Contemporary Engineering Sciences, Vol. 11, 2018, no. 11, 537 - 545
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2018.710148

Computer-Aided Exergy Analysis of a Palm Based-Biorefinery for Producing Palm Oil, Kernel Oil and Hydrogen

Steffy Arteaga-Díaz[1], José González-Díaz[2], Karina Ojeda-Delgado[2], María Pájaro-Morales[1] and Ángel González-Delgado[1]

[1] University of Cartagena, Chemical Engineering Department, Multifunctional Nanomaterials Research Group
Avenida del Consulado Calle 30 No. 48 – 152, Cartagena, Colombia

[2] University of Cartagena, Chemical Engineering Department, Process Design and Biomass Utilization Research Group (IDAB)
Avenida del Consulado Calle 30 No. 48 – 152, Cartagena, Colombia

Abstract

Palm oil is extracted from fruits of African palm (*Elaeis guineensis*), which has gain attention as raw material for the production of a huge amount of products in food and cosmetic industry. However, wastes of energy in extraction stage has limited its applicability. This work aims on identifying the major exergy sinks (related to higher useful energy losses) through first and second law of thermodynamics in the production process of palm oil, palm kernel oil and hydrogen. Simulation was performed in a commercial process simulation software, in which physical and chemical exergies of the species involved were quantified. The results showed a production rate of 5.07 t/h of palm oil, 0.5078 t / h of palm kernel oil and 6.8263 t/ h of hydrogen, as well as 0.739 t/h of animal feed from 30 t/h of palm bunches. An overall exergy efficiency of 38% was obtained, while the process of hydrogen separation had the lowest efficiency percentage (0.0078%). For increasing overall exergy efficiency of palm refinery, it is proposed a cleaning treatment to condensation streams leaving the sterilizing stage and its use as dilution water for settling stage.

Keywords: Exergy, Palm, Biorefinery, Computer-Aided Process Engineering

1. Introduction

Vegetable oil is currently used worldwide as a sustainable commercial raw material [1]. Some of them also contain high amounts of saturated fatty acids as palm kernel oil, coconut oil, and palm oil [2]. Oil from palm have been considered as a promising renewable energy source because it is a cheap-high yielding oil crop and can easily be converted to biofuels [3]. The production of palm oil is source of huge amounts of biomass including empty fruit bunch, fiber, shell, and palm oil mill effluent [4, 5], which contain lignin, cellulose, hemicellulose and other extractives allowing it to be suitable for thermal conversion process [6]. This biomass can be transformed into combustible gas by subjecting it to gasification process [7]. Palm Kernel oil is another by-product of palm oil production process, which exhibits high oxidative stability that differentiates itself from other commercial oils [8]. Many authors have estimated irreversibilities in extraction processes of palm and palm kernel oils, as well as hydrogen. For example, Rocha Ortega et al. [9] estimated the irreversibilities of the process of extraction of African palm including stages of sterilization, removing of fruits, digestion, pressing, clarification and drying. In this work, exergy analysis was performed for producing palm oil, palm kernel oil and hydrogen from rachis of palm in order to identify major exergy sinks and suitable alternatives for improving efficiency of the process.

2. Materials and Methods

Process description

Palm oil extraction process is shown in block diagram of Figure 1, where palm bunches are subjected to sterilization with steam in order to soften the pulp tissues by hydrolysis and prevent the effect of enzyme lipase on free fatty acids. The fruits are separated from palm rachis through a rotating drum. The fruits move towards digestion stage, while the rachis is sent to the hydrogen production process. In digestion stage, fruits are macerated and pressed to form a cake from which a liquor is extracted containing huge amount of oil. This liquid flows towards a decanting process that separates 90% of the oil. The resulting cake is sent to palmistry for clarifying by centrifugation until recovering 10% of oil and then, it is subjected to separation of fiber from nut. Fibers are used as fuel in the boiler for steam generation. The stream resulting from this process (stream 40) enters a stage of almond-husk separation. On the other hand, the almond goes through a stage of drying and subsequent pressing, where a liquor rich in palm kernel oil is extracted. On the other hand, the palm kernel cake leaves the process and is stored to be converted into animal feed. The liquor extracted from the almond enters a stage of clarification where finally palm kernel oil and a residual flow containing sludge are obtained.

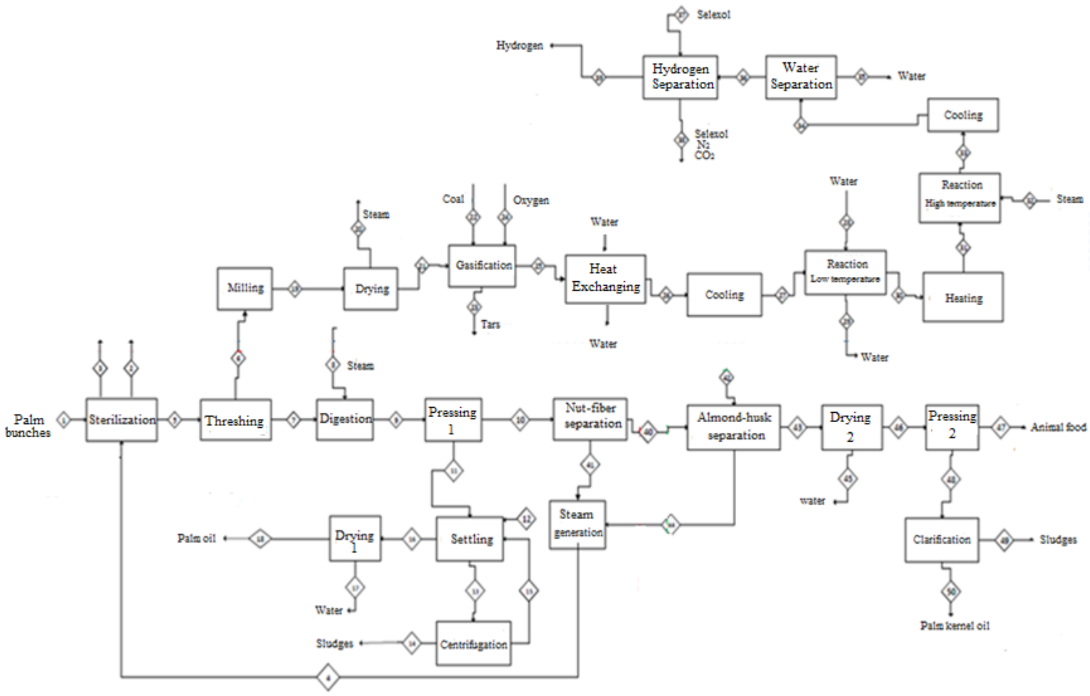

Figure 1. Block diagram of palm oil, palm kernel oil and hydrogen production.

Palm rachis milled and dried for increasing contact surface and reducing formation of tars in gasification. Biomass, pure oxygen and coal enters to gasifier allowing to obtain by means of chemical reactions, a synthesis gas composed by H_2, CH_4 and CO_2 and waste called tars. This gas is sent to a cooling step, which includes a heat exchange to reduce the temperature from 1173.15 K to 298.15 K and an electric cooling to 283.15 K. In order to carry out this gas production, huge amount of liquid water needs to be fed, generating a waste liquid water stream and a syngas with a higher concentration of hydrogen. The syngas is heated to 643.15 K and fed to the second shift reactor. The resulting stream (stream 36) is mixed with Selexol in order to dissolve undesirable components such as CH_4, CO and CO_2 and subsequently obtain by means of flash separation, pure hydrogen. Table 1 shows composition of raw material used for this work. Composition of syngas obtained after gasification is 60% H_2, 32% CO_2, 3% CH_4, 1% CO and 4% N_2. On the other hand, main components of palm oil are 1, 3-Dipalmitoyl-2-oleoylglycerol, 1, 2-dioleoyl-3-palmitoylglycerol and 1-Palmitoyl-2-oleoyl-3-linoleoyl-rac-glycerol (30%, 26% and 11%, respectively). Palm kernel oil obtained after raw material processing is composed mainly of Trilaurin, 1, 2-Lauroyl-3-miristoylglycerol, 1, 2-Miristoyl-3-Lauroylglycerol and 1, 3-Lauroyl-2-oleoylglycerol (0.36, 0.21, 0.14 and 0.11 %, respectively). Animal feed stream contents 34% cellulose, 32% water, 17% xylose and 17% lignin.

Table 1. Composition of palm bunches

Component	Mass fraction
Water (liquid)	0.3
Ashes	0.04
Silica	1.95×10^{-3}
Cellulose	0.18
Xylose	0.1
Lignin	0.12
Palmitic acid	0.01
Stearic acid	5.30×10^{-4}
Oleic acid	0.01
Linoleic acid	9.20×10^{-4}
Myristic acid	1.90×10^{-4}
Lauric acid	2.30×10^{-4}
Tripalmitin	0.01
1,3-Dipalmitoyl-2-oleoylglycerol	0.07
1,2-dioleoyl-3-palmitoylglycerol	0.06
1-Palmitoyl-2-oleoyl-3-linoleoyl-rac-glycerol	0.03
1,2-Dipalmitoyl-3-lauroylglycerol	0.02
Triolein	0.02
1-Palmitoyl-2-oleoyl-3-stearoyl-rac-glycerol	0.02
1,2-Lauroyl-3-miristoylglycerol	4.91×10^{-3}
Trilaurina	0.01
1,3-Lauroyl-2-oleoylglycerol	2.72×10^{-3}
1,2-Miristoyl-3-Lauroylglycerol	3.22×10^{-3}

Exergy analysis

The exergy balance at steady state in general can be written as the exergy that enters the system equating it to the sum of the exergy that leaves, destroys and loses the system respectively by Equation (1).

$$\dot{E}x_{in} = \dot{E}x_{out} + \dot{E}x_{lost} + \dot{E}x_{destroyed} \quad (1)$$

The physics exergy related with temperature, entropy and enthalpy:

$$\dot{E}x_{phy} = \left(\dot{H}-\dot{H}_0\right) - T_0\left(\dot{S}-\dot{S}_0\right) \quad (2)$$

Where H is the enthalpy, S is the entropy, T is the environmental temperature and superscript indicates dead state. Chemical exergy is given by Equation 3, where y_i is the molar fraction of component i, $Ex^0_{ch,i}$ is chemical exergy of pure compound, T_0 is reference temperature and R is the gas constant.

$$Ex_{ch,stream} = \sum_i y_i \times Ex^0{}_{ch,i} + RT_0 \sum_I y_i \times ln(y_I) \quad (3)$$

Lost exergy is defined by:

$$\dot{E}x_{lost} = \dot{E}x_{in,\ total} + \dot{E}x_{u,\ total} - \dot{E}_{out,\ total} \quad (4)$$

Physical exergy and enthalpy steams were calculated with UNIFAC model and SRK EoS. Hemicellulose and lignin are considered as Xylose and Propylbenzene respectively, which are their main constituent monomers. The exergy efficiency is given by Equation 5.

$$n = 1 - \frac{\dot{E}x_{destroyed}}{\dot{E}x_{in}} \quad (5)$$

3. Results and Discussion

Physical and chemical exergy of streams in palm oil, palm kernel oil and hydrogen production are shown in Table 2.

Table 2. Physical and chemical exergy of process streams

Stream	Chemical exergy (MJ/h)	Physical exergy (MJ/h)	Stream	Chemical exergy (MJ/h)	Physical exergy (MJ/h)
1	514117.71	3.17	26	715947.02	12619.51
2	1625.51	2228.21	27	715947.02	12638.65
3	491.60	270.60	28	1155.00	0
4	8831.03	8443.84	29	173.99	0
5	497356.92	444.00	30	805931.99	47.72
6	85508.99	121.45	31	805931.99	14989.40
7	364618.08	122.91	32	2855.42	3868.72
8	700.88	960.74	33	797602.78	61033.00
9	364538.53	2406.48	34	14945.47	5459.00
10	159536.94	181.33	35	18.59	0.35
11	205120.54	1187.35	36	16114.90	21.90
12	108.44	59.69	37	10347932.00	203.21
13	3826.64	181.68	38	10998665.20	214.98
14	3443.86	154.29	39	805.85	8.02
15	382.65	18.17	40	122911.14	167.57

Table 2. (Continued): Physical and chemical exergy of process streams

16	202132.13	57.11	41	16793.43	8.31
17	3.91	0.21	42	5632.96	146.95
18	202159.33	56.86	43	44155.44	57.22
19	85508.99	119.65	44	78756.41	153.29
20	3460.84	3270.69	45	98.39	31.59
21	30226.68	420.46	46	44157.37	20.87
22	568704.17	0.00	47	23623.08	15.74
23	560852.22	27171.49	48	20555.94	4.97
24	727.92	3674.27	49	725.32	1.89
25	715947.02	44174.41	50	19855.57	2.95

Figure 2 shows overall results for exergy analysis of palm oil, palm kernel oil and hydrogen production process. It is observed a global exergy efficiency of 38%, which is lower than that of the simple palm oil extraction process reported by Martínez et al. [10] whose overall efficiency is 59%. These results can be attributed mainly to the large amount of unused waste throughout the process. On the other hand, energy requirements in different stages are low, so exergy due to utilities does not mainly affect the amount of irreversibilities present in the process.

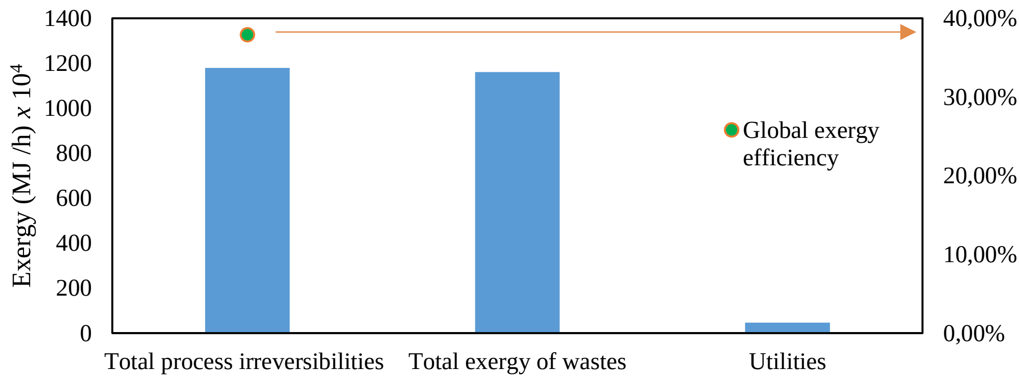

Figure 2. Overall results for exergy analysis

Figure 3 shows percentage of destroyed exergy, total process irreversibilities, exergy efficiency and total exergy of process wastes of each of the stages of the extraction process of palm oil, palm kernel oil and hydrogen production. It is observed that the exergy efficiency of hydrogen separation is the lowest (0.0079%), which is due to huge amount of exergy that is misspend when Selexol leaves this stage, thus global exergy efficiency would increase if Selexol stream is well used. On the other hand, in terms of exergy generated by process wastes, stages for palm kernel oil extraction present the lowest values because of exploitation of almost all residual streams.

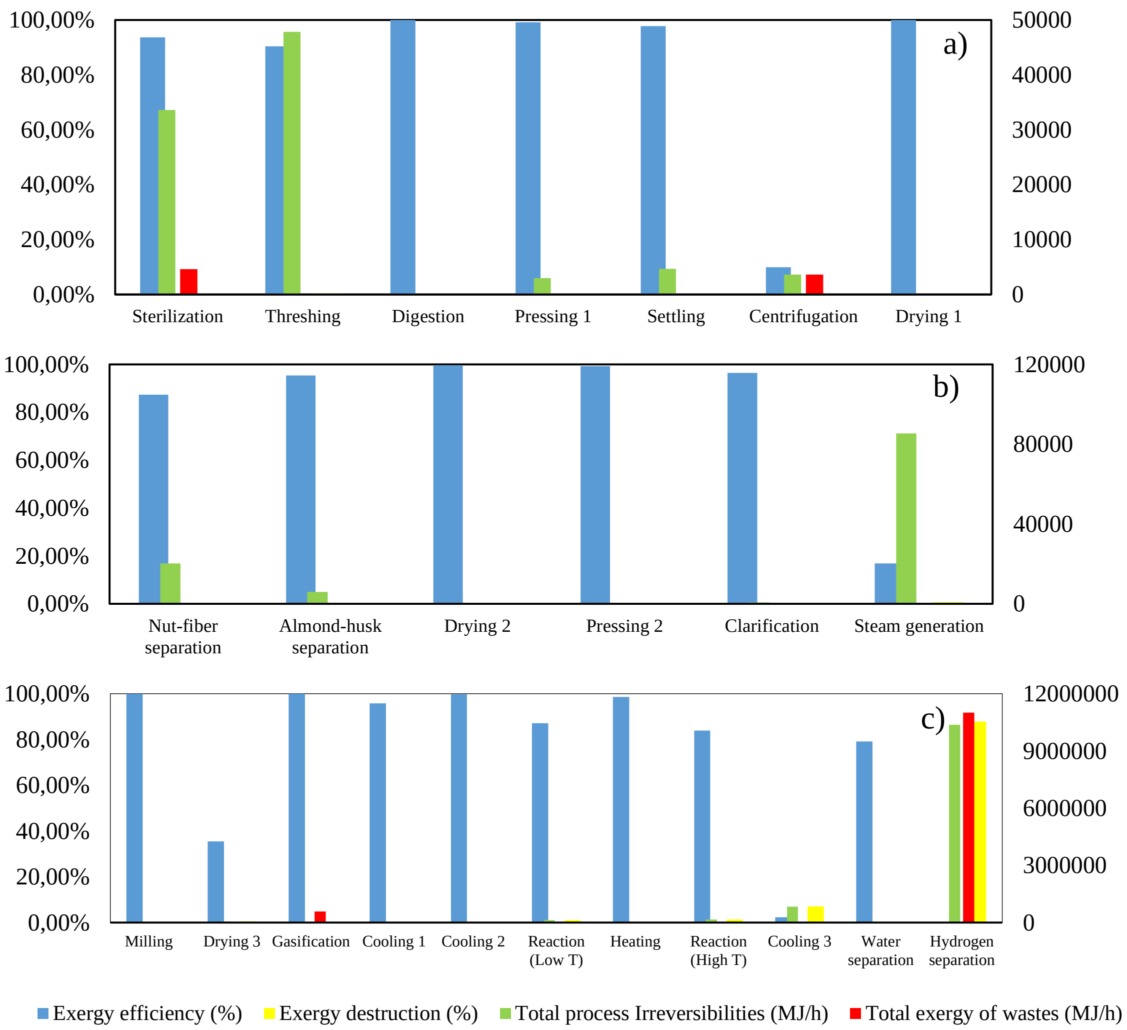

Figure 3. Exergy efficiency, exergy destruction (%), total process irreversibilities and total exergy of wastes for: a) palm oil, b) palm kernel oil and c) hydrogen production.

4. Conclusions

The Exergy analysis performed on palm oil, palm oil and hydrogen production process was a useful tool for identifying stages of greatest exergy destruction. The simulation included 30 t/h of African palm bunches as raw material, for which 5.07 t/h, 0.5078 t/h and 6.8263 t/h of palm oil, palm kernel oil and hydrogen, respectively, were obtained. Exergy of products, utilities and wastes were calculated indicating that utilities does not mainly affect global irreversibilities in the process and exergy efficiency could be improved through a better use of residual streams.

Acknowledgements. The authors thank the University of Cartagena for providing the software necessary for conclude this research.

References

[1] S.O. Kareem, E.I. Falokun, S.A. Balogun, O.A. Akinloye, S.O. Omeike, Enzymatic biodiesel production from palm oil and palm kernel oil using free lipase, *Egyptian Journal of Petroleum*, **26** (2017), 635–642. https://doi.org/10.1016/j.ejpe.2016.09.002

[2] T. Nwosu, M.O. Wegwu, B.M. Onyegeme-Okerenta, Investigation of the Effect of Aqueous Leaf Extract of Senna alata (L) Roxb on Palm Oil- Induced Hyperlipidaemic Plasma Lipid in Wister Rats, *Clinical and Experimental Medical Sciences*, **5** (2017), 19–34. https://doi.org/10.12988/cems.2017.721

[3] R. Khatun, M. Moniruzzaman, M. Reza, Z. Yaakob, Sustainable oil palm industry : The possibilities, *Renewable & Sustainable Energy Reviews*, **76** (2017), 608–619. https://doi.org/10.1016/j.rser.2017.03.077

[4] C.I. Agámez, Á.D. González-Delgado, Y. Y. Peralta-Ruiz, An Environmental Impact Based Approach for Synthesis of Palm Fruit Biorefineries from Palm Oil Production Chains, *Contemporary Engineering Sciences*, **10** (2017), 819–828. https://doi.org/10.12988/ces.2017.7881

[5] C.I.A. Nwoko, L.N. Ukiwe, Physicochemical Characteristics of Soils Treated with Palm Oil Mill Effluent in Three Localities in Imo State, Nigeria, *Contemporary Engineering Sciences*, **4** (2016), 1–8. https://doi.org/10.12988/pacs.2016.5127

[6] Á. González-Delgado, V. Parejo, T. Herrera, Computer-Aided Environmental Evaluation of Bio-Hydrogen Production from Residual Biomass of Palm Cultivation, *Contemporary Engineering Sciences*, **10** (2017), 773–783. https://doi.org/10.12988/ces.2017.7770

[7] J. Hossain A, Jewaratnam, P. Ganesan, Prospect of hydrogen production from oil palm biomass by thermochemical process-A review, *International Journal of Hydrogen Energy*, **41** (2016), 16637–16655. https://doi.org/10.1016/j.ijhydene.2016.07.104

[8] M.C. Law, E.L. Liew, S.L. Chang, Y.S. Chan, C.P. Leo, Modelling microwave heating of discrete samples of oil palm kernels, *Applied Thermal Engineering*, **98** (2016), 702–726. https://doi.org/10.1016/j.applthermaleng.2016.01.009

[9] S. Rocha Ortega, J.N. Vesga Pinto, Extracción exergética del proceso de extracción de aceite de la palma africana, (2011), 33.

[10] D. Martínez, A. Puerta, R. Mestre, Y. Peralta-Ruiz, A. González-Delgado, Exergy-based evaluation of crude palm oil production in North-Colombia, *Australian Journal of Basic and Applied Sciences*, **10** (2016) 82–88.

Received: November 1, 2017; Published: March 28, 2018