ALCOHOLIC FERMENTATION WITH TEMPERATURE CONTROLLED BY ECOLOGICAL ABSORPTION CHILLER—EcoChill

By

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Abstract

THE FERMENTATION process in ethanol production is where less efficiency and more losses can be found. One of the operational parameters that maximises ethanol production is the control of the fermentation temperature to maintain it at the optimum point. Usually the cooling systems are comprised of evaporative coolers where the lowest temperature that can be reached is a function of the wet bulb temperature. Thus, in tropical countries like Brazil, the temperature in fermentation normally reaches values above 32ºC and can reach 36ºC in hot periods. This condition has a negative effect in the cellular metabolism reducing ethanol productivity and damaging the viability of cells. To determine the engineering parameters to optimise the ethanol fermentation process in industrial scale designs, Dedini S/A built and installed a semi-industrial demonstration plant in a sugar and ethanol mill of the Cosan Group. The main parameter of the experiments was the control of the fermentation temperature, which ranged from 28º–32ºC, as a function of the ethanol content increase and the influence of feedstock in the fermentation yield. The results obtained show that there was a significant increase of alcohol concentration in fermented mash, which reached about 16°GL at 29ºC. Thus, increasing ethanol concentration leads to a decrease in steam demand for distillation and a big reduction in volume of vinasse generated. The low temperature of mash leads to a low level of contaminants, assuring good quality and greater fermentation yield. The lithium-bromide absorption chiller operated effectively, indicating that it is a proven product for application in ethanol production.

Introduction

Several references in literature (Dias *et al.*, 2007; Jones *et al.*, 1981; Prescott and Dunn, 1987; Yamakawa, 2008) report a high concentration of ethanol in the fermentation broth from most diverse sucrose feeds (sugarcane, wheat, corn and rice). Operating ethanol fermentation in high concentrations fundamentally increases industrial productivity, reduces steam and utilities consumption, and minimises losses with contaminants and, especially, reduces the volume of vinasse generated. Vinasse requires significant resources for final disposal.

Fermentation is a unit operation in ethanol production in which there is less efficiency and, consequently, greater loss. One of the parameters directly involved is the temperature. The biochemical reaction of converting sugar into ethanol is an exothermic reaction; usually, the Brazilian ethanol plants use water from a closed circuit evaporative cooling system to control the temperature of fermentation by indirect exchange. The evaporative cooling naturally undergoes a change depending on the wet bulb temperature and, in tropical countries like Brazil, the lowest temperature of cooling water is 29°C (Prescott and Dunn, 1987).

In different environmental and nutritional conditions, the yeasts can adopt distinct metabolic routes for the production of different compounds. In anaerobic conditions, glucose can be converted into ethanol, acetic acid, lactic acid and carbon gas. One of the factors associated with the yeast's preferred reaction is temperature, and there are many references in literature defining that the most favourable temperature for converting sugar into ethanol is below 32°C:

- Rivera *et al*. (2006): considered temperature as the variable to evaluate the optimum expected parameters of ethanol fermentation; based on experimental data, maximum ethanol production is achieved at 28°C–31°C.
- Prescott and Dunn (1987): found that the optimum temperature for cell growth and ethanol production is 30ºC, but higher temperatures (35°C ~38ºC) are acceptable. However, at these temperatures, cell growth rate, ethanol production and death rate can be affected negatively.
- Jones *et al*. (1981): reported that the *S. cerevisiae* yeast can bear up to 33ºC in industrial conditions for ethanol production; minimum growth range is 10ºC and the maximum is 40ºC, and the optimum temperature is between 28ºC and 35ºC.
- Dias *et al*. (2007): reported that high temperatures in fermentation affect the yeasts metabolism and reduces the ethanol concentration in the final broth, which increases steam consumption in distillation. Fermentation at 28ºC allows operation with higher concentration sugars in the must, and this reduces the steam consumed in distillation and vinasse generation (5.76 L/ L EtOH).

Therefore, there is a great indication that the fermentation conducted at a controlled temperature below 32°C will result in an increased industrial yield and also will provide the very high gravity fermentation. However, all these studies and conditions are for small scale experiments. To effectively evaluate the optimised temperature of the ethanol fermentation in industrial conditions and scale, in 2008 DEDINI built and operated a 20 000-L ethanol/day demonstration plant with temperature control at 28°C and 32ºC. An absorption chiller made by THERMAX was used for this purpose. The results indicate that temperature in the range of 28ºC to 30ºC is the most appropriate to obtain high alcohol content.

Process description

A detailed description of the cooling system process by the steam absorption chiller cooling system and the process of alcoholic fermentation is presented.

Absorption chiller cooling system

The goal of the cooling system by absorption chiller is to chill water in the range of 16 to 20°C for controlling the temperature of fermentation in the range of 28 to 32°C. Figure 1 represents the diagram of the refrigeration cycle steam absorption by the solution of lithium bromide. This system uses the principle of vacuum and the capacity of the solution of lithium bromide to absorb steam. The absorption cycle involves three circuits: the cooling water is pumped to the evaporator (1), the lithium bromide used as absorbent flows over the tubes of the evaporator through the heat exchanger for the generator, the cooling water flows in series initially through the tubes of the absorber (1) and partly through the tubes of the condenser (3).

The water to be chilled enters the tubular bottle evaporator (1) where it is chilled indirectly by water spray. The steam is absorbed by a concentrated solution of lithium bromide at low pressure in the absorber (1). Lithium bromide having absorbed the steam is then pumped to the generator (2) to reconstitute the diluted solution. In generator (2) the solution is heated indirectly by hot water at low pressure for concentrating the salt solution before it enters the absorber. The flow of solution coming from the generator (2) goes to the absorber (1) by the difference in gravity and pressure. The water from the generator (2) by boiling is then condensed with cooling water, becomes liquid in the condenser section (3) and condensed back to the evaporator (1).

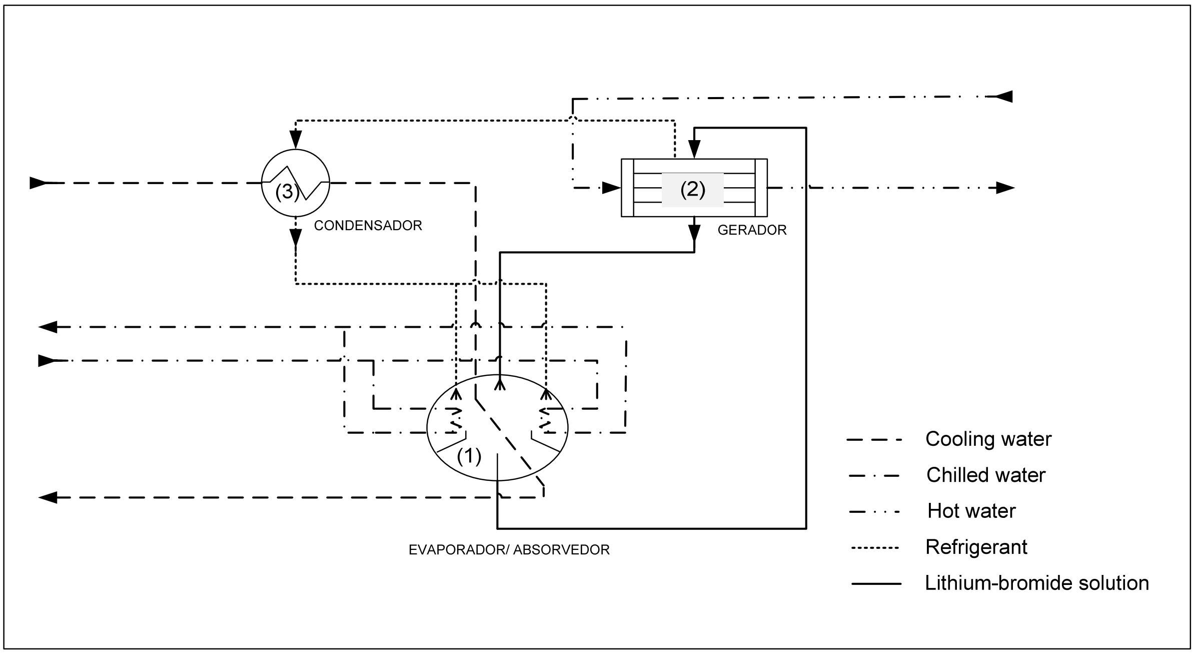

Fig. 1—Flowchart of the absorption chiller system (Thermax Inc.).

The application of the absorption chiller in the ethanol process is the reuse of non-thermal sources such as vinasse, flegmass or low steam pressure, replacing the current of hot water in the absorption circuit as shown in Figure 1.

In the case of the demonstration plant, the heat source is the vinasse after the process of regenerative heating of the wine in the distillation column. The temperature range of the waste is 80 to 85°C and the range flow is 100 to 150 m^3 / h.

Alcoholic fermentation process

The process assumed in this work was fed batch fermentation prepared with juice, syrup and molasses from cane sugar and with cell recycle *Saccharomyces cerevisiae*.

In Figure 2, the process flowchart of the demonstration plant Dedini installed at Usina Bom Retiro is presented.

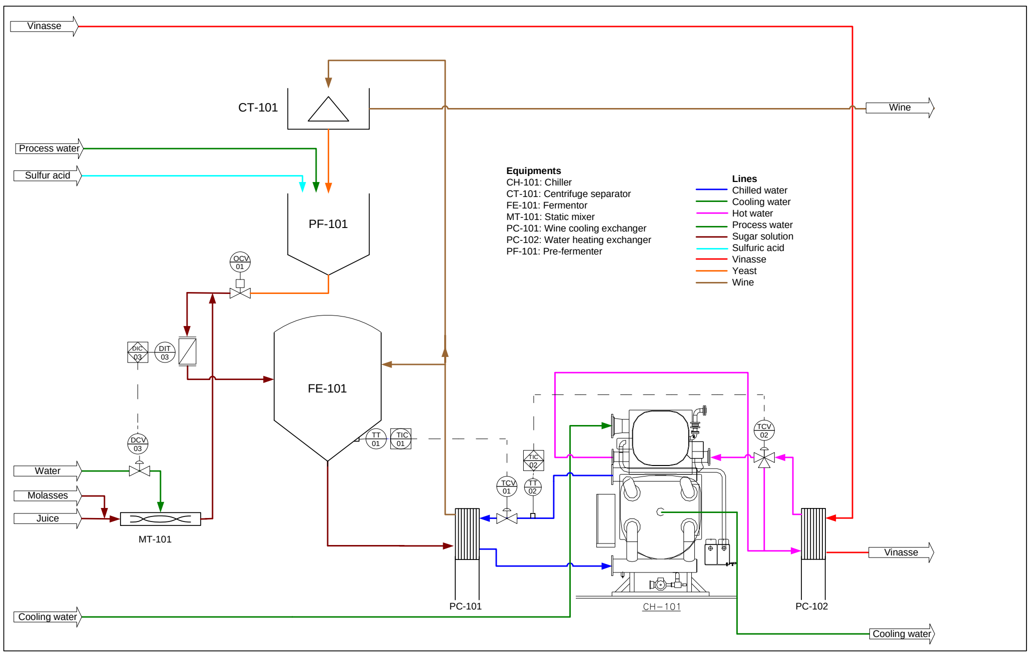

Fig. 2—Flowchart of the demonstration plant.

The process begins with the sterilisation of the fermentor (FE-101) and peripherals such as tabulations, heat exchangers and pumps. At the same time, the yeast is reactivated by an acid treatment maintained under aeration and agitation for a period of 30 minutes in a pre-fermentor (PF-101). Then the yeast is transferred to the clean fermentor. The feed was started with set process parameters for temperature and percentage of sugar in the must. The feed is prepared and controlled by addition of juice, molasses, syrup and water in a static mixer (MT-101).

The must flow is controlled such that the biochemical reaction of converting sugars into ethanol does not result in inhibition by substrate, thus slowing the reaction. In this work the flow feed was 6 to 12 m^3/h.

The temperature control is enabled when feeding of the sugar solution starts. The temperature transmitter (TT-01) is located in the fermentor and it provides the temperature of the controller (TIC-01) which compares with the value set-point and thus modulates the percentage of opening control valve (TCV-01).

Upon completion of the batch, the wine is discharged to the centrifugal separator (CT-101) and the clarified phase (wine) is sent to the distillation process and the heavy phase (cream yeast) is sent to the pre-fermentor (PF-101) to be treated and reactivated. Then, after the sterilisation process, the yeast returns to the fermentor (FE-101) for a new batch.

Materials and methods

In 2008/09 milling season, Dedini S/A Indústrias de Bases built and operated a demonstration plant, with nominal capacity to process 20000 litres of ethanol/day (Figure 3), equipped with a 100-m^3 stainless steel fermentor, one 300 TR Thermax absorption chiller and one 315 m^3/h evaporative cooling tower. The plant is located at COSAN, Usina Bom Retiro, in Capivari city, state of São Paulo.

Fig. 3—Dedini's demonstration plant.

The way to get very high gravity fermentation is to increase the amount of sugar in the must by the addition of molasses or syrup. In the 2008 milling season, we used 2 and 3 molasses to raise the alcohol content of the final wine. In the 2009 milling season, we used syrup. The molasses resulting from boiling, comprised of two massecuites, presents higher purity when compared with the molasses from boiling of three massecuites, which is usually called final molasses. Table 1 shows the comparison of the quality of the raw material of juice.

Table 1—Comparison of the raw material quality.

	Brix %	Pol %	Purity %	TRS %
B Molasses (2 massecuites)	80.40	52.15	64.86	62.50
C Molasses (3 massecuites)	79.80	46.68	58.80	59.56
Syrup	55.00	47.85	87.00	50.00

Thus, the must made from molasses will have a lower quality when compared to wine made from syrup. Henceforth, the terms B and C molasses are called only molasses.

Results and discussions

We present the main results obtained since the start of operation of the demonstration plant until the middle of 2009. The results were divided into two groups according to the raw material used to prepare the must: molasses and syrup.

Must from molasses

Figure 4 shows the result of the fed batch prepared with molasses and controlled temperature of 28°C. The average percentage of ethanol is 9.59°GL and the average standard deviation is 1.1%.

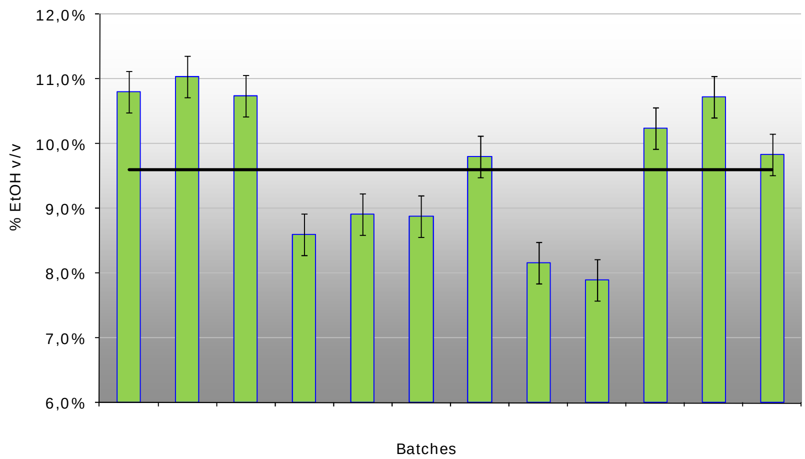

Fig. 4—Percentage of ethanol in batches conducted with molasses at 28°C.

Figure 5 shows the result of the fed batch prepared with molasses and controlled temperature of 30°C. The average percentage of ethanol is 11.98°GL and the average standard deviation is 1.2%.

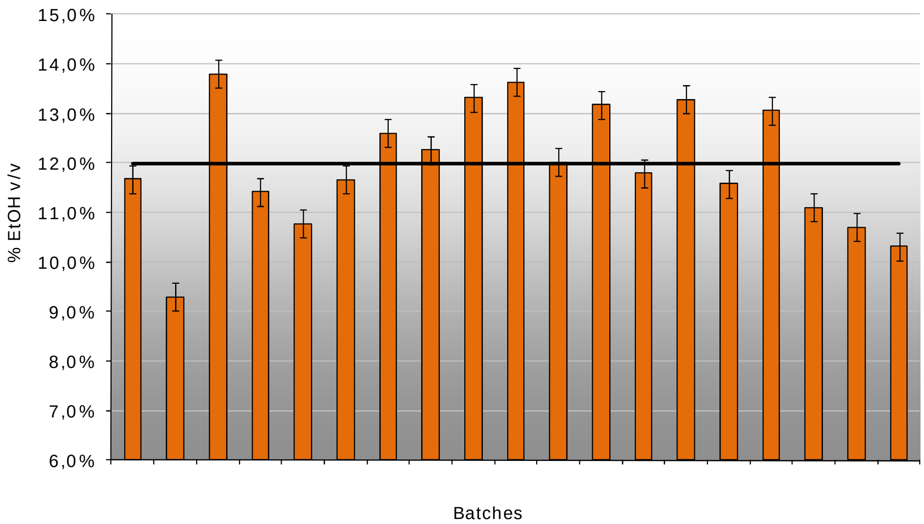

Fig. 5—Percentage of ethanol in batches conducted with molasses at 30°C.

Figure 6 shows the result of the fed batch prepared with molasses and controlled temperature of 32°C. The average percentage of ethanol is 11.37°GL and the average standard deviation is 1.2%.

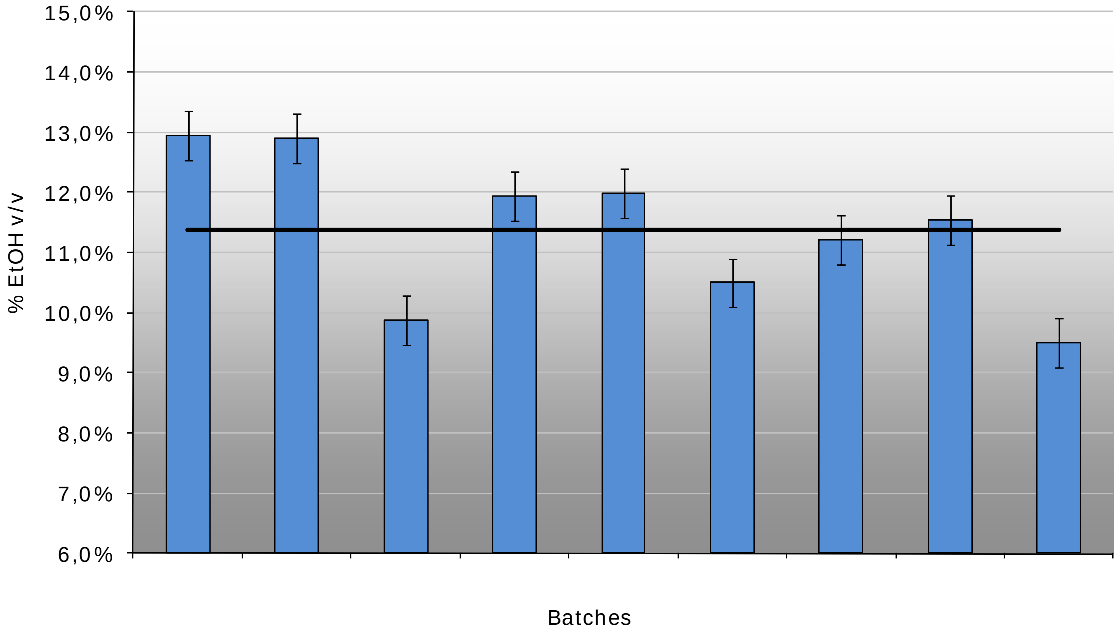

Fig. 6—Percentage of ethanol in batches conducted with molasses at 32°C.

The results of fermentation temperatures controlled at 28, 30 and 32°C show that it is feasible to obtain alcohol levels above 9°GL. Furthermore, there is a tendency of an optimum temperature at 30°C.

The fermentation yield is reported in Table 2. The mean score was 85% and the results reinforce that a temperature of 30°C is promising.

Table 2—Fermentation yield by sub-products method.

Temperature	Fermentation yields (%)
28	84.02
30	86.79
32	85.05

These results indicate it is feasible to reduce the generation of vinasse with the fermentation of concentrated must and obtain alcohol levels above 8°GL. For example, for 9°GL the generation of the vinasse is 9 L / L ethanol and for 13°GL generation of vinasse is 6 L / L ethanol, i.e., there is a reduction of 33%.

Must from syrup

Since the best result was previously controlled temperature at 30°C, the tests were conducted with syrup at this temperature in order to produce wines with alcohol levels above 14°GL. Figure 7 shows the result of the fed batch prepared with syrup at 28% of total reducing sugar concentration in average and temperature controlled at 30°C. The average percentage of ethanol is 13.82°GL and the average standard deviation is 0.7%.

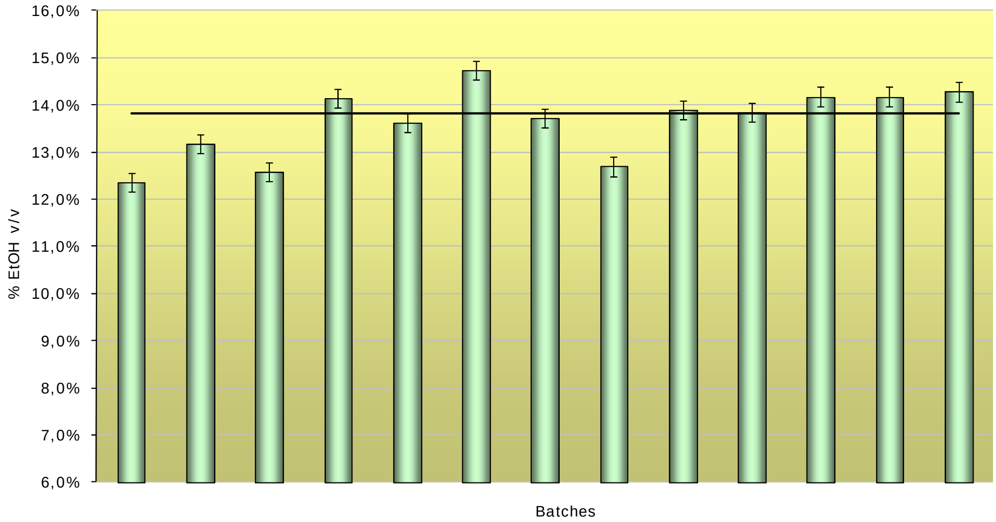

Fig. 7—Percentage of ethanol in batches conducted with syrup at 30°C.

Figure 8 shows the result of the fed batch prepared with syrup at 35% of total reducing sugar concentration in average and temperature controlled at 30°C. The average percentage of ethanol is 15.45°GL and the average standard deviation is 1.2%.

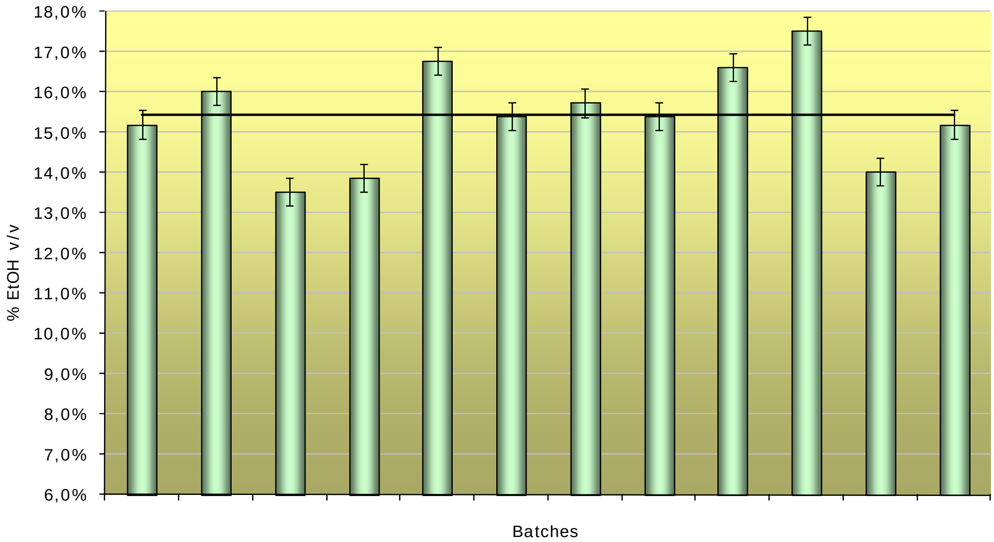

Fig. 8—Percentage of ethanol in batches conducted with syrup at 30°C.

Fermentation with high quality must enables the production of average alcohol content up to 15°GL, unlike wine from molasses. So, it can be inferred that the salts present in molasses limit the very high fermentation.

The parameter temperature should be evaluated under these conditions because it is not possible to infer the ideal temperature from these results.

Conclusions

According to the results obtained, we can conclude that:

- The operation of the pilot plant in the 2008/09 season was succeeded well, and the results obtained at low temperatures are very promising for very high gravity fermentation;

- The increased wine in alcohol is directly related to the quality of raw materials;
- The lithium-bromide absorption chiller worked effectively, and one can conclude that it is a proven product for ethanol production applications;
- The results of fermentation with molasses indicate that there is an optimum temperature at 30°C.

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FERMENTATION ALCOOLIQUE AU MOYEN D'UN REFRIGIRATEUR D'ABSORPTION ECOLOGIQUE A TEMPERATURE CONTROLEE–EcoChill

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MOTS-CLÉS: Fermentation Alcoolique,
Température, Ethanol, Réfrigirateur d'Absorption.

Résumé

C'EST DANS le procédé de fermentation dans la production d'éthanol que se trouve le moins d'efficience et les pertes les plus élevées. Un des paramètres d'opération pour maximiser la production d'éthanol est le contrôle de la température de fermentation qui doit être maintenue au niveau optimal. Généralement, les systèmes de refroidissement sont constitués des refroidisseurs par évaporation par lesquels la température la moins élevée qui peut être atteinte, est une fonction de la température de bulbe humide. Ainsi, dans les pays tropicaux comme le Brésil, la température de fermentation atteint normalement des valeurs supérieures à 32ºC et peut même atteindre 36ºC dans les périodes chaudes. Cette condition a un effet négatif sur le métabolisme cellulaire en réduisant la productivité d'éthanol et tout en nuisant à la viabilité des cellules. Pour déterminer les paramètres d'ingénierie nécesssaires à l'optimisation du procédé de fermentation pour la production d'éthanol dans la conception des ensembles industriels, Dedini S/A a construit et installé une unité de démonstration semi-industrielle dans une usine à sucre associée à une unité d'éthanol du groupe

Cosan. Le paramètre principal des expérimentations était le contrôle de la température de fermentation, qui variait de 28º–32ºC, en fonction de l'augmentation du contenu d'éthanol et l'influence des matières premières pour le rendement de fermentation. Les résultats obtenus démontrent qu'il y avait une augmentation significative de la concentration d'alcool dans le moût fermenté qui atteint 16° GL à 29ºC. Ainsi l’augmentation de la concentration en éthanol entraîne une réduction de la demande en vapeur requise pour la distillation et une réduction énorme en volume de vinasse générée. La température basse du moût fermenté mène à un niveau faible de contaminants, assurant ainsi une bonne qualité et un rendement superieur en fermentation. Le refrigirateur d'absorption à base de bromure de lithium fonctionne efficacement, donnant ainsi la preuve qu'il s'agit d'un produit éprouvé pour être utilisé dans la production d'éthanol.

FERMENTACIÓN ALCOHÓLICA CON TEMPERATURA CONTROLADA POR ENFRIADORES ECOLÓGICOS DE ABSORCIÓN—ECO CHILL

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**Palabras clave: Fermentación Alcohólica, Temperatura,
Etanol, Enfriador de Absorción.**

Resumen

EL PROCESO de fermentación en la producción de etanol es donde puede encontrarse menos eficiencia y mayores pérdidas. Uno de los parámetros operacionales que maximiza la producción de etanol es el control de la temperatura de fermentación para mantenerla en el valor óptimo. Usualmente los sistemas de enfriamiento están constituidos por enfriadores evaporativos, en los que la temperatura más baja que puede alcanzarse es función de la temperatura de bulbo húmedo. Así en países tropicales como Brasil, la temperatura en la fermentación alcanza normalmente valores superiores a 32º C y puede elevarse hasta 36º C en períodos calurosos. Esta situación tiene un efecto negativo sobre el metabolismo celular reduciendo la productividad de etanol y dañando la viabilidad celular. Para determinar los parámetros ingenieriles para optimizar el proceso de fermentación de etanol en los diseños a escala industrial Dedini S/A construyó e instaló una planta demostrativa semi-industrial en una fábrica de azúcar-etanol del grupo COSAN. El parámetro principal de los experimentos fue el control de la temperatura de fermentación, que osciló entre 28 C y 32ºc, como una función del incremento del contenido de etanol y la influencia de la alimentación sobre el rendimiento de fermentación. Los resultados obtenidos muestran que se alcanzo un significativo incremento en el contenido de alcohol en el vino fermentado, que se elevó a cerca de 16º GL a 29º C. Resultando que el aumento de la concentración de etanol condujo a una disminución en la demanda de vapor para la destilación y una gran reducción en el volumen de vinazas generado, La baja temperatura del vino fermentado indujo una disminución de contaminantes, asegurando buena calidad y mayor rendimiento de fermentación. El enfriador de absorción de Bromuro de Litio operó con efectividad, indicando que es un producto probado para ser empleado en la producción de etanol.