



Evaluation of Biodiesel Production Process from Palm Oil (Eleais Guineensis) using Exergy Analysis Methodology

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The search for cleaner energy sources has motivated the development of fuels from oil crops such as soybeans, sunflowers, rapeseeds, palms, tartago, and others. One of the most important processes being developed in large-scale is biodiesel production from African Palm. However, one of the most critical disadvantages of biodiesel is a lower production of combustion energy output compared to fossil fuels and consequently, higher energy requirements for obtaining an energy unit.

In order to improve the biodiesel from palm oil production process, the stages of acid esterification, basic transesterification, biodiesel washing and purification were simulated in the software Aspen ONETM 8.4. The full compositional profile of palm oil (*Eleais Guineensis*) was included, considering both homogeneous and heterogeneous triglycerides. With the help of software, thermodynamic properties such as enthalpy, entropy, and Gibbs free energy were determined for all streams. Then, chemical, physical and thermal exergies for the streams of the process were calculated – i.e., the exergy destroyed in the process. The overall exergy efficiency was 41 %. The analysis also allowed the identification of the high consumption of utilities and the exergy losses. These can be reduced using process integration, yielding an increase in the global efficiency of the palm oil biodiesel production process.

1. Introduction

In recent decades, economic development has been largely dependent on the use of oil as an energy source. Still, natural gas and coal continue to be the main energy sources worldwide. Fossil fuels are used in a variety of fields such as food production - by the use of fertilizers-, the plastic industry, etc. In addition to that, people also use them daily one way or another to provide power, heating, and lighting. However, the use of non-renewable resources to supply the energy needs is an unsustainable practice; these non-renewable energy sources are projected to be exhausted in the near future (Gui et al., 2008). The situation has worsened with the escalating worldwide energy consumption due to rapid population growth and economic development. In order to supply this demand emphasis has been given to the study of biofuels during the last years (García-Prieto et al, 2014). Biodiesel in particular has received considerable attention because it is a biodegradable, renewable, non-toxic, and a more environmentally friendly fuel; it emits less polluting gases in the atmosphere than regular diesel. Nonetheless, the traditional production of biodiesel using vegetable oils has economic impacts due to their high costs and the need of arable land. This places it in direct competition with the food sector, thus making it a raw material of low viability (Marchetti et al., 2008). Biodiesel can partially and/or entirely substitute diesel in internal combustion engines. Although biofuel constitutes only a small fraction of the overall liquid fuel market, recently its worldwide production has been increasing. Nowadays, because of its many advantages in terms of environmental sustainability, biodiesel is frequently considered to be an environmentally friendly type of fuel in comparison with oil and others fossil fuels (Jaimes et al., 2010). Therefore the evaluation of the efficiency of biodiesel production from palm oil is a very important task to ensure the sustainability of this process. In order to solve this problem the methodology of exergy analysis was applied in this study.

Exergy analysis is a useful technique that allows in-depth discussion of energy utilization in chemical processes. Furthermore, it helps to discover specific areas in the process which are subject to energy degradation (Caballero et al, 2014). Exergy analysis is a methodology used for identification and evaluation of energy losses in the processes. The exergy losses of a system can be split in two. On one hand are those resulting from the irreversibility of the processes taking place in the system and on the other hand are those resulting from an exergy discharge to the environment. The irreversible exergy losses are the difference between the total input exergy and the total output exergy (Tarighaleslami et al, 2011). Therefore, it is considered a tool for analysis and diagnosis of systems useful in the design of alternative solutions to reduce the use of unnecessary resources, and thus the potential impacts generated by the process.

1.1 Biodiesel

Biodiesel is defined as a mixture of mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats. Biodiesel can be produced from different varieties of feedstock such as vegetable oils (palm, soybean, peanut, cottonseed, sunflower, rapeseed, and coconut), animal fats (tallow) and used oils (frying oils). Methanol is the most commonly used alcohol for the production of bio-diesel, though other alcohols like *iso*-propanol or ethanol can also be used. The most commonly used technology for the production of biodiesel is the trans-esterification of triglycerides (oil) with alcohol, yielding fatty acid alkyl esters (biodiesel) as the main product and glycerin as the by-product. Since the reaction is reversible, an excess amount of alcohol is required to shift the equilibrium to the product side. (Hanna, 1999).

1.2 Exergy

Exergy analysis is a technique based on the second law of thermodynamics, which provides an alternative to assess, analyse, and compare systems. Moreover, exergy analysis yields efficiencies, which provide a true measure of how closely actual performance approaches ideal performance, and identifies existing irreversibilities as well (Peralta et al, 2010). Consequently, exergy analysis can assist in the optimization of designs.

Generally, energy includes two parts: the part of the energy which is able to be transferred to work in a reversible process -this energy is called exergy-, and the part of the energy which is not able to be transferred to work in a reversible process. Exergy is defined as the maximum amount of work which can be obtained as a process is changed reversibly from the given state to a state of equilibrium with the environment or the maximum work that can be obtained from any quantity of energy (Dincer and Rosen, 2007).

The exergy of a system is defined as the maximum shaft work that can be done by the composite of the system and a specified reference environment. This is assumed to be infinite, in equilibrium, and to enclose all other systems. Typically, the environment is specified by stating its temperature and pressure. In accounting for local conditions, a reference environment can vary spatially and temporally. The exergy for a system depends on the reference standard environment. Hence a bad selection of a reference standard would lead to erroneous results. Exergy calculation is based on the determination of two thermodynamic state functions, enthalpy and entropy.

The total exergy of a system consists of four principal types of exergy, which are: physical $\dot{E}x^{PH}$; potential $\dot{E}x^{PT}$; kinetic $\dot{E}x^{KN}$ and chemical exergy $\dot{E}x^{CH}$ and this can be determinate using Eq(1).

$$\dot{E}x_{flow} = \dot{E}x^{PH} + \dot{E}x^{PT} + \dot{E}x^{KN} + \dot{E}x^{CH} \quad (1)$$

The physical exergy flow can be calculated as follows

$$\dot{E}x_{flow}^{PH} = (H - H_0) - T_0(S - S_0) \quad (2)$$

And chemical exergy flow can be determined in two different ways:

$$\dot{E}x_{flow}^{CH} = \sum_i (\mu_{io} - \mu_{oo}) N_i \quad (3)$$

$$\dot{E}x_{flow}^{CH} = \Delta G_f + \sum_i ex_i N_i \quad (4)$$

Where ΔG_f signifies the standard Gibbs free energy of formation of the substance; ex_i is the chemical exergy of the *i*th pure element of the substance; N_i molar fraction of the *i*th pure element of the compound; and μ_i chemical potential of substance *i*th for the system (Ojeda and Kafarov, 2009).

2. Methodology

2.1 Simulation of process topology

The process was simulated in Aspen ONETM 8.4, the first step is to introduce the different compounds were used. The African Palm oil is composed of triglyceride and free fatty acid, these last starts to form from the time the fruit is harvested. The composition was based on the data reported by Jaimes (2013) and it's shown in Figure 1.

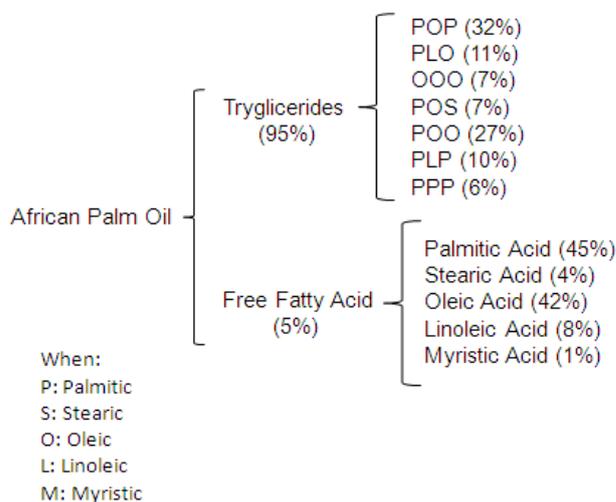


Figure 1: Composition of African Palm oil

The process has three important steps: Pre-treatment (esterification), trans-esterification, and purification of biodiesel. The pre-treatments in the production of biodiesel depends on the percentage of free fatty acids (FFA). When the oil has 5 % or more of free fatty acids is necessary to do this step, otherwise soap is generated in the trans-esterification reaction when in contact with the catalyst (NAOH).

The simulation of the process of producing biodiesel from palm oil starts with a pre-treatment step of raw material (oil), as this oil presents a free fatty acids (FFA) content of 5 %, which, as mentioned above, can generate soap in the trans-esterification stage. It is therefore recommended to decrease FFA percentage of 1 % by mass of oil for transesterification reactions using alkaline catalysts (Koh et al.2011), by an esterification reaction which takes place in the reactor (ESTERIFI), with a conversion of 97 % and thus managing to reduce FFA. Most FFA became biodiesel, which corresponds to approximately 5.4 % of the biodiesel produced in the process.

Then the resulting stream (S7) was passed through a decanter to remove the water produced in the esterification reaction, since this can promote the production of soap. Then the stream S2 which had its water content reduced, enters a step of neutralizing the unreacted catalyst in the esterification, in which sulfuric acid was used. The stream resulting from the neutralization (S11) was pumped and heated to enter the transesterification reactor (97 % conversion), where it reacts with a mixture of methanol and sodium hydroxide to form methyl esters (biodiesel) and glycerol. The molar ratio was 6: 1 methanol-oil and 1 % catalyst by weight of oil. Then the stream leaving the reactor is rich in biodiesel, but it also contains glycerol, excess alcohol which does not react, traces of catalyst, salts and water. The stream S17 enters a distillation column where most of the excess alcohol is recovered and this is recirculated. Glycerol, traces of catalyst and alcohol that did not react are removed from the biodiesel in a washing column, with a molar ratio of water / biodiesel unwashed; 65 for biodiesel that meets the ASTM normal requirements. The glycerol rich stream passed to a neutralization step with sulfuric acid, then salts present in this stream are filtered and finally purified in glycerol distillation column B18. Furthermore, the second stream resulting from the washing column (ST2), rich in biodiesel but also containing traces of oil that did not react, so the stream is treated in distillation column B16 to remove oil unreacted and purify biodiesel finally current biodiesel (FAME) is cooled to 25°C, to be stored.

2.2 Exergy analysis to biodiesel production

The global mass balance of all streams of the process was performed, and the thermodynamic properties needed to develop the exergy balance were obtained in the software. Each unit operation was made independently balance. Exergy was determined for each compound, mixture and utilities. As dead state conditions 25 °C for temperature and 1 atm for pressure were taken.

3. Results

The simulation of the biodiesel production plant described above and developed in the software Aspen ONE™ 8.4 is shown in Figure 2. In this process 12,000 kg/h of biodiesel were obtained from 12,500 kg/h of African palm oil.

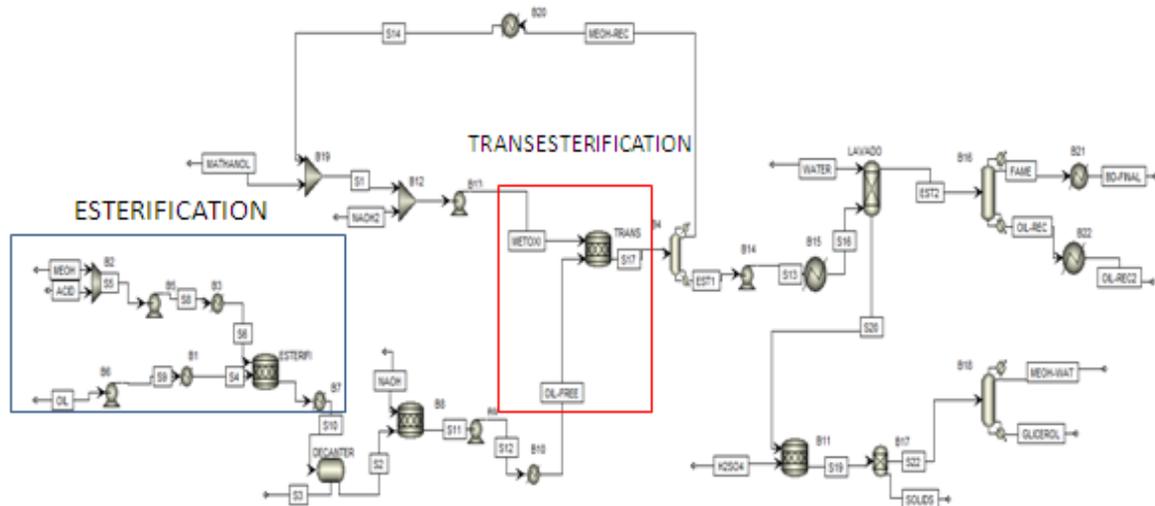


Figure 2: Simulation of biodiesel production from Palm Oil in Aspen ONETM using methanol with solvent.

Table 1 show the physical exergy, chemical exergy and total exergy for each of the input and output streams, which were calculated from the aforementioned equations.

Table 1. Exergy of the main streams of the process

Streams		Physical exergy	Chemical exergy	Total Exergy
Inlet	Outlet	MJ/h	MJ/h	MJ/h
MEOH		0	3,358	3,358
ACID		0	108	108
OIL		0	43,318	43,318
METHANOL		0	28,924	28,924
NAOH ₂		0	69,602	69,602
NAOH		0	68,948	68,948
H ₂ SO ₄		0	109	109
WATER		-0.04	2,140,924	2,140,924
	S3	936	0	936
	SOLIDS	34,801	0	34,801
	GLICEROL	68,948	14	68,963
	MEOH-WAT	2,599	1.92	2,601
	OIL-REC2	51,438	0	51,438
	BD-FINAL	14,374	0	14,375

From the exergy balance is obtained that the total exergy input streams which was 216,511 MJ/h and the exergy of the output streams was 118,124 MJ/h (excluding S3, MEOH-WAT and OIL-REC2 because are considered streams waste). On the other hand in Figure 3 shows the utilities exergy was 71,369 MJ/h, waste exergy was 54,974 MJ/h and the process presents a loss exergy of 169,756 MJ/h.

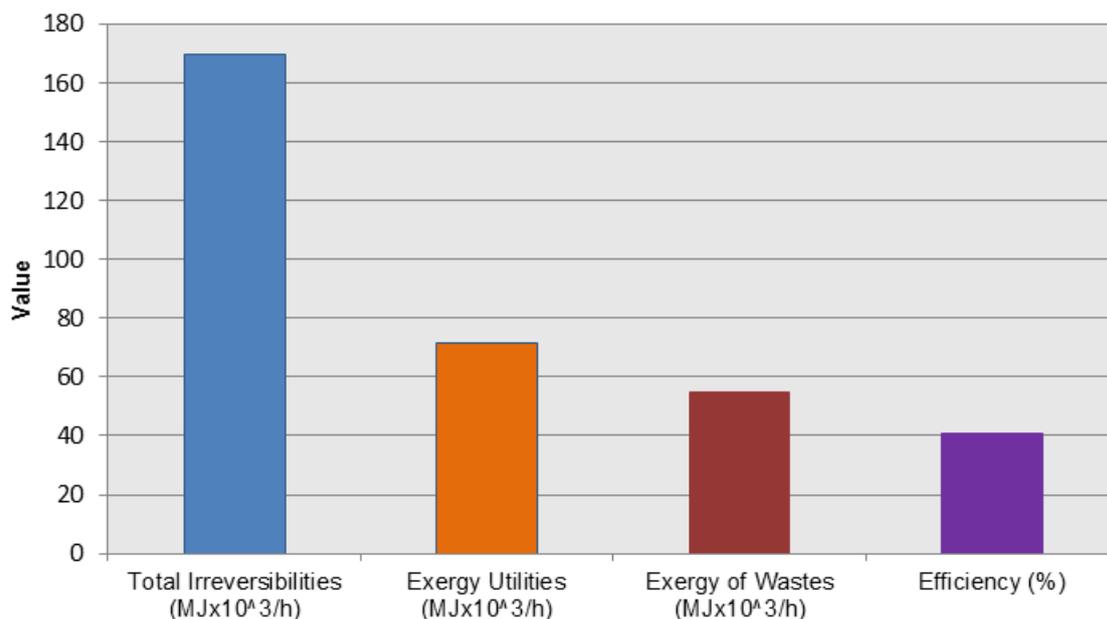


Figure 3: Summary of exergy analysis of the process

From the results obtained of total loss exergy, utilities of exergy, and waste exergy, analysis was done and the exergetic efficiency calculated was 41 %. As showed in the Figure 3 the process has a high value exergy losses for internal irreversibilities of the process, this indicates the need for technological improvements in the process and make use of emerging technologies that are emerging in the market for biofuels. It is also necessary to increase the co-products of the process and this could be done by taking advantage of waste neutralization process streams that have a high content of salts for use as fertilizers. Additionally, the exergy loss can be reduce using mass integration and heat integration, because is one way to increasing streams of recycled and decrease the utilities of the process.

4. Conclusions

In this study, an exergy analysis of biodiesel production from palm oil has been investigated in depth. The exergy analysis is a very powerful tool for evaluating the efficiency and sustainability of the biodiesel production processes; it allows the identification and localization of the major irreversibilities of the process as well as the quantification of its useful energy.

In this study, the results show an exergetic efficiency of 41 % and the need to reduce internal irreversibility of the process through a change or improvement in the technology used so far for this process, it can make use of new technologies or improvements that have been made to the currently existing.

Also, should be increase the number of recycles while reducing the utilities of the process.

It is recommended to apply energy integration in order to reduce the amount of heating and cooling services supplied to the process.

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