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Bioethanol Production Process from Palm Rachis Using the Computer-Assisted Intrinsic Safety Index Method

María José Sanjuan –Acosta[1], Karolayn Tobon- Manjarres[2], Samir Meramo –Hurtado[3]. Karina A. Ojeda –Delgado[4], Ángel D. González –Delgado[5*]

[1,2,3,5] Nanomaterials and Computer Aided Process Engineering Research Group (NIPAC), Chemical Engineering Department
Faculty of Engineering, University of Cartagena
Av. del Consulado Calle 30 No. 48-152, Cartagena, Colombia

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

Email: [1]msanjuana3@unicartagena.edu.co, [2]ktobonm@unicartagena.edu.co, [3]smeramoh@unicartagena.edu.co, [4]kojedad@unicartagena.edu.co, [5]agonzalezd1@unicartagena.edu.co (Corresponding author)*

Abstract: *This article evaluates the safety of the process of obtaining bioethanol from the African palm rachis; the process studied has a capacity of 10,000 kg/h of raw material and is designed implementing the route of saccharification and simultaneous co-fermentation (SSCF). This analysis was carried out through the methodology INHERENT SAFETY INDEX OF PROCESSES (ISI), which seeks to minimize the hazards of chemical processes from its conceptual design, evaluating two intrinsic variables of all processes: chemical and operational. The first one related to the chemical properties and dangerousness of the substances that intervene in the process such as reaction heats, flammability, toxicity, explosiveness, corrosiveness and the second one related to the operation variables of the process such as temperatures, pressures and equipment that conform the process. By means of this evaluation, an ISI of 23 points was obtained, with a chemical index of 18 and a process safety index of 5. Compared to the literature, this process had a good safety performance, however, it is important to pay special attention to by-products that can be generated from secondary reactions.*

Keywords: Bioethanol, SSCF, Hazards, Palm rachis, inherent safety.

1. INTRODUCTION

The use of residual lignocellulosic biomass to obtain biofuels such as ethanol is an issue that has generated great interest at present. Although almost all of the current fuel ethanol is generated from edible sources (sugars and starch), lignocellulosic biomass (LCB) has attracted much attention in recent times as it represents the use of waste to obtain value-added products[1]. Bioethanol is a renewable and sustainable liquid fuel; it has a promising future to face the current world energy crisis and the environmental problems generated by the consumption of fossil fuels [2]. Biofuels are not a fashion, they currently account for 10% of global energy demand and are seen as a complement to the conventional energy supply of the world, the country and the global energy sector[3]. The objective of designing this type of process is to create sustainable processes. As an unsafe plant cannot be profitable, the need arises to analyze the safety of these processes from their conceptual design with the aim of evaluating the possible dangers that these may generate associated with the process.

In this case, the bioethanol production process is designed using the SSCF technique, an agro-industrial residue from the palm oil production process, bearing in mind that palm oil is the most productive oilseed in the world, since less area is required to produce more oil than other types of oilseeds [4]. Colombia leads the production of palm oil in America, hence the concern to produce second generation bioethanol from this waste with no apparent added value and great energy potential.

However, this type of bioprocesses represent a great challenge for their industrial escalation, which makes it necessary from the conceptual design to examine factors such as the safety of the process, which can be achieved by analyzing the internal (inherent) safety and the safety of chemical processes [5], evaluating the possible risks of the equipment involved in it, as well as the degree of danger associated with the substances involved in the process.

2. DESCRIPTION OF THE PROCESS

The process was designed with a capacity of 10,000 kg/h of biomass fed[6] and consists of a series of consecutive stages (Fig. 1) as the adequacy of the raw material (palm rachis) already dry, through milling in order to reduce its size. Then occurs the pre-treatment, which is done through oxalic acid to solubilize hemicellulose and thus make cellulose more accessible to fermentation; The pre-treatment with this type of acids also causes the precipitation of lignin, in order to facilitate the hydrolysis that runs in the next stage. The hydrolysis seeks the transformation of polymeric sugars to their corresponding reduced sugars, and the stage of saccharification and simultaneous fermentation, in which the main product of the process (bioethanol) and some important secondary reactions occur, based on this stage the safety analysis of this process is performed.

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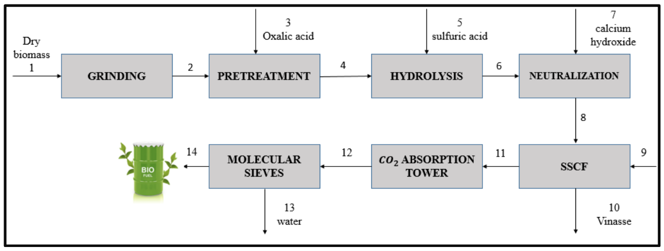

Figure 1. Bioethanol process block diagram

3. Inherent safety index

The inherent safety index is a methodology for the safety analysis of an industrial chemical process, ideal to be applied in the conceptual design stage of a process, where calculations are made based on the worst case scenario that could arise, thus anticipating the worst risk associated with the process.

$$ISI = CSI + PSI \qquad (1)$$

The ISI is calculated through equation (1), which consists of the sum of the chemical safety index and the process safety index. Table 1 shows the range of scores that can be given to each category, which were established by eight experts from different fields of the process taking into account the safety aspects they considered most relevant. Both experts mentioned the parameters, which they considered essential for assessing inherent safety and gave a score for each parameter that represents its relative importance[5].

The ISI uses the Environmental Protection Agency (EPA) matrix to classify risks due to chemical interaction in the processes[7].

Table 1. Score and symbols of Inherent safety sub-indexes

Chemical inherent safety index (Ici)	Symbol	Score
Heat of main reaction	I_{RM}	0-4
Heat of side reacton, max	I_{RS}	0-4
Chemical interaction	I_{INT}	0-4
Flammabilty	I_{FL}	0-4
Explosiveness	I_{EX}	0-4
Toxic exposure	I_{TOX}	0-6
Corrosiveness	I_{COR}	0-2
Process inherent safety ndex (Ipi)		
Inventory	I_I	0-5
Process temperature	I_T	0-4
Process pressure	I_P	0-4
Equipment safety	I_{EQ}	
Isbl		0-4
Osbl		0-3
Safe precess structure	I_{ST}	0-5

4. Results

4.1 Inherent safety of chemicals

This index represents the chemical factors that affect the process, among these factors are flammability, chemical reactivity, toxicity, explosiveness, corrosiveness [5]. The equation below is used to calculate the term.

$$CSI = I_{rs,max} + I_{rm,max} + I_{int,max} + (I_{fl} + I_{Ex} + I_{Tox})max + I_{cor,max} \qquad (2)$$

The reactions taken into account to perform the analysis with respect to chemical reactivity were chosen according to the exothermic grade, below are the two most exothermic reactions within the process.

Table 2. Heat of fermentation reaction, main reaction

Main reaction
$C_6H_{12}O_6 \rightarrow C_2H_6O + 2CO_2 \quad \Delta H_0 = -1945.6kj/mol$
Irm assigned 4

Table 3. Heat of reaction fermentation, side reaction

Side reaction
3 xylose $\rightarrow 5ethanol + 5CO_2 \quad \Delta H_0 = 603.2kj/mol$
Irm assigned 4

These reactions are highly exothermic.

The I_{intmax} shows that both reactions represent a high hazard index, but it is chosen as the main reaction to the one with the highest exothermic degree. The worst interaction occurs in the reactor in the formation of ethanol. That when there is a formation of flammable gases it is assigned an $I_{int} = 3$.

To determine the hazardousness of the substances present variables must be evaluated as toxicity is evaluated based on the threshold limit values since this expresses the harmful exposure limits of the substances in a time limit of 8 hours, flammability which is measured by their flash points or boiling points and explosivity which is measured as a "percentage by volume" of fuel vapour in the air which are no more than the range of vapour or mixture of gases in the air to be burned when they are ignited [5]. We find that ethanol the most dangerous substance. Below are the ethanol data and their respective scores.

Finally we evaluate the corrosion sub-index taking into account the material designated for the construction of the equipment, the material is selected according to the permissiveness of corrosion does not exceed the lifetime of the equipment[8]. For this case the material chosen is stainless steel, for which corresponds $I_{cor} = 1$.

In this way we have that the value of the chemical indicator replacing equation (2) is equal to CSI=18.

Table 4. Inherent safe assigned scores of chemical substances

Index	Value
$I_{rm, max}$	4
$I_{rs, max}$	4
$I_{int, max}$	3
$I_{fla}+I_{exp}+I_{tox, max}$	6
I_{cor}	1
CSI	18

Table 5. Assigned process inherent safety scores

Index	Value
I_i	1
I_t	0
I_p	0
I_{eq}	3
I_{st}	1
PSI	5

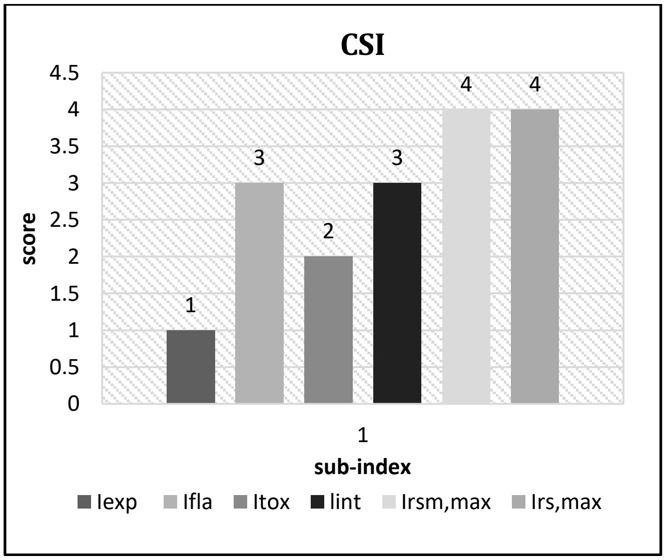

Figure 2. Comparison between CSI indicators

From the indicators, the importance that should be given to the reactions involved is highlighted since they represent the highest score among the "CSI" indicators. From Fig. 3 we can observe that the heat subscripts of the reactions, both primary and secondary, generate the highest hazard scores in the inherent chemical safety indicator; due, among other things, to the fact that they are highly exothermic reactions.

4.2 Intrinsic process safety

The safety process involves an evaluation of the equipment and operating parameters, this index has been divided into the inventory, temperature, pressure, safety conditions of the process and equipment involved in it[5].

$$IPS = I_I + I_T max + I_P max + I_{EQ} max + I_{ST} max \quad (3)$$

The inventory indicator is used according to the feeding capacity of the process, which is 10 tons/hour this gives us as result I_I=1; the maximum temperature of the process was adjusted to 50°C for this temperature the sub-index is equal to I_{Tmax}=0 ; the maximum pressure in the process is 1 atm which gives us an I_{Pmax}=0. Another determining factor is the indicator on safety of process equipment, for this we select the stages of fermentation and stages of purification to choose the equipment, which are the reactor, two distillation towers and the compressor as the most critical equipment in the process. When evaluating the equipment, we selected the sub-index of the compressor because it is the highest, obtaining I_{EQ}=3.

Finally, when taking into account the safe structure indicator, the process was evaluated in the literature with the result that I_{ST}=1 considering it as a process that has not been involved over time in accidents, so it is considered to present many risks. In general applying equation (3) we have a result of I_{PS}=5.

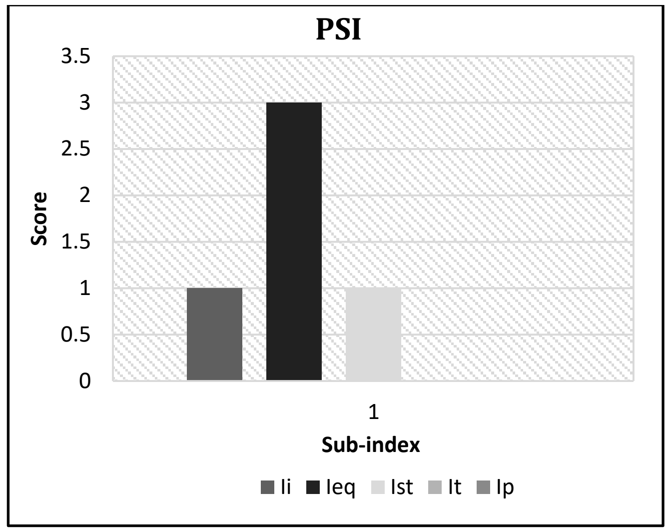

Figure 3. Comparison between PSI indicators

Making a comparison between the indicators we can highlight that one of the factors that must be taken care of in the process is the use of the compressor since it causes a quite high risk in comparison with the other indicators. Although, on the other hand, it is true that one of the advantages of this process is that the variables of pressure and temperature are handled very well since the conditions to which it is worked represent an insignificant risk that can balance the other indicators. Finally replacing equation 1 we have that our safety analysis (ISI) gives us 23 points, it is recommended that for safety processes give 24 points or less to consider them safe [5], so we can deduce that our process has favorable safety results.

5. CONCLUSIONS

Through this study, a risk assessment was developed for the process of obtaining bioethanol from the residual rachis of the African palm, based on the inherent safety index. A process with a capacity of 10.000 kg/h of palm rachis was simulated. From an overall point of view, the process has a good safety performance with an ISI of 23 points, a value below the limit established by some authors, which is 24.

6. ACKNOWLEDGMENT

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