60 kWh per ton.

$$Gas\ Consumption = 440 * (tons\ of\ waste\ cooking\ oil)$$

*Equation 15. Gas consumption*

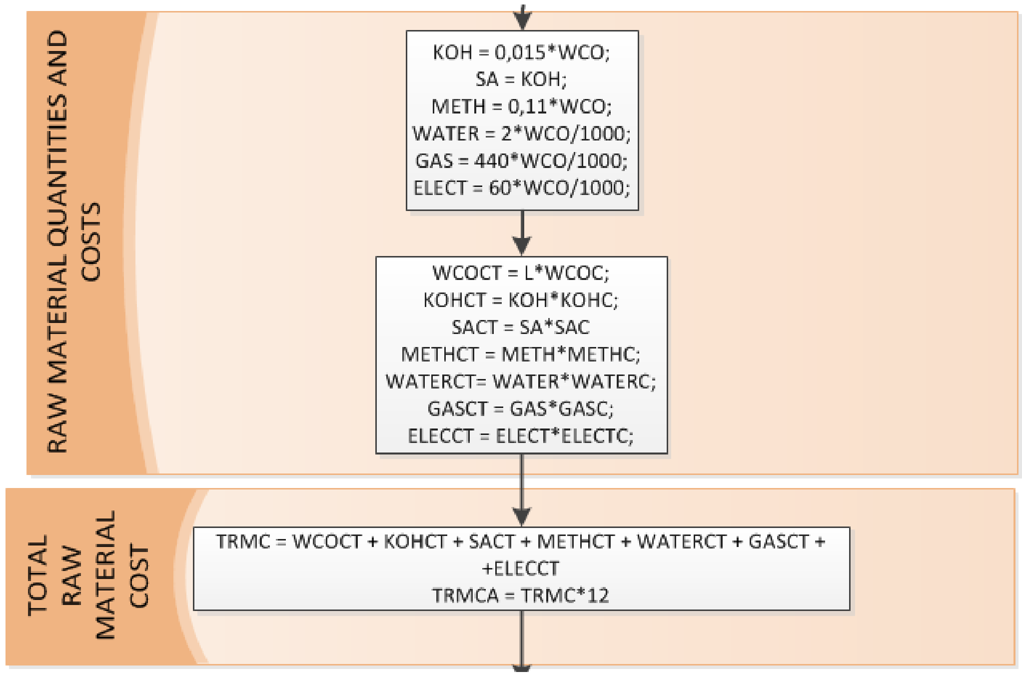
Source: The author.

$$Electricity\ Consumption = 60 * (tons\ of\ waste\ cooking\ oil)$$

*Equation 16. Electricity consumption*

Source: The author.

**Figure 11. Parametric algorithm: raw material quantities and costs**




Source: The author.

**Table 11. Variable designation for raw material quantities and costs**

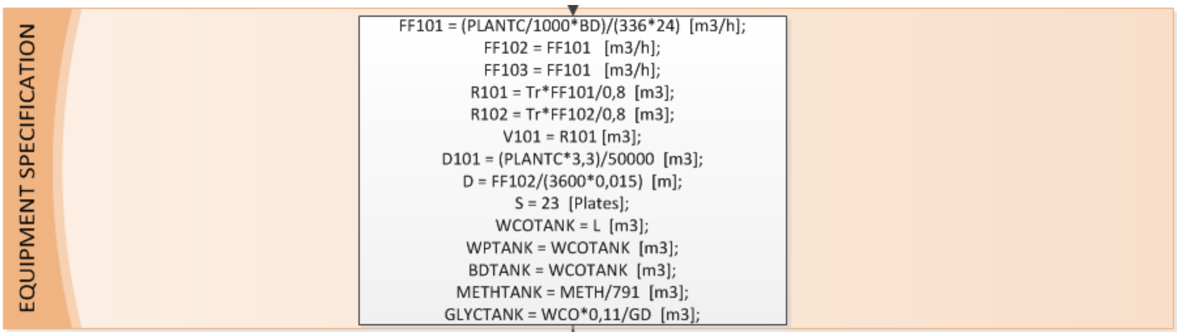
| VARIABLE NAME | VARIABLE DESIGNATION | UNIT |
|---|---|---|
| Quantity of potassium hydroxide | KOH | kg |
| Quantity of sulfuric acid | SA | kg |
| Quantity of methanol | METH | kg |
| Quantity of water | WATER | $m^3$ |
| Gas consumption | GAS | kWh |
| Electricity consumption | ELECT | kWh |
| Waste cooking oil cost | WCOCT | $COP |
| Potassium hydroxide cost | KOHCT | $COP |
| Sulfuric acid cost | SACT | $COP |
| Methanol cost | METHCT | $COP |
| Water cost | WATERCT | $COP |
| Gas service cost | GASCT | $COP |
| Electricity service cost | ELECTCT | $COP |
| Total raw material cost per month | TRMC | $COP/month |
| Total raw material cost per year | TRMCA | $COP/year |

Source: The author.

## 4.4 EQUIPMENT SPECIFICATION

Based on the process diagram of figure 8 in *section 3,* and considering the plant capacity (*PLANTC)* determined by the quantities of liters of WCO, the equipment specification is calculated by analyzing the total hours of the plant working assuming continuous production, three shift, during 336 days per year (28 days per month). Figure 12 shows the calculation for the equipment considering the analysis and the *equation 2* [27] for capacity of the reactors with a residence time of 1 hour. The specification of the distillation column is calculated based on the plant of Apostolakou et. al [27] for the high and changing the diameter of the plates based on the appropriate relation of 0,015 $m^3/h$ per one meter of diameter of plate exposed by Treybal [29].

**Figure 12. Parametric algorithm: equipment specification**




Source: The author.

**Table 12. Variable designation for equipment specification**

| VARIABLE NAME | VARIABLE DESIGNATION | UNIT |
|---|---|---|
| Residence time for reactors | Tr | hour |
| Reactor #1 volume | R101 | $m^3$ |
| Reactor # 2 volume | R102 | $m^3$ |
| Centrifuge # 1 flow | F101 | $m^3/h$ |
| Centrifuge # 2 flow | F102 | $m^3/h$ |
| Centrifuge # 3 flow | F103 | $m^3/h$ |
| pH adjustment and mixer tank volume | V101 | $m^3$ |
| Flash drum volume | D101 | $m^3$ |
| Diameter of the distillation column | D | m |
| Number of plates of the distillation column | S | plates |
| Waste cooking oil storage tank | WCOTANK | $m^3$ |
| Pretreatment oil storage tank | WPTANK | $m^3$ |
| Biodiesel storage tank | BDTANK | $m^3$ |
| Methanol storage tank | METHTANK | $m^3$ |
| Glycerol storage tank | GLYCTANK | $m^3$ |

Source: The author.

## 4.5 EQUIPMENT COST

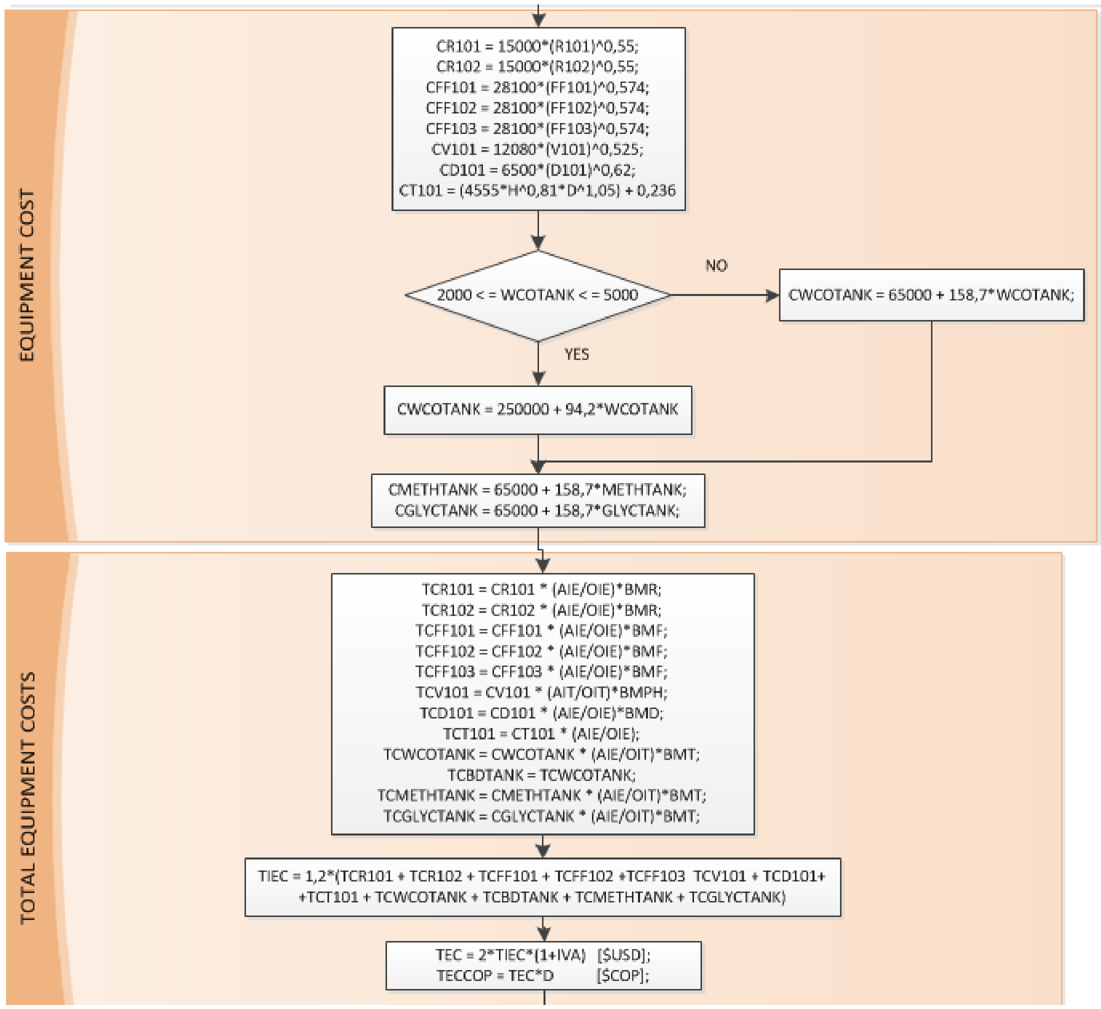
Using the equations of tables 8 and 9 and equation 14 in *section 2*, the total cost of equipment are calculated. Figure 13 shows the development of this part in the algorithm in order to estimate total equipment cost. Table 14 shows each variable designation for the expressions in figure 13.

**Table 13. Variable designation for equipment cost**

| VARIABLE NAME | VARIABLE DESIGNATION | UNIT |
|---|---|---|
| Total cost of reactor #1 | TCR101 | $USD |
| Total cost of reactor #2 | TCR102 | $USD |
| Total cost of centrifuge #1 | TCF101 | $USD |
| Total cost of centrifuge #2 | TCF102 | $USD |
| Total cost of centrifuge #3 | TCF103 | $USD |
| Total cost of pH Adjustment tank | TCV101 | $USD |
| Total cost of flash drum | TCD101 | $USD |
| Total cost of distillation column | TCT101 | $USD |
| Total cost of waste cooking oil tank | TCWCOTANK | $USD |
| Total cost of pretreatment tank | TCWPTANK | $USD |
| Total cost of biodiesel tank | TCBDTANK | $USD |
| Total cost of methanol tank | TCMETHTANK | $USD |
| Total cost of glycerol tank | TCGLYCTANK | $USD |
| Bare module for reactors | BMR | - |
| Bare module for centrifuges | BMF | - |
| Bare module for pH adjustment tank | BMPH | - |
| Bare module for flash drum | BMD | - |
| Bare module for tanks | BMT | - |
| Index value at present time for equipment | AIE | - |
| Index value at original time for equipment | OIE | - |
| Index value at present time for tanks | AIT | - |
| Index value at original time for tanks | OIT | - |
| Total equipment cost in dollars | TEC | $USD |
| Total equipment cost in Colombian pesos | TECCOP | $COP |

Source: The author.

**Figure 13. Parametric algorithm: Equipment cost**

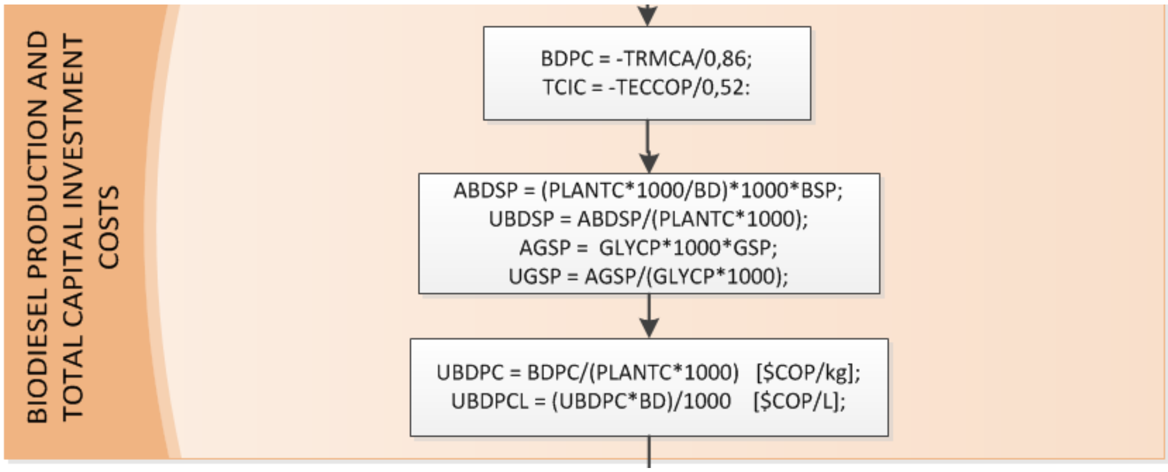



Source: The author.

## 4.6 BIODIESEL PRODUCTION AND TOTAL CAPITAL INVESTMENT COSTS

This step on the algorithm consists on calculate of biodiesel production cost, total capital investment cost, biodiesel and glycerol selling prices as values to generate the flow cash and later calculate the IRR and NPV. The expressions are based on the proportion analysis in tables 5 and 6 *section 1.5* where the total raw material cost (*TRMAC*) represents the 86% over the total biodiesel production cost (*BDPC)*; the total equipment cost (*TECCOP)* represents the 52% over the total capital investment cost (*TCIC*). The ratio between the biodiesel production cost (*BDPC*) and the plant capacity (*PLANTC*) determine the unitary biodiesel production cost.

**Figure 14. Parametric algorithm: biodiesel production and total capital investment costs**




Source: The author.

**Table 14. Variable designation for biodiesel production and capital investment costs**

| VARIABLE NAME | VARIABLE DESIGNATION | UNIT |
|---|---|---|
| Biodiesel production cost | BDPC | $COP |
| Total capital investment cost | TCIC | $COP |
| Annual biodiesel selling price | ABDSP | $COP |
| Unitary biodiesel selling price | UBDSP | $COP/kg |
| Annual glycerol selling price | AGSP | $COP/year |
| Unitary glycerol selling price | UGSP | $COP/kg |
| Unitary biodiesel production cost per kilogram | UBDPC | $COP/kg |
| Unitary biodiesel production cost per liter | UBDPCL | $COP/L |

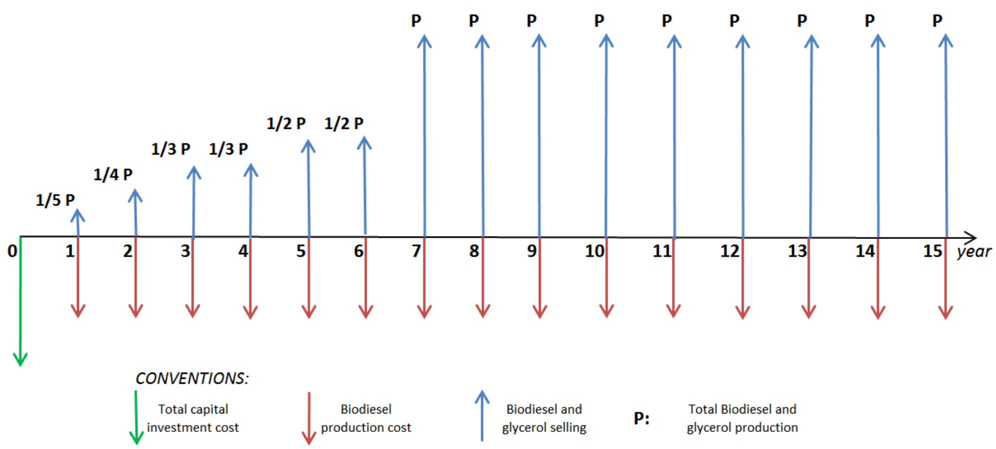
Source: The author.

## 4.7 ECONOMIC INDICATORS

Based on the methodology of Tarquin and Blank *[46]* the internal rate of return (IRR) and net present value (NPV) are calculated as economic indicators for estimate the economic feasibility in period of evaluation of 15 years. The functions are developed in Excel ® function as can be seen in equations 17 and 18, where the range of cells from 0 to n (period of evaluation) represent the total annual costs and sells and the capital investment cost in the first year, assuming biodiesel selling, glycerol selling, biodiesel production costs including maintenance and labor costs every year. In the case of equation 18, i% represents the annual inflation rate, assuming 4% of inflation annual in average according to the collected data in the Republic Bank in Colombia *[47]*. Table 15 and figure 15 represent the cash flow of the biodiesel production plant, to calculate the IRR and NPV using the equation

17 and 18, assuming 1/5 over the total biodiesel and glycerol production for selling for the first year, 1/4 for the second year, 1/3 for the third and fourth year, 1/2 for the fifth and sixth year and the selling of the total biodiesel and glycerol production the rest years, considering the market entry of a new biodiesel production plant.

**Figure 15. Biodiesel production plant cash flow**




Source: The author.

**Table 15. Cash flow table to use the Excel® functions (equation 17 and 18)**

| PERIOD [year] | CASH FLOW [$COP] |
|---|---|
| 0 | Total capital investment cost |
| 1 | 1/5P – Biodiesel production cost |
| 2 | 1/4P – Biodiesel production cost |
| 3 | 1/3P – Biodiesel production cost |
| 4 | 1/3P – Biodiesel production cost |
| 5 | 1/2P – Biodiesel production cost |
| 6 | 1/2P – Biodiesel production cost |
| 7 | P – Biodiesel production cost |
| 8 | P – Biodiesel production cost |
| 9 | P – Biodiesel production cost |
| 10 | P – Biodiesel production cost |
| 11 | P – Biodiesel production cost |
| 12 | P – Biodiesel production cost |
| 13 | P – Biodiesel production cost |
| 14 | P – Biodiesel production cost |
| 15 | P – Biodiesel production cost |

Source: The author.

$$IRR = IRR(cell0: celln)$$

*Equation 17. Internal rate of return in Excel® function.*

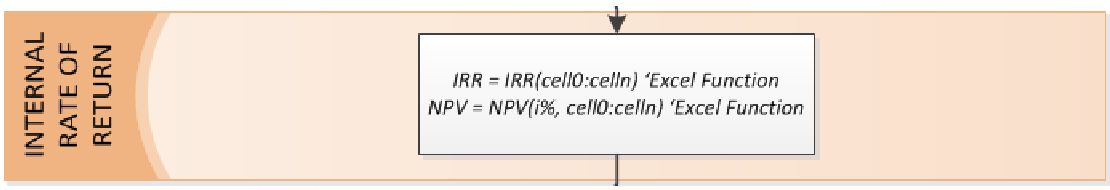
Source: *[46]*

$$NPV = PV(i\%, cell0: celln)$$

*Equation 18. Net present value in Excel® function.*

Source: *[46]*

**Figure 16. Parametric algorithm: economic indicators**

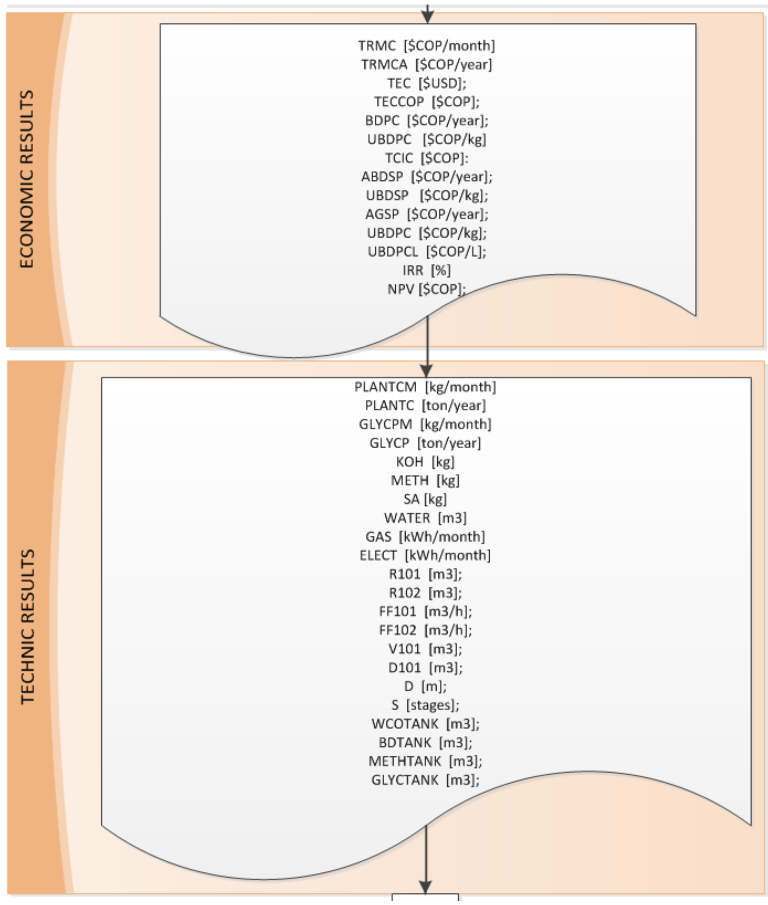



Source: The author.

## 4.8 TECHNIC AND ECONOMIC RESULTS PRINT

The last process for the algorithm is to print the obtained results in order to expose the technic and economic results.

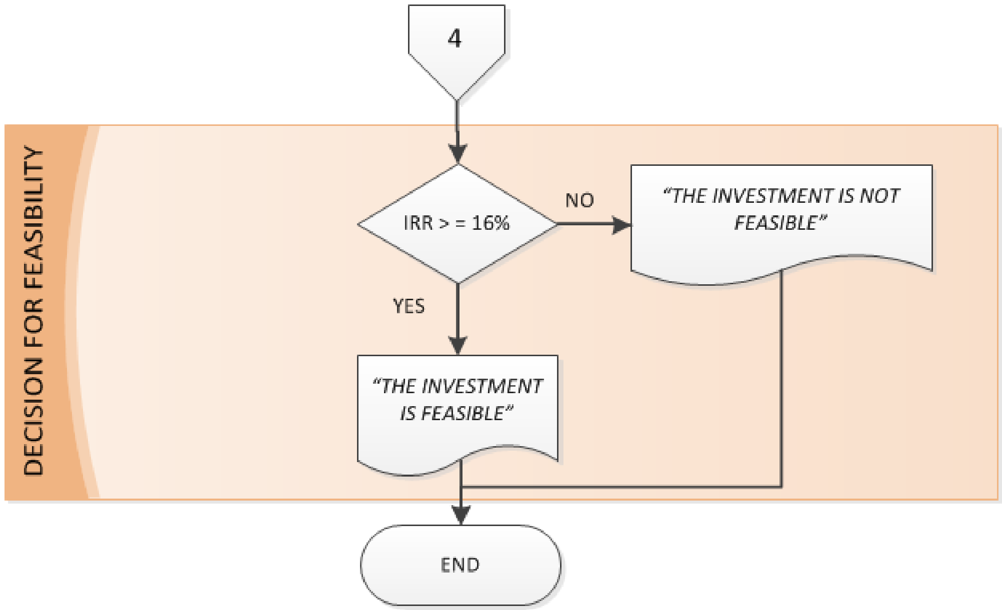
**Figure 17. Parametric algorithm: technic and economic results print**




Source: The author.

After the print of the results, the user could make an analysis in order to estimate the feasibility considering according to Marchetti [6] a good IRR must be in a range of 16% to 24% at 15 years for biodiesel production plants as an economic criteria for feasibility. The IRR is calculated after tax.

**Figure 18. Decision for feasibility**



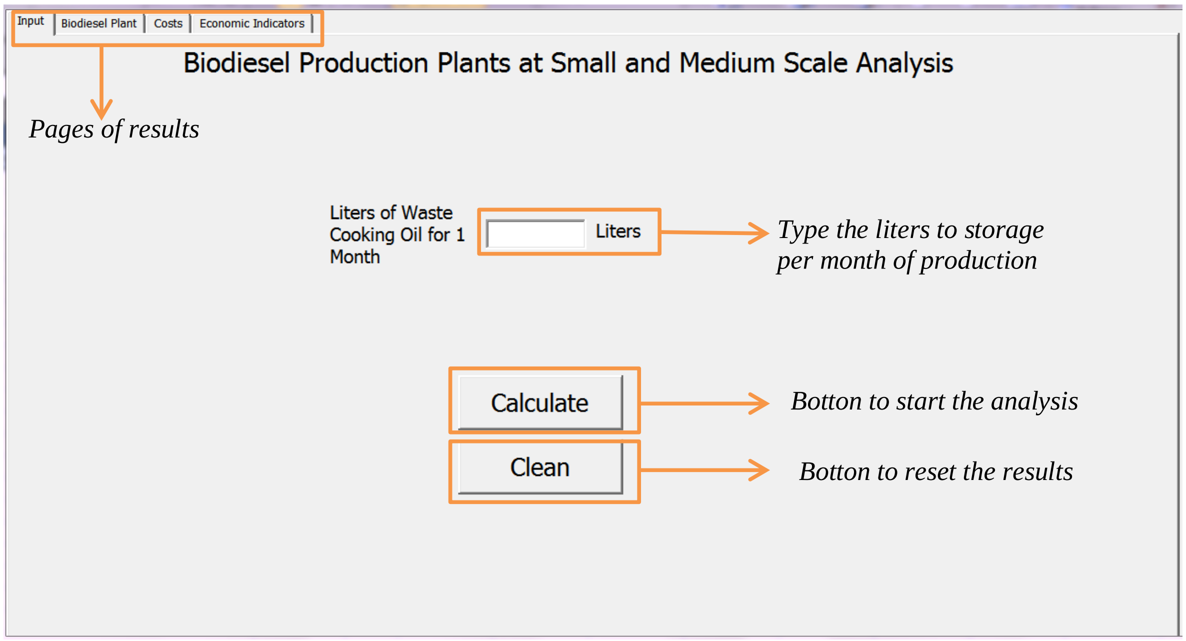

Source: The author.

The technic analysis could be derived by analyzing the size of the equipment considering the installation, size of the land for the plant of the user, and all the consideration about the possibility to get the equipment which the user can consider.

## 4.9 COMPUTATIONAL TOOL

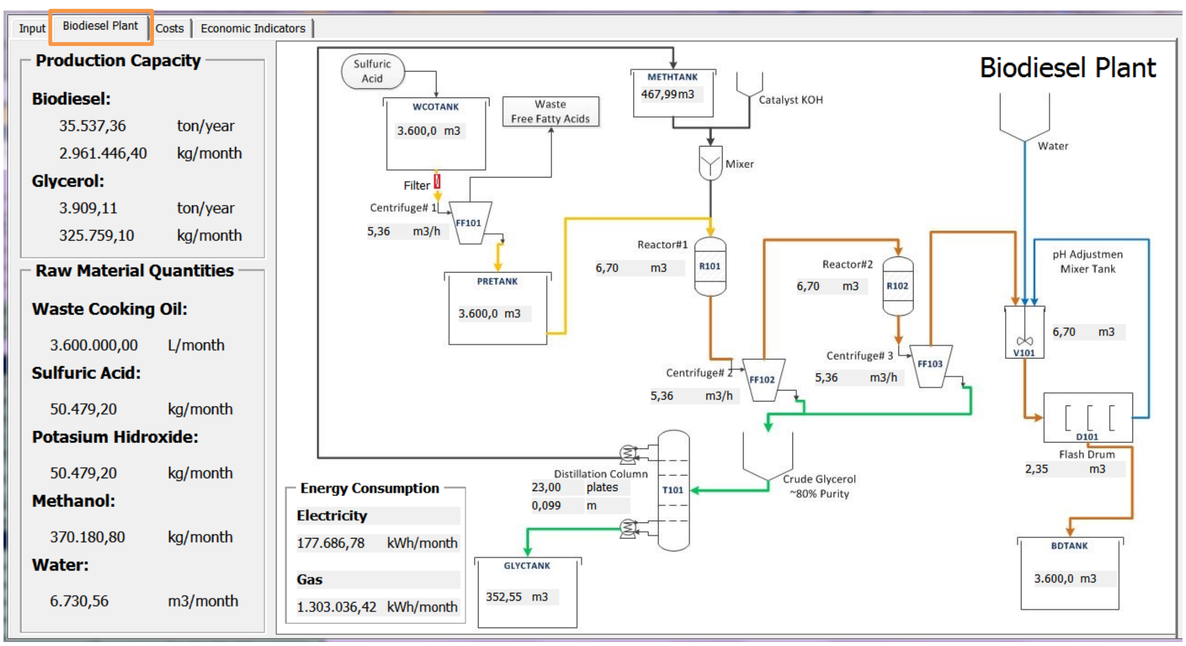
Based on the algorithm using an "User Form" in Excel ® the next user interface is development to determine the technic and economic feasibility for biodiesel production plant, for capacities less or equal than 50.000 ton/year (5.000.000 liters/month approximately). For the analysis, the user types the liters of waste cooking oil to storage per month for biodiesel production. The next figures show the process to see the results.

**Figure 19. User interface: input page**



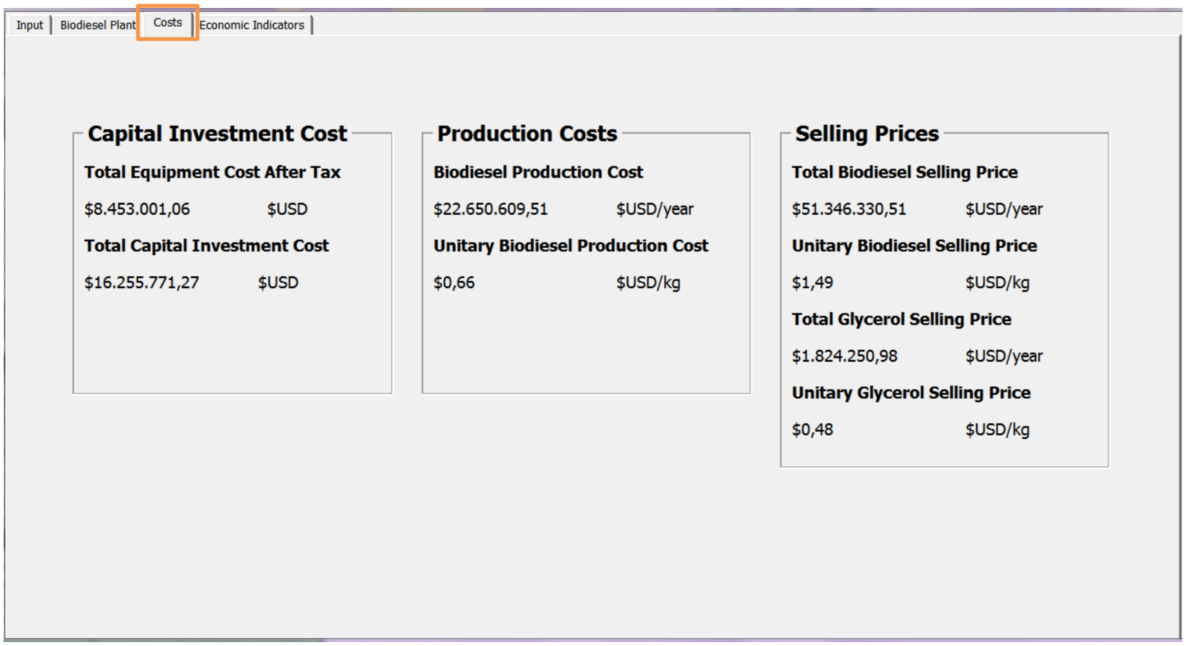

Source: The author.

**Figure 20. User interface: biodiesel plant dimension for technic result**



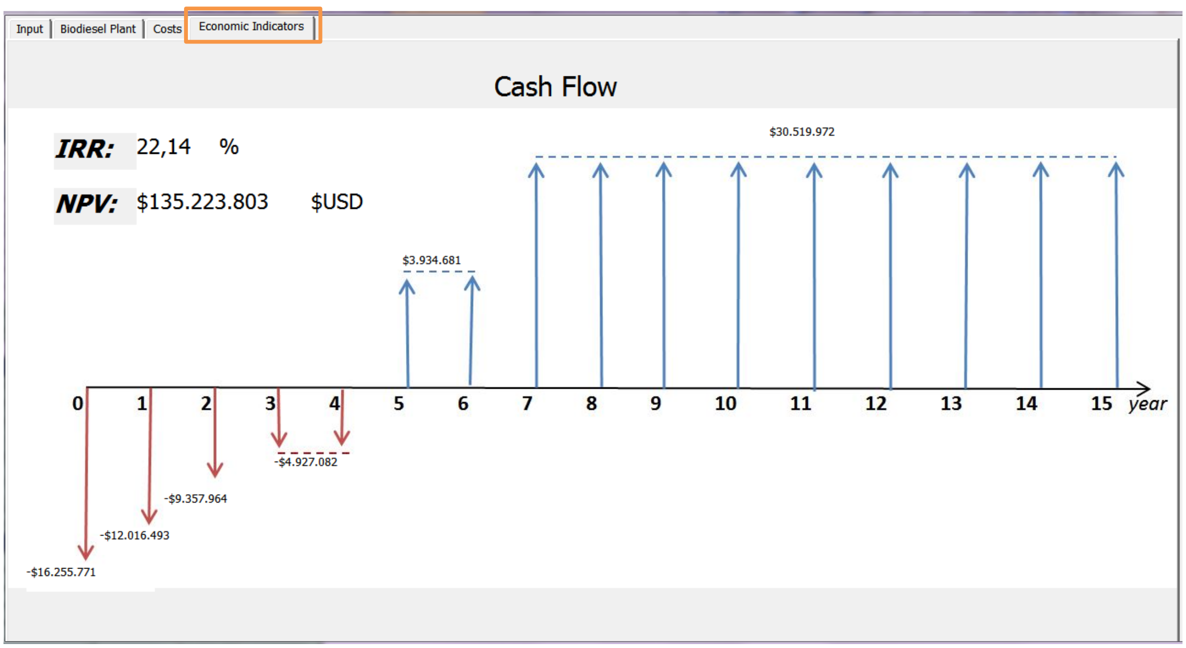

Source: The author.

**Figure 21. User interface: costs result**




Source: The author.

**Figure 22. User interface: Economic Indicators.**

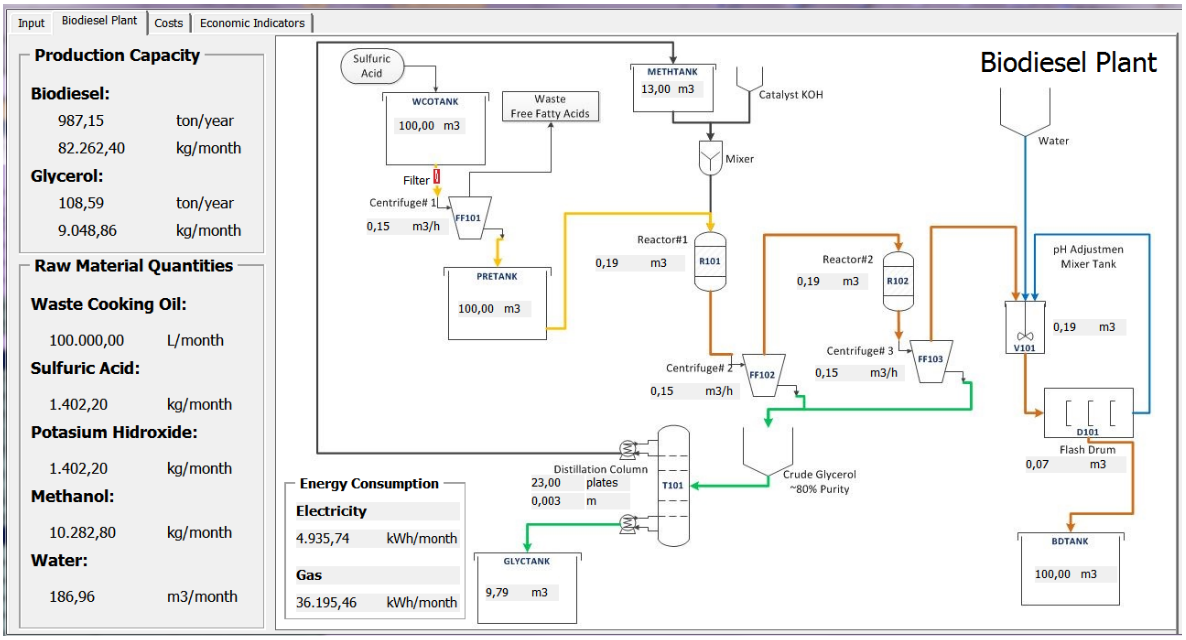



Source: The author.

# 5 RESULTS

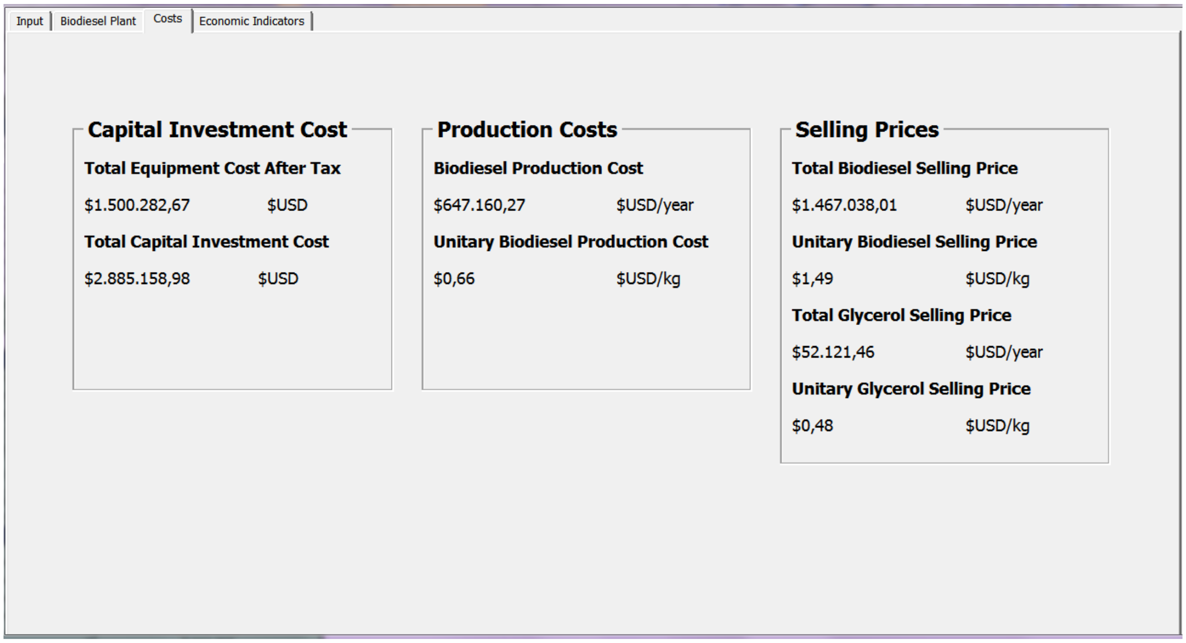
Using the computational tools, the next results were obtained analyzing three plant sizes using 100.000 liters/month (987 ton/year), 3.700.000 liters/month (36.524 ton/year) and 5.000.000 liters/month (49.357 ton/year). The results for each plant size are shown:

**Figure 23. Technic results: plant dimension for 100.000 liters/month**



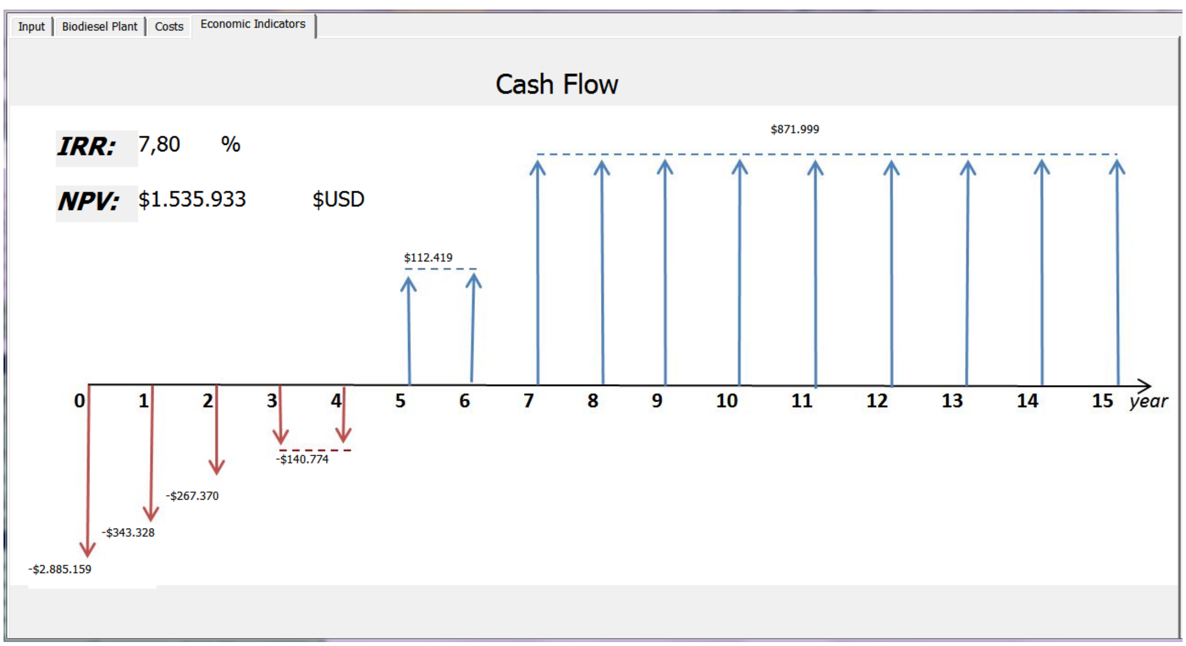

Source: The Author.

**Figure 24. Economic results: costs for 100.000 liters/month**



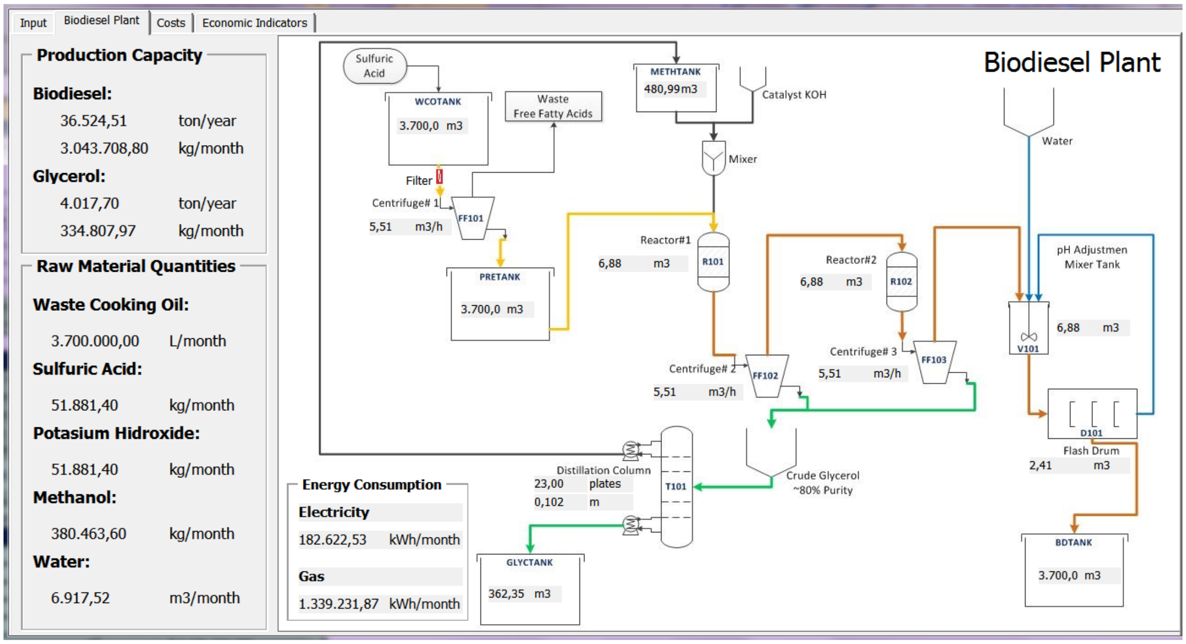

Source: The Author.

**Figure 25. Economic results: Cash Flow, IRR and NPV for 100.000 liters/month**



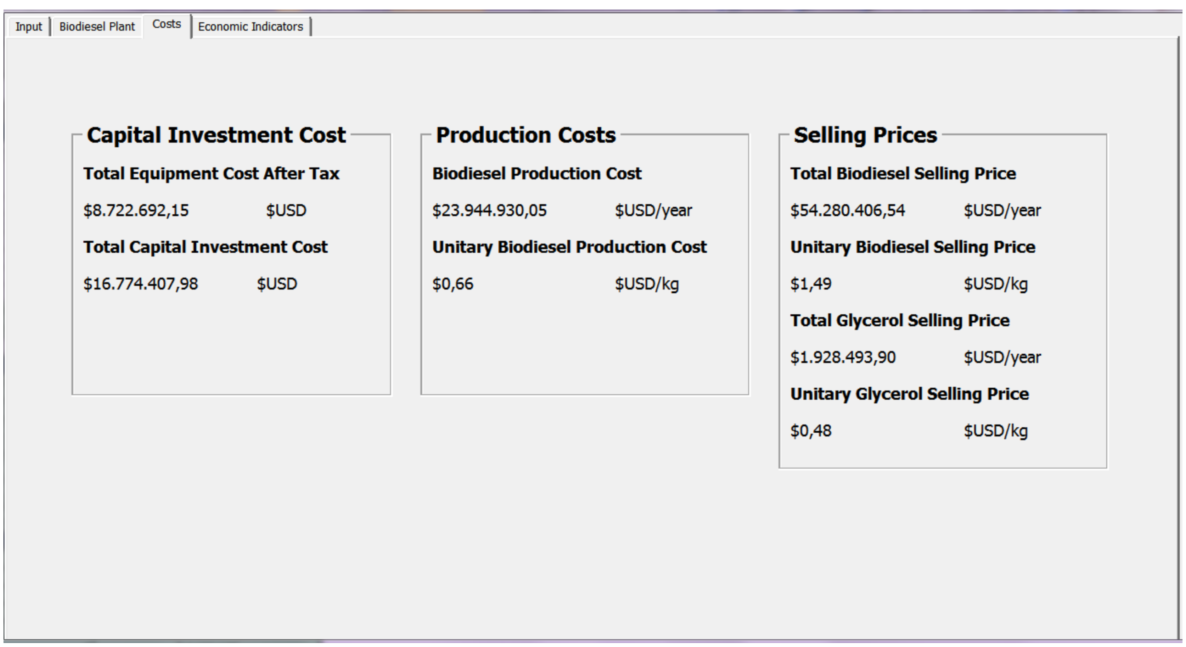

Source: The Author.

**Figure 26. Technic results: plant dimension for 3.700.000 liters/month**



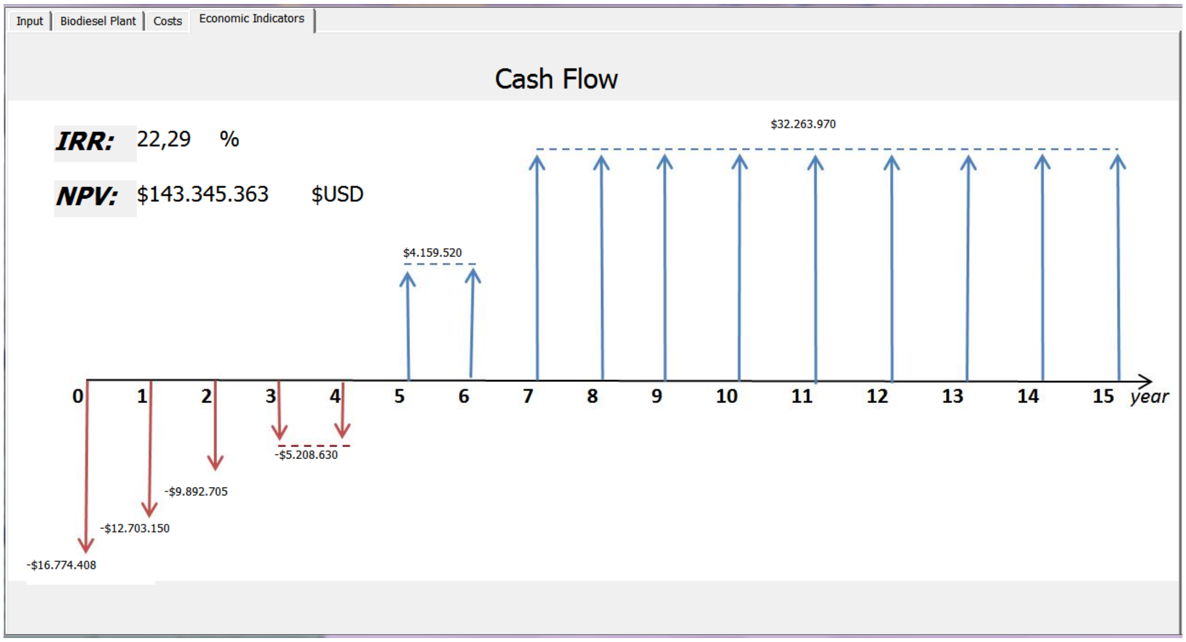

Source: The Author.

**Figure 27. Economic results: costs for 3.700.000 liters/month**



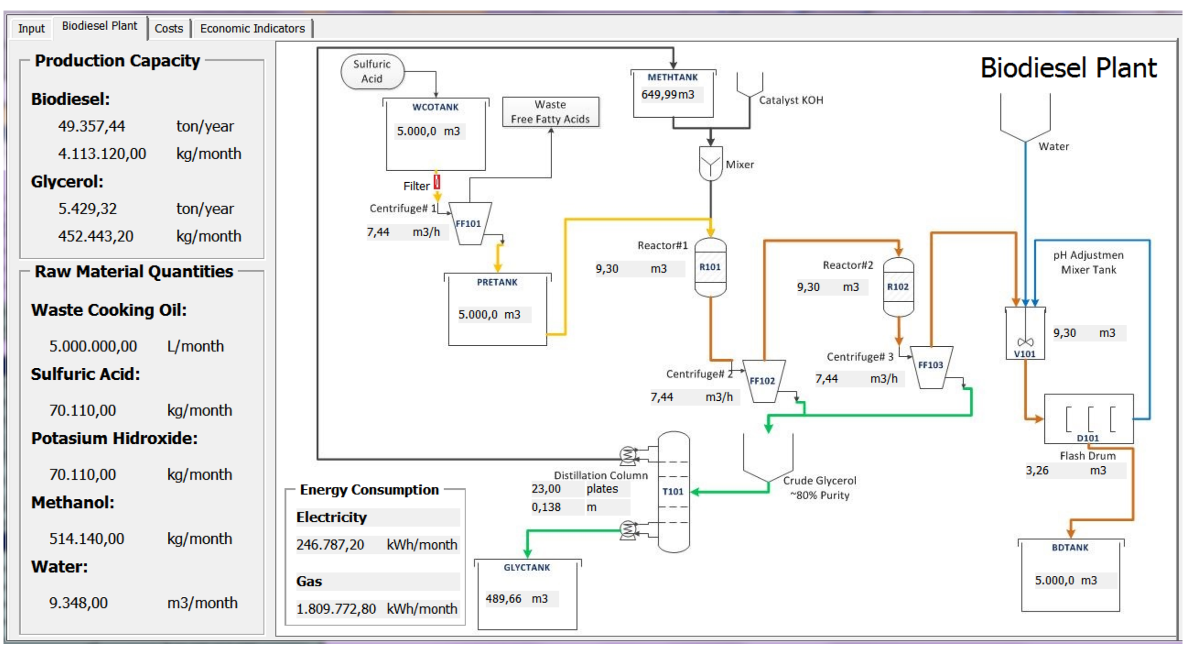

Source: The Author.

**Figure 28. Economic results: Cash Flow, IRR and NPV for 3.700.000 liters/month**



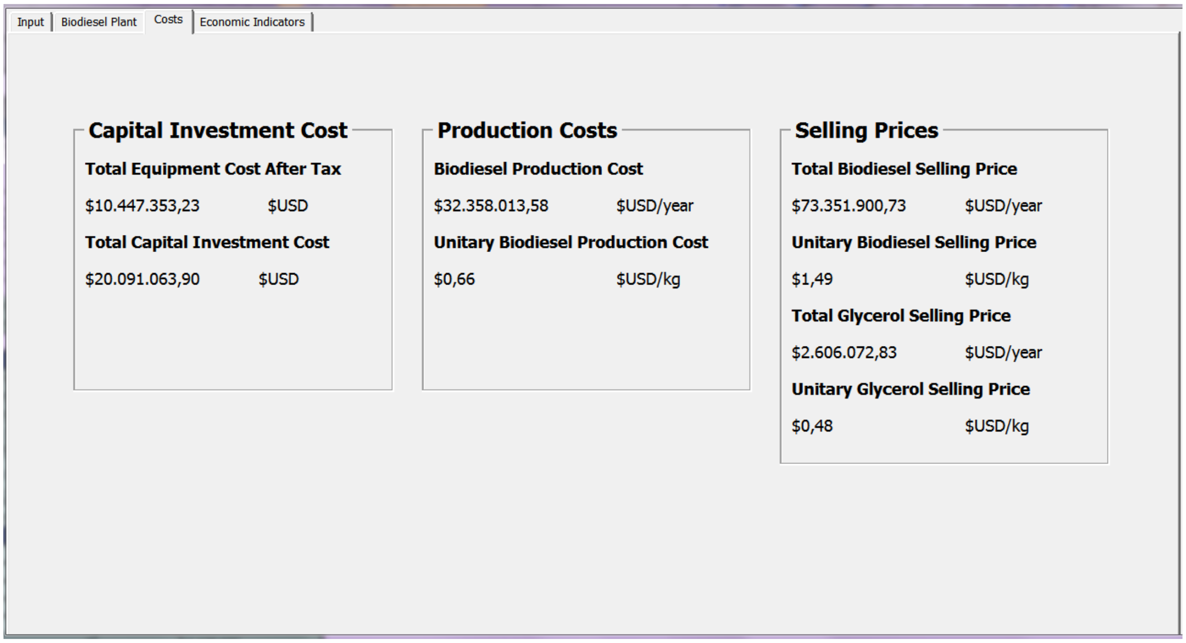

Source: The Author.

**Figure 29. Technic results: plant dimension for 5.000.000 liters/month**



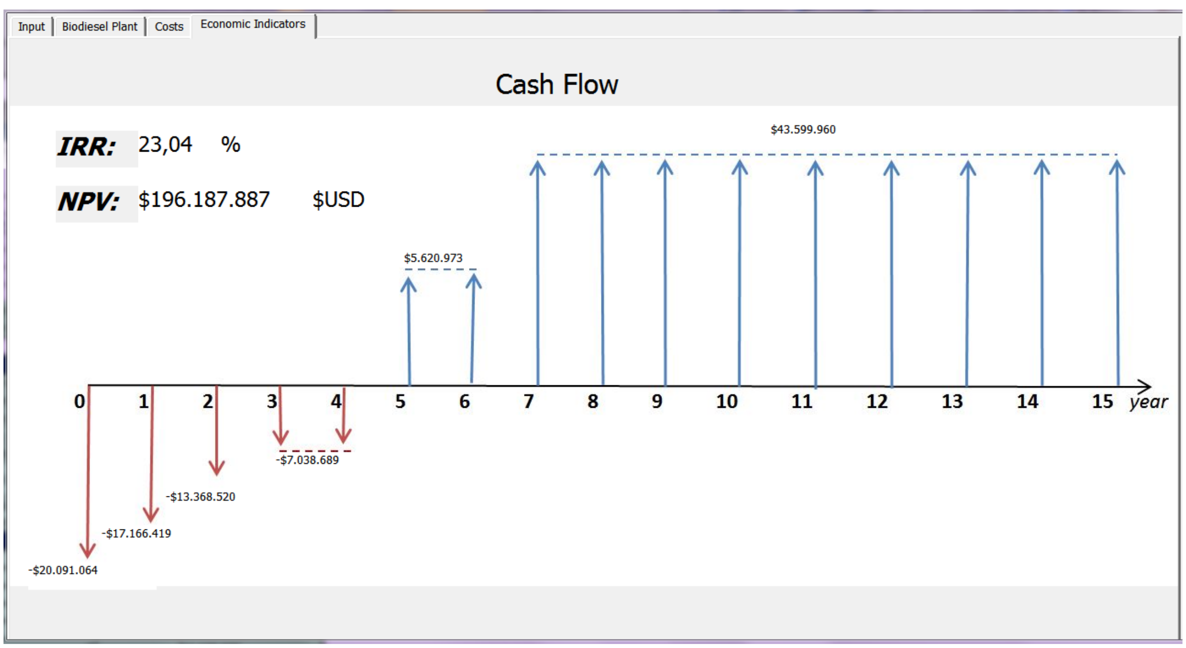

Source: The Author.

**Figure 30. Economic results: costs for 5.000.000 liters/month**




Source: The Author.

**Figure 31. Economic results: Cash Flow, IRR and NPV for 5.000.000 liters/month**



Source: The Author.

Comparing the results, the IRR is greater gas much as the plant size is increased. In the case of the plant with the smallest capacity (987 ton/year) the IRR is 7,8% in a period of 15 years which represents for that plant the project is not economically feasible according to the criteria exposed by Marchetti [6]. For the case of 36.524 ton/year and 49.357 ton/year, the IRR are 22,29% and 23,04% respectively in the same period of evaluation the results represents the projects are technic and economic feasible for that plant sizes.

In all the three cases, in the first fourth years there are not earnings as can be seen in the cash flows (figures 25, 28 and 31). That is the results of the assumption of the total selling in the first years where a new biodiesel plant does not covers an important part of the entire market and needs some years to get customers.

The medium plant capacity (36.524 ton/year) with a IRR of 22,29% can be compared to the plant exposed by Marchetti [34] and Errazu [35] in Table 4 with a capacity of 36.030 ton/year from waste cooking oil by transesterification with pretreatment, where the IRR is 11,17% evaluated at 15 years too. The differences in the results can be generated for the local costs and the different tax of the local economies, considering Marchetti [34] and Errazu [35] analyzed a plant in Argentine in the 2008. However, the result is into the range expected by Marchetti [6] (16% - 24%) for biodiesel production plants.

This investment cost can be compared with the recent investment in biodiesel plants in Colombia, where can reach costs over $41.000.000.000 COP for large plants (100.000 ton/year) [48] where comparing the results for a plant with a capacity of 50.000 ton/year the investment reach over $ 24.000.000.000 COP. It can represent a good validation making a relation between plant size with the investment cost of the developed algorithm.

Technically the dimension of the equipment of the obtained plants is feasible according to the flow rates and the capacities for storage where high volumes can be approach in more than 1 tank in order to select the most appropriate equipment considering the interest of the user. Normally the plants have storage tanks over 30 to 100 tons of capacity. Distillation columns can reach 10 meters or more of high, and the diameters of plates greater than 0,1 meters. This information can be validated by the actual biodiesel production plants in Colombia such as Odin, BioD and Oleoflores [2]. Additionally for technic analysis the obtained plant capacities are similar to the reality of our country about production plant exposed by Fedebiocombustibles [2].

Table 16 shows the capital investment and biodiesel production costs and IRR for different plant capacities.

**Table 16. Economic results for plant capacity**

| LITERS OF WCO REQUIRED | PLANT CAPACITY [ton/year] | CAPITAL INVESTMENT COST [$USD] | BIODIESEL PRODUCTION COST [$USD] | IRR AT 15 YEARS |
|---|---|---|---|---|
| 100.000 | 987 | 2.885.158 | 647.160 | 7,8% |
| 500.000 | 4.936 | 4.885.667 | 3.235.801 | 16,8% |
| 1.000.000 | 9.871 | 7.708.653 | 6.471.602 | 19,3% |
| 3.000.000 | 29.614 | 14.946.624 | 19.414.808 | 21,7% |
| 4.000.000 | 39.486 | 17.547.669 | 25.886.410 | 22,5% |

Source: The Author.

As can be seen in table 16, the tendency is linear: as the plant capacity is greater, the capital investment cost is increased. The IRR represent the project plant is economically feasible (greater than 16%) for all the plants bigger than 4.936 ton/year plants; to reach an appropriate IRR, high capital investment cost and liters of WCO are required.

The impact of the WCO cost over the biodiesel production cost and the IRR is represented in table 17. The increasing on the raw material increase the biodiesel production cost and affect the IRR negatively.

**Table 17. Impact of the WCO cost over the biodiesel production cost and the IRR for plant capacity of 49.357 ton/year.**

| COST OF WCO [$COP/L] | BIODIESEL PRODUCTION COST [$USD] | IRR AT 15 YEARS |
|---|---|---|
| 500 | 24.413.181 | 27,12% |
| 600 | 27.735.440 | 23,04% |
| 700 | 31.057.699 | 18,00% |
| 1.000 | 41.024.477 | 4,7% |
| 1.200 | 47.668.995 | -3,9% |

Source: The Author.

Technically, the increasing of the plant capacity impacts the size and capacity of the equipment and the energy consumption, directly affecting the capital investment cost. Table 18 shows size of the WCO storage volume required, the required flow rate for the centrifuges and the energy consumption per month for each plant capacity.

**Table 18. Technic results for plant capacity**

| PLANT CAPACITY [ton/year] | WCO STORAGE VOLUME [m^3] | CENTRIFUGE FLOW RATE [m^3/h] | REACTOR [m^3] | GAS CONSUMPTION [kW/month] | ELECTRICITY CONSUMPTION [kW/month] |
|---|---|---|---|---|---|
| 987 | 111,25 | 0,14 | 0,19 | 36.195,46 | 4.935,74 |
| 4.936 | 556,26 | 0,71 | 0,93 | 180.977,28 | 24.678,72 |
| 9.871 | 1.112,52 | 1,42 | 1,86 | 361.954,56 | 49.357,44 |
| 29.614 | 3.337,55 | 4,26 | 5,58 | 1.085.863,68 | 148.072,32 |
| 39.486 | 4.450,07 | 5,69 | 7,44 | 1.447.818,24 | 197.429,76 |

Source: The Author.

As can be seen in table 18, the WCO storage represents high quantities in all the cases, there is a need to employ various storage tanks to cover the volume requirement in order to the manufacturing of the tanks can be technically feasible.
The capacity of the reactors driven by the flow rate of the centrifuges and a residence time of one hour for the reaction, are technically possible for manufacturing because the small obtained sizes.

## 6 CONCLUSION

Considering the variables for economical decision, the most important is IRR, because it is a significant value which represents rightly the feasibility in a biodiesel production plant investment in an easy expression; in the way the IRR is higher the investment represents good reliability for the decision to invest in a new biodiesel production plant from WCO.

In order to generate a parametric algorithm the principal requirement is to define the technology to produce biodiesel, this factor drives the generation of the number of expressions by defining the capacity and the cost for each equipment to obtain finally an expression which shows the total equipment a capital investment cost, and the capacity of the entire plant as values that define the IRR and NPV of the investment. The total cost of equipment is the most important factor in order to estimate IRR as an interesting factor for economic feasibility. The plant capacity and the feedstock price are the most important factors that affect the economic viability. That is the reason why the dimension of the equipment as technic study, relates and determines economic criteria of a biodiesel production plant. Analyzing the effect of the plant capacity, the IRR is increased as the plant capacity is increased showing that production obeys an economy of scale; the results of the algorithm shows high IRR for plant capacity greater than 10.000 ton/year (medium scale) and in consequence it represents high capital investment costs to reach high IRR as can be seen in the obtained results.

The algorithm is allowed to show the impact of the raw material cost over the biodiesel production where using waste cooking oil for a plant capacity of 49.357 ton/year, the biodiesel production cost is $27.735.440 USD/year; using fresh vegetable oil the biodiesel production cost is increased to $47.668.995 $USD/year. It shows the algorithm as a flexible computational tool where any value can be change in order to support different analysis for technic and economic feasibility analysis preserving the same transesterification process.

Many authors, like Marchetti [18], Peterson [37] and Zhang [19] have made studies focus on different technologies to biodiesel production. The most used technology is the transesterification process, using an alkali catalyst, and methanol since it is a simple method, economic, and requires common feedstock like waste cooking oil, soybean oil or beef tallow, without affecting the human feed supply.

The authors Skarlis et. al [4] have defined the appropriate scale from the objectives of the company. In general large scale plants must have a capacity greater than 50.000 tons per year, and are very competitive for exportation. In contrast to, small scale plant has a capacity above 10.000 tons per year, and in spite of the fact that they have higher operating cost than large facilities, they are more suitable for enhance local development, and social retributions for public inversions and to reduce diesel cost in remote rural areas. In that case, the capacity must be the necessary to cover a specific area where diesel is used.

Compared with the biodiesel production worldwide, the production in Latin America at 2009 there was a total production of biodiesel about 3.361,61 millions of liters, and a consumption of 2.029,68 millions of liters. There is an expectation at 2018 where the biodiesel production will be growing up to 44 billion of liters per year. The biodiesel will be used principally by transport, and the costs of the production depend of the feedstock, technology to produce it, and the origin country. However, these considerations are modified according to the petroleum prices [9].

As a preliminary conclusion, the study for the feasibility of biodiesel production plant can be possible if there is enough information about the cost of local raw materials, process and technology for biodiesel production, equipment, building and services, land cost, and all the variables that associated in the process and the biodiesel price. Also, there is a need to develop custom-made tools to perform the feasibility analysis with the aim to determinate the dimensions of the equipment, and then estimate the capacity of the plant, total investment cost, final product price, sub-products selling price, internal rate of return for a established period, all of that with the final aim to study how these variables affect the project feasibility for a particular region and context in Colombia.

The develop of this project represents a good help to motivate businessmen to generate resource for implement new biodiesel production plant, because the project offers a practical tool to estimate the economic feasibility of invest in a new biodiesel production plant, by determining the capacity of the plant and the internal rate of return.

A software and programming tool for feasibility evaluation that can be potentially used for evaluation purposes related with implementation of Biodiesel plants. The use of the computational tool is addressed to research centers, governmental and private institutions which are involved in Biodiesel field and requires decision criteria for scaling their project.

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