CHEMICAL ENGINEERING TRANSACTIONS Volume 21, 2010
Editor J. J. Klemeš, H. L. Lam, P. S. Varbanov
Copyright © 2010, AIDIC Servizi S.r.l., ISBN 978-88-95608-05-1 ISSN 1974-9791
DOI: 10.3303/CET1021225

Exergy Analysis of Palm Oil Biodiesel Production

Wilmer Jaimes, Paola Acevedo, Viatcheslav Kafarov*
Industrial University of Santander, Chemical Engineering Department
Carrera 27 con Calle 9, Bucaramanga, Colombia.
kafarov@uis.edu.co

The global search for cleaner energy sources has motivated the development of fuels from oil crops (soybean, sunflower, rapeseed, castor, coconut, palm, etc.), with special importance of biodiesel from African Palm, due to its high yields (5900 l/ha) and decrease of emissions of vehicles (mainly carbon monoxide and volatile hydrocarbons).
One of the most important disadvantages of biodiesel is a lower energy output than fossil fuels and consequently requires greater quantities of energy to be consumed in order to produce the same energy unit. To evaluate the efficiency of biodiesel production from palm oil in this work the methodology of exergy analysis was applied. In this case biodiesel production process includes tree steps: 1. the pre-treatment performed to hydrolyze triglycerides presented in palm oil, 2. the esterification to fatty acids using sulfuric acid as catalyst, 3 the separation and purification stage. To evaluate the energetic and exergetic efficiency at each stage of the process the thermodynamic analysis was applied, and was found that the largest exergy losses were occasioned by absence of energy flows integration. Additionally, the methodology developed in this work could be employed as a tool to achieve more efficient use of energy in the biofuel industry, also as an instrument for comparison to other biodiesel production processes from renewable resources (soybean, castor, etc.). This work was supported by the Ibero-American Program on Science and Technology for Development (CYTED) project 306RTO279 "New technologies for biofuels production" UNESCO codes 330303, 332205, 530603, 330999 and the Colombian Department of Science, Technology and Innovation COLCIENCIAS, projects CT 475-2007 and CT 272-2008.)

1. Introduction

Nowadays, biodiesel is frequently considered to be a more ecological friendly type of fuel compared to oil and others fossil fuels because biodiesel have many advantages in terms of environmental sustainability. Even with the many positive characteristics of biodiesel, there are also inconveniences to these energy sources. One of the most important is a lower energy output than fossil fuels and consequently requires greater quantities of energy to be consumed in order to produce the same energy unit.
Therefore the evaluation of the efficiency of biodiesel production from palm oil is very important task to assure the sustainability of this process. To solve this problem, in this work the methodology of exergy analysis was applied.

Please cite this article as: Jaimes W., Acevedo P. and Kafarov V., (2010), Exergy analysis of palm oil biodiesel production, Chemical Engineering Transactions, 21, 1345-1350 DOI: 10.3303/CET1021225

According to Dincer and Rosen (2007), energy analysis is the traditional method of assessing the way energy is used in some physical or chemical process with transfer and/or conversion of energy. This usually entails performing energy balances, which are based on the first law of thermodynamic (FLT), and evaluating energy efficiencies. However, an energy balance provides no information on the degradation of energy or resources during a process and does not quantify the usefulness or quality of the energy and mass stream of system and exiting as products and wastes.

The exergy method of analysis overcomes the limitations of the FLT. The concept of exergy is based on both the FLT and the Second Law Thermodynamic (SLT). Exergy analysis clearly indicates the locations of energy degradation in a process and can therefore lead to improved operation or technology, also can quantify the quality of heat in a waste stream. A main aim of exergy analysis is to identify meaningful (exergy) efficiencies and the causes and true magnitudes of exergy losses. But, the exergy of a system depends on the Reference Standard Environment (RSE) and a bad choice of RSE would lead to erroneous results.

The total exergy involves the physical, chemical, kinetic and potential exergy and exergy transfer accompanying heat, equation 1, but for some exergy analysis the potential and kinetic are negligible and the results are valid.

The total exergy is:

$$\dot{E}x_{total} = \dot{E}x_{chem} + \dot{E}x_{phy} + \dot{E}x_{kin} + \dot{E}x_{pot} \tag{1}$$

1.1 Metodology

This work was made following a series of guidelines, to determine the Reference Standard Environment (RSE), the exergy of mass and energy flows and calculate the exergy efficiencies of process and each unit, based on suggestions of Dincer and Rosen (2007) and others authors Sorin et al (1998), Talens et. al (2007), Koroneos et. al (2003), Wall (1988).

At the first stage, the process was simulated to obtain information about the operation variables as temperature, pressure and flows for each stage of the process and some properties as enthalpy entropy about this stream, by the principles of conservation of mass and energy (FLT), equation 2 and 3 respectively.

Principle of conservation of mass:

$$\sum mi_{in} = \sum mi_{out} \tag{2}$$

The first law of thermodynamics:

$$\sum (mi * hi)_{in} - \sum (mi * hi)_{out} + Q - W = \frac{d(m * U)_{acum}}{d(t)} \tag{3}$$

But, but the process was conducted at steady state then the FLT is:

$$\sum (mi * hi)_{in} - \sum (mi * hi)_{out} + Q - W = 0 \tag{4}$$

This stage was performed with the ASPEN HYSYS industrial process simulator. The simulation of the production of biodiesel was made in three stages: The hydrolysis of triglycerides from palm oil, this reaction was made to conditions extremes of temperature and pressure, 290 °C and 20 MPa with molar ratio water/oil of 60 as proposed Saka and Minami (2006) in their work.

Then the heterogeneous esterification of fatty acids was considered, this stage was simulated in a PFR reactor with conditions proposed by Lopez et al. (2008), using zirconia sulfated catalyst because this catalyst was very active in the transesterification of soybean and esterification of fatty acids reactions, also the conversions were 98 % and 92 % for methanolysis and ethanolysis respectively according to Garcia (2008) and Kumar (2008). The molar ratio ethanol/acid was 100 and the kinetic model for heterogeneous reactions was Langmuir-Hinshelwood-Hougen-Watson (LHHW) type, Dossin et al (2009), Balakosa and Chuang (1995), Altıokka and Ödes (2009). The third step was the simulation of separation systems to purify the biodiesel according to the ASTM international standards and ethanol was recovered by an azeotropic distillation column using glycerol at the conditions suggested by Uyazan et al. (2005).

For exergy analysis, first was defined the RSE standard in 25 °C and 1 atm and these conditions were assessed standard enthalpy and entropy of each current to calculate the physic exergy by equation 4, also, the chemical standard exergy was evaluate with the equation 5, both suggested by Ayres et. al (1999) and were defined as the maximum work that can be extracted when that chemical is transformed by successive reactions into de reference species in the standard state of the temperature and pressure.

$$\dot{E}x_{PH,flow} = (H - H_0) - T_0(S - S_0) \tag{5}$$

$$b^0_{ch} = \Delta G^0_f + \sum_{el} n_{el} b^0_{ch\,el} \tag{6}$$

Where $\Delta G°_f$ is the Gibbs energy of formation of the target compound, $b°_{ch}$ is the chemical exergy of the target compound per mole, $b°_{ch,el}$ is the chemical exergy of the compound element and n_{el}, is the number of atoms of the element in the compound.

Next, calculate the irreversibility rate of all streams of the process by the equation 7

$$\dot{E}x_{heat} - \dot{E}x_{work} + \dot{E}x_{mass,in} - \dot{E}x_{mass,out} = \dot{E}x_{dest} \tag{7}$$

2. Result

The simulation of the biodiesel production plant is shown in Figure 1. The above mentioned three stages in which was divided this process and all flows are also shown in this scheme. The hydrolysis reactor date: inlet flows 8806 kg/h of palm oil and 12760 kg/h of water, outlet flows 979 kg/h of glycerol and 15240 kg/h of fatty acids. The esterification reactor date: inlet flows 15240 kg/h of fatty acids and 17960 kg/h of ethanol (1475 kg/h of fresh ethanol and the rest recycled ethanol). In general, the process inlet flows: 8806 kg/h of palm oil and 1475 kg/h of ethanol and outlet flows: 9145 kg/h, 1014 kg/h and 121 kg/h of biodiesel, glycerol and water respectively.

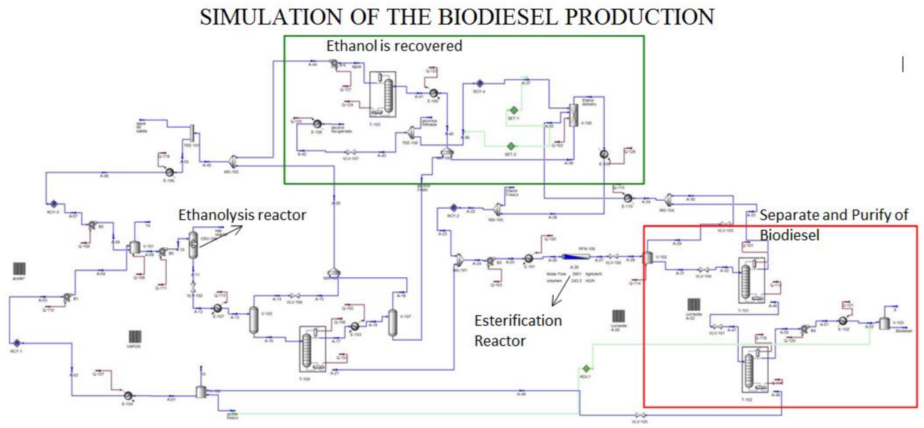

Figure 1: Simulation of Biodiesel production from Palm Oil and using heterogeneous acid catalyst in Aspen Hysys 2006.5 and ethanol with solvent

The irreversibility rates for all equipments were evaluated and 75.8 % the exergy efficiency for the hydrolysis reactor and 82.4 % for esterification reactor were obtained. Total exergy losses of the 10 heat exchangers were 25121 MJ/h, for 5 pumps 15527 MJ/h, for 8 valves 15646 MJ/h, and for 4 distillation columns 48405 MJ/h. respectively. The table 1 shows efficiencies and exergy losses for some equipment used in this process.

Table 1 Efficiencies and Irreversibility for some Process Equipment of the Biodiesel Production

Equipment	Efficiencies	kJ/h
Pump B1	37 %	618,825
Pump B2	68 %	85,282
Pump B5	67 %	30,571
Heat Exchanger E - 100	98 %	11,300,722
Heat Exchanger E - 101	77 %	20,908,468
Heat Exchanger E - 104	77 %	476,542
Valve VLV - 100	96 %	1,663,487
Valve VLV - 102	82 %	796,848
Valve VLV - 103	28 %	12,936,787
Reactor CRV - 100	80 %	1,095,737
Reactor PFR - 100	98 %	519,170
Column T - 100	25 %	2,645,845
Column T - 101	69 %	5,215,243

The figure 2 shows a general diagram of the process which specifies the mainstream and physical exergy.

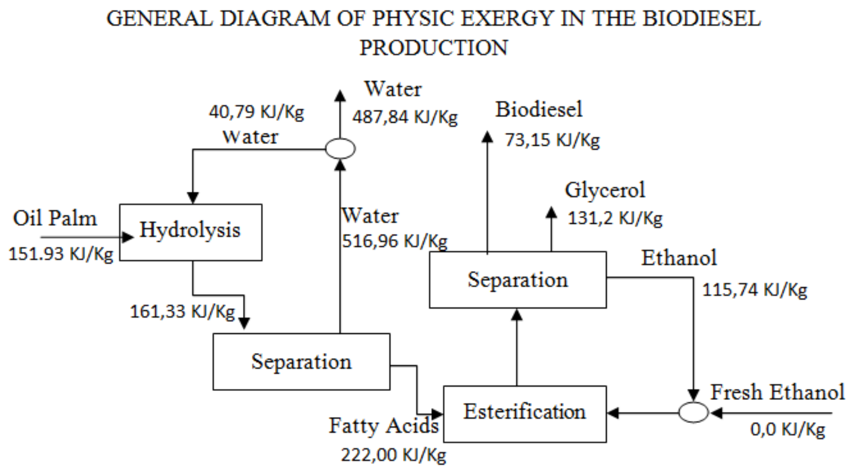

Figure 2: This diagram represent the general distribution of physic exergy in the Biodiesel production.

3. Conclusions

The exergy analysis is powerful tool for evaluation of efficiency and sustainability of biodiesel production processes.

With application of exergy analysis the irreversibility of the overall process was estimated (106,739 MJ/h) with the impact of separation and purification system about 42 % of total loses.

The exergy analysis also shows that energy integration is needed to reduce energy losses and to make the process more sustainable.

Acknowledgements

The authors thank to Colombian Department of Science, Technology and Innovation COLCIENCIAS, to the collaboration projects CT 475-2007 and CT 272-2008 and Ibero-American Program on Science and Technology for Development (CYTED) project 306RTO279 “New technologies for biofuels production” UNESCO codes 330303, 332205, 530603, 330999

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