Continuous and batch fermentation processes: Advantages and disadvantages of these processes in the Brazilian ethanol production

Figure 1. Dosage of antibiotics in yeast treatment

As for the disadvantages of the batch process, the installation costs are higher compared with the continuous process, as it is necessary to have relatively more fermenters and heat exchangers. The same is true for automation costs.

Findings

The bacterial contamination, mostly associated with Lactobacillus, is regarded as the major factor in reducing ethanol yield during the industrial fermentation process, as it not only consumes sugars (for biomass and metabolites) but also impairs the centrifuging step due to yeast flocculation (Amorim et al., 2004).

According to Ingledeuw (2003), the cost of contaminating bacteria in fermentation mash is significant. When bacterial counts reach one million to 10 million per mL, losses in alcohol production reaches 1-3%. A 3% loss in a 19.3 million gal / year (73.0 million liters/year) (53,000 gal / day (200,000 liters/day)) alcohol plant is a loss of 580,000 gallons (2.2 million liters) of ethanol per year. This potentially significant loss dictates that bacteria and fast growing wild yeasts must be controlled with antibiotics in continuous fermentation.

Due to the fact that in the continuous process the control of contamination is more difficult, more antibiotics is generally required, which invariably results in increased ethanol production costs, as shown in the figure 1.

The evolution of the control of bacterial contamination was one of the most important factors contributing to increasing the fermentation yield in the Brazilian distilleries (see Table 1).

Table 1. Effect of the bacterial contamination on fermentation yield

<table>
<thead>
<tr>
<th>Decade</th>
<th>Bacterial contamination levels</th>
<th>Fermentation yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>10^5</td>
<td>75 - 80</td>
</tr>
<tr>
<td>80</td>
<td>10^6</td>
<td>83 - 86</td>
</tr>
<tr>
<td>90</td>
<td>10^7</td>
<td>86 - 90</td>
</tr>
<tr>
<td>00</td>
<td>10^8</td>
<td>&gt; 90 - 92</td>
</tr>
</tbody>
</table>

(*ORS: due to the fact that with the continuous fermentation process it is not possible to have a high level of precision on measuring the volumes (mash, beer and treated yeast), normally the fermentation yield for the continuous fermentation processes are overestimated)
It is apparent from Figure 2 that with, the continuous process, bacterial contamination levels in the beer are higher compared with the batch process. This is largely due to the fact that the fermentors in the continuous process are not cleaned frequently, whereas cleaning in batch system is facilitated after each fermentation cycle.

The effect of the high level of contaminants during continuous fermentation process has adverse effect on yeasts, and consequently, reduces the fermentation yield, and increases ethanol production costs, as shown in figures 3 and 4.

**Case studies**

**Case 1**

Until the 2001 harvest season, the following distillery was operating with continuous fermentation process. After that, during the 2002 harvest season, it changed to a batch fermentation process. Table 2 highlights the yields parameters.

This example firmly confirms the superiority of the batch process in promoting a better condition for yeast, increasing its viability, the bacterial contamination control was much more effective, with contamination being 24-fold lower.

The performance of the centrifuges increased due to the reduction of the flocculation.

With improved condition for yeast to operate in, complete fermentations was achieved, in accordance to the concentrations of TSAI in beer. When this distillery was operating the continuous process, the amount of sugars lost in beer was 3.1%, compared with only 0.2% with the batch process.

It was possible to increase the beer % ethanol to 36%, and when the beer has a higher content of ethanol, it results in lower losses of ethanol in stillage.

There was a reduction of 64% in the antibiotics consumption, and an insignificant increase in sulfuric acid consumption to compensate for the reduction in antibiotics use to control the bacterial contamination.

Change to the batch process therefore resulted in increase in productivity by 2.29% amounting to an additional annual output of 3.3 million liters more ethanol. So, the replacement with the batch process was paid back in one year.

**Case 2**

In this second case study, the distillery in question, after many years of optimization on its continuous fermentation process, reached a peak of 90.0% on its fermentation yield.

For this reason, during the 2004 season it was decided to change its process for a batch process, for the 2005 harvest season. When the 2005 season started, the new batch fermentation process was still under construction, and this distillery operated the first 18 weeks using the same continuous process, until the batch process was ready to operate.

After the first 18 weeks, the installed new batch process came into operation.

**Table 2.** A comparison between the harvest seasons using continuous and batch fermentation process

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>2001 SEASON (Continuous Process)</th>
<th>2002 SEASON (Batch Process)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Yeast Viability</td>
<td>68.94</td>
<td>77.18</td>
</tr>
<tr>
<td>Alive Bacteria / mL in Beer</td>
<td>2.3x10^4</td>
<td>9.6x10^4</td>
</tr>
<tr>
<td>Beer % Ethanol</td>
<td>6.47</td>
<td>8.81</td>
</tr>
<tr>
<td>% TSAI in Beer</td>
<td>3.1</td>
<td>0.2</td>
</tr>
<tr>
<td>% Yeast on Cream (centrifuged)</td>
<td>0.18</td>
<td>81.13</td>
</tr>
<tr>
<td>% Ethanol lost in Stillage</td>
<td>0.26</td>
<td>0.14</td>
</tr>
<tr>
<td>Antibiotics (mg / L ethanol)</td>
<td>9.46</td>
<td>3.39</td>
</tr>
<tr>
<td>Sulfuric Acid (g / L ethanol)</td>
<td>9.54</td>
<td>10.03</td>
</tr>
<tr>
<td>% Fermentation Yield</td>
<td>89.59*</td>
<td>91.88</td>
</tr>
</tbody>
</table>

* Overestimated

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Findings shown in Figures (5, 6, 7) confirmed the merits of both the systems described and discussed earlier.

Discussion

The advantages of continuous fermentation system include elimination of the lag phase of yeast growth, the yeast being "locked" into exponential phase growth where conditions exist for maximal ethanol formation, long term continuous productivity, high volumetric productivity, reduced labor costs while in steady state, reduced downtime for cleaning, filling and sanitation, easier process control and savings in construction of smaller fermentors with higher output (Ingledew, 2003).

Higher technological capability to operate such systems is needed, but the main disadvantages of this system are the problems with contaminating bacteria and wild yeast that disturb the balanced nature of the fermentors, problems of maintenance of high fermentation rates, and genetic stability of the culture used— all of these negating, in part, the advantages mentioned above. Contamination leads to losses in yields of ethanol and unplanned shutdowns of the fermentation trains - factors that lead to lower than expected yields of product and less efficient conversion of sugars to ethanol (Ingledew, 2003).

The brewery sector, which invests significantly more in research and technologies of fermentation than the fuel ethanol sector, have made similar observations with continuous and batch fermentation processes. In the brewery segment, over the last 100 years, of the many breweries which opted for continuous beer fermentation, only a few have survived (Virkajärvi et al., 2001).

At the end of the 1960s, most continuous fermentation projects were abandoned, the famous exception being the Coutt's process in New Zealand (Virkajärvi et al., 2001).

The reasons for failure of continuous fermentation systems have been widely reported. Many of its disadvantages are listed below (Virkajärvi, 2001):

- inflexibility in the output rate or in charging the boor type;
- the high standard of hygiene needed;
- possibility of yeast mutation;
- extra procedures needed in diacetyl reduction;
- lack of control over degree of attenuation;
- need for highly skilled supervision;
- the large amount of ancillary equipment needed;
- the need for extremely flocculent yeast;
- the need for a separate vessel for excise declaration;
- the need for unpitched wort storage.

A similar rethink is occurring in the fuel ethanol sector in Brazil. During the 2006 harvest season, around 83% of the distilleries were working with the batch process, and the majority of the new ones are opting for the batch process.

Considering that the fermentation process for ethanol production does not take place in a sterile condition, it is apparent that the harmful effects of the bacteria on the yeast performance and the costs for its control invariably dictates the choice of the fermentation process selected by distilleries.

References

Continuous and batch fermentation processes: Advantages and disadvantages of these processes in the Brazilian ethanol production

By A. Godoy*, H.V. Amorim, M. L. Lopes and A.J. Oliveira

Fermentec Ltda, Av. Antonia Pizinatto Sturion, 1155, 13420-640, Piracicaba-SP, Brazil.
Web: www.fermentec.com

*Contact author: Email: alexandre@fermentec.com.br

abstract

Studies were conducted with 62 Brazilian distilleries during the last nine years to elicit the advantages and disadvantages of continuous and batch fermentation processes. Of these, 51 were batch and 11 continuous. Findings indicate that the batch fermentation process with yeast recycle is superior for the following main reasons. The process parameters are more easier to measure and invariably control and manage. In particular, it is less susceptible to bacterial and wild yeast contamination which otherwise would invite hosts of problems including decrease in productivity. In a case study presented, the increase in output (of 3.3 million litres) through the replacement of a continuous process with a batch process resulted in payback within the year. While the continuous system is relatively cheaper to install, this is negated by poor productivity levels associated with bacterial and wild yeast contamination as it does not lend itself to be cleaned more frequently, the additional costs of antibiotics to address this and yeast shocks when they pass from one fermenter to other where the composition of the substrate (namely alcohol and sugars) and temperature are both different. This suggests why 83% of the Brazilian distilleries have adopted the batch process and new ones are also opting for this as process of choice.

Keywords: bacterial control, batch fermentation, continuous fermentation, ethanol, fermentation yield

Procesos de fermentación continua y en batch: Las ventajas y desventajas de dichos procesos en la producción de etanol en Brasil

Durante los últimos nueve años se llevaron a cabo estudios con 62 destilerías de Brasil con el objetivo de determinar las ventajas y desventajas de los procesos de fermentación continuos y en batch. De estos, 51 eran en batch y 11 continuos. Los resultados indican que el proceso de fermentación en batch es superior por las siguientes razones principales. Los parámetros del proceso son más fáciles de medir, de control invariable y manejo. En particular, es menos susceptible a la contaminación bacteriana y de levaduras silvestres que podrían causar una variedad de problemas tales como la disminución de la productividad. Como se puede ver en el ejemplo de un estudio presentado, el aumento en la producción (de 3,3 millones de litros) obtenido mediante el reemplazo de un proceso continuo por un proceso en batch, resulta en una compensación de costos logrado en un año. A pesar de que el sistema continuo es relativamente más barato de instalar esto está contrarrestado por los bajos niveles de productividad asociados con la contaminación bacteriana y de las levaduras silvestres ya que no se presta fácilmente a un proceso de limpieza frecuente. El costo adicional de los antibióticos necesarios para eliminar la contaminación y el ataque de las levaduras cuando se pasa de un fermentador a otro donde la composición del substrato (específicamente alcohol y azúcares) y temperatura son diferentes. Esto explicaría la razón por la cual 83% de las destilerías de Brasil han adoptado el proceso batch y por qué las nuevas destilerías también están optando por este proceso como el preferido.

Kontinuierliche und Batch-Fermentationsprozesse: Vor- und Nachteile dieser Prozesse bei der brasilianischen Ethanolproduktion

Overview of the ethanol production in Brazil

Ethanol production in Brazil takes place during the cane harvesting season lasting 200-230 days. The industrial processes are based on large-scale fermentations of sugar cane juice, molasses or a mix of both. Alcoholic fermentations are carried out in very large fermentors with capacity ranging from 0.4 to 2.0 million liters. Feed-batch and continuous fermentation systems are common. Approximately, 83% of the distilleries use the feed-batch system.

Moreover, the industrial fermentations are well characterized by its high yeast cell concentrations (8-17%), very short fermentation times (6-10 hours) and alcoholic concentrations of between 6 and 11% (v/v). After the end of each fermentation cycle, yeast cells are centrifuged off from the beer and treated with diluted sulfuric acid for 1-2 hours at pH 2.0-2.5 to kill bacteria. After this treatment, the yeast cells are returned to fermentation vats to start a new fermentation cycle. Yeast strains PE-2 and CAT-1 (Fermentec) and BG-1 and SA-1 (Copersucar) are widely used in the industry. These were selected from industrial fermentations by karyotyping technique and evaluated in laboratory over many years. These strains are adapted to industrial processes and show high resistance to stress conditions. In 2006, more than 190 distilleries opted for these four selected yeasts strains (Amorim, 2006).

The actual stage of the fermentation processes in Brazil

In 2006, 329 ethanol plants with an average production capacity of between 600 and 800 m3/day were in operation, producing 17.6 billion Liters. This is set to expand by further 77 new mills by 2012 increasing the annual output to up to 28 billion liters.

Typical for the Brazilian technology is the yeast recycling concept which results in high transformation rates to ethanol, because less carbon source is used for yeast growth (Dorfler and Amorim, 2007).

Since the inception of the Brazilian Ethanol Program (Proálcool) in the 70's, advances in technology over the last 30 years in Brazil has significantly improved productivity levels (Dorfler and Amorim, 2007). These include:

- Conditions to improve the fermentation yield;
- Development of analytical methods to accurately and rapidly measure sugar concentrations in juices, molasses and beers applicable in each industrial laboratory;
- Online counting of live bacteria by light microscopy in up to 15 minutes;
- Method to choose an effective antimicrobial agent (in 6 hours) to control bacterial growth;
- Karyotyping of yeast cells for identification;
- Identification of contaminating bacteria by DNA sequencing;
- Accurate and precise determination of alcoholic content by digital densimeters;
- Introduction of NIRS (Near Infrared Spectroscopy) for routine analysis;
- Reduction of sugar losses and consumption of chemicals.
- Selection of the yeast strains from the industrial environment;

Without effective measurement, it is impossible to manage and evaluate the process and assess technological performance.

In the early 90's, there was a general tendency to convert batch to the continuous process in the Brazilian distilleries. However, it was apparent this was not based on any critical scientific scrutiny of the relative merits of the both systems. This paper, with particular reference to case studies compares the merits and demerits of the continuous and batch processes commonly used in Brazil. Some 62 distilleries, 51 with batch and 11 with continuous fermentation system were evaluated for their performance over the period 1998-2007.

Before presenting the findings, brief overviews on both the systems are noted first.

Continuous fermentation process

Continuous fermentation processes are generally preferred in some industry sectors for cost reasons. But opting for the continuous system have not always been successful (Linko et al., 1998).

In the case of the continuous fermentation for ethanol production, similar reservations have been observed.

The main advantages of the continuous fermentation process over the batch ones are:

- Lower costs of installation (lower volumes of fermenters, less heat exchangers, and also there is no need for a beer tank to keep the pressure constant to the centrifugal machines);
- Lower costs with automation.

On the other hand, the continuous process also has many disadvantages. These include:

- Difficult to evaluate the fermentation yield due to problems with measuring volumes;
- Bacterial and wild yeast contamination risks, as well as their control, are much more difficult in the continuous system, as they are not frequently cleaned as the system does not lend itself to frequent cleaning. It is necessary to have more fermenters.
- The yeast shocks (stress) when they pass from one fermenter to another are much higher in the continuous system (due to differences in the alcoholic concentration, sugar content, and sometimes temperature).
- Even under optimal conditions, the continuous process rarely produces comparable yields to the batch process.

Batch fermentation process

In the batch fermentation process, the treated yeast is sent to the fermenter, and after that, the fermenter is filled with mash, in a controlled flow, accordingly to the desired beer % ethanol.

This process gives yeast a more favorable condition to operate in, with less stress, as it is not exposed to cosmic shock.

The batch process has the following advantages:

- It is easier to measure fermentation yield (by volume);
- Less susceptible to bacterial and wild yeast contamination, as the fermenters are cleaned after each fermentation cycle;
- The beer presents lower acidity levels;
- The risk of flocculation is reduced;
- The centrifugates can operate optimally;
- It is easier to optimize the time to feed fermenters;
- The fermentation yield can reach 92.0 - 92.5%.
- If a problem occurs with the yeast, for example, when a wild yeast contaminates the process, it is possible to change the yeast without an interruption in the process, as each fermenter can be treated individually. Besides this, if some problem occurs during fermentation cycle, it is possible to increase the fermentation time reducing the risk of residual sugar lost in the fermented beer.