# Improvement of a Biorefinery from Palm using Exergetic Sensibility Analysis

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#### Abstract

**Background:** Vegetable oils have received a great attention to reduce depending on fossil fuels because of its biodegradable, low toxicity and being derived from renewable resources. Palm oil is the most important vegetable oil and it is transformed commercially into numbers of product. Nevertheless, great amount of energy have been wasted in oil production when residues such as palm rachis and palm cake are not used to obtain value-added products. **Objectives:** In this work, sensibility analysis was performed to palm-based biorefinery in order to evaluate the effect of process variations (stream leaving hydrogen separation stage and considering sludge as products instead of wastes) and exergy efficiency of gasifier on global exergy efficiency. **Methods/Analysis:** Physical and chemical exergies of process stream were quantified using a robust commercial simulation software. An exergy balance was performed to determine total exergy entering and leaving the system. **Findings:** The global exergy efficiency was 37.90% for original process, however, when sludge were considered as products, global exergy efficiency was 37.93%, showing a non-significant increase. In addition, exergy efficiency of gasifier did not affect considerably global exergy efficiency and the total exergy of wastes was reduced when stream of selexol leaving separation stage was assumed as product. **Novelty/Improvement**: These results indicated that exergy efficiency of palm oil; palm kernel oil and hydrogen production could be improved through adding commercial value to selexol wastes.

Keywords: Exergy, Efficiency, Hydrogen, Palm, Vegetable oil

## 1. Introduction

Energy demand and depleting oil resources let to a search of sustainable and environmentally friendly alternative for fuel production<sup>1</sup>. One of the most popular renewable source is vegetable oil which can be directly converted to liquid fuels, this is due to its sustainable nature, physicochemical characteristics, abundance and effective role in carbon dioxide

atmospheric sequestration<sup>2,3</sup>. African palm oil crop (*Elaeis guineensis*) has been intensively cultivated because of its high productivity generating residues derived from plantation and milling activities, which are rich in cellulose, hemicellulose and lignin and can be potentially employed as raw material for producing value-added products<sup>4,5</sup>. It has been reported that inappropriate disposal of these wastes could affect public health because of contamination of groundwa-

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ter and attraction of vector-borne diseases<sup>6</sup>. The palm and palm kernel oils are found in the flesh and seed (kernel) of the palm fruit, respectively<sup>2</sup>. Byproducts such as rachis are renewable resource for obtaining combustible gas when biomass is subjected to gasification process under high temperature and using a gasifying agent as air, oxygen or steam<sup>8</sup>.

On the other hand, exergy analysis is recognized as a powerful tool to identify exergy efficiency, exergy emissions and irreversibilities for the process<sup>9</sup>. Many works have been focused on performing exergy analysis for vegetable oil production from palm biomass. In<sup>10</sup> carried out an exergy analysis for a biorefinery of vegetable oil in southwestern Nigeria, where 100 tons of palm kernel were used as raw material. The performance of this biorefinery was evaluated considering exergy losses of each processing unit. They calculated an exergy efficiency of 38.6% with a total exergy loss of 29,919 MJ<sup>6</sup> also evaluated the hydrogen production from palm oil solid wastes from an exergetic viewpoint and reported overall exergy efficiency of 20%. In this work, an exergetic sensibility analysis was performed to identify promising improvements for producing palm oil, palm kernel oil and hydrogen from palm rachis. In addition, the effect of process modification (sludge and selexol leaving separation stage as products instead of wastes) and exergy efficiency of gasifier on global exergy efficiency was evaluated.

# 2. Materials and Methods

#### 2.1 Process Description

The process to extract palm and palm kernel oils is shown in the block diagram of Figure 1. The mass frac-

tion of main components of raw material entered to simulation software is: water (0.3), ashes (0.04), cellulose (0.18), xylose (0.1), lignin (0.12), palmitic acid (0.01), oleic acid (0.01), trilaurina (0.01), 1,3-Dipalmitoyl-2oleoylglycerol (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) and Triolein  $(0.02)^{11}$ . Cellulose and lignin are represented by its main constituent monomers (xylose and propylbenzene). Palm bunches are sent to sterilization stage and the palm rachis is removed from fruits using a threshing stage. These fruits are fed into a digestion stage and rachis is employed for hydrogen production process, which is shown in Figure 2. In digestion stage, a cake is formed from fruits maceration and pressing and liquor with high content of palm oil is also generated, which is sent to palmistry for clarifying by centrifugation. One of stream leaving pressing stage is sent to nut-fiber separation and almond-husk separation. Palm kernel oil and sludge are obtained after drying, pressing and clarification stages. Then, milled and dried palm rachis passes through a gasifier with the aim of reacting with pure oxygen and coals to produce synthesis gas and tars. This gas is subjected to following reactions at low and high temperature. The stream that leaves reactor is cooled and sent to water and hydrogen separation.

#### 2.2 Exergy Analysis

An exergy analysis allows identifying components or equipment of systems with the greatest thermodynamic inefficiencies, quantifying inefficiencies and determining







Figure 2. Process diagram of hydrogen production in a palm based biorefinery.

sources and processes that cause them. This information, which cannot be obtained with another type of energy analysis, is useful to improve the overall efficiency of a system, or to compare several systems. Inlet exergy is related with lost exergy, out exergy and destroyed exergy as is defined by Equation 1.

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

In this work, kinetic and potential exergy were considered negligible; hence, total specific exergy of stream is defined by means of two components: chemical and physical exergy, as described by the Equation 2.

$$\dot{E}x_{stream} = \dot{E}x_{phy} + \dot{E}x_{chem}$$
(2)

The physical and chemical exergies are given by Equations 3 and 4, respectively.

$$\dot{E}x_{phy} = (\dot{H} - \dot{H}_{o}) - T_{o}(\dot{S} - \dot{S}_{o})$$
 (3)

$$Ex_{ch,stream} = \sum_{i} y_{i} \times Ex_{ch,i}^{0} + RT_{0} \sum_{i} y_{i} \times ln(y_{1})$$
(4)

The exergy can enter to this system via mass flow or utilities. Hence, the total input exergy is described by Equation 5.

$$\dot{E}x_{in} = \dot{E}x_{stream} + \dot{E}x_{utilities}$$
(5)

Where the exergy of utilities is calculated by Equation 6.

$$\dot{E}x_{utilities} = \dot{E}x_{work} + \dot{E}x_{heat} \tag{6}$$

The exergy of heat transfers around the system is highly dependent of temperature as described by:

$$\dot{E}x_{heat} = \sum \left(1 - \frac{T_o}{T}\right)Q\tag{7}$$

Heat transferred to this system was calculated by first law of thermodynamics as is shown in Equation 8. In addition, enthalpies were obtained using computer aided tools.

$$Q + W = \Delta H \tag{8}$$

Equation 9 shows that exergy of work in a system where there is no volume change is equal to the work

$$\dot{E}x_{work} = W \tag{9}$$

The exergy leaving the system is divided into exergy of product and waste streams as shown in Equation 10.

$$\dot{E}x_{out} = \dot{E}x_{stream, \, products} + \dot{E}x_{stream, \, wastes}$$
 (10)

The irreversibilities and exergy efficiency are calculated by Equations 11 and 12, respectively.

$$\dot{E}x_{loss} = \dot{E}x_{inlet} - \dot{E}x_{stream, \, products} \tag{11}$$

$$n = 1 - \frac{\dot{E}x_{loss}}{\dot{E}x_{in}} \tag{12}$$

#### 2.3 Sensibility Analysis

Figure 3 shows three cases considered for sensibility analysis: effect of exergy efficiency of gasifier (Case 1), sludge



Figure 3. Exergetic Sensibility analysis methodology.

as product (Case 2) and Selexol leaving hydrogen separation stage as product (Case 3).

### 3. Results and Discussion

The process to generate palm oil, palm kernel oil and hydrogen exhibited a global exergy efficiency of 38%, value less than obtained by other authors such as<sup>12</sup> who reported a global exergy efficiency of 59%.

**Case 1:** Figure 4 shows the effect of exergy efficiency of gasifier on global exergy efficiency. It is observed a linear relation between both efficiency, when exergy efficiency of gasifier increases from 0 to 100%, the global exergy efficiency of palm oil, palm kernel oil and hydrogen production process increases gradually from 34.58% to 37.90%. This result indicated that exergy efficiency in gasification stage does not affect significantly exergy efficiency of the process.

**Case 2:** Oily sludge is useful for palm cultivation. The use of dry sludge and liquid effluent reduces the time of plant nursery stage and is a complementary alternative that does not replace the conventional fertilization. In addition, it reduces the contamination of the water sources. Figure 5 compares global exergy efficiency given the following considerations in the process:

- The sludge generated during palm and palm kernel oils extractions are products.
- The sludge generated during palm and palm kernel oils extractions are wastes.

It is observed a slight increase when sludge is considered as product instead of wastes, changing the global exergy efficiency from 37.90% to 37.93%.

**Case 3**: Figures 6(a) and 6(b) show global exergy of products and waste when stream of selexol leaving hydrogen separation stage is considered as waste and product, respectively.

It is observed a considerable increase in exergy of products when stream of selexol from hydrogen separation is assumed as product. Therefore, according to Equation 10, destroyed exergy decreases, which contributes to a significant increase in the global exergy efficiency of the process?

#### 4. Conclusions

The sensibility analysis performed to palm oil, palm kernel oil and hydrogen production was useful to improve



Figure 4. Global exergy efficiency versus exergy efficiency of gasifier.1



**Figure 5.** Global exergy efficiency versus exergy of products for: sludge as product (•) and sludge as wastes (•).



**Figure 6.** Global exergy of products and waste when stream of selexol after hydrogen separation is considered as: (a) waste and (b) product.

global exergy efficiency through evaluating the effect of sludge, selexol leaving hydrogen separation and exergy efficiency of gasifier on exergy study of this process. The global exergy efficiency did not exhibit significant changes when exergy efficiency of gasifier increased from 0 to 100% and similar behavior was reported when sludge were considered as products instead of waste. Hence, main contributions for enhancing performance of palmbased biorefinery in terms of exergy were obtained in case 3, when selexol is assumed as products, which indicated its effects on global efficiency of wastes.

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