EXERGY ANALYSIS OF BIOFUELS PRODUCTION ROUTES

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Abstract. *The purpose The industrial revolution drove society to increase the use of energy resources, and in the 20th Century to the intensive use of petroleum derivatives, which have originated environmental problems derived from their intensive use. This scenario evidences the necessity to research alternative energy resources with less environmental impacts, such as biofuels.*

In this work, based on exergy analysis, different biofuel production processes are evaluated: acid hydrolysis of starch from banana fruit pulp and banana; enzymatic hydrolysis of lignocellulosic residual material from banana production to produce sugars that are fermented and distillated to produce ethanol; production of ethanol from sugar cane; and the African palm oil extraction and transesterification to biodiesel production.

The exergy efficiency for each control volume of the production routes is defined and calculated aiming at the optimization of main thermodynamics variables that take part in the production process. From the analysis, it is concluded that the greater irreversibilities are generated in processes where termochemical irreversible reactions take place, specially: the combustion, hydrolysis and fermentation ones. The study also shows that it is necessary to reduce the use of raw material as well as steam and mechanical work in order to improve the exergy efficiencies of the biofuels production processes.

Keywords: *exergy analysis, biofuels production, , biodiesel, ethanol, hydrolysis*

1. INTRODUCTION

Global warming, urban pollution, reserves depletion and high cost of fossil fuels have been the driving forces for current research on the use of alternative energy sources, especially those derived from biomass.

Ethanol and biodiesel produced from different renewable feedstocks constitute the most widely used alternative fuels for internal combustion engines (Mann and Spath, 1997; Wang *et al.*, 1999; Hsieh *et al.*, 2002; Kadam, 2002; Demirbas, 2003; Malça and Freire, 2006). These biofuels are considered biodegradable and are sulfur free. Additionally, their carbon content has a vegetable origin and consequently when it is released during the combustion process; it does not contribute to the accumulation of carbon dioxide in the atmosphere. Ethanol and biodiesel can be used neat or blended with gasoline and conventional diesel fuel, respectively, and so their use allows to decrease fossil fuel consumption as well as to increase the energy security of a region or country.

In Brazil, sugarcane has been used to produce ethanol for almost 90 years. It has proved to be a key raw material due to its high content of sucrose, which through milling, fermentation and distillation, can be used as a feedstock to produce ethanol. Developments in bioprocesses are being made to allow the use of amilaceous and lignocellulosic materials to produce ethanol through hydrolysis, fermentation and distillation. Vegetable oils or animal fats can be converted into biodiesel by the transesterefication reaction.

A primary tool to analyze the production processes of biofuels from an integrated point of view is offered by exergy analysis. Exergy is defined as the maximum (theoretical) work that can be extracted from a mass or energy stream when it passes from a given thermodynamic state to one in chemical, mechanical and thermal equilibrium with the environment in a reversible way, interacting only with components of the environment. Therefore, any deviation from the environmental reference can be assumed as exergy content (Szargut *et al.*, 1988).

When exergy analysis is performed, the thermodynamic irreversibilities can be quantified as exergy destruction, which is a wasted potential for producing work (Bejan *et al.*, 1996). In addition, exergy allows comparisons between all inflows and outflows, regardless if they are mass or energy streams, using the same physical basis (Rosen, 2002; Ayres, 1998).

Exergy analysis has been used to evaluate biodiesel production from cooking oils (Talens *et al.*, 2007). Similar studies have been developed using palm oil as a raw material (Velásquez *et al.*, 2007a; Velásquez *et al.*, 2007b). The combined production of sugar, ethanol and electricity taking into account different configurations of the cogeneration plant, have been analyzed using exergy-based costs (Pellegrini *et al.*, 2007; Pellegrini and Oliveira, 2007) and Pellegrini *et al.* 2008).

The objective of this work is to apply exergy analysis for obtaining the exergy efficiency of sugar and ethanol combined production from sugarcane, ethanol production from amilaceus and lignocellulosic material, and biodiesel production from African palm oil.

The study takes into account the different production stages and the utility plants for the generation of steam and electromechanical energy used in the processes. For sugar and ethanol production from sugarcane, the following stages were considered: milling, juice clarification, concentration, sugar boiling and refining, fermentation, distillation and dehydration; for ethanol production from amilaceus and lignocellulosic material: pretreatment, hydrolysis, purification, fermentation, distillation and dehydration; and for biodiesel from palm oil: oil extraction plant, biodiesel production and purification.

For all cases, the chosen control volume includes only the fuel production stages, it does not consider the end-use of biofuels and residues treatment plant. For instance, the use of biofuels in internal combustion engines is considered as an independent control volume in the analysis (Kadam, 2002; Carraretto *et al.*, 2004; Sheehan *et al.*, 2004; Botha and Blottnitz, 2006; Malça and Freire, 2006).

Finally, the exergetic efficiency of the biofuels production processes is obtained and the main variables affecting the process behavior are identified.

2. ETHANOL PRODUCTION PROCESS FROM SUGAR CANE

Sugar and ethanol production stages from sugarcane are shown in Fig. 1. The scheme is based on a specific plant located in Colombia. A total of 120 t/ha year of sugarcane are produced, and another 60 t/ha year of residual biomass as leaves and other lignocellulosic material are left on the land as protecting material.

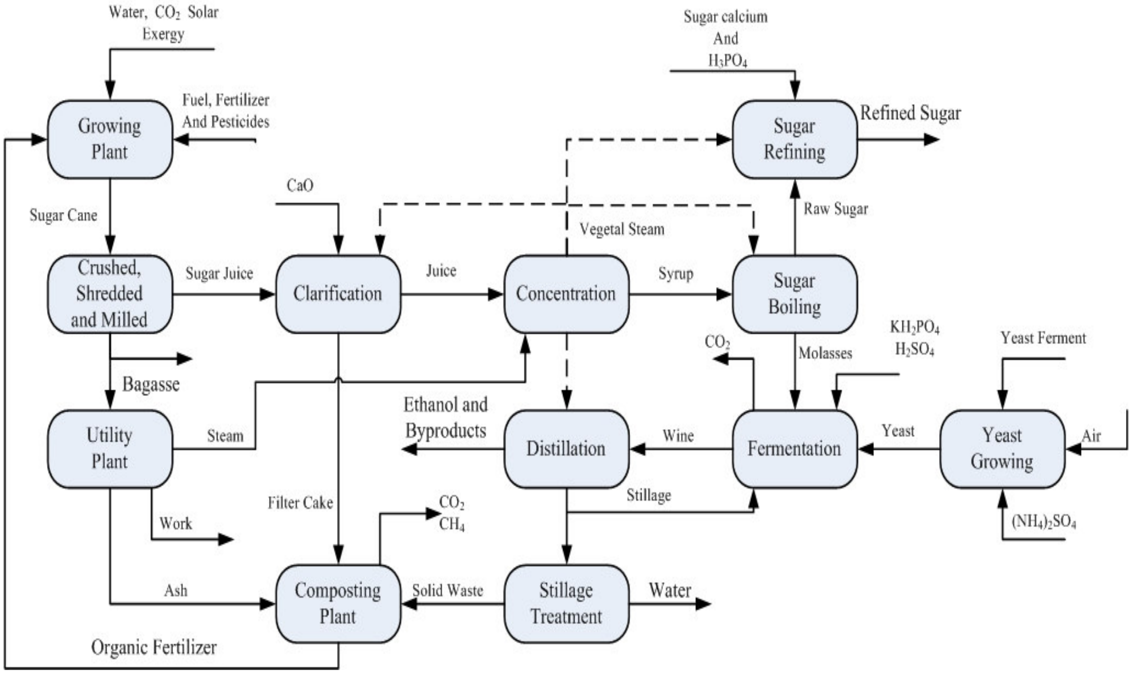


Figure 1. Scheme of sugar and ethanol production process from sugarcane.

Sugar and ethanol production may be separated into 5 different control volumes:

- **Extraction System:** Sugarcane is composed mainly by fiber and juice, in which sucrose is dissolved. Thus, the aim of this process is to recover as much juice as possible, but also to produce a final bagasse in suitable condition for fast burning in boilers.
- **Juice Treatment:** Raw juice from the extraction system is treated in order to remove non-sugar impurities using chemicals. During this process, the juice is heated using vegetable steam from the multiple-effect evaporator. CaO is used as precipitator agent for the impurities, and a by-product, known as filter cake, is obtained and brought to the composting plant to produces organic fertilizer.
- **Sugar Production:** Clarified juice obtained in the treatment plant undergoes a concentration process by removing the water contained in it. The first stage of concentration is carried out in a multiple-effect evaporator. This equipment is responsible for the concentration of juice into syrup, and the production of vegetable steam used for heating purposes in others parts of the process (treatment plant, cooking and distillery). Due to the high

viscosity of the syrup leaving the multiple-effect evaporators, it is no possible to concentrate it in normal evaporators. Thus, equipment called pans is used, which operates under vacuum conditions in a discontinuous way. The sugar solution that lives the pans is called end-syrup or molasses, and it is sent to the fermentation process for making ethanol. Sugar extracted by the centrifuges is dissolved in water again and sent to the refined process in pans under vacuum conditions to obtain a product knowing as “high sugar quality.”

- **Ethanol Production:** During the fermentation process about 2% of the molasses is used for yeast growing in aerobic conditions, the rest of molasses is used to produce ethanol. When the yeast is subjected to anaerobic conditions, it deviates its metabolic route to produce ethanol and CO_2. The theoretical fermentation reaction yield is 51%; however it is only possible to reach between 89% and 91% of this theoretical conversion. Furthermore, during the fermentation process others compounds are produced such as: aldehydes, heavy alcohols, fatty acids, residual biomass, etc. Ethanol at 96 % w/w is produced in the distillation process. Normally two distillation columns are used and some by-products as aldehydes and heavy alcohols are recovered. Stillages (water together with other by-products) are separated, and then about 70% of this liquid mixture is sent again to the fermentation process for increasing the process efficiency. Finally, the stillages are carried to the stillage treatment plant where the water is treated and the solids are separated and sending to the composting plant, where they are mixed with ashes and the filter cake to obtain an organic fertilizer. At the end of the process the product is dehydrated using molecular sieves to produce anhydrous ethanol at 99.8% w/w.
- **Cogeneration System:** Bagasse generated in the extraction system is sent to the cogeneration plant to produce steam to be used in backpressure turbines. This equipment is responsible for the electromechanical demands of the mill. Backpressure steam is used to fulfill the thermal requirements of the process, and its condensate is returned to the boiler. Normally, the electromechanical energy produced is only for internal use.

3. ETHANOL PRODUCTION FROM AMILACEOUS AND LIGNOCELULLOSIC BIOMASS

The stages of ethanol production from banana fruit and its biomass residuals are present in Fig. 2. A total of 13,4 t/ha of dry biomass is produced, but only residual banana fruit and the clusters support are used as feedstock to produce ethanol. Two producing routes for hydrolysis reaction are studied:

i. The banana fruit is peeled and the banana pulp is subjected to acid hydrolysis, taking advantage of amilaceous material, while the banana skin is used in boilers as fuel.
ii. The clusters support is subjected to enzymatic hydrolysis, taking advantage of lignocellulosic material.

During the acid hydrolysis, diluted sulfuric acid (H_2SO_4) is used for reducing the pH of the mixture, which is stirred and heated by steam until 100 ^{0}C. After 6 hours of treatment, approximately a 95% of the starch chains are transformed in glucose (Bohórquez and Herrera, 2005). The chemical reaction is represented by: $(C_6H_{10}O_5)n + nH_2O \rightarrow n(C_6H_{12}O_6)$.

The syrup obtained must be neutralized by adding NaOH to reach the pH suitable for fermentation. Then, the mixture is filtered in order to separate residues, which may be used as fuel or fertilizer.

The lignocellulosic material is shattered and crushed before passing through the delignification process. NaOH is used in the delignification process to increase the pH. The lignin is a by-product that can be sold as agglutinative agent or as feedstock for the food animal industry.

The mixture is also neutralized and filtered before the fermentation. The fermentation, distillation and dehydration processes for ethanol production are carried out in a similar way as ethanol obtained from sugarcane. Electro-mechanical energy and steam are generated in the utility plants using banana skin and another hanging cluster as fuel, with similar parameters to those from sugarcane mills.

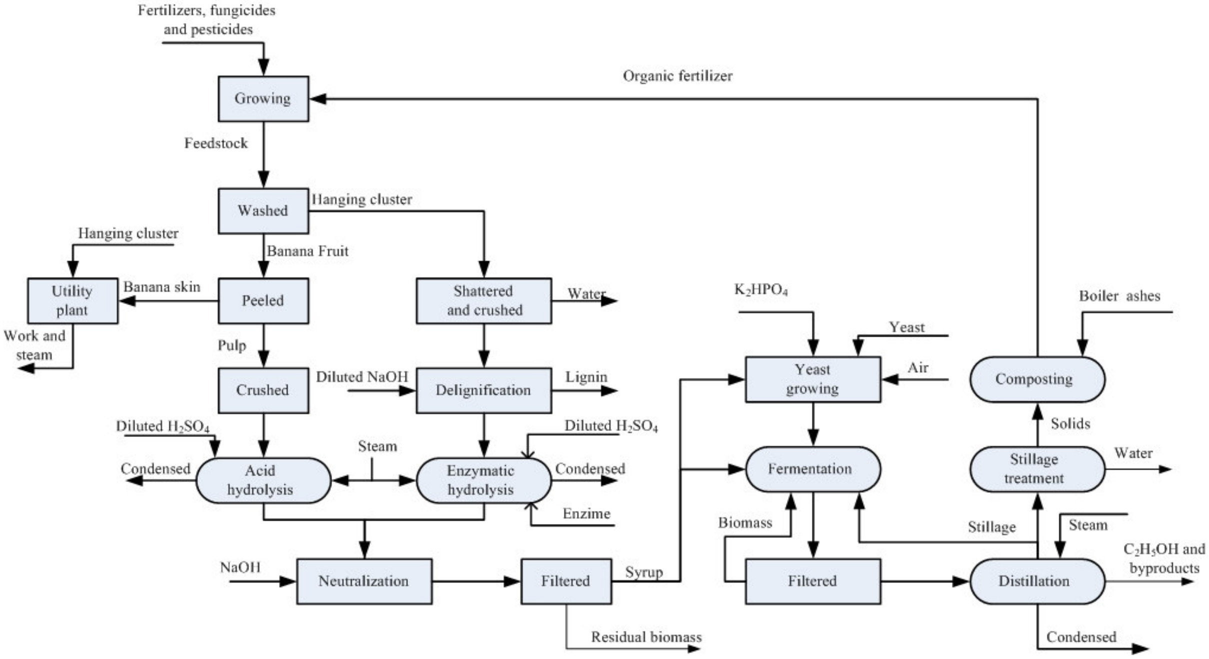


Figure 2. Scheme of the ethanol production process from banana fruit and its biomass residuals.

4. BIODIESEL PRODUCTION PROCESS

Biodiesel production stages are shown in Fig. 3. Biomass production is around 30-36 t/ha, with a 75% of fresh fruit bunches (FFB). The biodiesel production involves three control volumes: palm oil milling, biodiesel production plant and utility plant. Palm oil milling involves the following steps:

- **Fruit Reception:** in order to obtain good-quality palm oil, it is essential that the damage to the fruit is minimal and therefore the handling of the fruit branches (FFB) from the field to the sterilizers must be carried out with high care.
- **Sterilization:** it is carried out by placing the sterilizer at a steam pressure of 2.6 bar during approximately 60 min. The objectives of sterilization are: prevention of further rises in the free fatty acid (FFA) of the oil due to enzymatic reaction; facilitation of mechanical stripping; preparation of the pericarp for subsequent processing and preconditioning of the nuts to minimize kernel breakage.
- **Stripping:** its objective is the separation of the sterilized fruit from the bunch stalks.
- **Digestion:** its objectives are to reheat the sterilized fruits, to loose the pericarp from the nuts and to break the oil cells before passing to the oil extraction unit. The best digestion conditions are obtained by mixing the fruits at a temperature between 95 ºC and 100 ºC for approximately 20 min. Heating is done from direct steam injection.
- **Oil Extraction:** oil extraction is generally carried out using continuous screw presses comprising a perforated horizontal cage in which two screws or worms run. There are two products from the press: a mixture of oil, water, and solids; and a press cake containing fibers and nuts.
- **Clarification:** the crude oil from the press has an average composition of 66% oil, 24% water, and 10% non-oily solids (NOS). The crude oil is screened to remove fibrous materials and then pumped to a continuous settling tank where it separates into two parts: oil and sludge.
- **Nut and Fiber Separation:** when the oil is extracted from the digested fruit, a cake of nuts and fiber is produced. This is fed, via a ‘‘breaking’’ conveyor, to a vertical column having an upward airflow at a velocity of 6 m/s. At this velocity all the fiber is moved upward or held in suspension, and the nuts drop to the bottom of the column. The fiber is led to a cyclone for use as a boiler fuel while the nuts pass to a rotating polishing drum installed at the bottom of the column.
- **Nut and kernel treatment:** this treatment covers four distinct operations: nut conditioning, nut cracking, kernel-shell separation, and kernel drying.

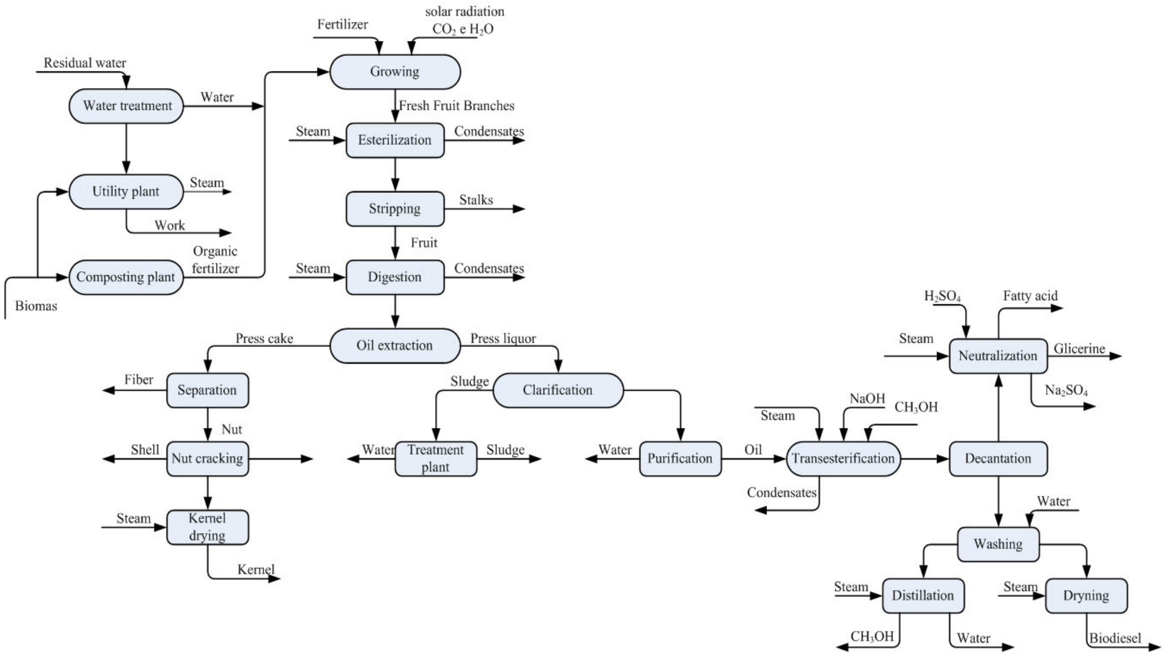


Figure 3. Scheme of biodiesel production process from African palm oil.

Biodiesel or methyl esters (ME) production plant is shown to the right of Fig. 3. The data used in this study came from a pilot plant designed to test several raw materials with a capacity to process 1 ton of oil per day.

The first step is the mixing of methanol with the selected catalyst (NaOH). The reaction taking place is exothermic and leads to water formation ($CH_3\text{-}OH + NaOH \rightarrow CH_3ONa + H_2O$). However, the heat released is not recovered and the quantity of water formed is low and does not affect the course of the transesterification reaction. For refined palm oil (RBD), composed only by triglycerides (TG), a 6:1 molar ratio of methanol to oil (100% excess alcohol) and a 0.6% by weigh of NaOH are used. In the case of crude palm oils having FFA contents in the range 3%-5% by weight, it is necessary to increase the alcohol excess (12:1 molar ratio) and to use the additional quantity of catalyst, required to neutralize the FFA (FFA + NaOH → Soapstock + H_2O).

The second and main step is the transesterification reaction ($TG + 3CH_3OH \xleftrightarrow{NaOH} 3ME + G$). The alcohol-catalyst mixture is combined with the palm oil in the reactor and agitated for 1 hour at 60ºC. Once the reaction is complete, the reactor content is separated in two phases, one rich in ME and the other rich in glycerol (G).

The separation step can be promoted by gravity using a settling vessel and/or by centrifugation. The lighter ME rich phase can also contain catalyst and free glycerol traces, variable concentrations of bonded glycerol, mono glicerydes and diglycerides, depending of the reaction yield, soaps (proportional to the oil FFA content), and a substantial amount of the excess methanol. On the other hand, the denser rich glycerol phase contains most of the catalyst used and soap formed, the rest of the excess methanol and any water formed in the occurring reactions.

After separation from the denser phase, the ME rich phase is washed gently with fresh water. In this step, it is necessary to guarantee a close contact between water and the washed phase in order to remove almost all the methanol present. This removal is favored by the chemical affinity between water and methanol. The water also removes soaps formed by dissolution. Following the washing step, any remaining water is removed from the ME phase by a vacuum flash process or a normal distillation. Once dried, the biodiesel can be sent to storage. On the other hand, the used water must be treated in order to be reused in the process or to be disposed adequately and specially for recovering the methanol.

The denser phase is only about 50% glycerol and so it has little value and disposal may be difficult. Also, the methanol content requires the glycerol to be treated as hazardous waste. The glycerol refining step begins with the addition of a diluted acid, such as phosphoric or sulphuric one, to split the soaps into FFA and salts. The added acid also neutralizes the catalyst present. This neutralization step requires heating and mixing. The FFA is not soluble in the glycerol and will rise to the top where it can be removed. The salt precipitates out and can be filtered and dried. The methanol and water in the glycerol are removed by evaporation.

3. MODELING APPROACH AND SIMULATION

The developed models aim at simulating the steady state operation of all control volumes studied. It is composed of mass, energy and exergy balances, also considering heat, work and mass transfer conditions.

For sugar and ethanol production processes derived from sugarcane, the model presented in (Pellegrini *et al.*, 2007; Pellegrini and Oliveira, 2007; Pellegrini, 2009) was used. This model has already been used to evaluate different configurations of cogeneration systems in Brazilian sugarcane mills ((Pellegrini *et al.*, 2007; Pellegrini and Oliveira, 2007), Pellegrini et al., 2008, Pellegrini, 2009). Thermodynamic properties of sucrose-water solutions were calculated according to the correlations given in (Nebra and Fernández-Parra, 2005)). Exergy of ethanol-water solutions were taken from (Modesto and Nebra, 2005)).

The elemental composition of different kinds of biomass (palm oil fiber, sugarcane bagasse, banana fruit, banana skin, hanging cluster of banana brunch), higher and lower heating values (HHV and LHV), necessary to develop the exergy analysis, were obtained by experimental analysis carried out at the Thermal Laboratory in National University of Colombia, and they were analytically corroborated using expressions proposed in literature (Hugot, 1986; Channiwala and Parikh, 2002).

The composition of palm oil, biodiesel and kernel oil were obtained by chromatographic analysis and its properties were calculated using the Joback method of contribution groups (Poling *et al.*, 2000; Reid *et al.*, 2000).

The thermodynamic properties and chemical exergy of other substances, like: NaOH, H_2SO_4, Na_2SO_4, CaO, CH_3OH and KH_2PO_4, were obtained form differences bibliographic sources (Szargut *et al.*, 1988; Smith *et al.*, 2003; Ball, 2004; Moran and Shapiro, 2006).

Technical parameters needed for sugar and ethanol production from sugarcane were taken from Azúcar Manuelita S.A, a Colombian sugarcane mill with a milling capacity of 3 million tons per year. The extraction oil plant was modeled using technical parameters of Aceitesa S.A, a Colombian palm oil extraction plant and the technical parameters for biodiesel production were obtained from a biodiesel pilot plant built at the National university of Colombia. The technical parameters for ethanol from amilaceous and lignicellulosic materials were obtained from analyses carried out at the Bioprocesses Laboratory of the National University of Colombia, based on the design of a pilot plant with capacity of processing 4000 kg of material per day.

This model was implemented and simulated in EES software, using its data base of thermodynamic properties for H_2O, CH_3OH, C_2H_5OH and ideal gases such as CO_2, H_2O, O_2, CO, N_2, CH_4 etc (Klein and Alvarado, 2007).

4. EXERGETIC EVALUATION

The exergetic evaluation of a biofuel production process was carried out considering the product obtained or the useful exergy and the exergy used on the process, as shown Eq. (1) (Gong and Wall, 1997; Tsatsaronis and Park, 2002):

$$\eta_B = \frac{B_e - B_w}{B_i} = \frac{B_p}{B_i} \qquad (1)$$

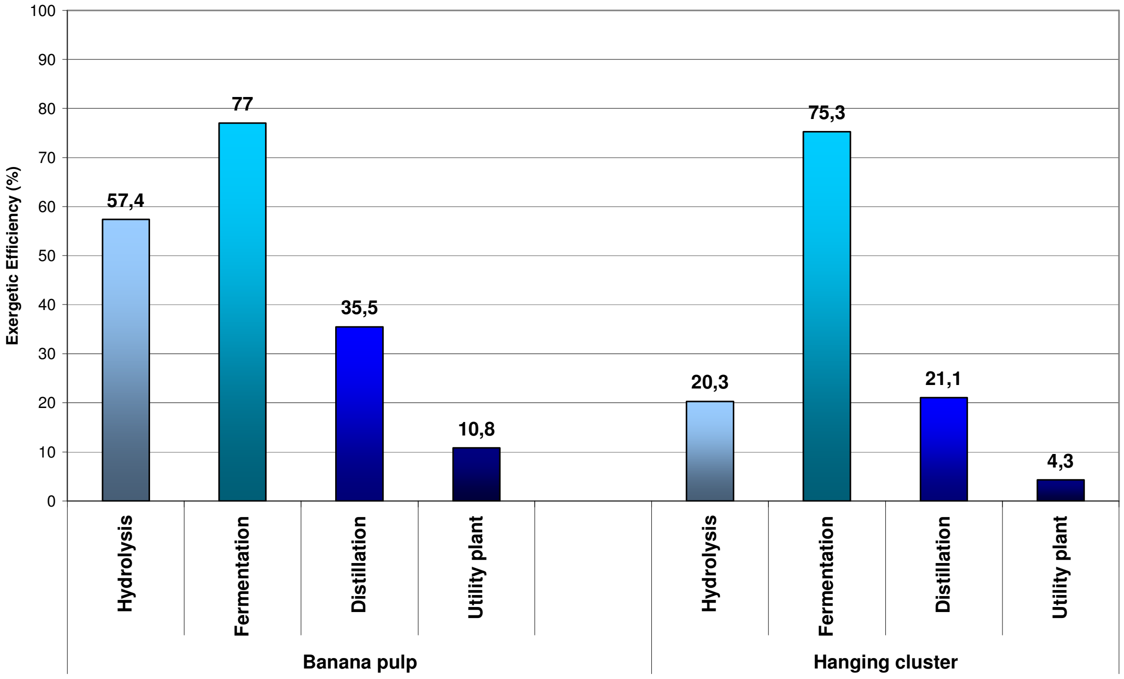
where B_e is the exergy of exit flows, B_w is the exergy considered as waste, B_i is the flow exergy entrance to the process and B_p is the exergy in products.

Using this criterion, the exergy destroyed inside the system together with the flow considered as waste represent the exergetic inefficient into the system.

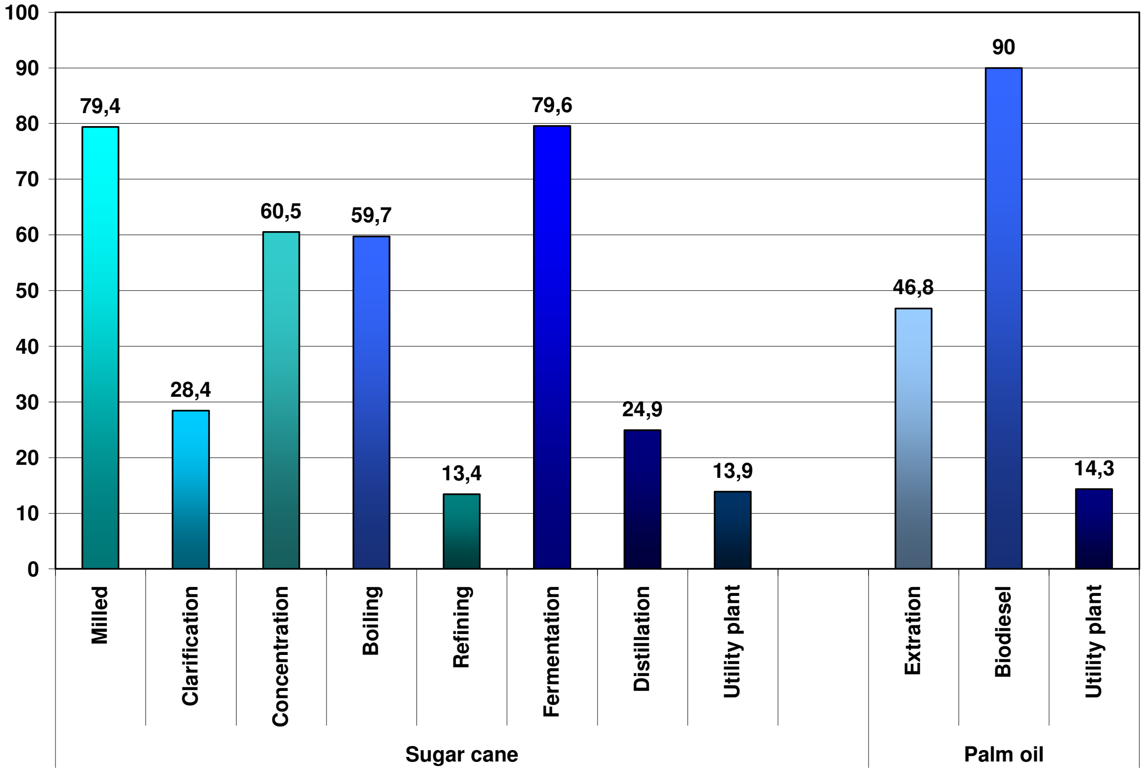
The processes used in biofuel production are classified into two forms:

1. Substance separation: as sugar cane milling, sugar cane juice concentration and boiling, sugar refining, palm oil extraction and ethanol distillation. In these processes water steam and mechanical work are used to separate the substance. For example, in sugar cane milling, mechanical work is used to separate the sugar cane into bagasse and juice. In concentration, steam and mechanical work is used to concentrate the sugar juice, getting the vegetable steam and hot water used in other plant process.
2. Chemical reactions: as hydrolysis of banana pulp and hanging cluster, sugars fermentation, oil transesterefication and combustion reaction in boilers. In these processes, the product obtained and the exergy used are taking into account. For example, in the hydrolysis process the syrup as product and the biomass, raw materials, steam and work used are considered, in a utility plant steam and work as products and the biomass used as fuels are considered.

The results of the exergetic efficiency of the biofuels production processes are shown in Fig. 4



(a)



(b)

Figure 4. Exergetic efficiency of biofuels production processes. (a) Amilaceous material in banana pulp and lignocellulosic material in hanging cluster of banana to produce ethanol. (b) Sucrose in sugar cane to combined production of sugar and ethanol, and palm oil to produce biodiesel.

The banana pulp hydrolysis exhibits a better exergetic efficiency (57,4%) than hanging cluster (20,3%) due to several causes, especially for the higher content of amilaceous material in banana pulp (80,2%) with relation to cellulosic material in hanging cluster (40,9%) (Montes.V and Torrez. C, 2004; Hoyos and Pérez, 2005); and the higher hydrolysis efficiency when banana pulp is used (92,3 %) with relation to lignocellulosic material (55,2%) (Bohórquez and Herrera, 2005).

The fermentation process exhibits similar performance for all raw materials because the process conditions are similar for the three cases. Nevertheless, the exergetic efficiency is higher when sugar cane is used since the sugar molecule for fermentation is sucrose. On the other hand, the syrup sent to fermentation in the case of the hydrolysis of the amilaceous and lignocellulosic materials is glucose.

The lower exergetic efficiencies correspond to the utility plant due to the high exergy destroyed in the boilers. This can be explained for two factors: high exergy destruction in combustion reaction and high difference in temperature between the combustion gases and steam produced. The worst case is for ethanol production using the banana hanging clusters because in this case the steam used for mechanical work production consumed in the plant production is higher than the steam consumed in the chain production process (hydrolysis and fermentation) and so it is necessary to use a steam condenser diminishing the exergetic efficiency.

The exergetic efficiency in a distillation process can be improved by reducing steam consumption. With common current technologies the steam consumed is 3,8 kg/kg ethanol, using another technologies steam consumption could be reduced to 2,2 kg/kg ethanol, increasing the exergetic efficiency (Pellegrini, 2009).

The exergetic efficiency in biodiesel production was obtained taking into account only biodiesel as product. It is high due to the intrinsic transesterification reaction characteristics. Since the reaction is considered reversible the exergy destruction is low. If glycerin is also taken as a product, the exergetic efficiency increase to 96,3%.

The global efficiency taking into account the whole process chain, from the biomass entrance to biofuel production including the utility plant, is defined as the ratio between the exergy in products (B_P) and the difference between the summation of the exergy in biomass (B_{Bio}) and the exergy in raw materials (B_R), and the flow exergy that it is not used on process (B_W), as shown in Eq. 2.

$$\eta_{B,Global} = \frac{B_P}{B_{Bio} + B_R - B_W} \tag{2}$$

The flows taking into account for obtaining the global exergetic efficiency for the production studied routes are shown in Tab. 1.

Table 1 – Substances considered for obtaining global exergetic efficiency

Substances	Products	Biomass	Raw material	Waste
Palm oil	Biodiesel and kernel	FFB	CH_3OH, NaOH e H_2SO_4	Stalks, AG e Na_2SO_4
Starch	Ethanol and by-products	Banana pulp	NaOH, H_2SO_4, $Ca(OH)_2$ e KH_2PO_4	Stillage
Lignocellulose	Ethanol and by-products	Hanging cluster	NaOH, H_2SO_4, $Ca(OH)_2$ e KH_2PO_4	Stillage and lignin
Sucrose	Sugar, Ethanol and by-products	Sugar cane	NaOH, H_2SO_4, CaO e KH_2PO_4	Residual bagasse, filter cake and Stillage

The flows considered as waste can be used in other process as raw materials. For example: the residual bagasse can be used for paper production; the AG can be used to biodiesel production using the fisher esterefication reactions; lignin can be used in chemical industry; stalks, filter cake and stillage can be used in composting plants. The results for global exergetic efficiency are presented in tab. 2.

Table 2 - Global exergetic efficiency for biofuel production routes.

Biomass	$\eta_{B,Global}$ (%)
FFB of palm oil	74,7
Sugar cane	45,5
Banana pulp (starch)	35,1
Banana hanging cluster (lignocellulose)	12,2

When African palm oil is used a high exergetic efficiency is obtained due to various factors (Velásquez, 2009):

- The lower exergy destroyed in oil extraction (345,3 MJ/t-FFB) and in the biodiesel production plant (221,1MJ/t-FFB) in comparison with other processes, in banana pulp hydrolysis exergy is destroyed 895.6 MJ/t-pulp and in syrup fermentation 743.5 MJ/t-pulp.
- The high chemical exergy in products (10.172 MJ/t-FFB) in comparison with other processes as ethanol production of banana pulp (2.343 MJ/t-pulp).
- The high exergy in residual biomass that can be used in other process, the stalks obtained in palm oil extraction has 2.079 MJ/t-FFB in comparison with exergy in residual bagasse 552 MJ/t-sugar cane.

When sugar cane is used to produce sugar and ethanol the best behavior in comparison with the other biomass studied (amilaceous and lignicelullosic material) is obtained. This result can be explained for the high chemical exergy in products (2.487 MJ/t-sugar cane) in comparison with 1.720 MJ/t-banana when banana pulp is used, the energetic integration of plant production and the residual bagasse that can be used in another process (Velásquez, 2009).

The result obtained for global exergetic efficiency in sugar and ethanol production can be compared with the value of 43,5% obtained for sugar and ethanol plant working at the same conditions in Brazil (Pellegrini, 2009).

When lignocellulosic material is used, the worst result is obtained due to various factors: the low efficiency in the hydrolysis process, the high mechanical work consumed in stirrers leading to the use of additional biomass in utility plant.

5. CONCLUSIONS

The exergy analysis is a tool that can be used to evaluate the behavior in the production chain used to produce biofuels.

The way as the process were classified as substance separation and chemical reactions in biofuels production, allowed to obtain the exergetic efficiency that can be used as process optimization parameter.

Chemical reactions as hydrolysis, fermentation and combustion, are the principal causes of exergy destruction in biofuel production.

The global exergy efficiency of palm oil used to produce biodiesel is high due to the reversibility of the transesterification chemical reaction, low exergy destroyed in oil extraction and the biodiesel high chemical exergy in relation to the exergy consumed in its production.

Sugar cane exhibits the better global exergetic efficiency results for ethanol production in comparison with banana pulp or banana hanging cluster.

New researches are necessary for improving the results obtained when starch in banana fruit or lignocellulosic material from banana production is used for ethanol production.

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