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Mobile Plant for Biodiesel Production from Jatropha Curcas Seeds, in Colombian Caribbean Regions

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Jatropha Curcas is a wild plant whose parts offer a viable and sustainable alternative in various applications. This work presents the conceptual design of a mobile plant for producing biodiesel from *Jatropha Curcas* seeds, and a basic analysis of the technical viability for its operation in rural areas in the Colombian Caribbean region, where energy demands are not fully covered, and where the climatic conditions and soil quality are appropriate for growing *Jatropha Curcas*. The mobile biodiesel plant consists of a unit for the extraction of oil from the *Jatropha* seeds and a production unit where the oil is processed to obtain biodiesel. Once the plant starts the production, the energy required for its operation is self-supplied using the biodiesel that is produced. Due to its mobile design, this biodiesel plant can be moved around small crops to process the *Jatropha Curcas* and supply energy in farms. The potential applications of the products obtained in the mobile plant, apart from the biodiesel, are also explained, as a reference for future projects that support the sustainable operation of a biorefinery from *Jatropha Curcas.*

1. Introduction

The high demand for fuels, together with the environmental pollution generated by their use, the economic and energetic dependence of plantation owners to electricity companies and fuels, and the need to provide nutrients to the field for fertilizing crops, promote the need for structuring a system for an integrated utilization of *Jatropha Curcas* seeds, in order to reduce the environmental impact caused by products of fossil origin. This is a viable solution that can generate profits for small growers, and also creates better life quality for rural workforce (Van der Putten, Franken and De Jongh, 2010).
Considering the high cost of oil import demand, the existing high level of unemployment in the Caribbean region of Colombia, the need for reforestation, many semi-arid and desertified land available by indiscriminate logging and overgrazing, the development of an alternative energy source such as *Jatropha Curcas* for biodiesel production is vital, in order to improve the life quality and employment conditions in rural areas and farmers involved.
Apart from this, fossil fuels are a non-renewable source of energy; in this regard, the governmental entities in Colombia have concluded that the main cause of air pollution in this country is the use of fossil fuels. For a fuel to be considered “clean” in Colombia, the regulation stablished that the Sulphur content must be lower than 50 ppm, both for diesel and diesel-biodiesel blends (Colombian Ministry of Environment, 2010). The implementation of the mobile plant described in this paper for the production of biofuel from *Jatropha Curcas* seeds would help reducing the need and prolonged use of fossil fuels. Thus, *Jatropha Curcas* constitutes a local source of renewable energy that allows farmers to generate economic profit from the products obtained therefrom, rather than using fossil fuels, electric and inorganic fertilizers. The analysis presented in this work is a case study for the Caribbean region in Colombia, considering the extreme tropical weather and the needs for a regular supply of energy for small growers. This work is an effort to encourage the use of *Jatropha Curcas* seed as an energy source for the production of oil, Biodiesel and covering several primary electricity needs, in order to support rural communities through changes in agricultural commodity value-added products

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that contribute protection against soil erosion, helping to increase the market potential of the crops, and achieving the reduction of fossil fuel use and sustainable agriculture at the local level.

Jatropha Curcas. (scientific name), better known as "*Jatropha*" is a wild plant that produces seeds with a high oil content. The seeds are toxic and inedible, and their dimensions vary depending on the origin of the plants and seeds. On average, *Jatropha Curcas* seeds are 18 mm long, 12 mm wide and 10 mm thick, their mass ranges between 0.5 to 0.8 grams per grain. A kilogram of *Jatropha Curcas* seeds contains around 1333 seeds. Toxic components contained in the *Jatropha Curcas* seeds are phorbol esters, Curcin, trypsin inhibitors, lectins and phytates. These seeds also have a hard shell that represents about 37% by weight of the total, and a white bean that represents the remaining 63%. Dry seeds have a moisture content of about 7% and 50 to 60% of oil content. It grows in subtropical conditions, even under severe drought and low soil fertility. The annual output is 10 tons of fruits and 4 tons of seeds per hectare. Because of its ability to grow in poor soils and to restore eroded areas, *Jatropha Curcas* is suitable for phytoremediation, due to the addition of organic waste to the soils. It is not a food or forage crop, which makes it suitable for deterring cattle, and then protecting food or other commercial crops or food value (Van der Putten, Frankend and De Jongh, 2010). Traditionally, the *Jatropha Curcas* seeds and other parts of the plant are used in the production of oil, soap and medicines. The plant became popular as a renewable energy source due to its unique characteristics such as drought tolerance, rapid growth, easy propagation, its higher oil content compared to other crops, small gestation periods, the wide range of ecological benefits of adaptation, a simple technology requirement for growing, a modest investment capital, optimum size and good architecture (Pandey et al, 2012).

In this context, the production of Biodiesel from *Jatropha Curcas* has several advantages that make it viable. The oil produced by this crop can be easily converted into liquid biofuel that meets American and European standards, through a chemical reaction involving triglycerides (which are present in the oil) and alcohol in the presence of a catalyst to form esters (biodiesel) and glycerol. This transesterification involves three reversible reactions, where the use of a base as a catalyst, promotes the conversion of triglycerides to esters because of the higher reactivity and moderate processing conditions such as a lower temperature for the reaction (Koh and Mohd, 2011).

Table 1 shows the properties of biodiesel obtained from Jatropha seeds, compared to the conventional diesel. *Jatropha Curcas* can also grow without irrigation in a wide range of rainfall regimes, 250 to 3,000 mm per year (Achten et al., 2008); all this makes it of current interest for investors, farmers and non-governmental organizations, focused on the economic growth of communities.

Table 1: Properties of Jatropha Curcas Biodiesel versus diesel

Parameters	*Jatropha Curcas* Biodiesel	Diesel
Specific gravity at 15°C	0.860-0.933	0.82-0.86
Sulfur	0.13	1.2
Viscosity (cSt)	37.00-54.80 a 30°C	1.3-4.1 at 38°C
Pour point (°C)	-3	-33 to -15
Cloud point (°C)	2	-15 to -5
Flash Point (°C)	210-240	60-80
Cetane Index	38-51	40-55
Heat Value (MJ/Kg)	37.83-42.05	42

2. Methodology and tools

The mobile plant described in this work for the utilization of *Jatropha Curcas* seed is a plant whose dimensions allow it to be moved between strategic points in rural areas, as a trailer. The main components are an oil press extractor, a reactor for the transesterification process, and a generator that provides electrical power to them and which in turn is powered by the biodiesel obtained in the mobile plant once it starts the production, so the whole process is self-sustainable. The components mentioned above (press, reactor and generator) can be connected through black iron pipe 1" nominal diameter. Galvanized, cast iron, aluminum or copper pipes have to be avoided, due to the chemical reactions that they can generate upon contact with the biodiesel. *Figure 1* shows the block diagram for the mobile plant. The description of the main components of the plant is shown in Table 2, with the prices that are managed in Colombia, converted to US dollars. An advantage represented by this mobile plant, is that the generator of the plant can also supply electric power to electrical devices and light machinery at farms with no access to electric supply. Thus, the mobile plant covers several basic energy needs in rural areas.

Extracting oil from the seeds of *Jatropha* is performed by pressing. The separated shell at the press can be used in biogas production or as an organic fertilizer. The press extraction removes up to 90% of the oil present in the seeds. This oil is fed to the transesterification reactor without prior purification. Methanol and sodium hydroxide also enter the transesterification unit. When the biodiesel production process is performed at temperatures around 60°C, and in the right oil-methanol molar ratio (4:1 to 6:1), the reaction yield is about 98% (Koh and Mohd, 2011). The biodiesel process is batch type, therefore, the dimensions of the transesterification unit depend on the amount of biodiesel to be obtained; The transesterification reactor described in Table 2 has a capacity of 50 L and occupies an area of 1 m^2.

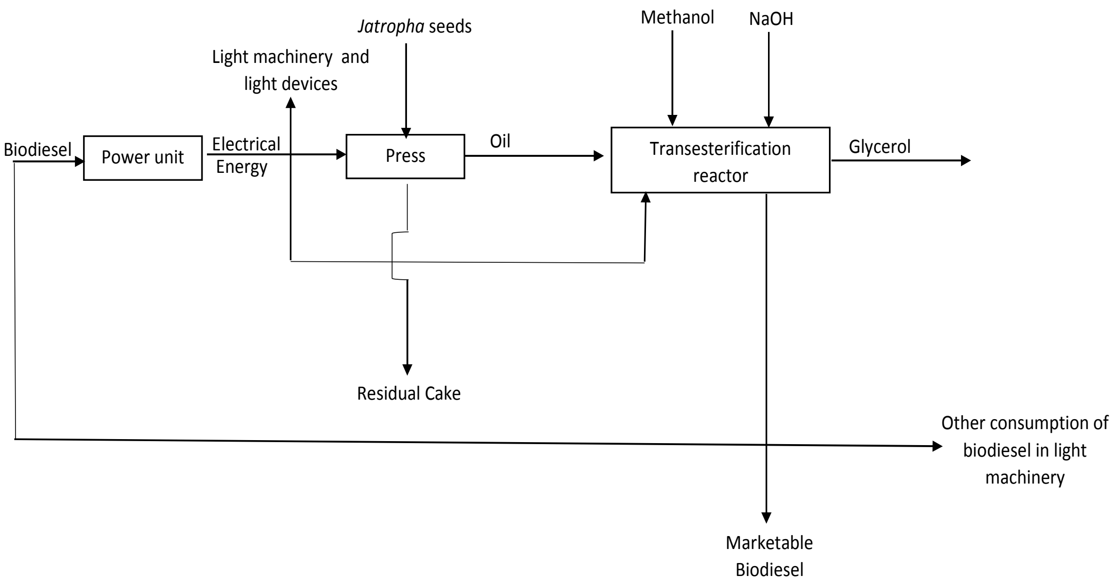

Figure 1: Block diagram of the mobile unit to full utilization of Jatropha.

Table 2: Initial investment for the main plant components.

	Initial Investment	
	Specifications	Price (USD)
Diesel	Conventional	25
Press filter	Model: DD-85G Capacity: 50 kg/h Consumption: 3 kW Weight: 900 kg	800
Transesterification reactor	Model: BIODYS-50 Batch type Consumption: 2 kW 40L Biodiesel per production batch Capacity: 50L Resistance: 1x1.2 kW, with the thermostat 14L HDPE methoxide tank with mixer and injector Pump 370 W – 40 L/min	2,000
Generator	Model: GDTI-6 Speed: 3,000 rpm Power: 11 HP or 8.206 E Fuel Tank Capacity: 15 L Requires 350 g fuel / kWh	1,600
	Total	USD 4,425

Temperature control in the transesterification reactor is required in order to keep the process temperature around 60°C, which is lower than the boiling point of methanol; this prevents the evaporation of methanol; high temperatures for transesterification are to be avoided, since the oil viscosity will be lower, and the production of soaps (saponification reaction) would be accelerated, apart from a decrease in the performance of the biodiesel. The amount of catalyst (sodium hydroxide, NaOH), to use in the process of biodiesel must be determined carefully, because if too little is added, the reaction will take longer to be performed, and conversely if it is added in excess it leads to the formation of soaps. Methanol is suggested, since its use is more widespread than ethanol in biodiesel production (Koh and Mohd, 2011).

2.1 Calculation of currents involved in the mobile plant

A quantitative example, based on the production of *Jatropha Curcas* and size of the mobile plant is described: Considering that the mass of one seed is in average 0.65 g, and that the oil content is 55% by weight, then there are 0.3575 g of oil present in one seed. Pressing allows the extraction of up to 90% of the oil present in the seeds, therefore 0.32175 g of oil per seed are removed. Additionally, considering that 1 kg of *Jatropha Curcas* seeds contains around 1333 seeds, then 429 g of oil per kilogram of *Jatropha Curcas* seeds are obtained by extracting entered into the mobile plant. The density and the molecular weight of *Jatropha Curcas* oil are 896.5 kg/m^3 and 870 g/mol, respectively. Then, 1 mol of oil corresponds to 870 g or 970 ml. To produce 1 mol of oil, 2 kg of *Jatropha Curcas* seeds are needed. The oil obtained from the pressing of the seeds can be used directly for many products in the chemical industry, but the major destination is the biodiesel production (Shuhairi, Zahari and Ismail, 2015). For the calculation of the amount of catalyst, it is considered that a 10% of the amount of oil is necessary. Further, the catalyst concentration ranges from 1 to 1.5 %w/w, but use of 1% w/w is suitable. Thus, 87 g of NaOH at 1% w/w are required to react with 1 mol of oil from *Jatropha Curcas* seeds.

Now, to calculate how much alcohol is needed, it is known that 3 moles of alcohol are theoretically required to react with 1 mole of triglyceride (oil), however, to ensure a complete reaction, a 6:1 molar ratio of methanol oil is proposed, instead of 3:1 theoretical ratio. The molecular weight of methanol is 32 g/mol, and it has a density of 791.8 Kg/m^3, that is, 6 moles of methanol equals 192 g, which corresponds to a volume of 243 ml of methanol to react with the oil in a 6:1 molar ratio. Now, to calculate how much biodiesel is obtained from the reactants mentioned above, based on preliminary tests on a laboratory scale to obtain biodiesel, the yield varies between 84-98 %. Considering an average yield of 91 %, and an average density of 870 kg/m^3, 910 ml of biodiesel are obtained from 1 mole of theoretical oil. Since the monthly output of mobile plant is 160 L of biodiesel , therefore, to obtain the necessary amounts, each variable value is multiplied by the same numerical factor, so that upon the operation it results in 160000 ml Biodiesel (160 L), as following: 352 kg of *Jatropha Curcas* seeds enter the press during 7 hours to produce 171 L of oil, which enters the transesterification reactor, together with 15 kg of sodium hydroxide 1% w/w, and 43 L of methanol, to obtain 160 L of biodiesel. 56 L of the biodiesel produced from Jatropha seeds are consumed by the generator to meet the energy requirements of the plant; it also provides energy for basic appliances in the farm, and a mill; 11 L are consumed by water pump and grass cutter, and the remaining 93 L are destined for marketing. The plant operates once a month. Table 3 summarizes these quantities. Another consideration is that the plant does not operate at its maximum capacity during the 24 hours (this is because the press filter operates at 30% and the transesterification reactor operates at 66% of its capacity), this means that, according to the inventory, the mobile plant can process 1.5 hectares of *Jatropha* seeds. Therefore, if a larger amount of Jatropha seeds is going to be processed (that is, a larger area of the plantation), it is necessary to use a larger transesterification reactor. Table 4 shows the monthly consumption of electricity and fuel, associated to the *Jatropha Curcas* plantation and biodiesel production.

Biodiesel from *Jatropha Curcas* has several valuable properties such as low acidity, good oxidation stability compared to soybean oil, low viscosity relative to castor oil and best cooling properties with respect to palm oil. In addition, viscosity, free fatty acids, the density of oil and Biodiesel are stable products in their storage period (Sandquist and Matas, 2012). Sulphur emissions from the combustion of the biodiesel obtained from Jatropha are minimal, with a difference of 1.07 compared to diesel. Also, biodiesel from *Jatropha* is free of paraffinic, naphthenic and aromatic compounds, which represents lower emissions to the environment. Moreover, biodiesel from Jatropha seeds has a higher flash point, thus ensuring safer handling and storage. An indicator for a high yield of biodiesel and oil extraction is the amount of cake that is produced in the press: considering that one hectare of *Jatropha* produces 1 ton of cake, it can be used as a feed in gasifiers to produce biogas, gas for engines, or as a fertilizer. The transesterification process, apart from producing biodiesel, 15% of glycerol occurs; the glycerol is decanted and separated from biodiesel. This glycerol can be marketed or refined, so it can be used as a lubricant for specific machinery, raw material in varnishes production, preservation in the leather industry or to provide elasticity and softness to fabrics in the textile industry. The electricity produced by the generator is stored in a battery cell while the plant is in operation, so that it can subsequently be used to turn electrical devices and some light machinery.

Table 3: Consumption and production of mobile plant

Requirements and production in the mobile plant	
Jatropha seeds (kg)	352
Oil produced (L)	171
Methanol (L)	43
NaOH (kg)	15
Biodiesel produced (L)	160
Biodiesel consumed in generator (L)	56
Other biodiesel consumption (L)	11
Marketable biodiesel (L)	93
Glycerol (L)	24

Table 4: Inventory and use of mobile plant Biodiesel

	KW	Time (min)	Time (h)	N. Days/Month	KW h
Mobile plant					
Press Filter (KW)	3	422	7.03	1	21.1
Transesterification reactor	2	960	16	1	32
Home					
Refrigerator (KWh/Day)	2.61			30	78.3
2 Bulbs (KWh/Day)	0.12			30	3.6
Fan (KWh/Day)	0.07			30	1.95
Plantation					
Mill (KW)	3.73	30	0.5	2	3.73
		Time (min)	Time (h)	N. Days/Month	L
Biodiesel (production and uses)					
Produced biodiesel (L)					160
Pump (L/h)	1.4	120	1	4	5.6
Grass cutter(3.7 Kw)		120	2	2	5
Generator (L)					56.27
Marketing (L)					93.13

3. Viability

One aspect to consider in the viability of the operation of the mobile plant is the crop yield of Jatropha. Dividing the total time of growth and maturation of the Jatropha in three periods, the following aspects are considered:

Period 1: Comprises the first 8-12 months after planting seed; the first harvest is done with an annual yield of 240 kg of seed/ha and a monthly yield of 20 kg of seed, that produce 9 L month. This is insufficient to complete the required monthly production of about 160 L of biodiesel. Therefore the next suggestions: 1) it is suggested to launch the plant in areas with previous Jatropha crops, especially for longer time than the year of sowing; this way, there will be no need to buy conventional diesel during that first year, resulting in a shorter recovery time of the investment, and 2) if the plantation owner decided to launch the mobile plant after the first harvest Jatropha, we recommend selling the oil produced (in the press) as soon as possible to avoid acidification thereof, as this would imply an increase in the recovery time of investment.

Period 2: Occurs between the 18th to 36th months from sowing seed, two annual harvests are carried out, with a yield per hectare of 6,480 kg of seeds for three semesters, distributed in 2,160 kg of seeds per semester (or 360 kg of seeds per month).

Period 3: After 36 months, the monthly yield of *Jatropha* will be 500 kg of seeds per hectare. Considering the production for the periods 2 and 3, there will be three alternatives for using the products: 1) produce biodiesel with strict recommended amount of seeds and reserve the remaining plantation for future production, 2) extract all the oil from the seeds that are collected monthly and produce biodiesel, with the disadvantage that at the end of period 2, the new seed culture is not fully developed for harvesting; and 3) extracting the oil in the press, and convert only a part of it into Biodiesel, and selling the remaining amount of oil extracted in the press.

The calculations done in this study are related to the Caribbean region in Colombia. The yield per hectare of plantation is based on the data that were gathered. This yield is higher than in other regions, since the seeds that were considered for the plantations are from genetically modified species,that allow higher production of seeds and biodiesel. The results are locally dependent, so the amount of seeds and biodiesel production have to be calculated for the specific area under study, in case that it needs to be extrapolated.

4. Conclusions

A basic process for obtaining biodiesel from *Jatropha* seeds was described, considering a mobile plant that can provide for the energy needs in rural areas in a coastal region in Latin America, specifically the Caribbean region in Colombia. Through the implementation of this mobile plant, the growers associations can improve their life quality thanks to an increased rural employment, energy security and reducing dependence on fuel fossil (imported oil), apart from the products that can be marketed. This way, the production of biodiesel from Jatropha seeds helps promoting the economic independence of the country and or plantations of *Jatropha Curcas* through *insitu* Biodiesel production and self-sufficiency of biofuels and electricity, encouraging regional development on a larger scale, and creating new business options for the rural area. At the same time, Jatropha crops will help to recover marginal and degraded land in semi-arid regions, without competing with food production.

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