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Brazilian Bioethanol Program

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Abstract

Brazil is the largest producer of bioethanol, and sugarcane is the main raw material. Bioethanol is produced by both batch and continuous processes, and in some cases, flocculating yeast is used. This article analyzes the Brazilian Ethanol Program. For the 1996–1997 harvest, Brazil produced 14.16 billion L of ethanol and 13.8 million metric t of sugar, from 286 million metric t of sugarcane. These products were produced by 328 industries in activity, with 101 autonomous ethanol plants producing only ethanol, and 227 sugar mills producing sugar and ethanol. The sugar-ethanol market reaches about 7.5 billion US$/yr, accounting for direct and indirect revenues.

Index Entries: Sugarcane; alcohol; bioethanol program; ethanol.

Introduction

Ethanol is produced from different raw materials, of different origins, such us petroleum and agricultural crops or residues. Ethanol made from petroleum is used in industrial applications, and ethanol from agricultural

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crops is primarily used in fuels, beverages, perfumes, and pharmacology. Ethanol made from residues is mainly used as motor fuel.

A great proportion of the ethanol produced in the world is used as fuel (68%). Industrial application consumes about 21% of the produced ethanol, and beverages about 11% *(1)*. In 1997, worldwide ethanol production was about 33.3 billion L.

Ethanol production is not evenly distributed throughout the world. North America is responsible for 66%, Asian and Pacific Ocean countries for 18%, Europe for 14%, and Africa for 2% *(1)*. Countries that contribute a great share of the global production are Brazil (about 53%), the United States (19%), and other countries besides China, India, and Russia *(1)*. The objective of this article is to present a review of the Brazilian Ethanol Program.

The Brazilian National Alcohol Program

In Brazil the sugar-ethanol market trade reaches about $7.5 billion/yr (all dollar amounts refer to US$ throughout), taking into consideration direct and indirect payments. This amount corresponds to 2.3% of the Brazilian GDP. Brazil is the largest world producer of sugar from sugarcane and the sole country to implant a large-scale, renewable, alternative fuel to petroleum. Ethanol is recognized worldwide as a more ecologically satisfying fuel because of its advantages for the ambient, as well as its social and economical advantages. During the 1997–1998 harvest season, 300 million metric t of sugarcane was milled, resulting in 14.8 million metric t of sugar and 13.8 billion L of ethanol. Ethanol is produced in the form of hydrated ethanol (the azeotropic mixture) and anhydrous ethanol. The latter corresponds to 5.41 billion L, which is used for blending with gasoline, usually in a proportion of 22–24% of anhydrous ethanol by volume. The hydrated ethanol is used as straight motor fuel for alcohol-driven automobiles. A large share (87%) of this ethanol production is concentrated in the central/southern region. The state of São Paulo alone produced a 9 billion L of ethanol, of which 1 billion L was of the anhydrous type. The Brazilian industrial park contains 328 industries in activity, with 101 autonomous ethanol plants producing only ethanol and 227 sugar mills producing sugar and ethanol. This industrial sector generates about 602,000 direct jobs *(2,3)*.

The Brazilian National Alcohol Program, Pro-Alcohol Program, was implemented in 1975 and is responsible for the impressive increase in ethanol production in Brazil from 500 million L, at the beginning of the program, to approx 13 billion L of alcohol per year, since 1986 *(4,5)*. This enormous production volume derives exclusively from the fermentation of sugarcane juice.

Since 1986, Brazil has maintained a constant fleet of about 4.5 million alcohol-driven cars. Nonetheless, the gasoline-fueled fleet, equipped with engines using a 24% ethanol–76% gasoline mixture, has been increasing steadily and now consists of approx 9 million vehicles.

This enormous production volume makes the program indisputably important in Brazil. Its socioeconomic impact is significant because an estimated 600,000 to 1 million jobs are directly connected to the production of alcohol. Its importance also lies in its strategic impact, because it reduces the country's dependence on foreign sources of energy by substituting part of Brazil's oil consumption requirements. In 1997, the country reduced its oil imports from 400 to 300 million barrels. The program is also responsible for saving cash resources by reducing the trade balance deficit. In 1997, Brazil's deficit was $8 billion of which $6 billion was spent on crude oil. Finally, the Pro-Alcohol Program has a supporting role in preserving the environment. Besides the fact that anhydrous ethanol substitutes tetraethyl lead as a gasoline additive, sugarcane also removes CO_2 from the air.

Reasons for the Program's Implementation

Three factors led to the implementation of the Pro-Alcohol Program in Brazil *(4,5)*. The first factor was that it allowed the country to steer clear of trade deficits resulting from the high imported crude oil prices, which had soared from $2.50/barrel in 1973 to more than $20.00 in 1979, reaching $34.40/barrel in 1981. This huge price hike forced Brazil to spend exceedingly large cash reserves on imported oil, i.e., from $600 million spent in 1973 to $2.6 billion in 1974 and up to $10.6 billion in 1981.

The second factor was that the program enabled Brazil to depend to a much lesser degree on imported energy. Basically, Brazil had imported 34% of its total energy consumption in 1973 in the form of crude oil. This figure dropped to 18% in 1986, after implementation of the Pro-Alcohol Program. The transportation sector depended exclusively on oil-derived products. In other words, 98% of that energy came from crude oil, of which 65% was gasoline. This meant the program had to concentrate on finding a substitute for this oil derivative.

The third most important factor for implementation of the Pro-Alcohol Program was that international sugar prices had dropped from $1400/metric t—the all-time high in November 1974—to $268/metric t in December 1975 *(6)*. Sugar mill owners in Brazil have always exerted a strong influence on the federal government's decisions, and the program represented the ideal solution to their problems. The production of alcohol allowed for flexibility in the sector, preventing the formation of large stocks of sugar by diverting the raw material to produce ethanol.

Implementation of the Program: Two Phases

In 1975, the Brazilian government established the Brazilian National Alcohol Plan with the aim of protecting the Brazilian economy from fluctuations of the petroleum market, largely attributed to social and political instabilities of oil producers in the Persian Gulf *(5)*.

The implementation of the Pro-Alcohol Program was divided into two well-marked phases *(4)*. The first phase, which began in 1975, took advantage of the structure and capacity of existing sugar mills (those that already produced sugar) to produce only hydrated alcohol. The ethanol replaced tetraethyl lead as a gasoline additive. The proportion of ethanol in the ethanol-gasoline mixture was increased from 1.1% in 1975 to 16.7% in 1979, without the need for alterations in automobile engines.

In the second phase, which began after 1979, hydrated alcohol began to be produced for direct use as automobile fuel, which required a complete modification of the engine. This change came about as the result of an agreement between the federal government and the National Association of Automobile Manufacturers (ANFAVEA), the official representative of the Brazilian automotive industry.

ANFAVEA was committed to developing technology for automobile engines driven exclusively by hydrated alcohol and for engines using a mixture of >20% anhydrous alcohol with gasoline. The federal government agreed to keep the price of hydrated alcohol at 65% of the price of gasoline, and the tax on industrialized products (IPI tax) for alcohol-driven automobiles was lower than for gasoline-driven cars.

As a result, by 1986, 96% of the automotive industry's production consisted of alcohol-driven cars, sugarcane plantations expanded to new areas, and autonomous ethanol plants were established exclusively for ethanol production. In 1989, nearly 4.5 million units of ethanol-fueled vehicles were sold out and, at that point, nearly $11 billion was invested in the infrastructure to attend the increasing demand for this environmentally friendly biofuel.

The federal government offered financial incentives consisting of interest rates below the inflation rate (negative interest rates) and average 12-yr loan repayment terms extendable for 3 yr. This resulted in a stunning annual growth of 35% in the sector, and Brazil's 1994–1995 sugarcane harvest yielded an ethanol production of 12.6 million L, produced by 160 mills with mixed sugar and alcohol production and 138 producing alcohol exclusively.

Problems Plaguing the Program

In 1980, several problems caused by a variety of factors began to plague the program *(4)*. The period of the "Brazilian miracle" was over and was replaced by a retraction of the country's economy. As a result, the government was forced to redefine national priorities. Stabilization of the price of crude oil at about $10/barrel no longer made the substitution of gasoline by alcohol advantageous, as had been the case in past years. The government, therefore, decided to reduce the price of ethanol to be paid to the producers. This price was set based on the average cost of the different producers, but production costs varied significantly between modern, productive mills and outdated mills with their high production costs, located in areas that were not traditionally sugarcane-producing regions. This difference in costs further aggravated the situation for the outdated mills.

The year 1986 brought a new reduction in Pro-Alcohol Program incentives. The special credit line for the cultivation of sugarcane was cut, wors-

Table 1
Fuel Consumption in Brazil

Fuel	1996 (10^9 L)	1997 (10^9 L)
Gasoline + 20% ethanol	19.0	21.3
Gasoline	14.8	16.7
Ethanol, anhydrous	4.2	4.5
Ethanol, hydrated	9.4	9.5
Diesel	27.0	29.2

ening the situation of the mills. The resulting lack of sugarcane caused a drop in production of 4 billion L of alcohol in 1987, which represented the difference between the installed industrial capacity (16 billion L) and the production capacity of the agricultural sector. The idle capacity caused production costs to increase even further.

In 1988, the accumulated problems culminated. As a result of the growth of the international market, which caused production to be diverted from ethanol to sugar, and the continuous growth of the demand for hydrated alcohol, Brazil faced a crisis in its alcohol supply, which led the country to import ethanol and methanol. Brazil has always had to export its excess production of gasoline. The imports of ethanol and methanol at prices above those received for exported gasoline led to a deficit, known as the Alcohol Bill.

From the point of view of the automotive industry, after total sales of 4.5 million vehicles in the 10-yr period that succeeded the ANFAVEA agreement, several unfavorable factors related to the production of alcohol-fueled vehicles began to plague the industry: Fuel supplies became unstable; the price of hydrated alcohol gradually increased in relation to gasoline—rising from 64.5% in 1979 to the current 80%; and the federal government established IPI tax incentives for gasoline-driven automobiles while reducing the IPI tax incentive for alcohol-driven vehicles. These factors led the industry to reduce the production of alcohol-fueled vehicles, which fell from 96% of total domestic sales in 1985 to 3.3% in 1996, representing a mere 0.07% of the fleet in 1997. Table 1 gives the Brazilian average fuel consumption for 1996–1997.

According to ANFAVEA, 1,244,463 cars were produced in Brazil in 1998, but only 1188 of these units were equipped with ethanol-fueled engines, i.e., <0.1% of the overall national production. Nevertheless, ethanol still represents nearly 51% of the liquid fuel consumed in Brazil (hydrated alcohol plus blends with other fuels), and a demand for 12.7 billion L of ethanol was identified in 1997, with 63% being utilized as a hydrated alcohol fuel. On the other hand, the sugarcane industry still generates nearly 1.3 million direct jobs, 54% of which are directly related to ethanol production. Therefore, the maintenance of the program is not only strategically important under the technoeconomic viewpoint but also extremely critical, because its complete deactivation would impart a tremendous social problem for those regions where sugarcane is the main source of revenue.

The Pro-Alcohol Program's Performance

The production of sugarcane in Brazil has expanded quite substantially during the last few years, rising from 240×10^6 t in the 1994–1995 harvest season to nearly 300×10^6 t in 1997–1998. According to recent surveys, this massive production corresponds to 25% of all sugarcane produced worldwide. The amount of land devoted in Brazil for sugarcane plantation corresponds to approx 5% of all available arable land, which provides nearly 1×10^6 direct jobs in rural areas.

On the other hand, production of ethanol from fresh sugarcane juice and molasses (the mother liquor resulting from the oscillating parcel of the crop directed to the production of table sugar) reached 13×10^9 L in 1994–1995 and increased slightly to 14×10^9 L in 1996–1997, but dropped to 12.3 $\times 10^9$ L in 1997–1998 as a result of the decreasing demand for ethanol as a hydrated alcohol fuel. Even though there was a noticeable decline in the entire national ethanol production during this last season, the production of anhydrous ethanol increased from 2.8×10^9 L in 1994–1995 (21.5% of national production) to 4.6×10^9 L in 1997–1998 (37.4%). This tendency was a direct result of government policies toward ethanol/gasoline blends, which now correspond to 24% and could increase to 25 to 26% in the near future with pending government actions. The remainder of the national production of ethanol is devoted to hydrated ethanol-fueled automobiles (ethanol concentration in the range of 92.8–93.6%) and other industrial and domestic uses. Of course, fresh sugarcane juice and molasses, and anhydrous alcohol, have been reduced in their share of the national production, from 9.7×10^9 to 7.4×10^9 L for the former and 0.5×10^9 to 0.3×10^9 L for the latter during the same aforementioned period. Table 2 gives the current market prices of fresh sugarcane, fuel ethanol, and gasoline in Brazil.

In the time course of the Pro-Alcohol Program, sugarcane-derived ethanol has experienced a sale price reduction >50% (Fig. 1) as result of improvement in the production technology and as a positive answer to the requirement from a more competitive fuel market.

A simple mass balance based on 1 t of harvested sugarcane stalks points to a yield of 750 L of raw sugarcane juice and 250 kg of wet bagasse containing nearly 50% of its weight in moisture. On average, the former contains 18.5% sucrose and 1.7% of other fermentable sugars such as glucose and fructose, accounting for a total of approx 150 kg of fermentable sugars in 1 t of sugarcane stalks. On the other hand, 125 kg of dry bagasse contains 53.8 kg of cellulose (43%), 31.3 kg of xylan (25%), and 28.8 kg of lignin (23%); 3% of acetyl groups in heteroxylans (corresponding to 4 kg of acetic acid); 6 kg of extractives including residual sucrose (4%); and 3 kg of ashes (2%) *(7)*. Therefore, considering that the amount of fermentable sugars found in bagasse could be recovered at 90% efficiency after a two-stage acid treat-

Table 2
Current Market Prices of Fresh Sugarcane, Fuel Ethanol, and Gasoline in Brazil

Commodity	Market price (Brazil) (US$)[a]
Fresh sugarcane	10.00/t (gross); 8.00/t (net)
Fuel ethanol (92.8–93.6%)	1.18/gal (about 3.8 L)
Gasoline ([EtOH] = 22–24%)[b]	1.05/gal (about 3.8 L)[b]

[a]As of April 27, 1999, within a realistic currency exchange ratio of 1US$ = 1.70 R$.

[b]In the United States, a range from 1.00–1.25 US$/gal with, at most, 10% ethanol blend but only in urban regions or in the winter season (pollution control). The current ethanol market price in Brazil is about 40% of the price in 1976.

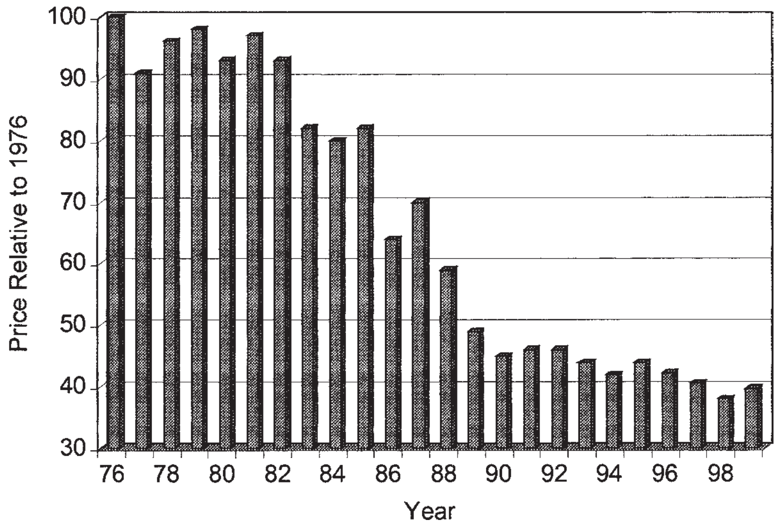

Fig. 1. Evolution of the ethanol market price in relation to 1976, when the Brazilian National Alcohol Program was launched. The Brazilian government has programmed a cut in ethanol subsidies after October 1999 that will increase the ethanol market price by 20%.

ment and/or enzymatic hydrolysis, the theoretical yield of fermentable sugars from whole sugarcane (juice plus bagasse) would reach 227 kg/t. Thus, bagasse adds a 50% bonus over the total amount of ethanol produced from sugarcane. Nevertheless, most, if not all, bagasse actually produced in Brazil is used for purposes other than ethanol production (e.g., cattle feeding and power cogeneration). Considering that moist bagasse has a calorific value of 1800 kcal/kg, the surplus energy arising from its burning is sold by several sugar mills to neighbor companies processing unrelated business such as citrus and paper plants. Because bagasse and sugarcane stalk straw have a similar cellulose:lignin:hemicellulose composition, the latter deserves the same energy-providing purpose.

The Cooperative for the Cane, Sugar, and Ethanol Producers and Its Sugarmill Complex

The Cooperative for the Cane, Sugar, and Ethanol Producers from the State of São Paulo (COPERSUCAR) is the major sugar mill complex in Brazil, with a network enrolling 88 associates. In 1998, 38 associated ethanol plants (>20% of the total 350 mills/ethanol plants mainly widespread in Paraná, Pernambuco, Alagoas, Rio de Janeiro, and Minas Gerais states) processed 70×10^6 t of sugarcane. In the crop year of 1998–1999, 4×10^6 t of table sugar and 3.2×10^9 L of ethanol were produced, which corresponds to 25% of the national market for these products.

With the impressive background of 40 yr in this field, COPERSUCAR has always invested quite substantially in research and technology development. Thirty-one sugarcane varieties have been developed in its laboratories, and field trials with specific transgenic clones have been already authorized. Field tests conducted with the chemical ripener ethyltrinexapac has enabled a 1.0–2.1% pol increase in four varieties, and the utilization of Landsat/TM satellite imaging enhanced the capability of controlling the plantation areas and of identifying all the different varieties.

In 1998, the largest ethanol plant of the COPERSUCAR conglomerate, Usina São Martinho (Pradópolis, São Paulo), was responsible for an average industrial processing of 36×10^3 t/d of sugarcane stalks, crushed for the production of both ethanol and sugar (sucrose). Ethanol is produced there in fed-batch vats, and the installed capacity of this particular mill is capable of reaching 2×10^6 L/d of ethanol at its season processing peak—in fact, enlarged to 8 mo for every 1-yr crop season.

The average performance of the COPERSUCAR-associated mills reached rather impressive numbers in 1998, with a 91.5% average fermentation yield (best at 93%), average fermentation time of 9 h (best at 5 h with cell recycling), average ethanol final concentration of 11.0% with no antifoam agent needed and almost complete energy self-sufficiency, with several mills being able to sell their surplus-generated power to the grid.

As compared to the São Martinho mill, two of the COPERSUCAR-associated sugar mills, Using Santa Adélia (Jaboticabal, SP) and Usina São José da Estiva (Novo Horizonte, SP), operate in a continuous fermentation mode and have an average production of 6×10^5 and 5×10^5 L of ethanol/d for the same 8- to 12-mo operation period, respectively.

More recently, several activities have been conducted at COPERSUCAR to diversify the product portfolio obtained from sugarcane, and some of the results achieved so far have shown great potential for commercialization. In this regard are two examples of value-added goods. First, the production of biodegradable plastic substitutes such as polyhydroxybutyrate (PHB) (mean mol wt 4×10^5), developed in conjunction with the Institute of Research and Technology of São Paulo State, was attained at a pilot plant scale. Second, and even with more success, there is the Baleme pellet, a blend of hydrolyzed bagasse, *Saccharomyces* single cell protein

(SCP), and molasses is already being commercialized as fodder for cattle and other animals.

The full commercial Program on Single Cell Protein (*Saccharomyces cerevisiae*) achieves value addition because the protein contents range from 31 to 40% by weight, with increased digestibility, reduced moisture content (10%), and the suitable acidity leading to good organoleptic properties. Because there is a surplus availability of about 20 g of dried yeast cells/L of produced ethanol, these qualification marks have ensured sales of $300.00/t of SCP. The main local and export applications are as fodder for cattle, dogs, and cats, and for fish farming.

Brazilian Bioethanol Progress: Continuous Processes

In Brazil, the development of new technologies for alcoholic fermentation processes from sugarcane juice, or molasses, was aimed at the maximization of productivity and minimization of production costs that plagued traditional technologies. The main technological innovation was the development of continuous fermentation processes, which were improved for at least 10 yr since 1975, and represent today's modern, reliable, and less expensive way of producing ethanol on an industrial scale. Modern continuous processes incorporated optimization methods and mathematical modeling with the objectives of new plant design toward maximization of productivity and higher flexibility, with the capability of absorbing fluctuations in raw material quality and quantity.

In spite of the significant advances, the pressing need to decrease the costs of ethanol production (approx $1.00/gal in 1998) has led to new process modifications: either use recentrifugation of yeast or modify the process in order to avoid centrifuges.

Alcoholic fermentation in Brazil was begun in the first half of the twentieth century. The raw material for ethanol production was molasses, and plants were mainly associated with sugarcane production. The classic process was batch fermentation of diluted molasses in which the first vat used fresh yeast as starter. Each subsequent vat to be fermented used half of the volume of the previous vat as the yeast for fermentation, and the other half from the previous vat was sent to distillation columns.

From 1960 to 1970 the fermentation process known as the Melle-Boinot Process was introduced in Brazil. It was developed in France in the early 1930s. The main characteristic of this process is the use of disk-bowl centrifuges for separation of the yeast cream, which is then diluted with freshwater and treated with sulfuric acid to decrease the pH to 2.0–2.5, and maintained in agitation for about 1.0–1.5 h before a new batch is started. It is a fed-batch process, in which the substrate is fed under controlled conditions until the total useful volume of the fermentor is reached.

The first generation of continuous fermentation processes appeared in the 1970s, as low-cost adaptations of batch processes. Several operational problems were detected in this adaptation, such us high level of contamina-

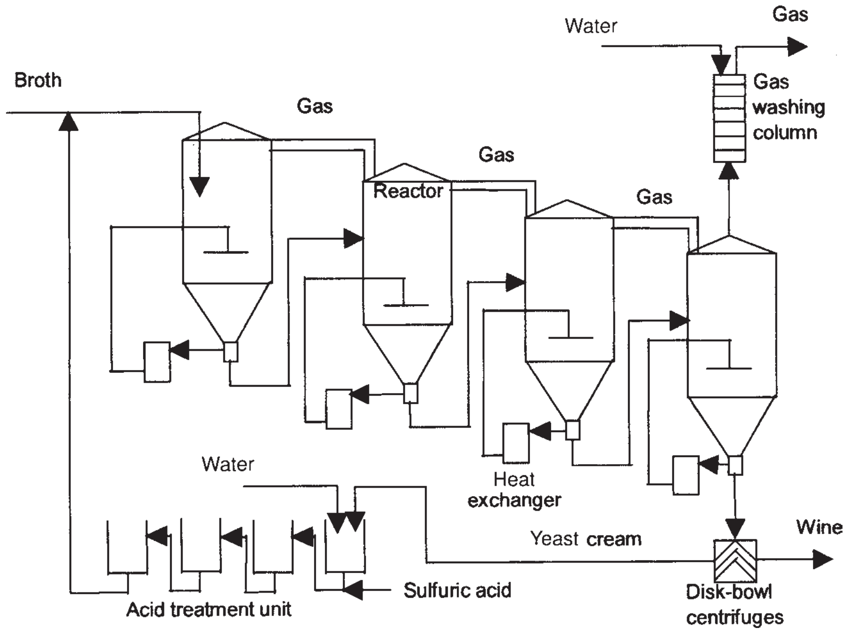

Fig. 2. Flowsheet of a continuous process using centrifuges.

tion, low productivity, low yield, and problems with solid flow, leading to a delay in the process implementation.

In 1981, a second process of generation appeared with the following main characteristics: introduction of basic engineering concepts such as agitation, control systems, and improvements on materials flow. Even with such improvements, the second-generation process still is not an optimized process in the sense of productivity and reactor design. As a consequence, a third generation of continuous processes was launched with the objective of overcoming some of the previous technological limitations. These kinds of processes are based on kinetics models and have a specific reactor design. The process updating resulted in higher productivity (typically 10 mL/[L·h]), higher process flexibility and stability, and lower consumption of chemicals.

The main features of third-generation processes are multiples stages (four or five) of variable sizes. The initial broth is fed to the top of the first reactor together with the yeast cream and comes out through the bottom of each stage, flowing then by gravity to the middle of the next stage, as depicted in Fig. 2. The reactors have a conical bottom inclined at 60° and an aspect ratio (height/diameter) of 1.2 in the cylindrical part. Each reactor has an external plate-type heat exchanger for removing the heat released by fermentation. The kinetic energy of the liquid at the heat-exchanger outlet is used for liquid agitation in the reactor, decreasing energy consumption in the process. Gases and foam released from the fermentation process are conducted from the top of each reactor to the next reactor and washed in a perforated plate column. The biomass produced in this process is separated

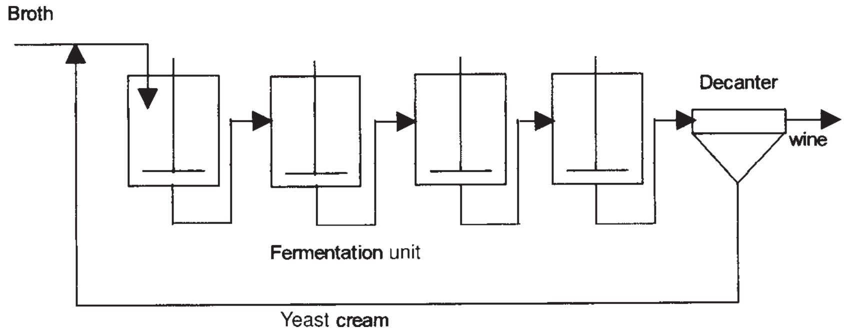

Fig. 3. Flowsheet of a continuous process using decanters.

Table 3
Maximum and Minimum Values of Typical Parameters for MGS Process

Parameters	Maximum	Minimum
Concentration of total reducing sugars in the broth	17.5% in weight	16% in weight
Recycle rate	45%	35%
Operation temperature	35°C	33°C
Broth temperature	32°C	—
Yeast temperature	30°C	—
Cell concentration in yeast milk	—	60%
Cell concentration in treated milk	40% in volume	30% in volume
Cell concentration in wine without yeast	1% in volume	—

from the wine by disk-bowl centrifuges, forming a yeast cream that contains from 70 to 80% of cellular mass. The yeast cream flows by gravity to the acid treatment unit, where it is diluted with water (up to 35–40% in volume) and mixed with concentrated sulfuric acid to reach a pH of about 2.2. Figure 2 is a flowsheet of a continuous process using centrifuges. Because of the high costs of centrifugation, new developments were carried out to substitute centrifuges with decanters or new reactor designs. A typical third-generation process of this type is named the MGS process; Figure 3 depicts this process with decanters. Table 3 gives maximum and minimum values of typical process parameters for the MGS process.

Continuous Fermentation Process Using Flocculent Yeast

Almost all industrial plants in Brazil use the Melle-Boinot process, which is based on the recovery of yeast through centrifuges. The NATRONTEC's process uses a flocculent strain of the yeast *S. cerevisiae* and, consequently, it does not use centrifuges for yeast recovery, which occurs in settlers.

Currently, the NATRONTEC's process is used in the following Brazilian industrial plants: Usina Trapiche (Sirinhaém, PE); Usina Cucaú (Rio Formoso, PE); Destilaria Giasa (Pedras de Fogo, PB); Usina Marituba (Igreja Nova, AL); Destilaria Itaúnas (Conceição da Barra, ES); Destilaria Alcomat (Comodoro, MT); and Destilaria Califórnia (Osvaldo Cruz, SP).

In this process, the fermentation broth is continuously fed to the fermentation vessels, and after completion of the fermentation process, the broth is driven from the vessel to the settlers, where the yeast is recovered and sent to the treatment vessel to be treated with sulfuric acid or antibiotics. The cleaned broth is driven from the settlers to a storage tank for future distillation.

The main advantages of the NATRONTEC's process observed at industrial-scale operations can be summarized as follows:

1. Fermentation efficiency is up to 1.5% higher than that obtained with the Melle-Boinnot process.
2. Production costs are lower (<\$6.8/m^3 of alcohol).
3. Settlers are used (centrifuges are more expensive and have higher operational and maintenance costs).
4. Chemical expenses, mainly antifoam, are lower as a consequence of the lower production of foam by the flocculent strain (<\$1.25/m^3 of alcohol).
5. Operational and maintenance costs are lower.
6. Operation is easy.
7. It can be easily installed in the conventional units.
8. It requires lower investments.
9. The yeast strain always keeps its flocculent characteristics.

Future Perspectives for the Pro-Alcohol Program

More than two decades since its creation, it is easy to recognize that the Brazilian Pro-Alcohol Program demands a redirection to minimize the huge conflict now existing between the historical policy and the current unfavorable reality (e.g., the "green" fleet stagnation). This redirection could be based on several actions, such as returning to the original policies of tax incentives and price control, implementing new policies to ensure availability of fuel, and establishing strict regulations for commercialization and good standards for quality control.

Based on a gradual return to the original ruling established for the national plan, one could anticipate a new boom in the Brazilian ethanol market based on the (re)creation of a renewed "green" fleet of taxis and other small transportation vehicles. This has been strongly supported by the government, and steps to somehow subsidize the future of this activity are now being studied (e.g., "green" taxation over diesel and gasoline consumption).

Apart from these structural changes, there is also a need for the identification of new market opportunities. This is being pursued by the government through the following actions:

1. An increase in the anhydrous ethanol content in fuel blends with gasoline from 24 to 25 to 26%

2. The utilization of 3% anhydrous ethanol in diesel blends for diesel engines
3. The increase of the aforementioned level to 11–13% by applying a cosolvent that could stabilize the anhydrous ethanol/diesel mixture.

Alternative technologies such as cogeneration are still under evaluation, and their potential has been identified as promising for further reductions in the cost of producing ethanol from renewable resources. All these perspectives refer to ethanol as the main product. These government directions are under the responsibility of the Interministerial Council for the Sugar/Alcohol Industry and the National Department for Energy Development—Ministry of Mines and Energy.

Companies that produce ethanol jointly created Brazil Alcohol S.A. This company has the mission of stocking the excess ethanol available in the market, which now is estimated at 1.3 billion L/yr. The company congregates 200 mills at the central-southern region of Brazil. The main objectives of Brazil Alcohol S.A. are first to increase the price paid by the large distributors to the mills, currently $0.10/L, and second, to favor the external market and improve the quoted value of Brazilian sugar in the international stock markets.

Sucrose itself is the other target. However, there is an urgent need to identify ways to again encourage the industrial private sector to open new possibilities for the utilization of sucrose in alternative and improved fermentation processes. Joint ventures between the academia, autonomous research institutes, and the private sector are required for this enterprise more than ever to achieve lower cost and product diversification. As already cited, the production of PHB from cane molasses and bagasse formulations for cattle feeding are just two examples for a large array of opportunities. These also includes high-value SPC enriched in oxygenated carotenoids from selected yeast strains grown in low-cost media such as raw sugarcane juice and urea *(8)*, ethyl esters of soybean oil (biodiesel) *(9)*, bacterial cellobiofilms of medical interest from cellulogenic *Acetobacter* strains fed on inverted sucrose and tea infusions *(10)*, and citric acid or fumaric acid as examples of organic acids with at least a double market destination *(11)*. Paraná State, also known as the nation's "granary state," thanks to its no. 1 ranking for production of corn, soya, wheat, and potatoes (also ranked no. 2 for cassava and no. 3 for sugarcane, as well as having the best performance in continental fish farming), is obviously the best geographical candidate for the launching of parallel biodiesel and improved new SCP facilities. A reverse enzymatic approach for "neolipid" biosynthesis from less usual sugars and fatty acid is under development *(12)*. Another alternative use of sucrose is the production of glucose-fructose syrup by enzymatic processes *(13)*.

Finally, the main byproduct of sugar mills, and the largest secondary phytobiomass residue in Brazil, sugarcane bagasse, must be increasingly viewed as an acceptable starting material for new alternative agroindustrial businesses. These might include the production of biodegradable composites; lignocellulosic matrices for solid-state fermentation; and new materials derived from natural polymers such as lignin, cellulose, and hemicellulose *(14)*. Pretreatment of bagasse with the more "physiologically friendly catalyst," namely, aqueous thermopressurized phosphoric acid *(15,16)*, ensuring a selective xylan depolymerization along with an increased digestibility-residual lignocellulose for cattle feeding, is being reexamined. Steam-based pretreatments are also under consideration *(17)*. The production of xylitol from hydrolyzed sugarcane bagasse is another alternative being considered in Brazil (FAENQUIL, USP, UFRJ) *(18,19)*.

Ethanol fermentation is also actively researched at ESALQ/USP, a renowned school of agriculture in Brazil. Examples of these studies include how thermal stress leads to surplus ethanol and protein-enriched SCP *(20)* and the identification of dominant strains of *S. cerevisiae* displaying longer residence time in the fermentation vats and higher ethanol productivity *(21)*.

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