Contemporary Engineering Sciences, Vol. 10, 2017, no. 17, 819 - 828
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2017.7881

An Environmental Impact Based Approach for Synthesis of Palm Fruit Biorefineries from Palm Oil Production Chains

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Abstract

Waste generated in agroindustrial processes are improvement opportunities from an environmental viewpoint when this is used for obtaining valuable products and energy. In this work, the Waste Reduction Algorithm was implemented for the evaluation of biorefinery alternatives designed for the crude palm oil (CPO) production process under Northern Colombian conditions. Results showed that CPO (Case 1) and CPO-Palm kernel oil-Hydrogen (Case 3) topologies are more suitable compared to CPO-Palm kernel oil (Case 2) topology, since the case 2 had a positive PEI generated under the situations analysed. On the other hand, Case 3 presented a greater consumption rate of impacts generated due to the use of palm fruit bunches and palm cake to obtain products with less environmental effects such as hydrogen and palm kernel oil, respectively. However, this supposes a great expenditure of energy, which brings with it emissions of greenhouse gases depending on the source of energy.

Keywords: Biorefinery design, palm, environmental impact, CAPE

1. Introduction

Recently, biomass has become one of the most suitable alternatives for both global warming and increasing energy demand [1], due to its sustainable nature, physicochemical characteristics, abundance and effective role in carbon dioxide atmospheric sequestration [2–4]. Agricultural biomass wastes are considered as an alternative approach for non-competing against food crops for land and fresh water [5]. The biomass characteristics (e.g. moisture content, availability and need of pre-treatments) determines its uses for energy production through an integrated evaluation of economic, environmental and energy aspects [6]. Palm oil production processes are sources of huge amounts of biomass including empty fruit bunch (EFB), fiber, shell, and palm oil mill effluent (POME) [7, 8]. The extraction of African palm oil generates a large quantity of lignocellulosic wastes rich in cellulose, hemicellulose and lignin, which are mainly obtained from plantation and milling activities and can be potentially used as raw material for the hydrogen production by a thermochemical gasification process [7, 9]. However, taking advantage of agroindustrial wastes would integrate more operations that can enhance environmental impacts or increase the operational costs [10]. In this sense, detecting improvement opportunities through a systematic analysis of the potential environmental impacts that would generate the processes must be performed.

2. Process description and environmental assessment

Two alternatives for the use of waste (Case 2 and Case 3) were designed for a crude palm oil extraction plant located in Northern Colombia (Case 1). In Case 2, the cake obtained in the pressing stage of Case 1 is used to extract palm kernel oil, while in Case 3 the palm fruit bunch is used as the product of the Case 2 to produce hydrogen.

Case 1: Crude palm oil production process

The palm oil extraction process is illustrated in the block diagram of Figure 1, where mature palm fruits (stream 1) are subjected to sterilization by the action of saturated steam (stream 4). Condensed water and steam flow through the streams 2 and 3, respectively, and the sterilized clusters (stream 5) are separated into fresh fruits (stream 7) and rachis (stream 6) by a threshing rotary drum. The separated fruits pass to the digestion stage, subsequently, the digested fruits (stream 9) are pressed, where a liquor containing a large amount of oil (stream 11) is extracted. This liquor is generated through the mechanical action of two endless regression screws, which rotate parallel in the opposite direction, and at the top of these screws comes the pressing cake (stream 10). To dilute the press liquor, water is added (stream 12), facilitating the separation and purification of the oil. In decantation, up to 90 % of the oil is removed, which is collected by overflow and pumped (stream 16) into a drying process. In centrifugation, the heavy fraction of the decantation enters (stream 13), where the water and the heavy sludge leave the nozzles (stream 14) and the oil and light sludge are concentrated in the centre, being discharged by a collecting tube, which are recirculated towards decanting with the press liquor (stream 15). Finally, the oil is subjected to a drying process to minimize the percentage of moisture (stream 17). Due to the high temperature at which the oil leaves, this drying takes place under vacuum. The dry palm oil is pumped from this stage as the final product to its respective storage (Stream 18).

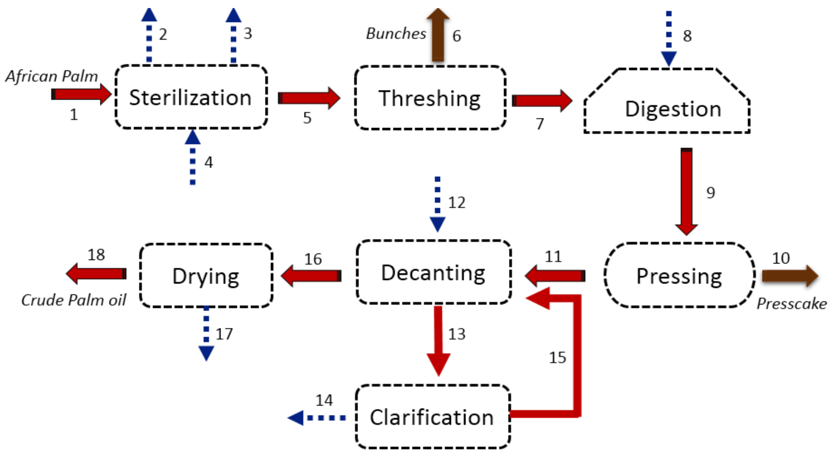

Figure 1: Block diagram for case 1

Case 2: Crude palm oil and palm kernel oil production process

The design for the oil extraction process from the cake that is formed in the pressing step is represented in Figure 2. The residual cake from the pressing, composed of wet fiber, whole and broken walnuts (stream 10), is conveyed towards the separation column and at the same time crumbled on an endless type pallet conveyor to unpack the cake, reduce moisture and facilitate separation of walnuts.

The fibers are separated from the nuts (stream 11) in a pneumatic separator where an air current is injected with a linear velocity that can be adjusted between 8 and 12 m/s (stream 12), which draws the fibers that be sent to the boiler (stream 13). While the almonds or walnuts fall into a polishing drum that gives off the fibers that still stick to them and that are separated with the same air flow of the pneumatic column. The cleaned and polished nuts are sent to a hot air drying column (streams 14 and 15, respectively) to break the shells and facilitate grinding. The resulting brittle nuts are fed into a size sorter drum to allow more precise adjustment of the breakage degree and more efficient operation of equipment. Each batch of walnuts classified breaks in mills called "ripple mill", generating a mixture composed of walnuts, husks and powder (Stream 16), which is led to separators (pneumatic and hydrocyclone) to obtain almonds with a low content of impurities. The shells are fed to the boiler (stream 17) and the combustion gases leave by the stream 18. To remove the moisture from the almonds, they are transported to the drying silos where they must have permanence sufficient to reduce the humidity up to 6-7 % (stream 19). The dried almond is sent to press to extract the oil that is purified (stream 25).

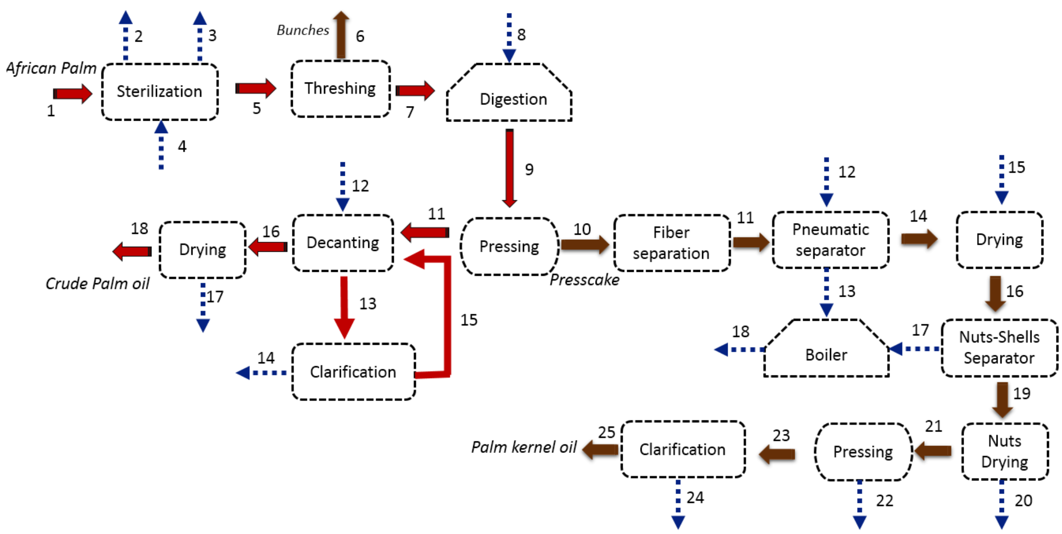

Figure 2. Block diagram for case 2

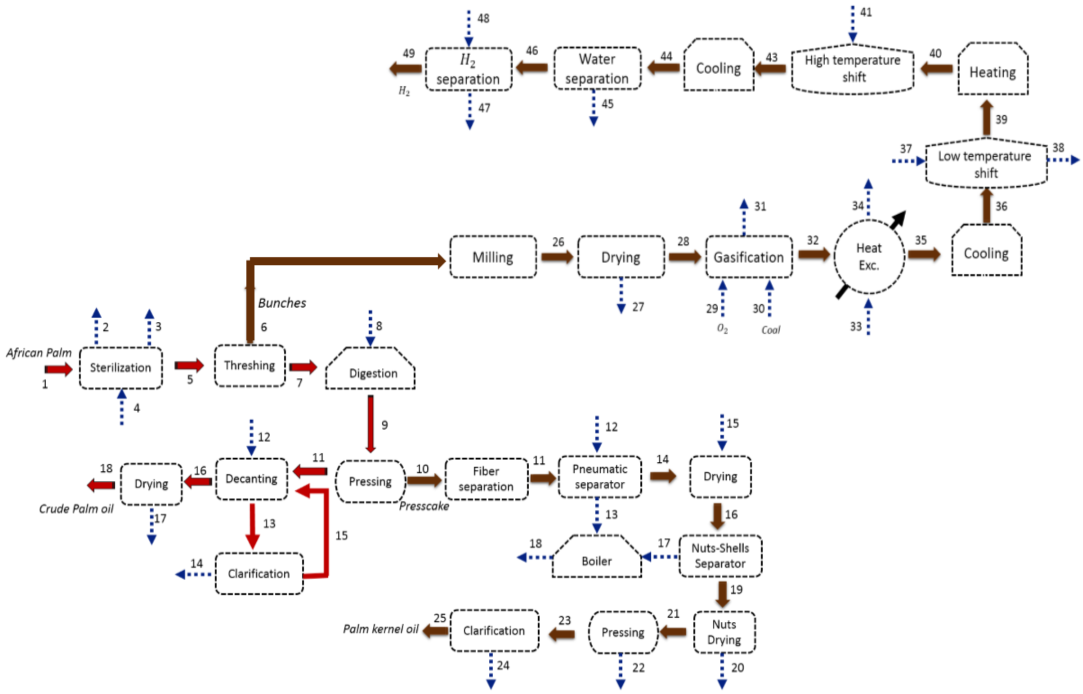

Figure 3. Block diagram for case 3

Case 3: Crude palm oil, palm kernel oil and hydrogen production process

Palm rachis represented by stream 6 of case 2 is processed to reduce the particle size, and dried from a wet basis of 55.6 % at 101 °C. In the gasification stage, coal and pure liquid oxygen (stream 29 and 30, respectively) are mixed with biomass into the reactor. Biogas obtained is cooled using a heat exchanger (stream 32) and an electrical cooler to decrease temperature from 1173.15 K to 283.15 K (stream 35). In order to increase the hydrogen concentration in the biogas, methane is converted into CO_2 and H_2 in a water gas conversion reactor (stream 36). The mixture is heated and fed to a high temperature reactor (HTS) to increase the conversion efficiency. The synthesis gas goes through a cooling step to reach a temperature of 553.15 K (stream 43). The resulting Syngas is separated from water (stream 44) and mixed with selexol to dissolve undesired components such as CH_4, CO_4 and CO. Finally, the gas-selexol mixture is subjected to a flash separation process where H_2 is obtained (stream 49).

Environmental assessment using WAR algorithm

An environmental assessment of the three alternatives was carried out using the WAR GUI software based on WAR Algorithm, which considers eight categories that assess the potential of environmental impact of both chemicals and the process: Human Toxicity Potential by Ingestion (HTPI), Human Toxicity Potential by Inhalation or Dermal Exposure (HTPE), Ozone Depletion Potential (ODP), Global Warming Potential (GWP), Potential Photochemical Oxidation (PCOP), Acidification Potential (AP), Aquatic Toxicity Potential (ATP) and Terrestrial Toxicity Potential (TTP).

3. Results

Total PEI generated and output for processes

Figure 4 shows the total PEI generated and output for the basic analysis, including energy and energy-product streams. According to Figure 4 (a), in Case 2, the generation of impacts is positive since the product obtained (palm cake) is marketable and transformed to generate palm kernel oil, however, during this transformation new residues as fibers, are generated to incinerate them. Case 3 doubles the rate of consumption of impacts for the base case, situation that is environmentally beneficial, due to it is derived from the use of the palm rachis. When the product stream is taken into account, it can be observed an increase in the generation rate for Case 2 (by 75 %), and a decreasing in Cases 1 (by 100 %) and 3 (by 30 %). On the other hand, Figure 4 (b) shows that more products are obtained in the biorefinery, the process will have higher impacts output. The greatest increase in emission rate of PEI (by over 100 %) is seen when the hydrogen production process is taken into account (Case 3) due to the products emitted such as CO_2 and CH_4. However, the inclusion of the product stream has no significant effects on the emission rate of PEI due to the low impacts of hydrogen and the low efficiency for the obtaining process from lignocellulosic biomass. In Case 2, there is an increase in PEI compared to Case 1, however, they are not significant.

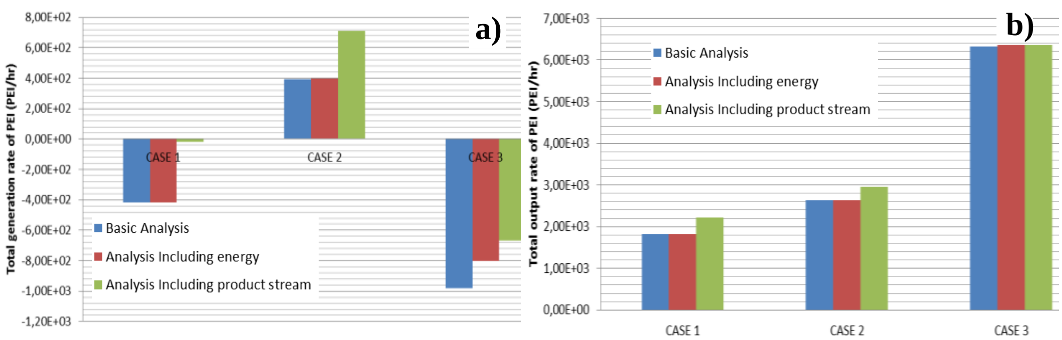

Figure 4: Total PEI (a) generated and (b) output per time unit for topologies evaluated.

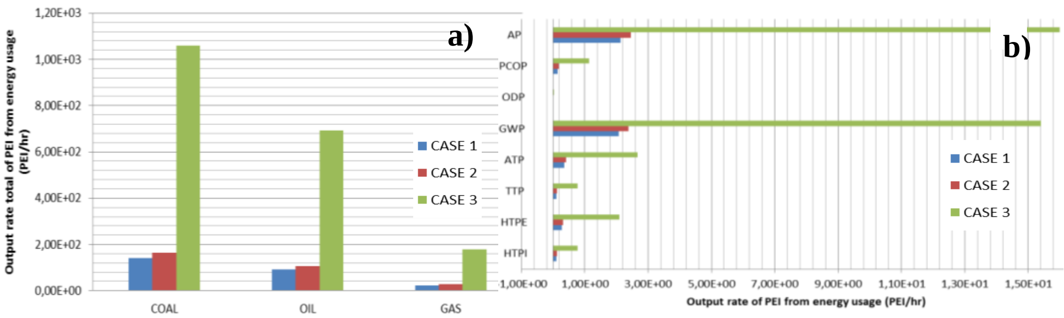

Figure 5: Total PEI output using (a) different energy sources and (b) based on impact categories using gas.

Figure 5 shows the total PEI output using different energy sources and based on impact categories using gas as energy source. In Figure 5 (a) can be observed that the energy source has an influence in the PEI output for the three cases, therefore, the use of gas is recommended because of in all cases, it shows lower environmental impacts compared to fossil fuels as oil and carbon. For Case 3, the impacts derived from the use of energy increase significantly due to the quantity of unit operations and reaction systems required to produce and purify the hydrogen, whereas the increase in these impacts is not significant when palm kernel oil is obtained (Case 2) respect to Case 1. Finally, Case 3 offers improvement opportunities in terms of energy consumption in order to reduce the impacts of biorefinery. On the other hand, Figure 5 (b) shows the total PEI output based on impact categories using gas as energy source. It can be observed that all categories are more significantly impacted with the incorporation of the hydrogen unit (Case 3), being the most affected AP and GWP, due to the gases obtained as products and by-products have the facility to disperse into the environment, in addition to obtain certain greenhouse gases.

Total toxicological impact without including energy: generated and output

In Figure 6, it can be seen that for Case 3, the human toxicity potential by ingestion (HTPI) and terrestrial toxicity potential (TTP) have the highest rates of PEI, while Case 2 has the highest value for the human toxicity potential by inhalation or dermal exposure (HTPE). On the other hand, Figure 7 shows low values for HTPE for the 3 cases. Case 2 is the only one that generates impacts under HTPI and TTP categories, due to the dust generated in the palmistry unit and the gases obtained during the combustion in the boiler. On the other hand, using the rachis to produce hydrogen is viable because of reduces HTPE levels significantly.

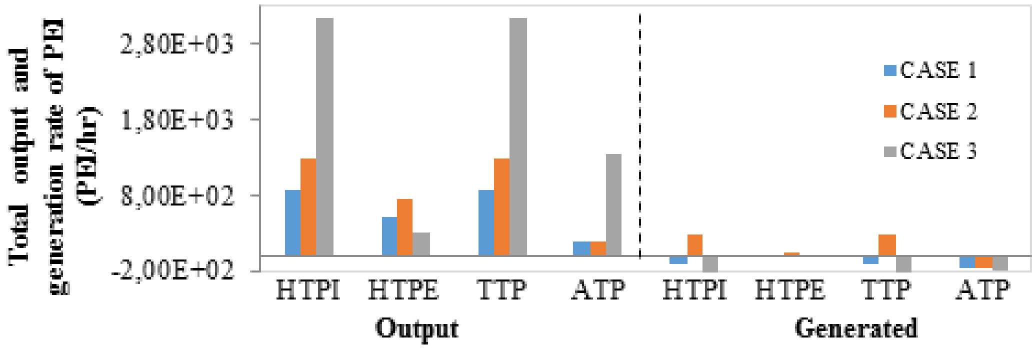

Figure 6: Total toxicological impacts generated and output without including energy source.

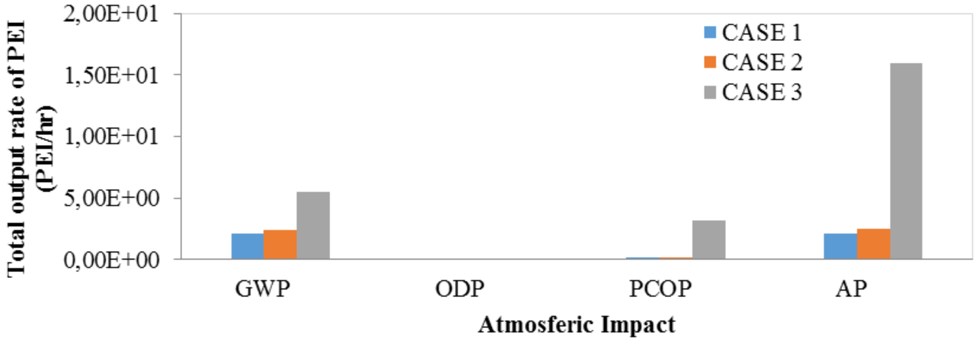

Figure 7: Total output atmospheric impacts for topologies evaluated.

Output atmospheric impacts including energy

Figure 7 shows atmospheric impacts composed of global (GWP and ODP) and regional (AP and PCOP). For all three cases, it can be seen that the values in the ODP impact category are zero, which leads to the conclusion that this process is environmentally neutral, so the only contribution to atmospheric category comes from the use of fuels in the process as energy sources. The values of GWP and AP categories indicate that this process emits volatile organic compounds that persist longer in the environment due to their low oxidation, changing the concentration of ozone. While for the PCOP category, Case 3 is the only one that has significant effects on the potential to generate greenhouse gases that would cause acid rain.

4. Conclusions

It can be concluded that Cases 1 and 3 are beneficial compared to Case 2 under the three situations analysed. On the other hand, the Case 3 presented a greater consumption rate of impacts generated due to the use of palm fruit bunches and cake to obtain products with less environmental effects. However, this supposes a high consumption of energy, which brings with it emissions of greenhouse gases depending on the source of energy. Therefore, Case 3 should be improved to reduce the impacts of this biorefinery. The use of gas is recommended because in all cases there were lower environmental impacts compared to fossil fuels.

Acknowledgements. Authors thank to University of Cartagena and Universidad del Atlántico for the supply of software necessary to carry out this research.

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Received: August 26, 2017; Published: October 4, 2017