

THE COLOMBIAN EXPERIENCE IN THE PRODUCTION OF BIOETHANOL FOR TRANSPORT USE

By

E.F. CASTILLO, J.E. LARRAHONDO,
A.L. GÓMEZ and J.I. SOCARRÁS

Colombian Sugarcane Research Center, CENICAÑA
efcastillo@cenicana.org

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Abstract

THE NATIONAL Colombian Program for promoting the use of oxygenated gasoline for transport purposes started in 2001 with the implementation of the governmental tax incentives and the definition of the required technical framework for blending and fuel quality. The maximum level of blend for ethanol and gasoline was determined to be 10% v/v and the minimum concentration of dehydrated ethanol 99.5% v/v. Since 2005, five ethanol plants, using sugarcane feedstocks, are operating in the country with an overall production of 1 050 000 litres/day. The technological configuration of all plants is alike, mainly conformed by a continuous fermentation section and a continuous ethanol dehydration section. This paper describes some specific features derived from the commencement of the plants and some problems found in the normal operation of the fermentation. These troubles are mainly related to persistent microbial contamination in the fermentors, which reduces ethanol production efficiency and causes an overproduction of toxic and inhibitor organic compounds like acetic acid and lactic acid, among others. From a monitoring campaign, it was established that each plant had to develop its own adaptation process, such as the usage of different feedstock blending relationships, and to follow different learning curves despite the common technology used.

Introduction

In the past 5 to 6 years, the acknowledgment and acceptance of ethanol as an oxygenating additive for fuels commonly used in automobiles have extended beyond the United States and Brazil, the countries with the highest production and consumption. As a result, different evaluative, legislative, economic, and research activities have been conducted in several countries of Asia, Africa, Europe, and Latin America, as well as Australia, to promote and expand the use of ethanol as a fuel (Shete, 2003).

The production of ethanol and the establishment of new alcohol production plants, or the expansion of existing plants, are important issues for the sugar and sucro-chemical sectors of the department of Valle del Cauca, Colombia, to satisfy the needs for oxygenating compounds or gasoline additives.

Plans, therefore, include the study and search for strategies that reduce the environmental impact of sugar industry effluents, commonly known as vinasses, the main by-product of the alcohol-chemical industry. It is therefore indispensable to have a good diagnosis and characterisation of vinasses in our national scenario.

In the Colombian alcohol-chemical industry, sugarcane molasses is currently used as the substratum and the yeast *Saccharomyces cerevisiae* as the biological catalyst. Vinasse is a high-volume by-product, generated at a ratio of 14 litres per litre alcohol produced.

During production, vinasse is characterised by its high temperature, low pH (4.2–4.6), and high content of suspended, dissolved organic matter. Vinasse also contains a considerable number of inorganic salts (sulfates, phosphates, etc.), calcium, potassium, sodium, magnesium (0.1%–4.4% in concentrated vinasse), and other elements in smaller amounts (6–300 ppm) (Briceño, 2006).

Vinasse has been broadly used in agriculture because it improves almost all soil fertility factors. In Brazil, because of prevailing soil conditions, vinasse is used as an organic fertiliser either alone or mixed with other products, depending on the specific characteristics of each region. In Colombia, however, rates above 50 m³ per hectare are not applied. Although the high organic matter content of vinasse justifies its use as fertiliser, this characteristic should be given special attention when considering new uses of this byproduct. The possibility of extracting organic compounds of high added value should also be studied (Graca, 2002).

In Colombia, ethanol production for transport started in October 2005. Table 1 summarises the capacities and starting date of each Colombian plant. By July 2009, the demand coverage of ethanol reached 85% to supply the biofuel just to the northern portion of the country.

Bioethanol projects and investments in Colombia

Over the last decade, technical, economic, and environmental studies have been conducted in Colombia to determine the feasibility of the country entering the 'bioethanol era'. As a result, several requests for clarification on legal and commercial issues have been presented before the national and departmental governments. The national program that has been established offers the opportunity to address the following sectors and topics:

- Farmers growing cane, maize, cassava, sweet sorghum, potato, and beet.
- Engineering and construction firms, installers, environmentalists, and transporters.
- Effective reduction of CO₂ emissions.
- Opening to biofuels and alcohol chemistry.
- Legal precautions for private investors.
- Sound legislation and regulations in related technical and environmental issues and regarding prices.
- Tax-related incentives (VAT, tax on gross revenue, and surcharge).

Colombia's national fuel alcohol program aims to produce ethanol from sugarcane and other agricultural inputs to improve the quality of gasoline. Legislation favouring this undertaking includes the following:

- Law 788 of 2002 exempts fuel alcohol from the payment of taxes normally charged on gasoline such as the tax on gross revenue, VAT, and surcharge (Articles 31 and 88).
- The Ministry of Environment, Housing, and Territorial Development, together with the Ministry of Mines and Energy, passed Resolution 0447 of 2003 to regulate quality characteristics of alcohol and oxygenated gasoline and to establish the minimum percentage of anhydrous alcohol (99.5%).
- The Ministry of Mines and Energy, by Resolution 181710 of 23 December 2003, established that the ceiling price would be established and then adjusted annually as follows: 70% based on the variation of the Producer Price Index (PPI) and the remaining 30% based on the annual devaluation.
- Conpes (2008) document 3510. Political guidelines for promoting sustainable production of biofuels in Colombia (March, 2008).

In Colombia, the main clients of oil refineries are large distributors that store and re-distribute fuels (petroleum derivatives) to smaller suppliers or clients, who, in turn, sell the product to typical users (citizens). This scheme will continue in the case of alcohol and gasoline mixtures. Each country must not only establish its own product specifications but also define how and where the mixtures are prepared, and how they are dispatched and received. The safety controls to minimise risks, ensure quality, and prevent losses or alterations vary depending on the methods and technologies involved. Figures 1 and 2 present a summarised scheme of the main factors related to important clients of distilleries (Calero *et al.*, 2003).

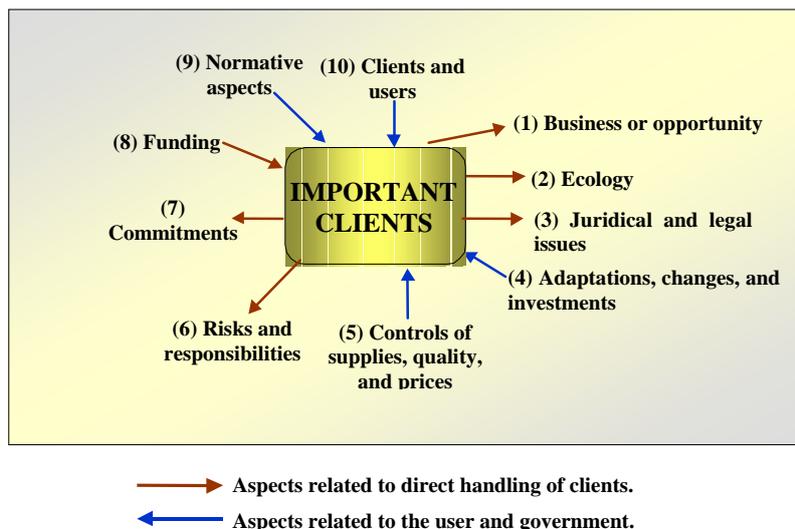


Fig. 1—Factors associated with the reception, mixture, and distribution of gasoline and alcohol that affect the businesses of important clients or distributors.

Figure 2 schematically shows the system of preparing and distributing gasoline-fuel alcohol mixture (10%), adopted in Colombia.

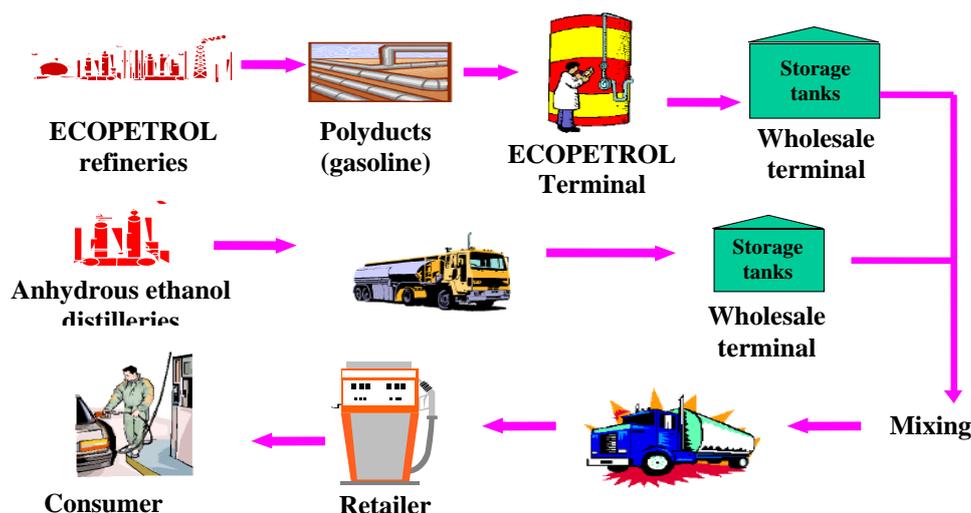


Fig. 2—System of mixing and distributing gasoline-alcohol fuel (10%) mixtures in Colombia.

Bioethanol projects and investments in Colombia

The production of bioethanol as an oxygenating additive for gasoline began in Colombia in October 2005 and, to date, there are five distilleries adjunct to sugar refineries (Table 1).

The building and putting into operation of these new processing plants in the geographical valley of the Cauca River implied the compliance of numerous environmental, technical, legal, commercial, and financial requirements. The factors found to have greater impact on ethanol production projects were the raw material and its permanent availability, the technology used (fermentation, dehydration, effluent concentration and treatment, etc), the effluents produced, energy requirements, automation, and capital costs.

Table 1—Bioethanol production of different cane sugar mills in Colombia.

Cane sugar mill	Bioethanol production (L/day)	Starting date
Mayagüez	150 000	March 11, 2006
Providencia	250 000	October 26, 2005
Risaralda	100 000	March 11, 2006
Manuelita	250 000	March 24, 2006
Incauca	300 000	October 27, 2005
Total	1 050 000	

Source: Briceño (2006).

The investors in new alcohol production plants should assess the opportunities that will arise with the increasing demand for the product worldwide as well as the competition between technologies, raw materials, effluent treatments, development of derivatives/byproducts and reduced investment costs, processes and quality.

In Colombia, the five recently established distilleries are adjunct to cane sugar mills and use technology of Praj and Delta T, with vinasse concentration and its subsequent use to obtain compost (see text boxes 1 and 2, Figures 3 and 4).

1—Proposed project scheme.

- Distilleries adjunct to cane sugar mills.
- Diversity of raw materials (juices, molasses, and syrup).
- State-of-the-art technology.
- Reduced production of vinasse.
- Optimal management of crop residues.
- Production of biomanures.

2—Selected equipment and processes.

- HIFERM-GR continuous fermentation plant (without pre-clarification of molasses and using a special yeast).
- Vacuum distillation.
- Dehydration (molecular screens).
- Vinasse concentration (ECOVAP-FB and FLUBEX fluidised bed evaporation system).
- Wastewater treatment plant.

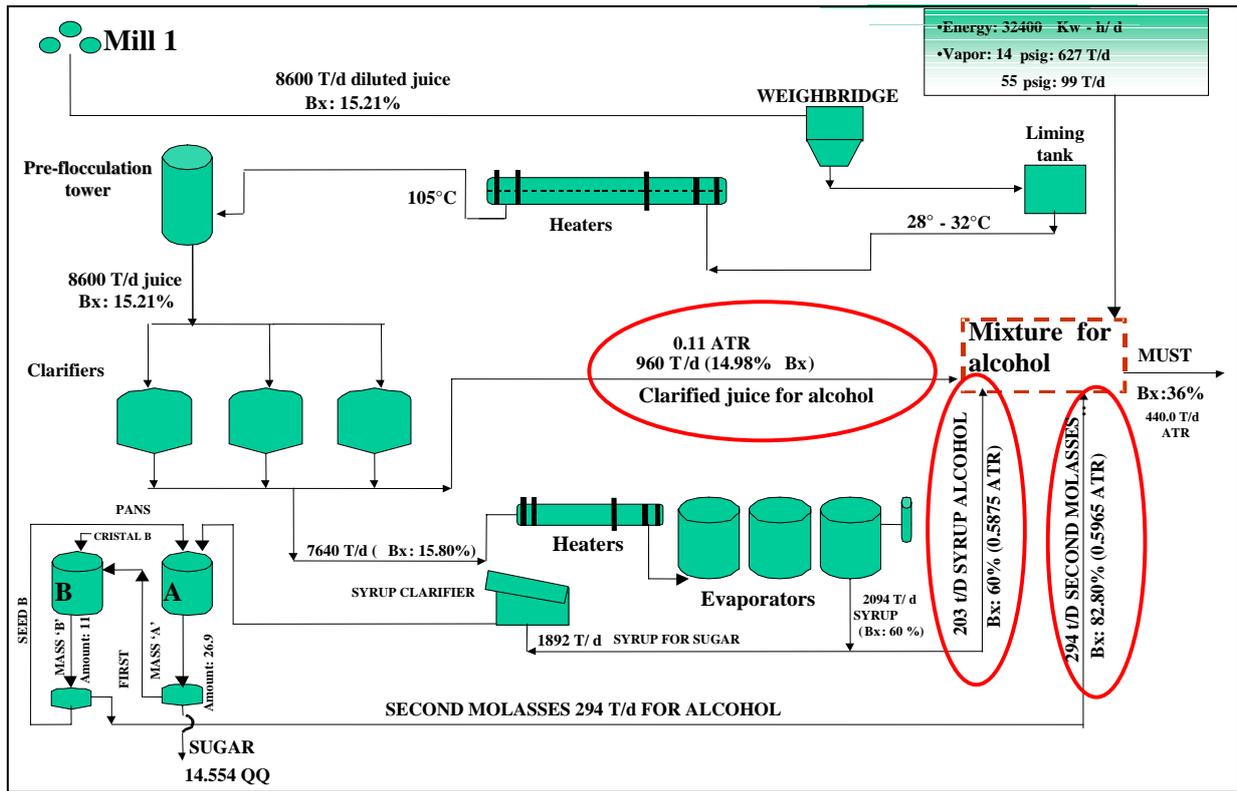


Fig. 3—Typical milling flow chart for sugar production in Colombia. Source: Vivas, A.L. (2006). ATR = Azúcar Total Recuperable (as original) (Total Recoverable Sugar).

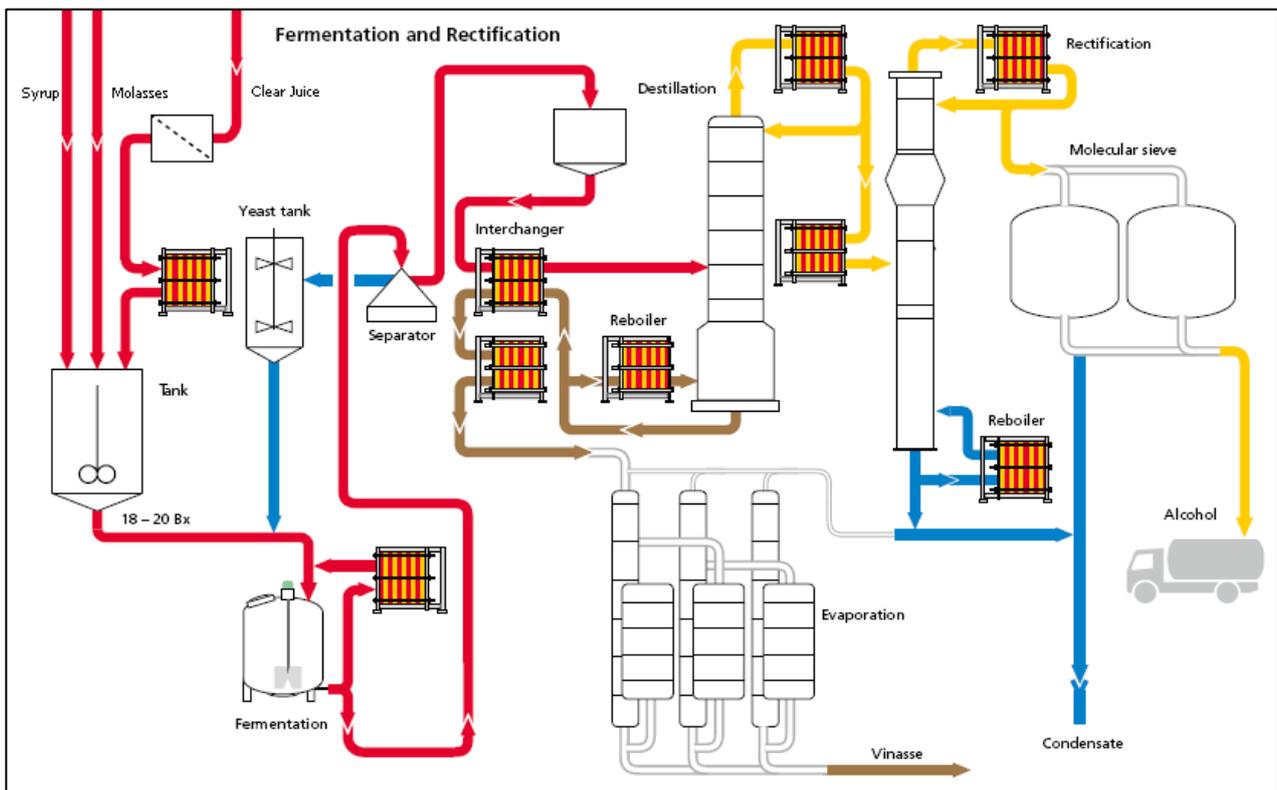


Fig. 4—Typical flow chart for ethanol production in Colombia. Source: GEA PHE Systems (2009).

Relevant features of the actual Colombian technology

The distilleries coupled to sugarcane mills in general use molasses B, with a recirculation system for vinasse. All plants are operating with continuous fermentation, distillation and dehydration process.

The distillation step has two units. From the first one, ethanol at 45% is obtained and from the second, ethanol at 95% is produced followed by the dehydration step. All bioethanol plants are using a strain from the yeast *Saccharomyces cerevisiae* as the biological catalyst, provided by Praj - Delta T Company.

To establish some indicators or parameters which can indicate the performance of the whole fermentation stage, a monitoring campaign was conducted for determining glycerol and organic acids concentration levels (lactic, acetic and butyric) during a steady state operation period of the plant. Then, during an abnormal and atypical operational condition of the fermentors, the same concentration levels were measured, in order to establish any possible relationship between microbial contamination and inhibitors formation. Other operational conditions at the fermentors such as temperature and pH were kept constant.. It must be noted that an abnormal condition situation was promoted by the continuous operation of the plant with no scheduled addition of any microbiological or chemical agent.

The plant uses two continuous fermentors with 8-hours-retention-time each one. Vinnasse was recycled to first and second fermentor. Samples for analytical chemical and microbiological tests were collected from global entering and exiting streams from both fermentors. Additional samples were collected too from the wine tank. Determinations of selected organic compounds were carried out at Cenicaña's lab using HPLC technique. Microbiological analysis uses plate count method. Each monitoring record included three samples of each location.

It was found during the stable or normal operation of the fermentation, that concentration levels of organic compounds were on average lower than 0.6% w/w, while during the atypical stages those reached in average 0.75% w/w (Figures 5 and 6). So, an important increase of 33% of total organic acids content during periods of higher microbial contamination can be reported, which can affect the fermentation process and ethanol production. Also, for glycerol, increases of 3 to 11% were found in its w/w concentration during atypical operation. Population of Lactic Acid Bacteria (LAB) was higher during the atypical operation ($> 2 \times 10^6$ CFU/mL) compared with the levels observed for stable operation ($< 8 \times 10^5$ CFU/mL).

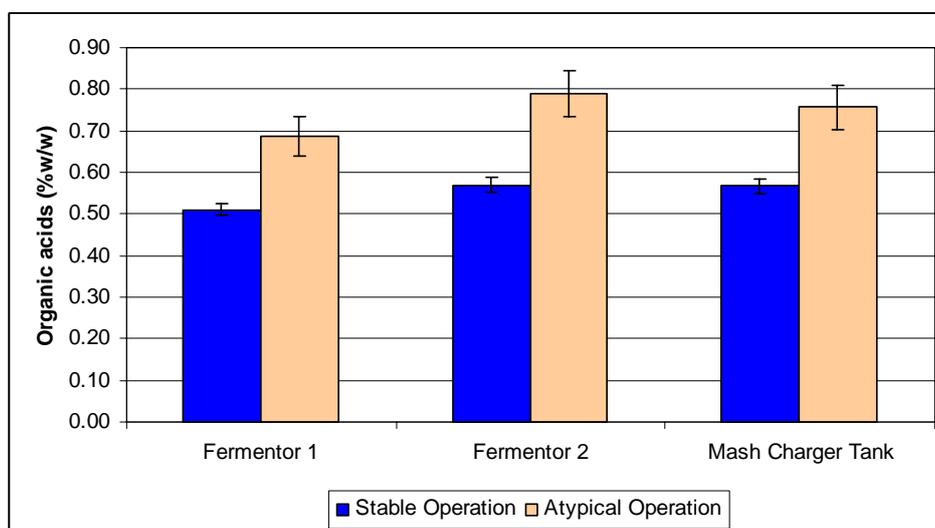


Fig. 5—Organic acids content in a fermentation stage during two different reactor conditions (lactic, acetic and butyric acids).

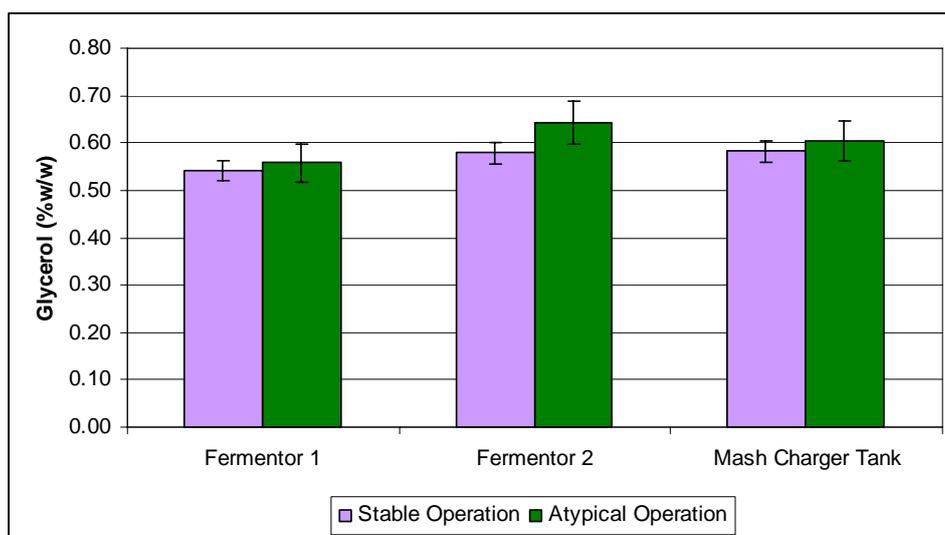


Fig. 6—Glycerol content in a fermentation stage during two different reactor conditions.

In a parallel way, a second monitoring campaign was conducted in a different distillery for assessing the mass and energy balance of the whole plant. It was observed that the ethanol plant produces different vinasse-ethanol ratios mainly explained for the quality of the substrate mixtures supplied to the fermenter. So, it can be established that the mixture of clarified juice-molasses B used as feedstock to the fermenter produced less volume of vinasse per ethanol volume (Figure 7).

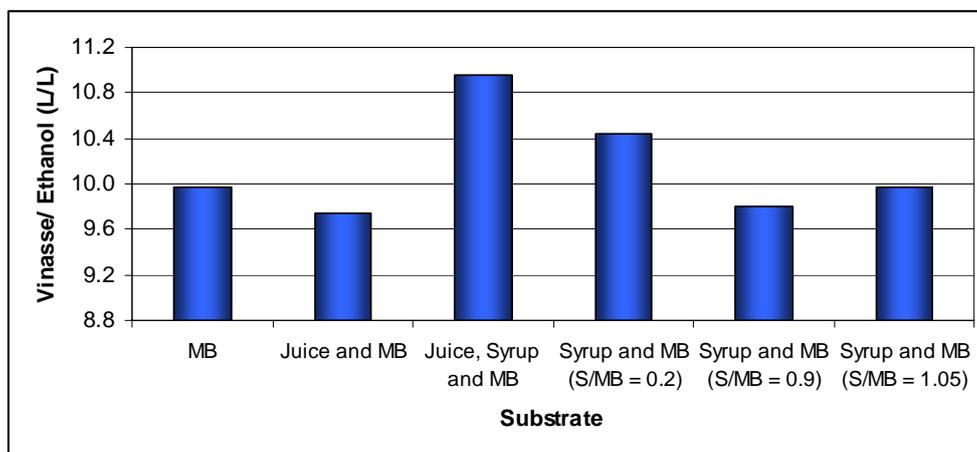


Fig. 7—Vinasse volume per anhydride ethanol produced for several substrates employed during continuous fermentation. (MB = Molasses B; S/MB = Syrup/Molasses B relationship).

It can be noted that some comments on the performance of the selected technological scheme for ethanol plants in Colombia are focused on often recurrent operational problems caused by microbiological contamination by wild yeast and other micro-organisms, such as lactobacillus. In order to establish a biological control for wild yeast or other kinds of micro-organism, further studies are underway which include a biological characterisation of the different strains which might affect ethanol production.

Conclusions

- In medium-term investments, the producer of fuel alcohol should consider aspects ranging from environmental permits granted by the State to commitments with companies responsible for the gasoline mixtures.

- The main use of bioethanol in Colombia is currently as a fuel oxygenating additive; however, a very broad range of derivatives or byproducts exists, all with significant market demand.
- The periodic evaluation of organic acids and glycerol concentration levels can be useful for getting a potential biochemical marker which can be a performance index of the fermentation process.
- Some operational problems arise during the production of bioethanol in Colombia, mainly related with microbiological contamination with wild yeast, causing the need for a new operational approach to the sugar plant.

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L'EXPÉRIENCE COLOMBIENNE DANS LA PRODUCTION DE BIOÉTHANOL COMME BIOCARBUARANT

Par

E.F. CASTILLO, J.E. LARRAHONDO, A.L. GÓMEZ et J.I. SOCARRÁS
Colombian Sugarcane Research Center, CENICAÑA
efcastillo@cenicana.org

MOTS-CLÉS: Sucro-Chimie, Produits Dérivés de Sucre, Industrie de l'Alcool, Vinasse, Bioéthanol.

Résumé

LE PROGRAMME national colombien de promotion de l'utilisation de l'essence oxygéné à des fins de transport a débuté en 2001 avec la mise en œuvre des incitations fiscales par le gouvernement et la définition du cadre technique requis pour le mélange et la qualité du carburant. Le niveau maximal de mélange pour l'éthanol et l'essence a été déterminé à 10% v/v et la concentration minimale d'éthanol déshydraté 99.5% v/v. Depuis 2005, cinq usines d'éthanol utilisent de la canne à sucre comme matière première, opèrent dans le pays avec une production globale de 1 050 000 litres par jour. La configuration technologique de toutes les usines est semblable, composée d'une section de fermentation continue et d'une section de déshydratation continue d'éthanol. Ce document décrit certaines fonctionnalités spécifiques provenant de l'ouverture des usines et certains problèmes rencontrés dans le fonctionnement normal de la fermentation. Ces perturbations sont principalement

liées à la contamination microbienne persistante dans les fermenteurs, qui réduisent les rendements de production d'éthanol et entraîne une production de composés toxiques et d'inhibiteurs organiques tels que l'acide acétique et acide lactique. À partir d'une campagne de suivi, il a été établi que chaque usine devait développer sa propre stratégie, telle que l'utilisation de différentes matières premières en mélange, et de suivre différentes courbes d'apprentissage malgré que la technologie soit communément en utilisation.

LA EXPERIENCIA COLOMBIANA EN LA PRODUCCIÓN DE BIOETANOL PARA USO EN TRANSPORTE

Por

E.F. CASTILLO, J.E. LARRAHONDO, A.I. GÓMEZ y J.I. SOCARRÁS
Colombian Sugarcane Research Institute, CENICAÑA

efcastillo@cenicana.org

PALABRAS CLAVE: Sucroquímica, Derivados del Azúcar, Industria Alcohólera, Vinazas, Bioetanol.

Resumen

EL PROGRAMA Nacional Colombiano para promover el empleo de gasolinas oxigenadas para propósitos de transporte comenzó en el 2001 con la implementación de incentivos gubernamentales de impuestos y la definición del marco técnico requerido para la mezcla y calidad de los combustibles. El máximo nivel de mezcla etanol- gasolina se determinó que era 10% v/v y la mínima concentración de etanol deshidratado 99.5%. Desde el 2005 operan en el país cinco plantas de etanol, empleando caña de azúcar como materia prima, con una producción total de 1 050 000 litros/día. La configuración tecnológica de todas las plantas son similares, conformada básicamente por una sección de fermentación continua y una sección continua de deshidratación de etanol. Este trabajo describe algunos aspectos específicos derivados de la arrancada de las plantas y algunos problemas encontrados en la operación normal de la fermentación. Estos problemas están básicamente relacionados con una contaminación persistente en los fermentadores, que reducen la eficiencia de la producción de etanol y causa una sobreproducción de componentes orgánicos tóxicos e inhibidores, tales como los ácidos acético y láctico, entre otros. A partir de una campaña de monitoreo, se estableció que cada planta debe elaborar su propio proceso de adaptación, tales como el empleo de diferentes relaciones de mezcla de materias primas y seguir diferentes perfiles de desarrollo y adaptación con independencia de la tecnología común empleada.