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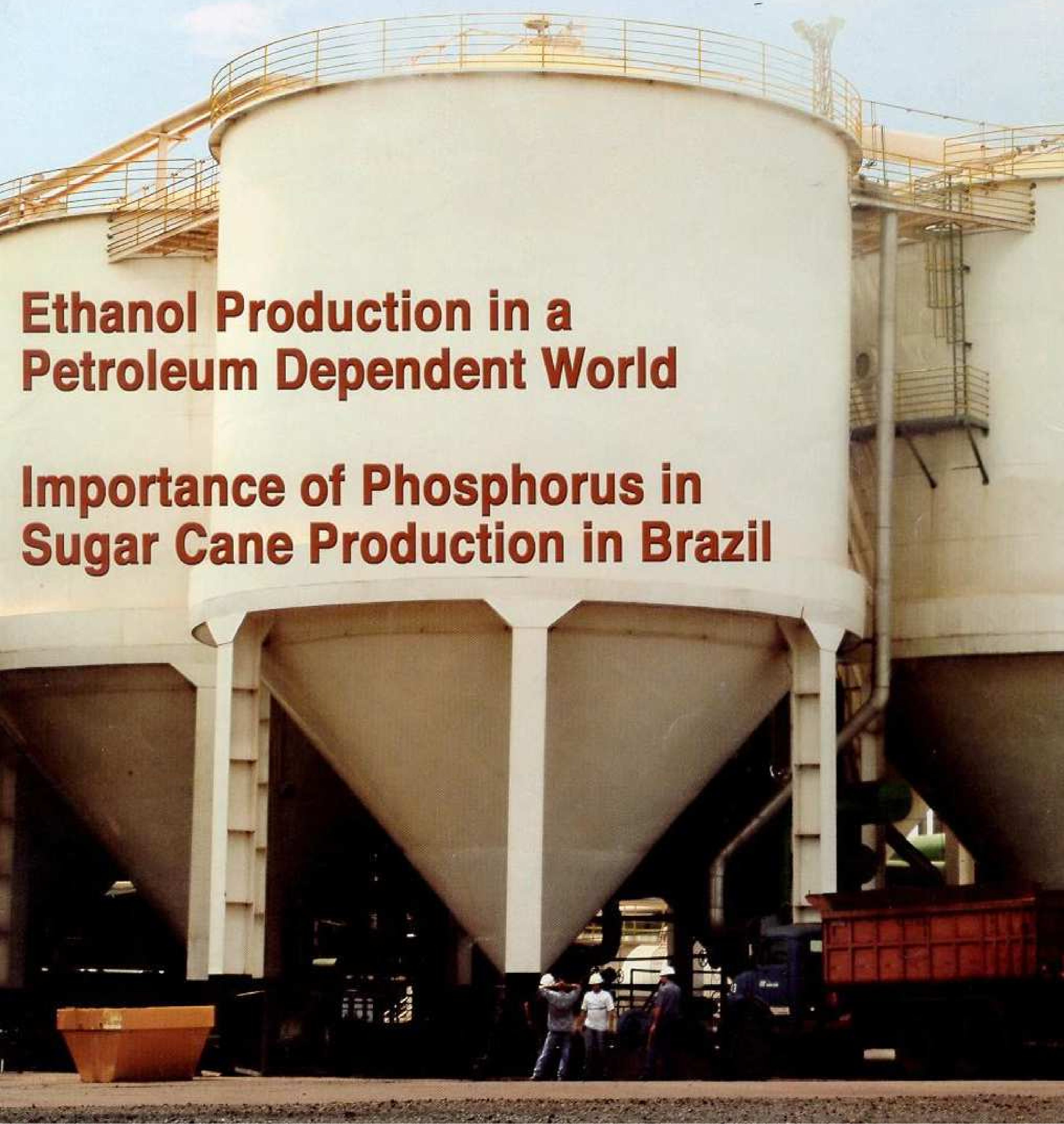
Ethanol Production in a Petroleum Dependent World

Importance of Phosphorus in Sugar Cane Production in Brazil



Ethanol Production in a Petroleum Dependent World: The Brazilian Experience

By Henrique V. Amorim & Mario L. Lopes

Abstract

Today we are living in a petroleum dependent world. With the high price of the gasoline and diesel oil, many countries are looking for new alternatives to replace fossil fuels. The ethanol made from sugar crops or grains has been considered the best alternative. However, world ethanol production represents only 2.5% of the consumption of gasoline and therefore the market is broad and world demand for ethanol is growing quickly. This paper reports the Brazilian experience in ethanol production, what has been done to survive the market oscillations, how distilleries work, and the use of molasses to ethanol production.

Introduction

The ethanol history as fuel began with the birth of the automobile. When the first cars of Ford Model T were made on an assembly line in 1908, ethanol was the fuel selected to move them while the oil industry was in its beginning. However, when gasoline began to be used as fuel, it was cheap and new petroleum reserves were being discovered worldwide. The fossil fuel reserves were formed from tiny aquatic plants and animals that lived million years ago. These remains were covered with layers of sediments under extreme pressures and high temperatures. On these conditions, the fossil biomass became a liquid that we know as petroleum or crude oil, which is made of a mixture of hydrocarbons. Refineries break down these compounds into different products as gasoline, diesel oil, liquefied petroleum gases, residual fuel oil, and many other products. During many years we saw the world consuming its own reserves of fossil fuel and releasing million tons of CO_2 into the atmosphere, as well as other gases and toxic compounds. However, this situation began to change when the international oil prices exploded in 1973 and the scientists began to announce that global warming was increasing while the world oil reserves were yearly being reduced. Today, the world consumption of gasoline is almost 1,200 million m^3 a year, while the fuel ethanol represents 2.5% of this demand (1). Today, there isn't another alternative fuel to replace gasoline and oil as well as ethanol. Therefore, the world demand of fuel ethanol has been increased by economical, social and environmental reasons and its production has been estimated to achieve 55 million m^3 by 2010 (2). Brazil has a special importance as the main producer and user of ethanol in a world dependent on petroleum.

Ethanol as a biofuel

Ethanol blends have been used since 1923 in Brazil in variable proportions from 5 to 40% in gasoline. However, the use of ethanol as fuel grew quickly from 1975, when the federal government launched the "Proalcool" program with the goal to reduce oil imports. The producers were encouraged to extend sugarcane production and build new distilleries to produce ethanol as a biofuel. In the last three decades, sugarcane production in Brazil was increased from 91 million tons in 1975 to 385 million tons in 2004 (Figure 1), which represents a primary energy production of 462 millions of oil barrels yearly (1 ton sugarcane = 1.2 oil barrels). The sugarcane is cultivated by 70,000 farmers in an area of 5.5 million hectares corresponding to less than 2.4% of total cultivated area in Brazil. Since the beginning of "Proalcool" program, the government has saved more than 141 billion dollars with importations of petroleum and taxes.

The Brazilian net of fuel distribution has more than 30,000 gas stations to attend 16 million cars moved on gasoline blended with

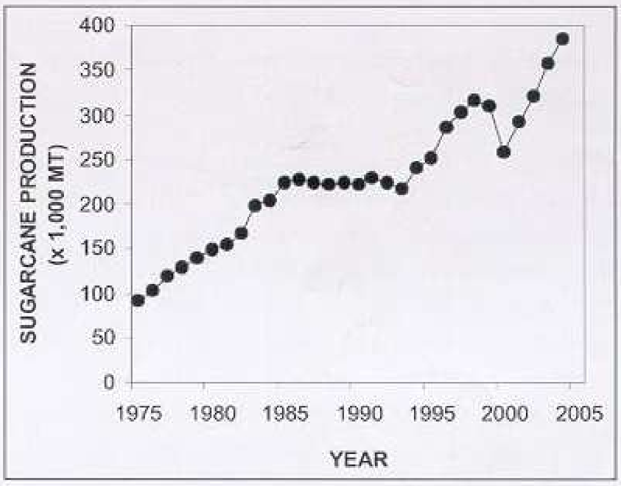


Figure 1. Evolution of sugarcane production in Brazil (Datagro, 2005)

22 to 26% of ethanol and more than 2 million cars running on pure ethanol. Moreover, automobile industries have launched the production of flex fuel vehicles, which have been designed to operate on pure ethanol, gasoline or any combination of both. They have become quite popular in Brazil and the sales achieved 379,328 units, which represents 25% of all vehicles sold in 2004. This popularity can be explained for three main reasons. First, with the high price of gasoline, many people are looking for alternative energy sources for their automobiles as ethanol, whose price to consumers represents around 60% of gasoline. Second, the flex fuel vehicles give drivers more flexibility to choose the fuel and leaves them less susceptible to variations of market prices. Third, the use of ethanol or ethanol-gasoline mix interacts with environmental reasons and social benefits as employment in the national industry and sugarcane farms. The sales of flex fuel vehicles have been considered fundamental to automobile industry growth in 2004.

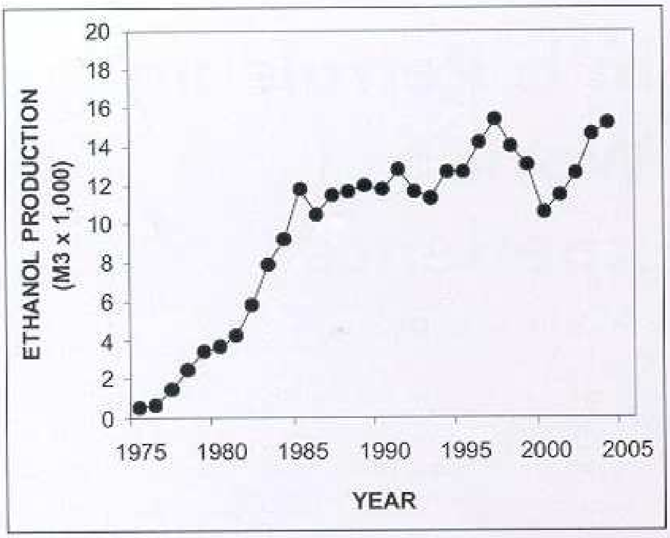


Figure 2. Evolution of the ethanol production in Brazil (Datagro, 2005)

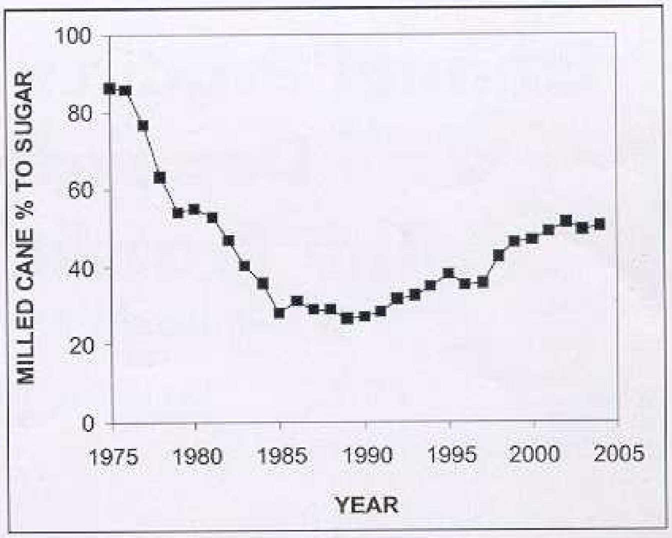


Figure 3. Variation in the percentage of cane sent to sugar production (Datagro, 2005).

Because of this success the automobile industry plans to launch the three-fuel car (gasoline, ethanol and gas) in 2005 following the strategy adopted for the first flex fuel vehicles. Moreover, new projects are being developed on fuel-cell based on ethanol while the Brazilian government is launching the "Biodiesel" program, what represents a new market to ethanol and vegetable oil with the potential to save 800 million liters of diesel oil in the first year.

Concerning the environmental impact, the main benefit of ethanol use as fuel has been the reduction of carbon dioxide, heavy metals and other toxic pollutant emissions in large cities like Sao Paulo and Rio de Janeiro. Ethanol is a clean fuel and the production process is almost entirely sustainable because carbonic gas is recycled by sugarcane without releasing fossil CO_2 into the atmosphere in the same proportion as gasoline or diesel oil. Because of its renewable process of production the distilleries have been considered potential candidates to receive carbon credits from the Kyoto Protocol. The bagasse produced is burned to give steam, producing energy for distillation and electricity. The molasses, resulting from sugar factories is mixed with sugarcane juice or diluted with water and sent to fermentation while stillage returns to sugarcane crop areas reducing the use and imports of potassium fertilizers.

Today, Brazil is the world leader in ethanol production employing more than one million people in the sugarcane farms and industries. Since 1975 ethanol production jumped from 0.56 million m^3 to more than 15 million m^3 a year (Figure 2). There are 324 distilleries dispersed in the country but the production is concentrated to center-south and northwest regions. In the next 5 years, 34 new distilleries will be built, each one with capacity to mill around 2 million tons of cane a year. Moreover, many distilleries are increasing their capacity of ethanol production to attend internal market demands and exports to countries that are looking for alternative fuels to reduce the oil price impact on their economy and environment.

How did distilleries survive the market oscillations?

During the "Proalcool" program, the ethanol prices, paid to producers, decreased from US\$700/m^3 in 1980 to less than US\$200/m^3 in 1999. The prices were liberated and the federal government abolished the market intervention, except for ethanol-gasoline mix. The prices of sugar and ethanol have a strong mutual influence in Brazil. Many sugar industries have distilleries. When the sugar prices in the international market are more profitable than ethanol, more sugarcane goes to sugar production, while the molasses is sent to fermentation and ethanol production. The industries use this mechanism to balance their production based in ethanol and sugar market prices. The percentage of cane sent to sugar production has been variable for 30 years (from 26.5% to 86.3%) but has been around 50% in the last 3 years (Figure 3).

To overcome the low prices and market oscillations, new technologies were developed and transferred to distilleries that helped them to survive during crisis times. The development of new cane varieties, better soil practices, use of fertilizers, control of pests, as well as new harvest systems, increased the field productivity from 53 tons per hectare in

1977 to 90 tons per hectare in 2004. Moreover, the percentage of sugar in sugarcane was increased from 9.5% to 14% while the sugar extraction from raw cane was improved from 88% to 95-98% in the same period.

Besides sugarcane productivity and sugar extraction, important contributions were made in alcoholic fermentation of sugarcane juice and molasses by the association between Fermentec and Escola Superior de Agricultura Luiz de Queiroz – University of Sao Paulo (ESALQ-USP). These improvements include results of research on:

- Conditions to improve the fermentation yield
- Selection of yeast strains from industrial environment
- Development of analytical methods to measure sugar concentrations in juices, molasses, musts, beers and industrial waters as low as 6 ppm
- Direct counting of live bacteria by light microscopy in up to 15 min
- Method to choose the best antibiotics (in 6 hours) to control bacteria
- Identification of contaminating bacteria by DNA sequencing
- Accurate and precise determination of alcoholic contents by digital densimeters
- Introduction of NIRS (Near Infrared Spectroscopy) to routine analysis
- Reduction of the sugar losses and chemicals consumption

Although many industrial parameters are controlled in Brazilian distilleries, the alcoholic fermentation yield can be drastically reduced by bacterial contamination (Figure 4), yeast-bacteria flocculation, excessive yeast growth, misuse of centrifuges, stresses caused by sugar, alcohol, salts, high temperature, molasses acidity and contamination by wild yeasts (3). To allow the best management of the industrial process, statistical analysis of more than 120 industrial parameters (starting from sugarcane quality up to fermentation yield) have indicated to the industry which factors affect its performance and where to invest to improve yields, to obtain high quality products, to decrease losses and to reduce chemicals consumption like antibiotic, sulfuric acid, antifoam and others (4). By measuring, controlling and improving industrial parameters, it was possible to improve the fermentation yield from 75-78% in 1977 to 90-92% in 2004 (based on a theoretical maximum production of 511g ethanol/kg glucose). Without this improvement, it would be impossible for the distilleries to survive with the low prices of the internal market. Only 5% of the ethanol production was exported in 2004. Great advances were obtained to distillation process that allowed an increase in efficiency from 95% in 1977 to 99% in 2004. The technological and scientific advances in sugarcane and alcoholic fermentation as well as the efficient process management have consolidated the ethanol industry in Brazil.

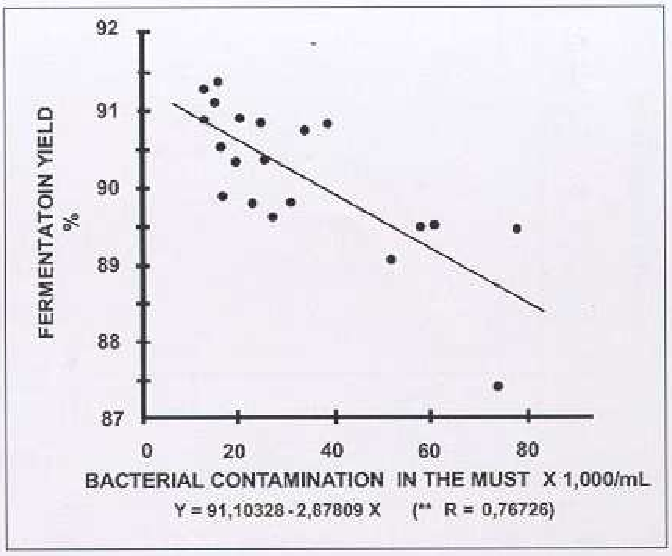


Figure 4. Effects of bacterial contamination on alcoholic fermentation yield in a distillery. Each dot represents weekly averages during the crop season (Fermentec, 2004).

How do Brazilian distilleries work?

Nowadays, the industrial production of ethanol is based on large-scale fermentation of sugarcane juice, molasses or a mix of both in fermentation vats, each with a capacity from 0.4 to 2.0 million liters. The main systems of fermentation are batch and continuous, but there are variations in these processes making each distillery different from any other. The batch fermentation system is used by 75% of the distilleries.

The ethanol production in Brazil is made during a continuous sugarcane harvest season over 200-230 days. Fermentations are made with very high yeast cell concentrations (8-17%), alcoholic concentrations between 6-11% (v/v) and very short fermentation times, between 6 to 10 hours (5). After the end of each cycle, the yeast cells are separated from fermented medium (beer) and concentrated by centrifugation to be used in the next fermentation cycle. The beer goes to distillation while the concentrated yeast receives a treatment with diluted sulfuric acid to kill bacteria. After the treatment, the yeast cells return to fermentation vats, where they restart a new fermentative cycle. Despite small modifications, this fermentation process is known as Melle-Boinot because it was patented by Firmin Boinot from the Melle region of France in 1930.

Besides fermentation characteristics, the choice of yeast strains is fundamental to obtain high yields and low consumption of antifoam. Special yeast strains as PE-2, CAT-1 and VR-1 (selected by Fermentec) or BG-1, SA-1 and CR-1 (selected by Copersucar) are used alone or mixed with baker's yeast and used as starter by many Brazilian distilleries. These strains were selected from industrial fermentations by karyotyping technique (a DNA-based test) and exhaustively evaluated in the laboratory. These strains are adapted to industrial processes and very resistant to stress conditions. However, the baker's yeast is very useful at the beginning of fermentation when distilleries need tons of yeast cells. Since 1996, Lallemand has produced and commercialized these strains in dry way as starter yeast to distilleries. In 2004, more than 160 distilleries began the fermentation process with these selected yeasts, which represents around 60% of the ethanol produced in Brazil.

Ethanol production from molasses

Today, the Brazilian distilleries are among the most flexible industries and have the best technology in the world to ferment sugarcane juices, molasses or a mix of both. In Brazil, the ethanol production from molasses is more profitable than molasses sales. However, fermentations that use musts of molasses need

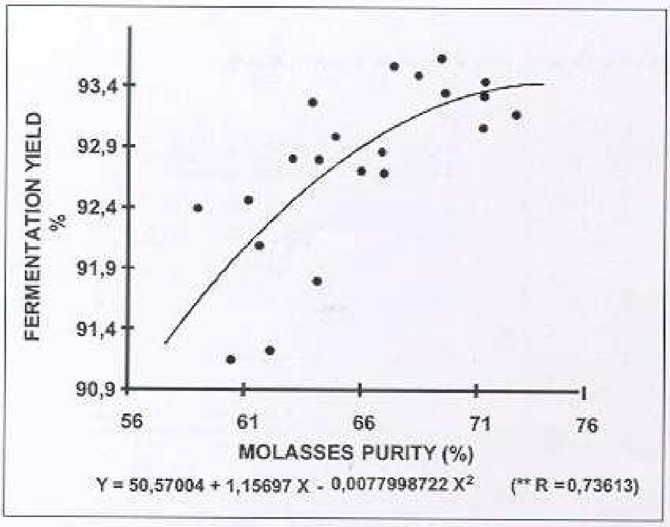


Figure 5. Effects of molasses purity on alcoholic fermentation yield in a distillery. Each dot represents weekly averages during the crop season (Fermentec, 2004)

special care. The low purity or acidic molasses affects the fermentation yield because of its toxicity to yeast cells (Figure 5).

On the other hand, molasses mixed to sugarcane juice can supply the must with minerals that are essential to yeast cells as magnesium, phosphate, zinc and nitrogen that sometimes are deficient in the sugarcane juices. However, some minerals can be in excess as potassium and calcium, stressing the yeast cells that deviate more sugar to glycerol production, reducing the fermentation yield.

The other aspect to be considered is that molasses contamination by lactic acid bacteria can affect the fermentation yield too. Some bacterial species are very resistant and difficult to be controlled during the alcoholic fermentation.

Besides equipment and trained staff, the success of the fermentation will depend on molasses composition (sugars, minerals, toxic compounds), its acidity and purity, contamination by bacteria and wild yeast, the proportion used in the must (low, medium or high), the choice of appropriate yeast strains and good analytical methods (chemical and microbiological) to measure and manage the fermentation process.

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