WINE FERMENTER WITH AN AUTOMATIC SYSTEM OF MONITORING AND CONTROL

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Abstract: A good tactic of monitoring and control of the fermentative process can contribute to the development of this area. This paper presents an alternative approach of intelligent monitoring and control, in a fermenting tank, to create a supporting system to the most efficient and reliable decision. So far, this work is still in a phase of collecting data and equipment tests, but as soon as sufficient information is obtained to characterize the process, the treatment of the data will be carried out and mathematical models will be improved in order to equate optimization and control strategies.

Keywords: Fermentation process, Monitoring, and Intelligent Control

1. INTRODUCTION

The wine sector development has to do, without a question, with the conception systems, which enable the matching of the established control theory, with the instrumentation methods, modeling and intelligent control.

Many of the biotechnological products, such as wine, are produced by fermentation or substrate reduction by bacteria.

Biotechnological industry has evolved rapidly in the most recent years, greatly because of the efforts taken in the sense of developing responsible methodologies by raising the fermentation efficiency and rentability in a large scale.

A good monitoring**,** followed by a good control strategy, play an important role in this area development.

The majority of the established control techniques are based on mathematical models of the controlled process. The state of the process variables must be sampled on-line so that the control strategy works. This approach is not always easy concerning to fermentative processes due, greatly, to the non-linear nature of the process.

In this context, the main goal of this project is to develop intelligent control and identification techniques (instead of the classical ones), in order to improve the efficiency and productivity.

With this work, we intend to measure (on-line) the state of a fermentation process and overcome all the deficiencies of the typical fermentation control systems, based in the operator decisions and actions. This automatic system of monitoring and control of fermentation intends to maximize product yield and production capacity; and decrease product degradation, production costs, downstream losses and batch-to-batch variations.

2. PROCESS DESCRIPTION

Most red wines are produced by two different kinds of fermentation. In the primary or alcoholic fermentation, sugar such as glucose and fructose, contained in grapes is transformed in ethylic alcohol, or ethanol with carbon dioxide release.

This complex process, assured by the action of living yeasts cells, may be translated by the following equation (Cooke, 1988):

$C_6H_{12}O_6$	$\rightarrow$	CH_3CH_2OH	+	CO_2	
1 molecule of glucose 180g	Fermentation (Yeasts)	2 molecules of ethanol 92g		2 molecules of carbon dioxide 88g	(1)

The secondary or malolactic fermentation is a completely different phenomenon from the alcoholic fermentation, being always followed by the activity of a bacterium, such as *Leuconostoc*, *Pediococcus* and *Lactobacillus* genera. This bacterium is responsible for the transformation of malic acid into lactic acid, with carbon dioxide release (Eisenman, 1998).

$H_2C_4H_4O_5$	$\rightarrow$	$HC_3H_5O_3$	+	CO_2	
Malic Acid 1 gm	Lactic Bacteria	Lactic Acid 0.67 gm		Carbon Dioxide 0.33 gm	(2)

2.1 Physical-chemical Factors That Affect Fermentation

The fermentation process involves many chemical reactions and its kinetic depends of several physical factors like pH, temperature and others parameters.

The maintenance of these optimal conditions assures a good evolution of this process and gives the guarantee the survival of microorganisms.

Oxygen Concentration. Oxygen is the gaseous substrate of greatest relevancy to the microbian metabolism and the most important metabolic product is the carbonic anhydride. Since the oxygen is not a very soluble gas – a saturated solution of oxygen contains approximately 9 mg/L of this gas in water- it becomes necessary to add air to the fermenter during the process.

Henry's law describes the oxygen's solubility in nutrients solutions related to the oxygen partial pressure in the gaseous form:

$$C = \frac{P_o}{H} \qquad (3)$$

Where C is the concentration nutrients (in a solution containing O_2), P_0 is the partial pressure of gas in the gaseous form and H is Henry's constant, which is specific to each type of gas.

It is important to enhance the existence of a critical oxygen concentration (word used to express the value of the specific speed of oxygen's absorption) that allows respiration. This critical concentration possesses characteristic values for each microorganism oscillating, generally, between 5% and 25% of the oxygen's saturation values in the cultures.

Temperature. Temperature is another essential parameter in the success of fermentation. Microorganisms growing at a temperature lower than the optimal reveal a delayed growth and a reduced cellular production. On the other hand, if temperature is too high, without being lethal, a thermic shock may be induced which origin reduction in the efficiency of protein products. In order to obtain a good efficiency, fermentations must be made in a narrow range of temperature and, if possible, at a constant one.

pH. Most microorganisms grow, in optimal conditions, at a pH between 5,5 e 8,5. However, during it's growth in a fermenter, the cellular metabolites are released which may lead to pH alterations. Therefore, the pH control must be done carefully and the necessary corrections must be made by the addition of an acid or alkaline solution. It is clear that this addition must be so quick that the pH remains the same in all fermenter.

Agitation, mixing and uploading. Agitation is an operation that creates or speeds the contact between two or more phases. The proper agitation is of main importance to fermentation, since it insures the air dispersion in the solution, the temperature homogenization, pH and nutrients concentration in the fermenter, color and perfume of wine by the grape's skin contact with the juice.

The different kinds of agitation used in fermentation may be included in this three classes: rotating agitators, which possess an internal mechanical system of agitation; gas columns bubbles in which the agitation is carried out by introducing air under great pressure and airlift system which may have an internal or external circuit.

The mixture and fluids circulation, which result from the airflows introduced, causes density differences in the distinct parts of the fermenter.

The first mentioned method is the most used, since it is the most flexible in the operation conditions, the most easy to obtain commercially and it offers an efficient transference of gases into cells.

3. SYSTEM CONCEPTION AND FUNCTIONING

The success of fermentation depends upon the existence of defined environmental conditions for biomass and product formation. Thus temperature, pH, degree of agitation, oxygen concentration in the medium and other factors may have to kept constant during the process.

The provision of such setting requires cautious monitoring of the fermentation so that any variation from the specified optimum might be corrected by a control system.

As well as aiding the preservation of constant conditions, the monitoring of a process may offer information of the progress of the fermentation. Such information may indicate the optimum time to harvest, or, that the fermentation is progressing abnormally. Thus, monitoring tools should be capable of being associated to a suitable control system as well as producing information indicating fermentation progress.

The prototype in study intends to guarantee all the conditions for a most advantageous fermentation and offers all the capabilities of monitoring and actuation in every one of the factors that affect, most, the fermentation kinetic. This system includes an intelligent control policy and assists the operator in his decisions.

Criteria, which are monitored in this system, are listed in the Table 1.

Table 1 – Process Sensors and their possible control functions

Category	Sensor	Control Function
Physical	Temperature Pressure Level	Heat/cool
Chemical	pH	Acid or alkali addition
	Redox	Additives to change redox
	Oxygen	Change feed rate

3.1 Fermenter

The fermenter prototype intends to assure optimal fermentation conditions in an aseptic environment (Pumphrey, 1996). Therefore, the fermenter was equipped with airing, agitation and monitoring systems of the main process variables, namely pH, temperature and oxygen. This design - smooth internal surfaces using, whenever possible, welds - allows the cleaning and maintenance operations. In order to decrease the operation and maintenance costs of the fermentative process, all the electro-mechanical system was conceived in a way to reduce, to the minimum, the energy consumption as well as the losses by evaporation.

To allow off-line measurements a solution samples collect system was also introduced.

3.2 Airing and Agitation Systems

The agitation method implemented in the prototype is achieved by the controlled movement of several shovels (pneumatic system), being its vertical movements responsible by must homogenization and contact between liquid and grapes in order to give color and flavor to the wine.

The refrigerating system is based on the functioning of an internal water coil.

To control the temperature of the must (which must be between 25º and 35º C), during fermentation, it is necessary to remove the heat generated along the process. Therefore, most of fermenters whose capacity is superior to 1000 liters need an internal coil. The heat transference area of an internal coil is:

$$A_S = \pi d L_S = \pi^2 d D_S n_S \qquad (4)$$

Where, $\mathbf{A_S}$, is the transference area of the internal coil's, **d** is the external diameter of coil's tube, L_S is the coil size, $L_S=\pi D_S n_S$ and D_S is the diameter of the coil.

3.3 System Constitution

Figure 1 shows the system constitution, which consists in placing next to each fermenter two boards, being one of data acquisition and state visualization and the other of action, connected to a CAN network (*Control Area Network*). Besides these two types of boards, there is a PC 104, with a touch screen that along with the CAN interface, possesses an RS232 interface and a card Ethernet.

The acquisition and visualization board is used to obtain data concerning the most important parameters to the fermentation control process specifically, temperature, density, pH, must level, redox potential and pressure to allow the user to know about the development of fermentation in a particular tank by showing available data on a liquid crystals display.

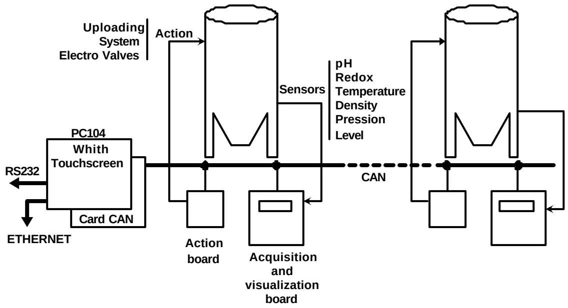

Figure 1- System elements and its distribution.

According to the acquired parameters and based on the control algorithm, decisions are made concerning the actions to be taken by the action boards in order to improve the fermentation process.

That is the function of the action board, i.e., to exert specific actions such as the uploading system activation in order to mix the must or act on electro valves, which control the water flow used for controlling the temperature.

The PC104 function is to coordinate the development of the entire process, as well as allow its monitoring and modification. Thus, the user may visualize in such terminal, the state of each fermenter and is able to modify the fermentative process evolution by introducing more adjusted data. Such data may refer to a particular tank or to the entire system. The RS232 interface allows data downloading for posterior studies.

The Ethernet card is used to allow remote control of the system, on Internet, since the user is an authorized one.

3.4 Control

In a recent past, some advanced computation techniques were used in the fermentation pre-processed (off-line) control, by the use of commercial control software then available. This has suffered little or nun alterations till this moment.

There are two control and optimization methodologies, which are presented as being well adjusted to the solution of this problem. The first one consists in using statistic techniques of optimization and the second, consists in using adequate models in the optimization and control processes, namely fuzzy logic based models.

In this project, is given preference to the second method, since besides allowing a greater understanding of the entire process it can be used in a real time optimization and control (on-line). Thus, the predictive capacity on the fermentative process's behavior improves the possibility of optimization.

3.5 Mathematical model

The alcoholic fermentation is dependent of a large number of factors, namely the yeast growth, heat generation, pH and oxygen.

So far, many models were developed to describe fermentation. These mathemathical equations are very important to the optimization and control strategies of the process.

After a comparative study of the established kinetics models of fermentation, the established by Boulton in 1977 should be noted, since it takes in account a large number of variables, as well as being one of the few models, which considers the effect of temperature.

According to this model is important to know the yeast growth, substrate utilization, inhibition effects, product formation and temperature effects.

4. RESULTS AND CONCLUSIONS

This project is still in a phase of collecting data and equipment tests, which will be carried out for a longer period in order to obtain a wider vision of the fermentative process, which is, by itself, long and slow.

As soon as sufficient information is obtained to characterize the process, the handling of the data will be carried out and mathematical models will be tested in way to equate strategies that will improve the performance of the entire system.

5. FUTURE WORK

In a posterior phase, will be developed a turbidity sensor to be integrated in the fermentation tank and a new monitoring technology based in the sensorial fusion and micro sensors.

At the same time, off-line measurements of new variables will be made, namely microorganisms (yeasts and lactic bacterium), lacase/tyrosin content, free/combined sulfur content, total polyphenol (tanin, antocianin) content, tartaric and malic acid content and residual sugar. With this new data, we intend to, mainly, improve the mathematical models of the fermentative process kinetic and create a supporting system to the most efficient and reliable decision.

The final model will consider all the parameters of the Boulton model and in addition will be introduced the effect of pH in fermentative process.

Finaly, we propose to build a system responsible for fault detections that helps, once again, the operator mission and, simultaneously, activate the correspondents actuators of the system in charge of this problems.

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