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Artículo Original

PROPOSAL FOR TECHNOLOGICAL MODIFICATION IN A CUBAN DISTILLERY BASED ON A CONSUMPTION INDEXES STUDY

PROPUESTA DE MODIFICACIÓN TECNOLÓGICA EN UNA DESTILERÍA CUBANA A PARTIR DEL ESTUDIO DE LOS ÍNDICES DE CONSUMO

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ABSTRACT

Introduction:

There are several distilleries in Cuban central region that are characterized by obtaining high quality alcohol as their main product. Technological schemes installed in each one are different, therefore, production can be carried out more efficiently or not taking into account water and steam consumption.

Objective:

To analyze the technologies in distilleries A and B that produce extrafine alcohol to propose modifications in the less efficient technology according to the one that performs better.

Materials and Methods:

Processes in the two analyzed distilleries were studied through material and energy balances, taking into account the operating characteristics of each industry.

Results and Discussion:

Distillery B has a lower steam and cooling water consumption per hectoliter of produced alcohol, due to energy use in certain process streams, such as alcoholic vapors coming out of the rectifier and hydroselector columns.

Conclusions:

A redistribution of streams in Distillery A reduces the cooling water and steam

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consumption rate by 35.3 % and 18.9 % of their current values. In this way, only steam generated by the boiler is needed for distillation and final rectifier columns.

Keywords: alcoholic steam; column; consumption index; distillery.

RESUMEN

Introducción:
En la región central de Cuba existen varias destilerías que se caracterizan por obtener alcohol de alta calidad como producto principal. Los esquemas tecnológicos instalados en cada una difieren y, por lo tanto, la producción se puede realizar de forma más eficiente o no en determinada industria, teniendo en cuenta los consumos de agua y vapor.

Objetivo:
Analizar las tecnologías en las destilerías A y B de alcohol extrafino con vistas a proponer modificaciones en la tecnología menos eficiente en función de la que presente mejor comportamiento.

Materiales y Métodos:
Se estudiaron los procesos en las dos destilerías analizadas a través de balances de materiales y energía, teniendo en cuenta las características de operación en cada industria.

Resultados y Discusión:
La destilería B presenta menor índice de consumo de vapor y agua de enfriamiento por hectolitro de alcohol producido, debido al aprovechamiento energético en determinadas corrientes del proceso, como los vapores alcohólicos de salida de las columnas rectificadora e hidroselectora.

Conclusiones:
Una redistribución de corrientes en la destilería A permite disminuir el índice de consumo de agua de enfriamiento y vapor en un 35,3 % y 18,9 % de sus valores actuales. De esta forma solo se necesita vapor generado por la caldera para las columnas destiladora y rectificadora final.

Palabras clave: Vapores alcohólicos; columna; índice de consumo; destilería.

1. INTRODUCTION

Alcohol as a by-product of sugar cane production, is one of the most important derivative industry in Cuba. Productions are destined to satisfy internal needs of domestic fuel, pharmaceutical, food and cosmetic industries, liquor store and for exportation (de Armas et al, 2019).

Currently, alcohol demand is higher than the production possibilities in country's distilleries. The main raw material used, final sugarcane molasse, is increasingly valued due to biotechnological productions growth. For this reason, it is necessary to achieve greater energy or process efficiency in existing processes. So, it is necessary to reduce the consumption rates of both raw materials and utilities. This would lead to increasing production profitability and achieving greater possibilities of satisfying this product growing demand.

In this sense, alcohol production in two Cuban distilleries is studied, in such a way that better productive indicators are achieved. Distillery A is one of them, being designed to produce extrafine alcohol (AEF), rectified ethyl alcohol (AER) and schnapps (Díaz, 2020). The installed distillation system is composed by two columns to obtain rectified ethyl alcohol, three columns to obtain extrafine alcohol and one to obtain recovered alcohol (Díaz, 2020).

Distillery B technology, places it among the most advanced and is characterized by its high-quality productions and process energy efficiency. Its main product is extrafine alcohol, in addition distillery produces bad taste alcohols and recovers fermentation CO2 (López, 2013); (Díaz, 2015). Installed distillation system to obtain extrafine alcohol consists of only five columns: distiller, preconcentrator, hydroselector, rectifier and demethilyzer (Albernas et al., 2012); (González et al., 2016).

The identification of Distillery A technological limitations shows the need to evaluate more efficient technological schemes to achieve required quality standards and reduce energy consumption. So, the objective is to analyze extrafine alcohol distilleries A and B technologies to propose modifications to less efficient technology based on the one with the best performance.

2. MATERIALS AND METHODS

2.1 Characterization of extra-fine alcohol process in studied distilleries

2.1.1 Characterization of extra-fine alcohol process in distillery A

Ethanol production process includes three stages: wort preparation, fermentation and distillation-rectification (Albernas-Carvajal et al., 2014); (de Armas, 2019), (de Armas et al, 2019). In Distillery A, plant molasse at 85 °Brix is mixed with previously treated water to make initial predilution. pH is adjusted with sulfuric acid to desired value for yeast growth in mother tanks (between 3.9 and 4). A part of this wort is diluted at 16 °Brix to send it to mother tanks, while the rest is prepared at 20 °Brix and fed to fermenters, where fermented wine is obtained and fed to distillation stage (de Armas, 2019).

In distillation section, ethanol is purified until obtaining a concentration between 94 and 95 ° GL (Klein et al., 2019). The fermented batter is fed to distillation column where alcoholic vapors from the top, pass to rectifier column and vinasses are obtained at the bottom. Vinasses constitute the main process residual and are used for biogas production. In rectifier column heads and 94.5 °GL rectified ethyl alcohol are separated. Approximately 51.2% of rectified ethyl alcohol is stored and the rest is used for its concentration to extra-fine alcohol (González et al., 2016); (Díaz, 2020). In this case, it is fed to washing column, where it is into contact with water to reduce its alcoholic concentration and facilitate the extraction of high molar mass impurities, known as amyl alcohols or fusel oil. Washed alcohol passes to second rectifier column to raise its concentration to extrafine alcohol with 96.3° GL, separating amyl alcohols that are sent to recovery column. The last stage is methyl elimination to finally obtain extrafine alcohol (González et al., 2016).

In order to increase its alcoholic concentration, the recovery column is fed with washing, final rectificating and demethylizing columns head products and the extractions carried out in final rectificating column. Depending on obtained alcohol quality, its destination is decided, as rectified ethyl alcohol or for recovered ethyl alcohol (phlegm alcohol) production.

Each of the columns in installed distillation scheme has its own condensation system with two condensers, except distillation column. All condensers use water as a cooling medium, in addition, each column consumes steam generated by the boiler, except rectifier.

2.1.2 Characterization for obtaining extrafine alcohol process in distillery B

In distillery B the process of obtaining extra-fine alcohol is carried out in the same way, but with some differences. The technology installed in this industry is designed to produce extra-fine alcohol through a distillation scheme composed of only five columns: distiller, preconcentrator, hydroselector, rectifier, and demethylizer (Albernas et al., 2012), condensing system has two condensers in each column, except in the distiller. The difference is that the main condensers of the hydroselector and rectifier columns are in turn demethylizer and distillation columns boilers, as is shown in figure 1. In this way, the process is integrated energetically, and steam consumption from the boiler is saved, as well as the amount of cooling water necessary to condense alcoholic vapors Albernas et al., 2012).

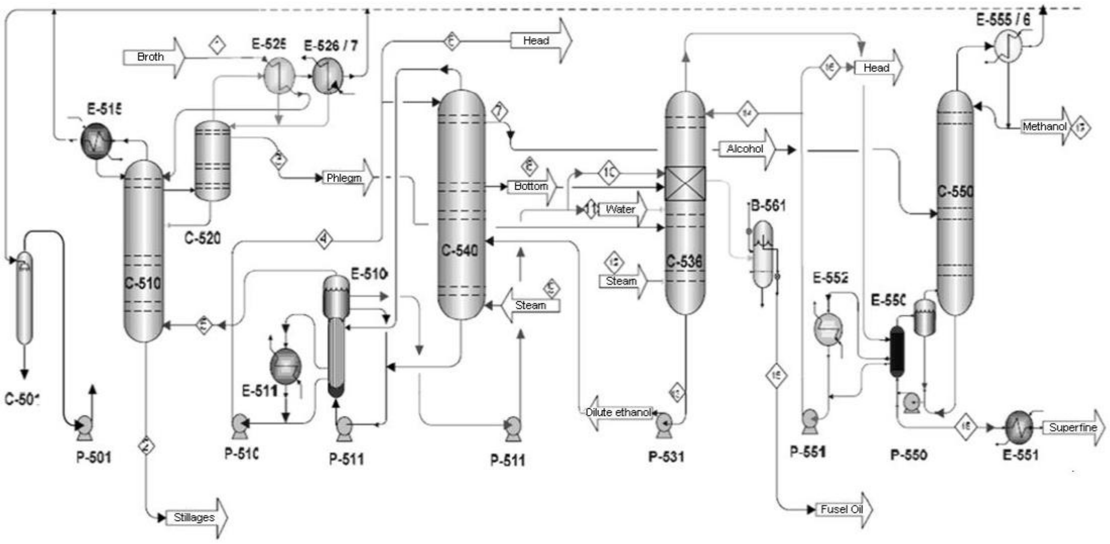

Figure 1. Distillation stage in distillery B

2.2 Material and energy balances in each process

Material and energy balances were carried out at each stage for the produced wine volume (Albernas et al., 2012). A summary used equations is shown in Table 1.

Table 1. General equations used in material and energy balances

Stage	***Equations***
Fermentation	fermentation molasses: $Me_f = \# \text{ fermentators} * \frac{ARF_f * V_f - V_{f_{inoculum}} * ARF_{pf}}{ARF_{molasse}}$ (1) fermentation water: $A_f = \rho_{water} * \left(9 * \left(V_f - V_{f_{inoculum}}\right) - \frac{Me_f}{\rho_{molasse}}\right)$ (2) Stillage to ferment: $M_f = Me_f + A_f$ (3) Alcohol in fermentation: $Al_f = M_f * \%Alc_{ps}$ (4)
Distillation	$\text{Feed} + \text{steam} = \sum \text{alc vapor outlet} + \text{residue}$ (5) $\textit{Feed} * \text{Composition}_{\text{alc feed}} = \sum \text{Vapors alc.} * \text{Composition}_{\text{vapors alc}}$ (6) $Qc = \text{Destilate} * [(R+1) * H_{G1} - R * H_{L0} - H_D]$ (7) $Qc = \text{water} * Cp_{water} * (\text{Temperature}_{intlet} - \text{Temperature}_{outlet})$ (8)

ARF

ARF_f: ARF in fermentation, Vf: volume of fermentation, Vf $_{inoculum}$: volume of inoculum, ARF_{pf}: ARF in prefermentation, % Alc_{ps}: % alcoholic in seed, JF: filter juice, Me_{JF}: molasse when using filters juice, vapors $_{Alc\ outlet}$: alcoholic outlet vapors, Composition $_{Alc\ or\ alc\ vapors}$: composition of alcohol in feed or in alcoholic vapors, Qc: heat evacuated by the condenser (Ec 9.54, Treybal, 1991).

From mass and energy balances in columns and primary condensers of Distillery A, the outlet currents that can generate the necessary steam in a certain column to carry out its operation are identified. To do this, the amount of water that would be used when combining the alcoholic vapors condensation - boiling with steam generation is calculated (9):

$$Qc = \text{Water} * Cp_{water} (\text{Temperature}_{Outlet} - \text{Temperature}_{Inlet}) + \text{Steam} * \lambda_{vapor} \quad (9)$$

3. RESULTS AND DISCUSSION

3.1 Material and energy balances results

Obtained results characterize and identify productions in both distilleries. They are differentiated by the number of final products considered in them, as well as by technological system that they have installed to develop the productions. A summary of the main streams involved in the process is shown in table 2.

Table 2. Main streams in both distillers

Stream	***Distillery***	
	A	***B***
Molasses in fermentation (kg/d)	187 709	342 000
Water in fermentation (kg/d)	770 562	1 005 949
Stillage (kg/h)	37 275	62 402
Vinasse residual (kg/h)	45 888	65 595
Rectify alcohol (hL/d)	1 224	-
Superfine alcohol (hL/d)	500	900
Total Steam (kg/h)	19 505	6 631
Total cooling water (m^3/h)	303.1	314.1

3.1.1 Steam and cooling water consumption index.

The steam consumption index was calculated from the generated by the boiler steam required by each column, in relation to the amount of extra-fine alcohol produced. The obtained results are shown in Figure 2.

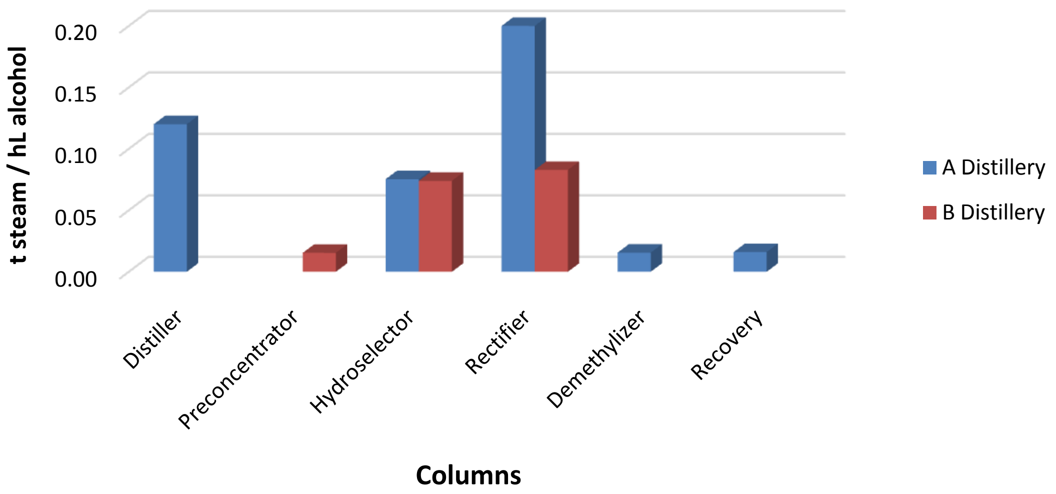

Figure 2. Steam consumption index

In both technologies, the carried-out calculations show that distillation column is the major steam consumer with an index of 0.256 t steam/hL alcohol in distillery A, and 0.26 t steam/hL alcohol in distillery B. This is due to its main function is to eliminate most of the water and to separate the alcoholic vapors at the column top. Although numerically there is no great difference in these columns steam consumption, in Distillery B the necessary steam is generated in a boiler and not by a steam generator as occurs in Distillery A.

In general, there is a notable difference in terms of total vapor rates of both technologies. Distillery A consumes 0.566 t steam/hL of alcohol, while distillery B only needs 0.172 t/hL from the steam generator, marking a difference of 0.394 t/hL. The results show how this latter distillery is more energy efficient than Distillery A in this regard. This is influenced by the two boilers present in Distillery B, one in distillation column, using the steam from the rectifier, and the other in demethylizer that operates with the steam from hydroselector column.

On the other hand, the cooling water consumption rates were determined in relation to the alcohol amount required in distillation stage in both distilleries. The obtained results appear in Figure 3.

From the obtained results, the total cooling water consumption rate in Distillery A is 13.34 m^3 of water/hL of alcohol produced, being higher than that Distillery B which requires 6.98 m^3 of water/hL of alcohol. This value is influenced by the presence of two boilers where the alcoholic vapors condense at the outlet of the abovementioned columns. However, in distillery A, each column has its own condensation system made up of two condensers and, therefore, requires more water (6.36 m^3/hL) to condense the vapors from the top.

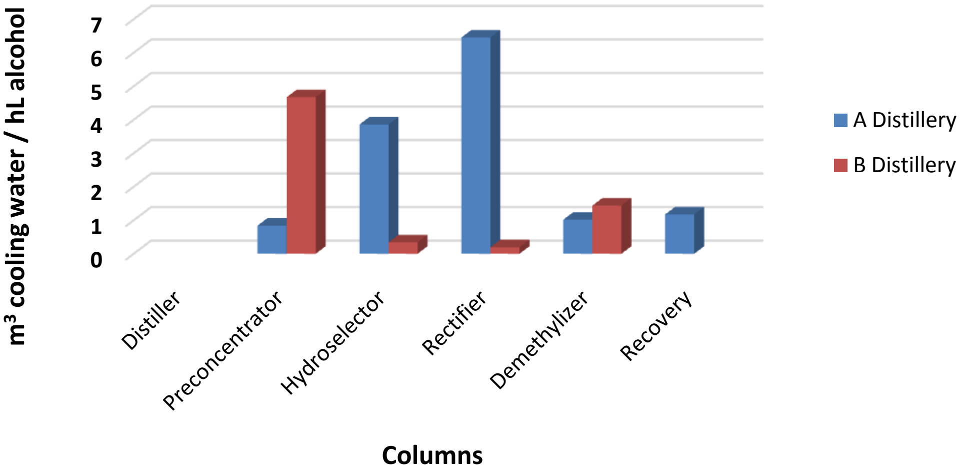

Figure 3. Cooling water consumption index

3.2. Proposals for technological changes

Because the explained above differences, changes in the technological system of Distillery A can be proposed, which improve consumption rates in it and, in turn, have a positive impact on total production costs. In this case, it is proposed to achieve a reduction in the steam generated by the boiler consumption and in cooling water in distillation. Using mass and energy balances, heat evacuated by the primary columns condensers is calculated, as well as the necessary steam to carry out the operation (table 3).

Table 3. Energetic behavior in distillery A

Columns	*Evacuated heat for primary condenser (kJ/h)*	*Necessary vapor (kg/h)*
Distillation	-	13 046
Rectification	84 719	-
Washing	175 167.21	1 568
Final rectification	309 428.83	4 234
Demethylation	42 149.76	323.78
Recuperation	49 196.74	333.05

Knowing these values, which outlet current in one column can generate the steam that is consumed in another, as well as the amount of needed water are determined. Observing the amount of necessary water to carry out the condensation - boiling (figure 4), the required steam by distillation column and final rectifier cannot be generated by the evacuated heat in any of primary condensers. Likewise, the demanded steam in washing column can only be generated by the alcoholic vapors of final rectification column. Whereas, steam from the demethylizer and recuperator can be obtained by the alcoholic vapors heat from the rectifier, washer or final rectifier columns.

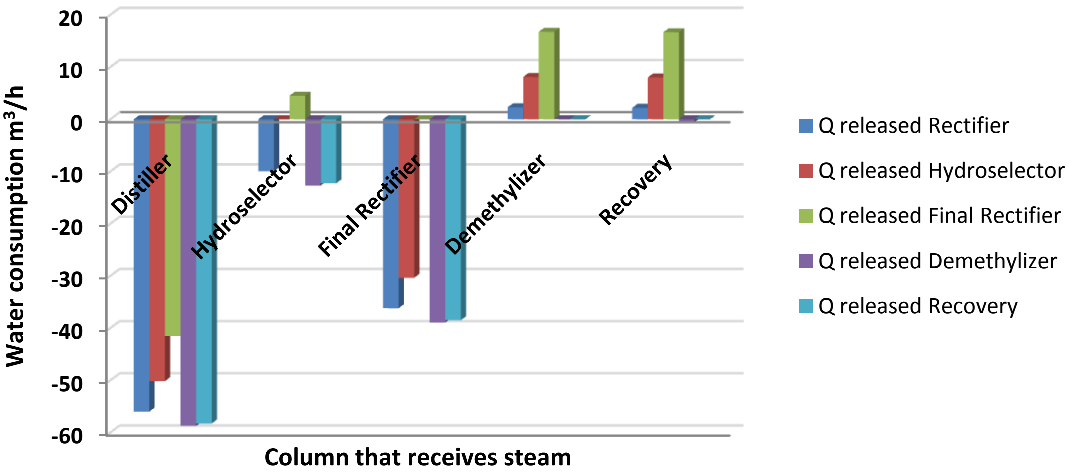

Figure 4. Relation between columns for condensation – boiling vapor generation

From these results, a possible distribution between columns can be selected, also considering the installed scheme in distillery B. It is proposed to generate steam in washing column with the condensation of alcoholic vapors from final rectifier. Steam in demethylizer can be generated with the vapors coming out from the washing column, and in recuperator would be obtained with the alcoholic vapors from the rectification column (Table 4).

Table 4. Columns selection for steam generation by condensation – boiling

Column that takes vapor	***Column that generates vapor with its Qc value***	***Necessary water (m^3/h)***
Washing	Final rectifier	4.44
Demethylizer	Washing	7.98
Recuperator	Rectifier	2.15

Proposed distribution schema is showed in Figure 5.

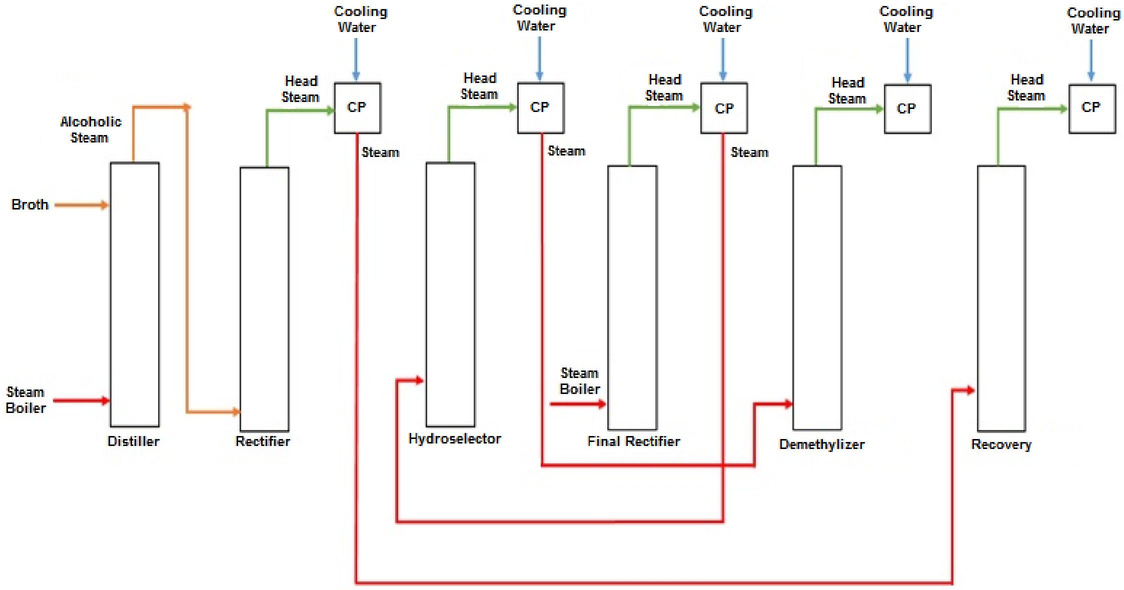

Figure 5. Proposed distribution schema for distillery A

The results have a significant impact on cooling water consumption of these columns in current operating conditions, and its decrease is summarized in table 5.

Table 5. Decrease in cooling water consumption in distillery A

Column	***Current water consumption (m^3/h)***	***Modified water consumption (m^3/h)***	***Current Index (m^3/hL)***	***Modified index (m^3/hL)***
Rectifier	42.83	9.57	0.84	0.19
Washing	80.39	14.88	3.86	0.71
Final rectifier	134.30	9.09	6.45	0.44

These values indicate that approximately 178 m^3/h of water is no longer consumed for cooling, decreasing from 13.34 m^3/hL to 8.63 m^3/hL of produced alcohol, which represents a reduction of 35.3%.

On the other hand, steam consumption also drops from 19.5 t / h to 17.28 t/h, for a ratio of 0.45 t steam/hL of alcohol, which represents a reduction of 18.9%. Boiler generated steam is consumed only by distillation and final rectifier columns. This index for alcohol production allows that the need for steam is in reported interval by Pérez et al., (2005).

4. CONCLUSIONS

1. Distillery A has a higher steam consumption rate (0.566 t/hL) compared whit Distillery B (0.172 t/hL), as well as a higher consumption of cooling water rate (13.34 m^3 of water/hL), while in distillery B it is 6.98 m^3 of water/hL.
2. Proposed redistribution scheme in Distillery A reduces cooling water consumption rate by 35.3%, reaching the value of 8.63 m^3 water/hL of alcohol.
3. Proposed scheme reduces steam consumption by 18.9%, bringing it to 0.46 t/hL and consuming boiler generated steam only by distillation and final rectifier columns.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

AUTHORS' CONTRIBUTIONS

- Orisleidy Carrazana Díaz, Eng. She did the calculations and wrote the article.
- Ana Celia de Armas Martínez, Ph.D. She coordinated research work and collaborated with article writing.
- Yailet Albernas Carvajal, Ph.D. She coordinated research work and collaborated with article writing.
- Irenia Gallardo Aguilar, Ph.D. She collaborated with calculations and results analysis.