Recycling technology of sugar industry by-products for animal feeding

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Recibido: 10 de junio de 2003. Aceptado: 26 de agosto de 2005.

Palabras clave: tecnología de reciclaje, fermentación en estado sólido, diseño de planta, planta piloto, subproductos.
Key words: recycler technology, solid state fermentation, plant design, pilot plant, by-products.

RESUMEN. En este trabajo se presenta el desarrollo de una tecnología de reciclaje y enriquecimiento proteico mediante fermentación en estado sólido de los subproductos de la industria azucarera para su posterior utilización como alimento animal. A partir de un estudio bibliográfico sobre los aspectos más importantes de las tecnologías actuales de fabricación de alimentos para el consumo animal y las herramientas para el desarrollo de tecnologías de fermentación en medios sólidos se ha desarrollado un procedimiento general para el diseño de una planta para la producción de un alimento a partir de bagazo y miel final, enriquecido proteicamente con levadura *Candida utilis* y que se le ha dado el nombre de *Bagames*. El diseño cuenta con varias etapas: preparación de las materias primas, fermentación en estado sólido, sistema de aireación, sistema de bombeo y transporte mecánico del producto, secado, humidificación del aire. El diseño de todos los equipos fue realizado en Microsoft Excel. La metodología desarrollada puede ser generalizada a otras plantas del país. Mediante un análisis de prefactibilidad económica se calculó que la inversión en el Complejo Agro Industrial ''Siboney'' es de $72 697,91 con un tiempo de recuperación de 2,44 años. Con un valor del VAN de $219 407, 48 y un TIR de 39,13 %. Se demostró que la tecnología es técnico económicamente factible.

ABSTRACT. In this work the development of a recycled technology and protein enrichment by solid state fermentation of the by-products of the sugar industry for their later use like animal food is presented. Starting from a bibliographical study on the most important aspects in the current technologies of production of foods for the animal consumption and the tools for the development of technologies of fermentation in solid means a general procedure has been developed for the design of a plant for the production of a food starting from trash and honey, protein enriched with yeast *Candida utilis* and that has been given the name of *Bagames*. The design has several stages: preparation of raw materials, solid state fermentation, aerating system, pumping and mechanical transport of the product, drying, air humidification. The design of all equipments was carried out in Microsoft Excel. The developed methodology can be generalized to other plants of the country. By means of an analysis of economics it was calculated that the investment in the *Siboney* Sugar Mill it is of $72 697.91 with a time of recovery of the same of 2.44 years old. With NPV value of $219 407.48 and IRR of 39.13 %. It was demonstrated that the technology is technically economically feasible.

INTRODUCTION

In Cuba, the sugar industry is broadly extended in all its geography and it produces considerable volumes of by-products rich in sugars, minerals and fiber such as the trash, the phlegm and the final honey. These by-products represent an enormous potential for the animal feeding, mainly in dry seasons, in which the grass, main base of the feeding is scare at the moment. The employment, however, of these by-products in the meat production, milk and egg has some inconveniences, mainly related to the lower protein levels that possess, and that it is a consequence of the characteristics of the plant from where they are obtained, which possesses lower levels of protein N.

Another important problem for its consumption in monogastric animals is the fiber high-level that it possesses, which is associated with those made up of the cellulose, hemicellulose and the lignin; polymers of very low digestibility for these animals. The inclusion of fibrous allowances in the portion of the monogastric animals, and more particularly the birds and pigs, it is limited by the digestive capacity of these animals to use the carbohydrate structures.[1]

To be enriched in other components, the idea arises from synthesizing the protein with part of these substances that are in excess, using for it foragers microorganisms as they are some molds and yeasts.[2] A possible road for the protein enrichment of the trash is the one of using as source of nutritioun other derivates from the sugar production as honey and phlegm, while this is an employee as inert support where microorganisms grow in solid fermentation.

Starting from this knowledge it has left developing technologies of fermentation in solid state for the protein enrichment of the cane trash with the objective of their later use as food animal.[3,4,1] In general the design of these technologies is almost always made in an empiric way, following the geometric similarity exclusively in the change of scale.[5] This method, as it is known, doesn't always drive to the results wanted with the biggest efficiency and possible effectiveness. To achieve better results it has been used with methodologies that combine the mathematical modeling and optimization.[2]

The general objective of this work it was to design a technology of recycling by-products of the sugar industry for the production of a food animal protein enriched, making use of computational tools.

MATERIALS AND METHODS

The present work start from previous studies.[1,4,6,7] It is a technology that allows enriching by-products of the sugar industry with a single cell protein to produce a food dedicated to the animal consumption. The production of this product can be made in three possible technological variants: batch process, fed batch process, and continuous process. Following this same order, these processes are more and more efficient because it takes better advantage of the installed productive capacity. Therefore it was considered the last variant as the best and the design was developed for a continuous process. This technology is novel in the country and it was patented.[1] It makes an integral use of the by-products of the sugar industry and it uses a forager yeast of grateful value in the animal feeding. This technology is also based at the moment on continuous bioreactors for the solid fermentation, novel equipments in via of patenting and it uses an aeration system based on the employment of efficient gas-liquid ejectors, with high effectiveness in the oxygen breakup. This work was developed making use of computational tools as the mathematical models simulator SB Model Maker Version 2.0c and Microsoft Excel. Starting from the last software was made a new one that is registered. The design of the plant was divided in different stages with the purpose of organizing the work, which were:

1. Raw materials preparation.
   It included a team of submerged fermentation and an aeration system by ejection.
2. Solid state fermentation.
   It included a solid fermenting and an air humidification tower.
3. Drying of the end product.
   It included a pneumatic transport dryer
4. Transport.
   It included the design of the pumping system and of material transport.
5. Analysis of economic feasibility.

In the first stage a submerged cultivation fermenting is needed for the propagation of the inoculum. This fermenting presents a cylinder - conical geometry which operates in a continuous way. For the design of this team it was carried out a mass balance making use of the rate expression in Monod model to determine the dilution coefficient. The dilution rate can be optimized making maximum the productivity in the reactor, and then the dilution rate is calculated assuming that this represents 90 % of the optimal dilution rate and with it to determine the effective team volume. With this volume and following the geometry the remaining dimensions of the fermenting were determined. A relationship of height-diameter equal of two was used.

For the submerged fermentation it is needed that the liquid mean be the most possible saturated in air, because the microorganisms are developed in an aerobic way. To achieve this aeration it intends the design of a gas-liquid ejector.

The methodology proposed by previous works was continued for the design.[8-10]

The total volumetric mass transfer coefficient is calculated according to the equation 1, which keeps in mind the dissipation energy, the gas fraction and the nozzle to mixing tube diameter ratio:

$$k_L a = 5{,}4 \cdot 10^{-3} \cdot \epsilon^{0.66} \cdot \varepsilon_G \cdot \left(\frac{d_N}{d_M}\right)^{0.66} \quad (1)$$

where:

$k_L\alpha$ Mass transfer coefficient (s^{-1}).
ϵ dissipation energy (W/kg).
ε_G gas fraction (adimensional).
$d_{N,M}$ nozzle diameter, mixing tube diameter (mm).

The dissipation energy is obtained:

$$\epsilon = \frac{P_{jet} - P_{compres.}}{\rho_M \cdot V_{Ej.}} \quad (2)$$

where:

$P_{compres.}$ Compression pressure (Pa).
$P_{jet.}$ Jet pressure (Pa).
ρ_M Medium density (kg/m^3).
$V_{Ej.}$ Ejector volume (m^3).

$$\epsilon = \frac{\left(0{,}5 \cdot \rho_L \cdot U_N{}^2 \cdot Q_L\right) - \left(\Delta P_{G,Ej.} \cdot Q_G\right)}{\rho_M \cdot V_{Ej.}} \quad (3)$$

where:

ρ_L Liquid density (kg/m^3).
U_N Nozzle fluid rate (m/s).
$Q_{L,G}$ Liquid volumetric flowrate, gas volumetric flowrate (m^3/h).
$\Delta P_{G,Ej.}$ Ejector pressure drop (Pa).

In the second stage the fermenting to employ is continuous, cylindrical and rotational. It is an adaptation of a dryer with these characteristics, as those that are used for the drying of sugar or trash. The calculations of this equipment are the most important into the design of this technology. Based on its production capacity the needed quantity of raw materials is determined previously optimized through a mathematical model minimizing the unitary cost of the same ones. Also, the design of the other equipments tour around the fermenting in solid state. The description of the phenomenon drives to the following: *The model that describes the micro blended and, consequently, the real behaviour of this fermenting, is a combination of movements in flow in piston (PFR), flow in perfect mixture (PMR) and recycling*. This model's objective will be the one of offering a mathematical expression to estimate the real concentration of biomass to the exit of the reactor. It is supposed steady state like first approach since later the transient processes of having started up of the process it will be studied on. Carrying out the mass balances in PFR and PMR the equations is obtained to calculate the real biomass conversion at the exit

$$X = \frac{\alpha}{1+\gamma} X_p + \left(1 - \frac{\alpha}{1+\gamma}\right) X_m \quad (4)$$

where:

α, γ Parameters that characterize the micro blended.
$X_{p,m}$ Biomass concentration in piston and perfect mixture [mol/(kg · MS)].

$$X_P = \frac{Xo'}{\left[\frac{Xo'}{X_{\max.}} + k_1 EXP\left(-\frac{\mu_{\max.}}{D_P}\right)\right]} \quad (5)$$

where:

Xo Initial biomass concentration [mol/(kg · MS)].

$X_{max.}$ Maximum biomass concentration [mol/(kg · MS)].

$\mu_{max.}$ Microorganism maximum specific growth rate (h^{-1}).

D_p Dilution coefficient in piston (h^{-1}).

$$Xo' = \frac{Xo + \gamma X}{(1+\gamma)} \qquad k_1 = 1 - \frac{Xo'}{X_{\max.}}$$

$$X_m = \frac{k_2(\mu_{\max.} - D_m) + \sqrt{\left[k_2(\mu_{\max.} - D_m)\right]^2 + 4Xo'k_2 D_m}}{2} \quad (6)$$

where:

D_m Dilution coefficient in perfect mixture (h^{-1}).

$$k_2 = \frac{X_{\max.}}{\mu_{\max.}} \qquad \gamma = \frac{f_R}{F}$$

of the reactor according to bibliografy.[6,11]

In these equations, α and γ are parameters that characterize the micro blended in the fermenting, they depend on the constructive characteristics of equipment and they are determined experimentally through the stimulus - answer technique.

With the objective of controlling the metabolic heat that comes off inside the fermenting product of the reaction that takes place in them, is made pass air through the equipment. This air should be humidified to maintain the necessary content of water for the optimal growth of the microorganism and therefore to guarantee the optimal yields. That's why a humidification column is designed that completes with the imposed requirements. The calculation of the humidification tower was carried out based on the mass transfer method proposed.[12] The method in a very general way consists on going increasing or diminishing the water flow passing trough the equipment to saturate the calculated air flow for the solid state fermenting. The geometric calculation of the tower and their filler will be in dependence of the values of the flows of water, air and of the entrance and exit temperature of both. In the third stage, for the drying of the product it is necessary to keep in mind the characteristics of the material. The same one is sensitive in front of very high temperatures and long contact times of material - heater agent; so it was reached to the conclusion that the optimal drying equipment is that of pneumatic transport. In this equipment the product is at great speed transported by means of a hot gas current that carries out the drying where retention of the material doesn't exist, that is to say, the product doesn't suffer alterations. It goes next by a classification mechanism in which the dry product separates the other ones, non-volatile fraction that is recycled to continue the drying with what high efficiency is achieved in the process.

For the selection of the pneumatic conveyor dryer it is needed the evaporation capacity and the working temperature of the hot gases according to the design developed.[2] The evaporation capacity was calculated by means of a materials balance keeping in mind the entrance and exit humidity of the product. With this value a standard equipment was selected that completed with the wanted characteristics.

The plant that is subjected to the modification has two screw conveyors. After studying the different types of transporters and keeping in mind that the material has danger of contamination, it was decided to maintain this transporter type to be the most convenient according to the demands of the product that it is wanted to obtain. For the system of transport, the design was divided in two parts: a first of modification of the existent screws in the plant, and a second of calculation of two conveyors of this additional type. It was carried out the calculations based on the productivity of the equipments, as well as their mechanical characteristics.

The normalized electric motors were selected by means of catalogs starting from the value of power to consume for each transporter.

Finally it was carried out the economic analysis, for it was analyzed two product variants: the first one a previous fermented humid mixture and the second the dry fermented product. The yearly average production of each product was calculated, with the costs and respective prices were calculated the yearly sales, and also the costs and the gain (Table 1). With the information already obtained it was proceed to evaluate the proposed investment (Table 2).

RESULTS AND DISCUSSION

All the designs were carried out by means of the help of two fundamental computational tools: the Model Maker and Microsoft Excel simulator softwares; in this last one it was scheduled in such a way that already constitutes a software registered, which can be used for the later design of future plants of this type all over the country.

The ejection system has as objective to saturate of air the liquid means, in this case, the inoculum. The ejectors will be placed sequential and for them it will pass a flow of 14.67 m^3 of liquid medium with a biomass flow of 10.16 kg BS/h, value for which are needed, keeping in mind the air – biomass yield, 47.61 m^3/h of air. The value of the mass transfer coefficient, kLa, obtained was 0.15 s^{-1}. Comparing this value with those ones obtained in previous works[8,9] are very small, but it must note that these studies were carried out for a desorption of oxygen from water system by means of an inert gas (nitrogen) and that for the design and scale–up of this type of ejectors a readiness of data is needed that describe the characteristics of the mass transfer as a function of the physical estates of the fluid and of the parameters related with the geometric design and with the process. In this case, the flowing means is essentially dilute honey – biomass and the gas is air.

References are not had for this system; their physical estates vastly differ of the utilized model system. Two fermenting will be used in solid state with a total production capacity of 20 t PS/d . A concentration of biomass is obtained with a value of 4.723 mol/kg MS, with that which a true protein of 8.31 % BS is obtained. This value of the protein is

Table 1. Calculation of the costs, annual mercantile production, gain and time of recovery for both products.

Year	Costs	Selling	Net profit
		$	
0	–	–	72 697.91
1	198 568.42	218 245.27	19 856.84
2	342 671.44	376 938.59	34 267.14
3	342 671.44	376 938.59	34 267.14
4	342 671.44	376 938.59	34 267.14
5	342 671.44	376 938.59	34 267.14
6	342 671.44	376 938.59	34 267.14
7	342 671.44	376 938.59	34 267.14
8	342 671.44	376 938.59	34 267.14
9	238 281.34	262 109.47	23 828.13
10	138 051.30	151 856.44	13 805.13
NPV5	$44 101.25	NPV10	$219 407.48
IRR5	29.79 %	IRR10	39.13 %

Table 2. Calculations of the NPV and IRR for 5 and 10 years of plant useful lifetime

Description	BMA	Bagames	Unit
Production cost	19.52	56.94	$/t
Selling price	21.47	62.63	
Daily production first year	35.00	10.50	t/d
Daily production years 2 to 8	52.00	21.00	
Daily production ninth year	35.00	15.00	
Daily production tenth year	15.00	10.50	
Daily average production	44.90	18.30	
Production days at year	155.00	155.00	d
Yearly average production	6959.50	2836.50	t/year
Production cost	$135860.93	$161499.18	$/year
Yearly mercantile production	$149447.03	$177649.10	
Yearly average gain	$13586.09	$16149.92	
Recovery time	5.35	4.50	year

much bigger if it is compared with the protein levels that it has the trash, main raw material of this product. A product is obtained with a stable quality with 85 % of dry matter, less than 15 % BS of gross fiber, 8 - 9 % BS of ashy and 8 – 10 % BS of total sugars.

The fermenting presents in their structure a screw conveyor in charge of the backmixing in the bioreactor, this mechanical device was designed for a productivity of 20 % of the production of the fermenting, that is, 3.22 t/d . The raw materials to use for the production of this food are: cane trash, "B" honey, *Torula* yeast, necessary mineral salts for the optimal growth of microorganisms and water. The daily production will be of 102.5 t of humid product. Of this production 51 t will be fermented to obtain 21 t/d of dry *Bagames*. Therefore, 20 t of trash and 29 t of honey will be used to in fact produce this food that will serve as much for ruminant animals as for monogastric animal, for their low concentration in ashy and gross fiber.

The humidification tower is cylindrical and padded of ½ inch Rasching rings, will have 0.33 m and 1.96 m of diameter and height respectively. The designed dryer is of pneumatic transport. It will operate to temperatures around the 315 - 371 °C, with this value and with the evaporation capacity calculated through the mass balances was carried out the election of the normalized equipment.[2]

The transport system it is formed by four continuous screw conveyors besides a another one of this type inside of the rotational drum fermenting. The investment to carry out in the plant keeping in mind the proposed modifications, their depreciation in the time and that their time of useful life is of 10 years it is of $72 697.21. The cost of production was calculated following the guide for the approved proposal of prices for the Ministerio de la Industria Azucarera.

The cost of production of the humid product *Bagacillo Miel Amoniada* is of $19.52/t - 12.92 CUC/t and the cost of production of the dry product *Bagames* is of $56.94/t - 35.49 CUC/t . It is observed that the dry product cost is almost three times bigger than the humid product cost. This owes mainly to the expenses in raw materials. This product when drying off diminishes its weight in almost 2.5 times, that which sensitivity elevates the unitary cost. The drying is, however, an important step because it guarantees a product of more quality and durability. In this form the product can be employed in species and categories of animals as they are the monogastrics, in those that the formulation of the portions demand that the product be dry. In these animals such as the egg-laying hens and the pigs could be substituted other cereals that have a high price in the international market.

The humid product cannot store for long periods of time since it breaks down losing all use value. The drying preserves the product and it could store for long periods of time. If either of the products variants proposed took place was proven that the investment recovery time would be 5.35 and 4.50 years for the first one and second variants respectively. On the other hand, taking place both variants at the same time it recovers the investment in 2.44 years. Starting from this result it was carried out the rest of the economic calculations and it is of noticing that just by 155 d of production a year the effectiveness of the investment becomes difficult to achieve at high levels, however, the NPV and the calculated IRR to 5 years of making the investment and paying in advance shows high securities, worthy of trusting the investment. The total annual average gain is of $29 736.01 with a NPV of $219 407.48 and IRR of 39.13 %, these results indicate that the introduction of this variant in *Siboney* Sugar Mill it will bring an economic benefit.

CONCLUSIONS

Applying this technology is possible to recycle in one day 19.89 t of trash and 28.70 t of final honey and to obtain 51.5 t/d of *Bagacillo Miel Amoniada* and 21 t/d of dry *Bagames* as food for the ruminant animals as well as monogastrics animals.

The resulting product presents stable quality with 85 % of dry matter; 8-10 % BS true protein; less than 15 % BS gross fiber; 8-9 % BS ashy and total sugars of 8-10 % BS.

The technical economical analysis of the plant is feasible because the investment is recovered in 2.44 years with a NPV of $219 407.48 and IRR of 39.13 %.

A favorable impact is achieved on the economy of the complex, accompanied at the same time of the reduction of the polluting load of the Sugar Mill, and of social benefits for the residents of the area.

It was registered a software in Microsoft Excel to design other plants of this type available all over the country.

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RESULTADOS CIENTIFICOS DESTACADOS MINISTERIO DE EDUCACION SUPERIOR DE CUBA

APLICACION DE MARCADORES MOLECULARES AL ESTUDIO DE LA BIODIVERSIDAD DEL GANADO BOVINO CUBANO

Centro Nacional de Sanidad Agropecuaria

Los estudios de biodiversidad son prioritarios en muchos campos científicos. La caracterización genética del ganado autóctono supone conocer la situación de las poblaciones para su conservación. Hasta el momento, el conocimiento de las características genéticas del ganado bovino cubano se ha basado en el análisis de polimorfismos bioquímicos de grupos sanguíneos y proteínas lácteas. Su clasificación se ha realizado según diferencias fenotípicas de cada raza y de la evaluación de parámetros productivos.

El trabajo realizado permitió determinar por primera vez, mediante marcadores moleculares, la estructura genética para los genes de las seis proteínas lácteas y de 30 loci microsatélites recomendados por la FAO, de tres razas bovinas cubanas: Criollo, Siboney y Cebú Cubano. Para la caracterización de dichas razas se calcularon las frecuencias alélicas, las heterocigosidades por locus y para cada población y se determinaron los parámetros de equilibrio y las relaciones citogenéticas entre ellas y con ocho razas españolas de referencia.

Se identificaron alelos específicos que pueden ser utilizados como marcadores raciales. Fue comprobado que existe una elevada variabilidad en las tres poblaciones cubanas analizadas, lo cual es importante para el diseño y control de programas de mejoramiento. El Cebú Cubano está más alejado filogenéticamente del Siboney y del Criollo de Cuba y este más cercano de razas españolas que se reportan como las que probablemente fueron introducidas en América en la época de la colonización.

Con los resultados obtenidos se dispone de una metodología de análisis de marcadores moleculares para la caracterización del ganado bovino cubano, tanto para estudios de biodiversidad, como para otras aplicaciones de interés económico.

El trabajo fue seleccionado como el más destacado en el curso académico 2004-2005 en la Sección de Ciencias Agropecuarias.