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Environmental Assessment of Dual Crude Palm and Kernel Oil Production in North-Colombia using WAR Algorithm

[1]Aury Stella Alvarez-Cordero, [1]Yuranis De Avila Alvis, [1]Maria Ortiz-Rincon,
[1]Angel Dario Gonzalez-Delgado and [2]Yeimmy Yolima Peralta-Ruiz
[1]Department of Chemical Engineering, University of Cartagena,
Avenida del Consulado #Calle 30 No. 48-152, Cartagena, Colombia
[2]Programa de Ingenieria Agroindustrial, Universidad del Atlantico,
7 km Via a Puerto Colombia, Barranquilla, Colombia

Abstract: The environmental assessment of a process allows detection of improvement areas from environmental point of view, serving as a tool for making decision and quantification of environmental benefits for a raw material transformation into a final product. This research presents an environmental assessment of a crude palm and crude palm kernel oil production process located in the North-Colombian Region using the software WAR GUI based on the Waste Reduction Algorithm (WAR) to evaluate 8 impact categories classified into two major groups: Local Toxicological Impacts on Humans (HTPI, HTPE) and Ecological (ATP and TTP) and Global (GWP and ODP) and Regional (AP and PCOP) atmospheric impacts. Results shows that in general terms, the process is environmentally friendly which is reflected in negative values obtained for the PEI generated due to products obtained are used for human consumption after refinement. In addition, atmospheric impact categories are not affected due to waste gases emitted from the process are mostly steam from sub-processes such as drying. Finally, if energy improvements are implemented by using the heat of gases emitted into the atmosphere, these values may decrease.

Key words: Environmental assessment, WAR algorithm, crude palm oil, crude palm kernel oil, implement, improvement

INTRODUCTION

African palm oil is a perennial tropical crop whose fruit has become one of the most widely studied and implemented raw material for obtaining oil which is mainly destined to the biodiesel production (Udonne *et al*., 2016) as well as can be use in food industry or oleochemistry. In Colombia, it has become a very dynamic agroindustrial activity oriented to sustainable economic and social development for rural communities, since, it promotes the creation of companies, generates permanent employment and it is environmentally friendly by preservation of ecosystems and protection of water resources. Among the residues generated from palmistry industry is found the palm kernel which due to its high oil content has developed an independent technology and given the evolution of its demand has become increasingly important (Ameera *et al*., 2016; Faisal *et al*., 2016). It has applications in the food industry as lauric oil for confectionery and bakery production, and in soap plants as a good substitute for coconut oil. On the other hand, palm oil is the second most consumed oil in the world due to its high temperature resistance, among other properties. In America, the largest oil producers are Colombia and Ecuador where Colombia is the first of Latin America and the fourth in the world, since, it has regions of tropical climate, adequate rainfall and luminosity (Martinez *et al*., 2016). The country has 3,531,844 ha without any restrictions for the planting of this crop; 6,133,381 ha are considered with moderate restrictions from which 35% are associated with a moderate deficit of humidity, situation that can be solved with irrigation systems and 23,032,885 ha have serious restrictions where 45.2% are slopes and surface soils. Adding unrestricted areas to those with moderate restrictions, Colombia has 9,665,225 ha suitable for planting African palm and the 35.5% of them are located on the Caribbean Coast. However, scaling up processes through the use of resources implies an impact on the ecosystem. In this sense, an environmental assessment provides an orderly, replicable and multidisciplinary analysis of the possible environmental impacts that a process may have on the

Corresponding Author: Angel Dario Gonzalez-Delgado, Department of Chemical Engineering, University of Cartagena, Cartagena, Colombia

ecosystem, either by causing an ecological imbalance or by exceeding the limits and conditions established to protect, preserve and restore the environment. Among the applied methodologies for this purpose (Young and Cabezas, 1999; Bicer *et al*., 2016), the WAR algorithm measures the Potential Environmental Impact (PEI) of a chemical process within the framework of the manufacturing process of a product without taking into account the other stages of the product's life cycle such as acquisition of raw material, distribution, use, disposal and recycling (Young *et al*., 2000; Barrett *et al*., 2011). This study presents the environmental assessment of the crude palm and crude palm kernel oil production in the Colombian Caribbean Region, using the WAR GUI Software developed by the United States Environmental Protection Agency (EPA) based on the WAR algorithm.

MATERIALS AND METHODS

Process description

Crude palm oil production process: The palm oil extraction process is illustrated in the block diagram of Fig. 1 where mature palm clusters (stream 1) are subjected to sterilization by the action of saturated steam (stream 4) in order to avoid the effect of the enzyme lipase on the free fatty acids and hydrolyze the palm rachis to soften the pulp tissues. The 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 where the fruit is reheated to facilitate the expulsion of the oil in the pressing step and to detach the pulp from the nuts by means of a maceration that includes the entrance of steam (stream 8). Subsequently, the digested fruits (stream 9) are pressed by means of a horizontal cylindrical perforated basket 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 the press liquor is added water (stream 12) to dilute it, facilitating the separation and purification of the oil. In the stage of decantation, up to 90% of the oil is removed which is collected by overflow and pumped (stream 16) into a drying process. In the stage of centrifugation, the recovery of 10% of the oil is achieved. In this stage, 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 center, being discharged by a collecting tube which are recirculated towards decanting with the press liquor (stream 15). As the last stage of the process, the oil is subjected to a drying process to minimize the percentage of moisture and residual impurities still contained in it (stream 17). Due to the high temperature at which the oil leaves this drying takes place under vacuum, reducing the pressure of the current which causes the evaporation of the remaining water. The dry palm oil is pumped from this stage as the final product to its respective storage (stream 18).

Crude palm kernel oil production process: The design for the oil extraction process from the cake that is formed in the pressing step (Umor *et al*., 2016) is also shown in Fig. 1. The residual cake resulting from the pressing composed of wet fiber whole and broken walnuts (stream 10) are conveyed towards the defibration

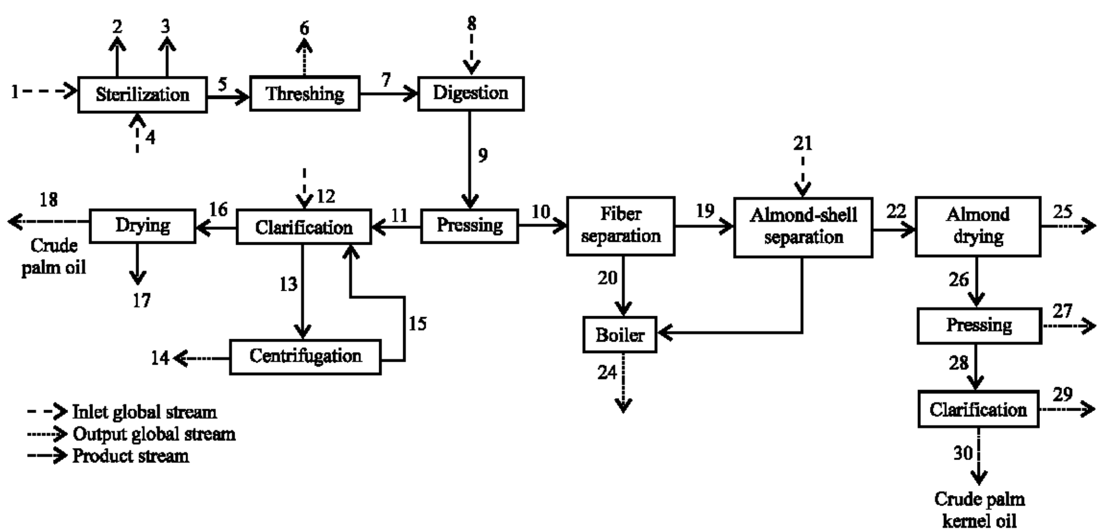

Fig. 1: Block diagram of crude palm and crude palm kernel oil obtaining process

column where the fibers (stream 20) are separated from the nuts (stream 19). Then, fibers are sent to the boiler and almonds are separated from shells by steam action (stream 21); the shells are fed to the boiler (stream 23) among with fibers and the combustion gases leave by the stream 24. To remove the moisture (stream 25) from the almonds, they are transported (stream 22) to the drying silos where must permanence sufficient time to reduce the humidity up to 6 and 7%. The dried almond (stream 26) is sent to press to extract the oil where it is obtained de palm kernel cake (stream 27) and the liquor (stream 28). This liquor is subjected to a static clarification process from which heavy sludge (stream 29) and crude palm kernel oil (stream 30) are separated, thus obtaining the desired product which will be finally stored.

Environmental assessment using war algorithm: An environmental assessment of the crude palm and crude palm kernel oil extraction process from African palm under North Colombian conditions was carried out using the WAR GUI Software based on WAR algorithm (Gonzalez-Delgado and Peralta-Ruiz, 2016). The WAR algorithm introduces the concept of balance Potential Environmental Impact (PEI) which involves the flow of an environmental impact throughout system boundaries, due to the mass or energy that crosses these limits. This index is considered from two points of view, PEI output and PEI generated. The first measures the PEI impact emitted by the process around and its main use consists in solving questions about the external environmental efficiency of the process, i.e., the ability of the process to obtain final products to a minimum potential environmental impact discharge. As regards the second, it measures the generation of PEI within the limits of the process and its importance lies in find out the internal environmental efficiency of the process, i.e., how much environmental impact potential is consumed in the process. The smaller is the value of these indexes; the process is more environmentally efficient. In addition, the WAR algorithm considers eight categories that assess the potential of environmental impact of both chemicals and the process which can be classified into two major groups: local Toxicological Impacts on Humans (HTPI, HTPE) and Ecological (ATP and TTP) and Global (GWP and ODP) and Regional (AP and PCOP) atmospheric impacts (Petrescu and Cormos, 2015). The analysis was performed from a global point of view, taking each process as a single block and considering only the global inputs and outputs of the process.

Human Toxicity Potential by Ingestion (HTPI): This indicator assesses the toxicity of chemicals and approximates the value of lethal ingestion dose that will kill 50% of a sample population of rats, LD_{50}. Using Eq. 1 can be calculated HTPI where LD_{50} is generally reported in units of mg of chemical/kg rat. In this system, a highest value of LD_{50} represents a less toxic substance:

$$\text{HPTI} = \frac{1}{\text{LD}_{50}} \tag{1}$$

Human Toxicity Potential by Inhalation or Dermal Exposure (HTPE): HTPE value was considered as the appropriate measure for chemical comparison that poses a threat to human health through inhalation and dermal exposure. This is approximated by using threshold values 8 h (TLV) as recommended by OSHA, ACGIH or NIOSH. Using Eq. 2 can be calculated the HTPE where units for TLV are mg/m^3:

$$\text{HPTE} = \frac{1}{\text{TLV}} \tag{2}$$

Ozone Depletion Potential (ODP): It is determined by comparing the rate at which a unit mass of a chemical product reacts with ozone to form molecular oxygen and the rate at which a unit mass of CFC-11 (trichlorofluoromethane) reacts with ozone to form molecular oxygen. In general, a chemical must contain an atom chlorine or bromine to have ODP. These values take into account the decomposition of chemicals in the atmosphere. ODP (kg CFC-11-equiv) can be calculated by Eq. 3 where $\delta[o_3]_i$ is the global ozone depletion produced by one unit of the gas i, $\delta[o_3]$FCKW-11 is the global ozone depletion produced by one unit of CFC-11 and is the mass (kg) of a gas i:

$$\text{ODP} = \frac{\delta[0_3]_i}{\delta[0_3]\text{FCKW-11}} m_i \tag{3}$$

Global Warming Potential (GWP): GWP is determined by comparing the amount of infrared radiation that a unit mass of a chemical and a unit of mass of carbon dioxide can absorb in 100 years. This impact category also takes into account the chemicals deterioration in the atmosphere during this same period. GWP (kg CO_2-equiv.) can be calculated by Eq. 4 where a_i is the heat radiation absorption per unit concentration increase of a greenhouse gas i, a_{CO_2} refers to this same absorption but per unit of carbon dioxide, $c_i(t)$ is the concentration of the greenhouse gas i at time t after release, $c_{CO_2}(t)$ is refered to carbon dioxide, t is the number of years over which GWP is calculated and m_i is the mass (kg) of a gas I:

$$\text{GWP} = \frac{\int_0^t a_i c_i(t)dt}{\int_0^t a_{Co_2} c_{Co_2}(t)dt} m_i \tag{4}$$

Photochemical Oxidation Potential (PCOP): This impact category is also called Smog Formation Potential (SFP) and is determined by comparing the rate at which a unit mass of chemical reacts with a hydroxyl radical ($OH^{\cdot}$) to the speed at which a unit mass of ethylene reacts with OH. PCOP (kg C_2H_4-equiv.) can be calculated using Eq. 5 where a_i is the change of ozone concentration due to a change in the emission of a Volatile Organic Compound (VOC) i, $a_{C_2H_4}$ refers to this same change regarding ethylene emissions $b_i(t)$ is the integrated emission of VOC_i up to that time t, $b_{C_2H_4}$ refers to this latter condition for ethylene and m_i is the mass (kg) of the VOC emitted.

$$\text{PCOP} = \frac{\frac{a_i}{b_i(t)}}{\frac{a_{C_2H_4}}{b_{C_2H_4}(t)}} m_i \quad (5)$$

Acidification Potential (AP): Potential acid rain or acidification potential is determined by comparing the H^+ release rate in the atmosphere promoted by a chemical, respect to the H^+ release rate in the atmosphere promoted by SO_2. AP (kg SO_2-equiv.) can be calculated by Eq. 6 where V_i is the acidification potential of component i, V_{SO_2} is the AP of SO_2, M_i is the unit mass of substance I, M_{SO_2} is the unit of the mass of SO_2 and m_i is the mass (kg) of significant component i emitted:

$$\text{AP} = \frac{\frac{v_i}{M_i}}{\frac{V_{SO_2}}{M_{SO_2}}} m_i \quad (6)$$

Aquatic Toxicity Potential (ATP): It is estimated by using the toxicological data of one representative species of fish, Pimephales promelas (fathead minnows). This specie was chosen because of its acceptance as a universal indicator water and prevalence data. The data for this assay are in the form of LC_{50}, a lethal concentration that kills 50% of the test samples. The data used in this database specifically come from an exposure time of 96 h. ATP value can be obtained by Eq. 7 where units for LC_{50} are mg/L:

$$\text{ATP} = \frac{1}{LC_{50}} \quad (7)$$

Terrestrial Toxicity Potential (TTP): It is determined by using toxicological data of rat as terrestrial specie. This one was chosen due to its acceptance as an indicator terrestrial and prevalence data. The TTP is presented in the form of a lethal dose that kills 50% of the specimens by oral ingestion, LD_{50}. This is the same value used to estimate human toxicity potential by ingestion in exactly the same manner as it is shown in Eq. 8:

$$\text{TTP} = \frac{1}{LD_{50}} \quad (8)$$

This study presents the environmental assessment of the production process under 4 scenarios. First, were evaluated the total impacts based on 4 cases (a base case and three another cases taking into account the product stream, energy process and the amount of energy-product stream), second, the toxicological impacts, third, the atmospheric impacts and finally, the effect of three energy sources.

RESULTS AND DISCUSSION

Total potential environmental impacts of the process: generated and output: This scenario was evaluated under 4 conditions, a base case having into account all energy sources present in the process (Case 1) and 3 cases where was considered the product stream (Case 2), the energy process (Case 3) and the amount of energy-product stream (Case 4). As it is observed in Fig. 2, PEI output per hour is higher in cases 2 and 4 (1.66×10^{-4} PEI/h for both of them) because of the product stream generated in the process. This same trend is presented for the case of PEI output per kilogram of oil produced, however the latter is lower (3.01) due to product quality which has low toxicity for being edible nature in addition, not aggressive chemicals solvents were used (Fig. 2). The fact that PEI generated values were negative for cases 1 and 3 indicates that the process when it is included the energy stream within it, has a good environmental performance. For cases 1 and 3, the PEI values are similar (-2.72×10^{-3} and -2.70×10^{-3} PEI/h, respectively), leading to the conclusion that the amount of product does not represent a significant influence on the value thereof. For cases 2 and 4, the PEI generated increased (8.52×10^{-3} and 8.79×10^{-4} PEI/h, respectively) due to it was taken into account the product stream, however, being close to zero suggests that the process within itself no generates environmental impact. In addition, not aggressive chemicals solvents were used such as methanol, chloroform or hexane, employed for the oil extraction process from microalgae to obtain biodiesel (Pardo-Cardenas *et al*., 2013).

Local toxicological impacts of the process: Figure 3 shows the local toxicological impacts generated and output of the process which includes humans (HTPI and HTPE) and ecological (ATP and TTP) impacts where for all categories studies, the contribution is significant and similar. The PEI output for the HTPE category (2.25×10^{-5}) is considerably lower compared to the HTPI, TTP and ATP (3.91×10^{-5} for the two firsts and 2.95×10^{-5},

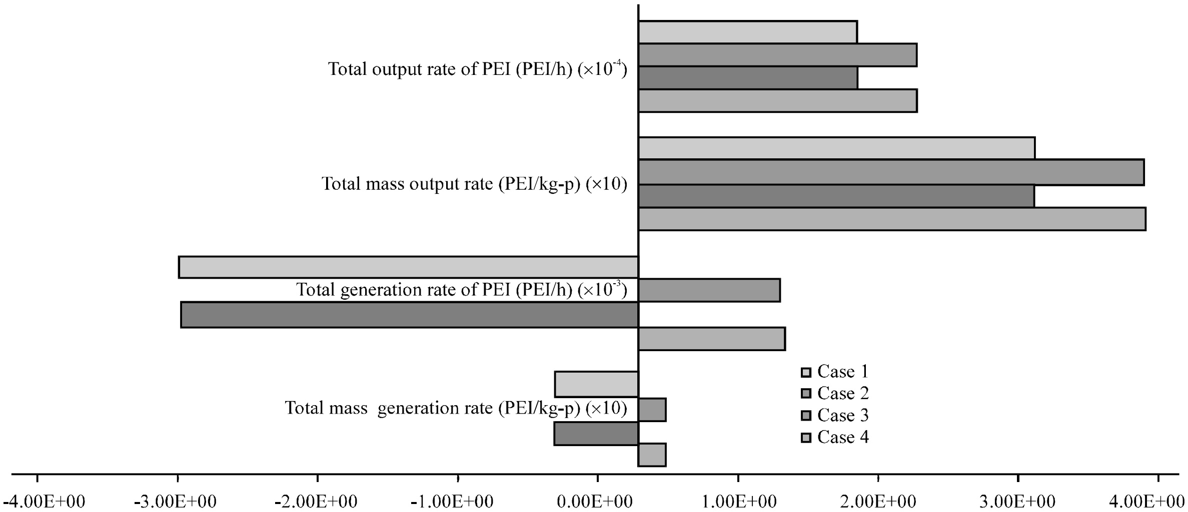

Fig. 2: Total PEI generated and output of the system for crude palm and crude palm kernel oil production process

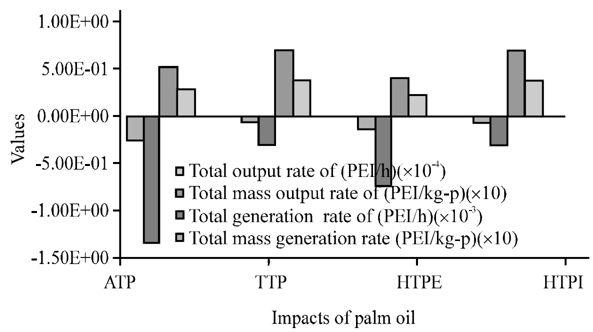

Fig. 3: Local output and generated toxicological impacts of crude palm and crude palm kernel oil production process

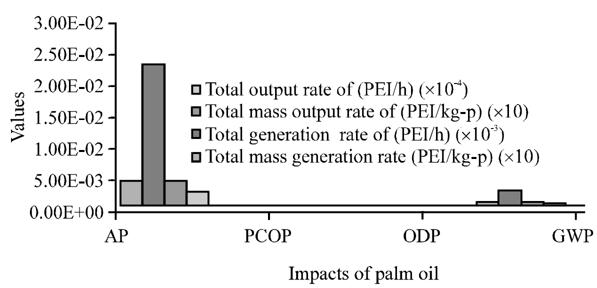

Fig. 4: Output and generated atmospheric impacts of crude palm and crude palm kernel oil production process

respectively), indicating that the impacts generated by this process as well as the mass flow ejected into the atmosphere and could be in contact with human are low. Furthermore, the PEI generated for the 4 impact categories is minimal (-1.37×10^{-3}, -3.04, -7.42 and -3.04×10^{-4} PEI/h, respectively), suggesting that the process have in the product streams, less toxic chemicals with Tolerance Values Limits (TVL) lower than those fed to the system because of the refined palm and palm kernel oil are used as raw material for margarines and other feed products. However, this value only increase under HTPI category due to it is considered oil output as product stream along with its possible impact on the environment.

Atmospheric impacts of the process: Figure 4 shows that atmospheric impacts (case 3 analyzed including energy) are composed for global (GWP and ODP) and regional (AP y PCOP) ones. For this particular process, it is observed that all values for ODP and PCOP impact categories are almost zero which leads to the conclusion that this process is environmentally neutral under these categories, so the only contribution to PEI output for atmospheric categories comes from the use of fuels in the process as energy sources. This is because the emitted water vapor has low potential for the ozone layer depletion and therefore, low photochemical oxidation potential. The PEI output for GWP and AP impact categories (2.38×10^{-8} and 1.30×10^{-4} PEI/h, respectively) indicates that this process emits components that persist longer in the environment due to its low oxidation and also can contribute to the generation of acid rain.

Effect of energy source: Under this scenario, three types of fuel were evaluated for each impact category, including the energy and excluding the product stream. Figure 5 shows the change in PEI output based on the type of fuel used. It is observed that there are categories under which is more convenient to use oil derivates and others where is more convenient to use coal. In this process, gas is used as fuel which has low impact on all categories except

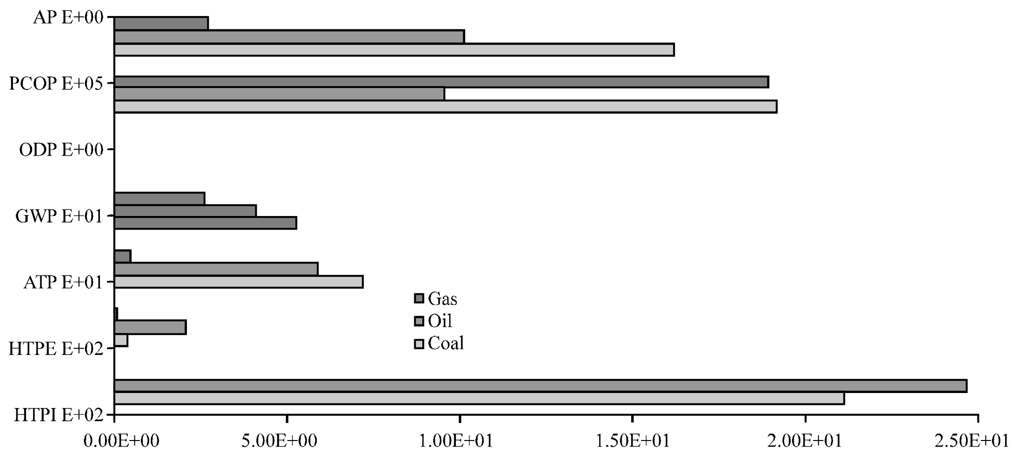

Fig. 5: Effect of energy source on output rate from energy usage for crude palm and crude palm kernel oil production process

for PCOP (1.74×10^6 PEI/h), due to changes caused by the concentration of ozone wake of volatile organic compounds emissions. In the case of the impact category AP it is observed that the gas generates smaller amounts of pollutants while coal as energy source releases more hydrogen ions than react with SO_2, causing acid rains.

CONCLUSION

Waste reduction algorithm was implemented for environmental analysis of crude palm and palm kernel oil production process in North-Colombia. For the different cases analyzed it can be said that despite product streams increase around 20% the PEI generated this value is negative which means that the process is beneficial in environmental terms due to they are used for human consumption after refinement. This fact is also applicable when analyzing the ATP, TTP, HTPE and HTPI categories. Moreover, atmospheric impact categories are not affected and in the case of GWP, the value obtained was $2.38\text{x}10^{-8}$ PEI/h due to waste gases emitted from the process are mostly steam from sub-processes such as drying.

RECOMMENDATIONS

Finally, the different output environmental impacts of the process are influenced by the type of fuel used in the boiler for steam generation. Therefore, gas is the recommended one due to might reduce pollutants emissions into the atmosphere compared to oil and coal. If energy improvements are implemented to the process by using the heat of gases emitted into the atmosphere, these values may decrease.

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