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Treball Final de Grau

Preliminary design of a small production plant of sparkling wine.
Disseny preliminar d'una petita planta de producció de vi escumós.

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“Sparkling wine is the only way to pack the time”

Popular saying.

REPORT

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SUMMARY

This project deals with the idea of a preliminary design of a small production plant of sparkling wine. From all over the process, the fermenter has been chosen as the element to be designed because of its importance in the process. The other parts and elements of the process are to prepare the main raw material, the grape juice, upstream and, downstream making the second fermentation inside the bottle known as "Traditional Method". The main aim of the sparkling wine production plant is to achieve the objective of producing 50,000 bottles of sparkling wine per year. Furthermore, in this project is intended to know what is required to accomplish this objective in terms of raw materials, equipment, services and the layout of the production plant.

Firstly, there is an extensive introduction which provides information about its characteristics and properties, the tendency of the markets, its regulatory, the description of the process and the recent improvements in this sector. Next, there is the proposal of the layout, once the requirements of the dimensions of the tanks and the fermenter, the space for aging, the automatic filling line are defined according to the objective bottle's production. Finally, there are all the calculations and all the decision-making for the design of the fermenter required for the performance of the reactor to be capable of transform all the raw material into base wine in the highest quality ready for the second fermentation.

The aim of this project is to do the preliminary design of the sparkling wine production plant focusing on the design of the fermenter which has to produce the base wine for the 50,000 bottles per year of sparkling wine.

To achieve this objective, it is required a research of many aspects of the process, such as the raw materials, the reaction of fermentation, the methodology of manufacturing. Having analysed all the variables to be considered, then, the design of the reactor is able to be done considering the dimensions, the service of cooling, the controlling system and the material to be built.

Keywords: sparkling wine, design, production, plant, fermenter, manufacture, industrial.

RESUM

Aquest projecte tracta de la idea d'un disseny preliminar d'una petita planta de producció de vi escumós. De tot el procés, s'ha seleccionat el fermentador com a element que s'ha de dissenyar per la seva importància en el procés. Les altres parts i elements del procés són preparar la matèria primera principal, el suc de raïm, aigües amunt i, aigües avall, fer la segona fermentació dins de l'ampolla coneguda com a "Mètode Tradicional". L'objectiu principal de la planta de producció de vi escumós és aconseguir l'objectiu de produir 50.000 ampolles de vi escumós a l'any. A més, en aquest projecte es pretén conèixer què és necessari per assolir aquest objectiu quant a matèries primeres, equips, serveis i la disposició de la planta de producció.

En primer lloc, hi ha una àmplia introducció que proporciona informació sobre les seves característiques i propietats, la tendència dels mercats, la seva regulació, la descripció del procés i les millores recents en aquest sector. A continuació, hi ha la proposta del traçat, un cop definits els requisits de les dimensions dels dipòsits i del fermentador, l'espai per a l'envelliment, la línia d'ompliment automàtica en funció de la producció objectiva de l'ampolla. Finalment, hi ha tots els càlculs i tota la presa de decisions per al disseny del fermentador necessari per al rendiment del reactor per poder transformar tota la matèria primera en vi base amb la màxima qualitat preparada per a la segona fermentació.

L'objectiu d'aquest projecte és fer el disseny preliminar de la planta de producció de vi escumós centrada en el disseny del fermentador que ha de produir el vi base per a les 50.000 ampolles anuals de vi escumós.

Per assolir aquest objectiu, es requereix una recerca de molts aspectes del procés, com ara les matèries primeres, la reacció de fermentació, la metodologia de fabricació. Després d'analitzar totes les variables que s'han de considerar, es pot fer el disseny del reactor tenint en compte les dimensions, el servei de refrigeració, el sistema de control i el material que es vol construir.

Paraules clau: vi escumós, disseny, producció, planta, fermentador, fabricació, industrial**.**

1. INTRODUCTION

The world of sparkling wine making is the full of sensations, ideas, odours, flavours, in short, histories. Lots of histories. The process of sparkling wine making is closer to the art of creating an experience rather than making just a beverage. It is said that the wine reflects the weather and the climate conditions of the harvesting and it is the experience of the oenologist who achieves the perfect bouquet for us to enjoy this worldwide known drink.

On the other hand, this beverage is associated with festivities, familiar meals, or even celebrations which requires a toast. However, it can also be drunk on weekdays because it suits perfectly with any sort of meals. That is why it is commonly known and drunk all around the world.

The decision to perform this project is to make the predesign of the winery in a familiar garage where once it had already been a manual small winery. Furthermore, this project deals with the intention of providing the information and provide a proposal for achieve the objective production focusing on the fermenter which transforms the grape juice to the base wine ready for the second fermentation known as “Traditional Method”.

1.1 THE PRODUCT: SPARKLING WINE

Sparkling wine comes from the grapevine whose fruit, the grapes, after a pressing provides the grape juice, which is highly sugared, is the main raw material for producing Cava. Vineyards has a big importance to the quality of the grape and, consequently, to the quality of the final product, the Cava.

The sparkling wine undergoes two transformations done by yeast where the first one, transforms the grape juice to the base wine just adding yeast which consumes the sugars in the grape juice producing alcohol and CO_2. The second fermentation is the responsible of producing the typically and famous bubbles on the Cava. This step is known as the “Traditional Method” that consist of adding yeast and some more sugar inside the closed bottle preventing the CO_2 created can escape and get dissolved in the liquid. The “Traditional Method” is also done, for example, to do Champagne although the difference between these two products in just the area where the vineyards are and where it is manufactured.

Sparkling wine is a gold-coloured or rosé beverage with low-alcoholic grade which is drunk all around the world in celebrations or festivities due to it is associated in this context although it can be also drunk as an aperitif or in the table talk besides, it goes well with fish and meats. However, Cava is related with the luxury and happiness and that is why it is usually drunk in parties and festivities.

1.2 PROPIERTIES OF CAVA

Almost 98% of most wines and sparkling wine in made up of water and ethanol. The other 2% is a combination of acids, sugars, volatile flavour and aroma compounds such as pigments and tannins. Amazingly, it is this 2% that makes all the difference providing the wine or Cava its unique colour, aroma and bouquet. So, it is in this 2% where chemistry really comes into play [1].

1.3 BIOCHEMICAL PROPERTIES

Its composition is complex. With an alcoholic graduation below 14%, in their nutrients there are water (in majority), alcohol, simple carbohydrates (sugars) and less quantities of vitamin B6, minerals salts (potassium, phosphorus, magnesium, sodium, calcium), organic acids and antioxidant substances such as phenolic acids, cinnamic acids, tyrosine derivates, stilbenes, flavonoids and condensed tannins.

Most of the nutrients come from the grape and the fermentation process, between them, polyphenols stand out because of their antioxidants features which provide hydrogen or electrons that catch the free radicals, stopping the oxidation process.

Some studies have shown that the moderate consume of wine or cava have many effects on the health of human body. It can reduce the possibility of suffering cardiovascular disease, decrease the risk of suffering diabetes Melius, higher level of “High Density Lipoprotein” (or good cholesterol) and limiting the “Low Density Lipoprotein” (or bad Cholesterol), improve the coagulation system, and so on. Finally, the moderated consume of Cava is considered to be beneficial to the human health [2].

Next, there is table 1 showing the main nutrients that can be found in Cava as nutritional aspects. The values of the table 1 are considered taking 100g of Cava.

Table 1: Main nutritional supply of Cava.

NUTRIENTS	QUANTITY
PROTEIN (g)	0.20
TOTAL FATS (g)	0.04
GLUCYDES (g)	1.50
FIBER (g)	0.00
CALCIUM (mg)	10.00
FERRUM (mg)	0.33
VITAMIN A (mg)	2.50
VITAMIN B (mg)	1.80
VITAMIN C (mg)	1.50
VITAMIN E (microg)	0.04

The calories of 100g of Cava is around 70.50 kcal that this supply is approximately the 3% of the daily calorie’s recommendation. The alcoholic graduation is around 12º that means each litre of Cava contains approximately 12 centilitres of alcohol [3].

1.4 CHEMICAL PROPERTIES

The principal composition of cava is on the one hand, the grape juice which contains water and sugar, and on the other hand, the ethanol in around 12%. The alcohol is a colourless liquid and inflammable, not in the winery due to the concentrations, that mixed in water at whatever composition produces an azeotropic mix with a composition of 96%. Its odour is characteristic and intense because the it has in their molecular composition the presence of a group hydroxyl and short chain. The miscibility of the ethanol contrast to other alcohols with longer chains. The mix of water with alcohol reduces the volume of the mix compared to their initial's volumes individually. The hydrogen bonds if the ethanol molecules are hygroscopic that means the it easily absorbers the water in the air.

The presence of the ethanol in the water of the grape juice reduces drastically the surface tension of the water. This propriety explains the phenomena of "the tears of the wine". When the wine or the Cava is shaken into the glass, the ethanol evaporates rapidly from the layer of the wine and remain into the wall of the glass. As the content of the ethanol in the liquid is reduced, its surface tension increases in the layer of the wine or Cava and slide down in the glass in a particularly and characteristic way.

1.5 IMPORTANCE OF CAVA IN THE CURRENT MARKET

The situation of Cava in the actual economy is stable because the product is well-known, and their use is associated to celebrations and festivities. For the last fifty years ago, the sector has been increasing the number of the sales and, in consequence, the number of the bottles produced. The Cava's sector is affected by the situation of the global economy because its situation goes together with the consume of Cava [4].

Nowadays around 214 Cava producer's companies situated around Alt Penedes, epicentre of the production of Cava. These wineries produce near 250 million of bottles per year, which is increasing year after year, with a increase of 2.07% about previous year. The sector of Cava generates over 1.2 billion euros per year that mean a significant impact to the economy of the country.

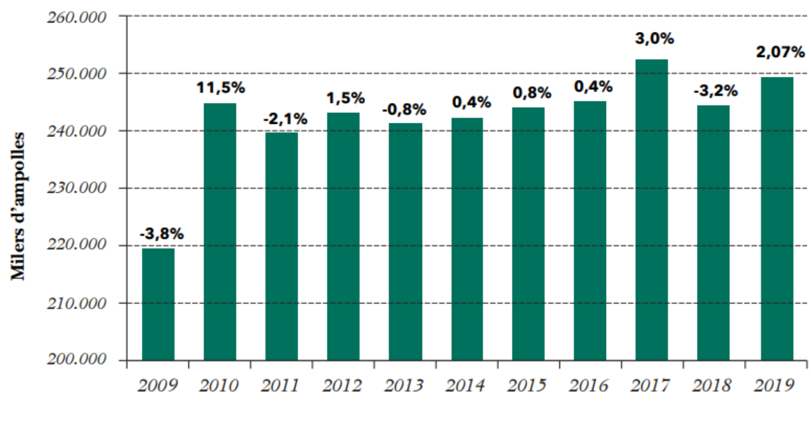


Figure 1. Number of Cava's bottles produced per year, in thousands of bottles.

The commercialization of Cava has undeniable presence in the international market because 66.1% of the Cava produced is exported. The majority of the 214 wineries are present in the international market because it is a potential growing market. The main exportations are to the Union European, where the top 3 consumer countries are Germany, Belgium and United Kingdom. However, EUA and Japan are increasing their importation too. On the other hand, the lowest exportations are around the 20.6% of the total production destinated to the underdeveloped countries, that shows the Cava is recognised as a valued product and associated to a luxury product and status.

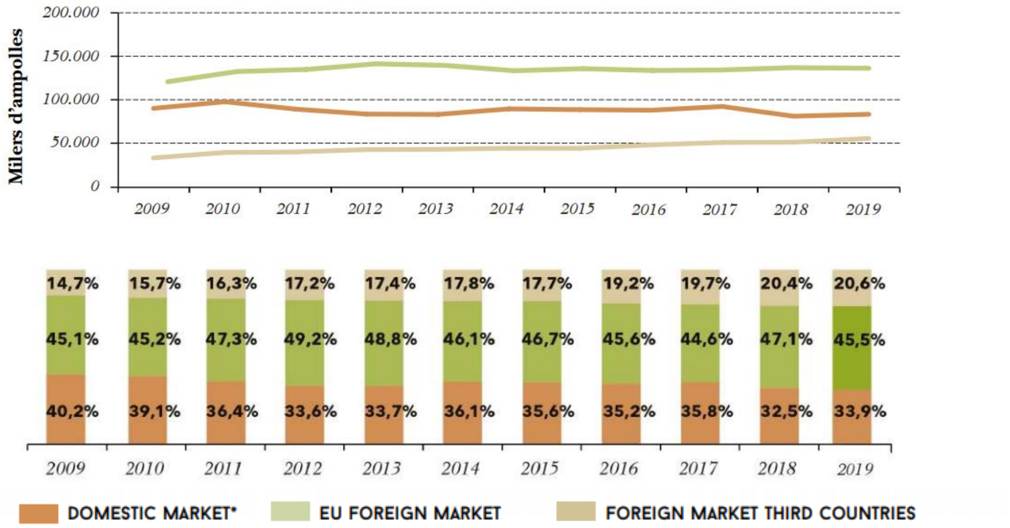


Figure 2. Number of sales according to the market. (Image from DO. Cava)

The domestic market is more static, although it represents the 33.9% of the total production, due to the tradition of drinking Cava in our culture has been united for hundreds of years ago. The competitivity between brands makes difficult to find a way to sell their products. Despite the fact that the crisis in 2008, the position of the sales Cava in our country is increasing year after year. In our country, the major part of the sales is done in two festivities of the year: Christmas festivities and Sant Joan which represents approximately the 46% of the total year's production.

Comparing the ranges of the Cava's ageing, the most produced Cava is the "Cava Traditional" which is 9-month minimum aged and represents the 87.7% of total. Next, is the "Cava Reserve" which is 15-month minimum aged and represents the 10.7% of the market share. The "Cava Large Reserve" which is 30-month aged in the caves, and only represents the 1.4% of the total production. Finally, the "Qualified Place Cava" which is the most aged, minimum 36-month in the caves, just represents the 0.1% of the total numbers of bottles produced.

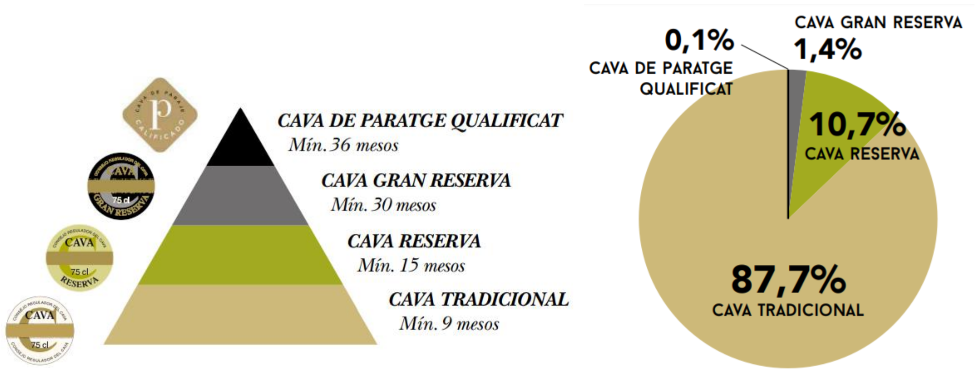


Figure 3. Percentage of Cava's aging range produced in 2019. (Image from DO Cava)

The recently years, there have been a constant effort by the producers and the legislation to improve the image and the quality rather than the volume of productions has had a positive impact on this sector due to costumers see Cava as an interesting product and this has built loyalty to the D.O. Cava. However, it has appeared recently the intention of produce a new way to produce ecological Cava beginning from the way that vineyards are cultivated and taken care of them.

New producers are developing their product to this way because customers are looking for this type of products which has increased 76% in relation of 2017, becoming now the 5.5% of the total Cava produced nowadays production. Talking about the Ecologic Cava, the main type produced is the "Cava Traditional" which constitutes the 63.9% of the total Ecologic Cava, whereas the 24.5% is made for "Cava Reserve", next there is the 11.5% by "Cava Large Reserve" and, finally, just 0.1% is for "Qualified Place Cava". The future of the Ecologic Cava is expected to increase for the next years because of the appreciation by the customers [5].

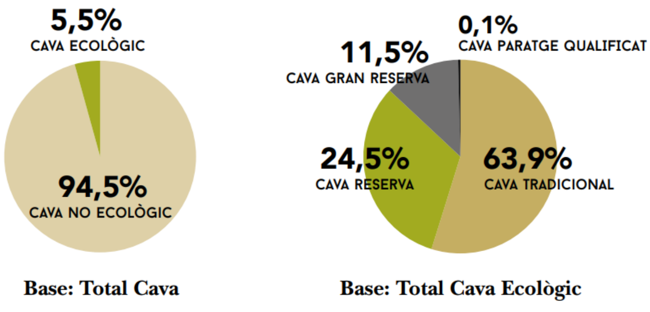


Figure 4. Percentage of Ecologic Cava and non-ecologic. And percentage of Cava aged range in ecologic Cava. (Image from DO. Cava)

1.6 TECNHOLOGY IN THE WINERIES

In the beginnings of the production of Cava, the process was totally hand-made and a lot of manual work which was very tiresome. From the working in the campsite, to the work done in the cellar.

Luckily, there has been an industrialization of the process that has revolutionized the manufacturing of the process. Furthermore, the use of new techniques and materials has increased the quality of the product such as the yeast, and the filters and also the quantity that is able to make a winery due to the automatization of the production lines and more specialized equipment that provide a perfect control of the process.

On the one hand, some wineries are trying to produce their Cava like in the past, making less quantity of product in order to achieve higher quality. Nevertheless, the Cava is made by the "Traditional Method" which consist of doing the second fermentation inside the bottle and this is compulsory to make D.O. Cava. Producing like in the past does not mean that the wineries are introducing technology for increasing their production and reduce the costs. That is why some innovations known as *BAT*, Best Available Technology, have been done in this sector like the "Cavagel machine". In the past, the yeast responsible for the second fermentation had to be removed by hand loosing too much liquid. Nowadays, this machine is the responsible for freezing the neck of the bottle and make easy to expel the solidified yeast inside the bottle in the second fermentation.

Another *BAT* introduced in the wineries has been the "Giropallet machine" which rotates the bottles in order to concentrate the yeast of the second fermentation inside the bottle without mixing with the liquid to the neck to be expelled later. In the past, this movement was done by hand which involved many workers and much time. These improvements are done by wineries that produces a considerable number of bottles. This information is provided by a builder of these machinery, RUBIO JULVÉ [6].

On the other hand, the researches in this sector are studying the behaviour of the yeast and how can be improved the performance of the yeast in the fermentation. The inoculation of the yeast is done in order to guarantee that it is achieved a considerable number of cells that will be able to do the fermentation. Besides, the inoculation of the cells provides to the base wine that the properties of the yeast is the same year after year. This makes that the product the same fermentation after fermentation and identifies the brand in the market to the customers.

There is a tendency the use of enzymes that increase and facilize the beginning of the fermentation and also increase the performance of the fermentation. In the industrial fermentations, is es estimated that the fermentation has a performance around 7% which is not a high value. That is why, it is being studied how to obtain more enzymes from the cellular wall of the grape [7].

1.7 THE CAVA'S REGULATORY COUNCIL

All the industries must obey the regulations that they are affected by. Cava manufacturing industry is under the Alimentation Union Trade. So, it means that the winery must accomplish the requirements that are mentioned in this legislation [8].

However, there is an organisation called “The Regulatory Cava Council” which involve the standards, methodologies, and parameters that the Cava’s producers must obey. This organisation regulates the procedure from the way to take care the vineyards and defines the legislation of the vineyards, for example: the prohibition to irrigate the plant, or the characteristics of the grape ready to be harvested, going throw the delimitations of the area and sort of the grapes, even the rules to be classified as an organic wine. Besides, The Regulatory Cava Council focus more on the way that the vineyards are grown and the parameters of the grape and its characteristics that must have in order to produce the base wine and lately the sparkling wine.

On the other hand, the Regulatory Cava Council also defines the procedure inside the cellar such as how to manufacture the product, the methodology, the forbidden products which can not be added, the time of aging, the quantity of sugars added, and the parameters of the product that have to be accomplished. So, the Regulatory Cava Council is the most responsible organisation that regulates the way that the Cava must be obtained [9].

However, there are other organisations which are responsible for other interest about Cava, such as, the Cava Producers Association, AECAVA. This association takes care about defending the sector in the producer’s interests, in front of the public administrations and negotiate the Cava Collective Labour Agreement. The internationalization of the Cava in trade fairs, promote projects which support the commercialization of Cava in international markets. The associations also organize events, courses, seminaries and lessons in order to enhance and broaden the knowledge of the new students and the associated wineries.

Furthermore, the AECAVA register the information about wineries and harvesting of each year in order to provide a wide data base which is important for the wineries to be competitive and take advantage of knowing how is going the sector of Cava’s producers [10].

In the appendix 1, there is collected the main information about the Regulatory Cava Council which its rules define how have to be made the Cava and its properties and characteristics. For more interest, have a look in the appendix 1.

2. THE OBJECTIVES

The aim of this project is to design the preliminary production plant where it will be settled down the different parts of the process’s production of winemaking, from the reception of the grape juice, going throw the fermentation, the aging and finally, the assembly of the final product ready to be sold.

Another purpose in this project is to study the fermentation’s reaction which is one of the most considerable part of the winemaking process because in this step has an important impact on the organoleptic features. So, this project will focus on the design of the fermentation and the needs that it will require in order to perform properly such as the size, the cooling system in order to take out the heat created during the fermentation and the controlling system of the process for a properly development of the fermentation reaction.

The winery will be settled in a garage where formerly it had already been an old winery in the middle of the town in Sant Sadurní d’Anoia (Alt Penedès) in Catalonia. The winery will have 250m^2 surface with 25 meters long, 10 meters wide and 6 meters high where the production objective will be 50.000 bottles of Cava per year. The space inside the production plant is reduced to produce this target of bottles although with the help of a Layout, the design of the dimensions of the tanks and fermenters and the distribution of the circulation of the process, can be achieved.

The space will have a big importance because of the number of the machines and the tanks used to produce the objective number of bottles. However, the space in the garage is limited and the proper distribution of the elements is essential to a good performance of the winery. To do so, it requires a layout to distribute the winery and the elements within. Thus, the process will be thought to run in a logical way within the winery so that materials, the product and the workers do the less movements inside the same. So, the winery will be divided in three zones: the fermentation zone, the aging and the mechanised filling line.

In short, the main objective is making the preliminary design of the winery, taking the dimension of the space, and focusing on fermenter which will be able to do the fermentation reaction. Furthermore, making the calculations of the exchange heat due to the exothermically reaction, providing a proposal for the controlling system and selecting the material for built the fermenter. Finally, show the final proposal of the layout that would have the winery.

3. THE MANUFACTURING PROCESS OF CAVA

3.1 THE PROCESS

The process of making has not changed too much form the past due to the regulations and the way the Cava have to be made. Cava come from the idea of a second fermentation which creates bubbles of carbonic dissolved in the basic wine. These bubbles are created thanks to a second fermentation inside the closed bottle, that does not allow to escape the gas formed during this second fermentation. This method is known as the “Traditional Method” [11].

In short, in order to produce Cava, the process consist of several steps which can be divided in two main parts. The first one, runs from the picking grape to the first fermentation when is obtained the base wine. The second one, runs from the mixing of the different sort of base wine, to the final product. Next there are the two-flow diagram which show the route of the cava-making’s procedure.

In this project, the plant is thought to be from the obtention of the must which have already been pressed out of our plant. Thus, it is received the grape juice directly in our winery and it is avoided a the two first steps although it has an important effect on the production of Cava, which include the possession of a pressing machine because it determinates the quality of the grape juice, besides that step is extremely expensive and the machine occupies a lot of space into the winery.

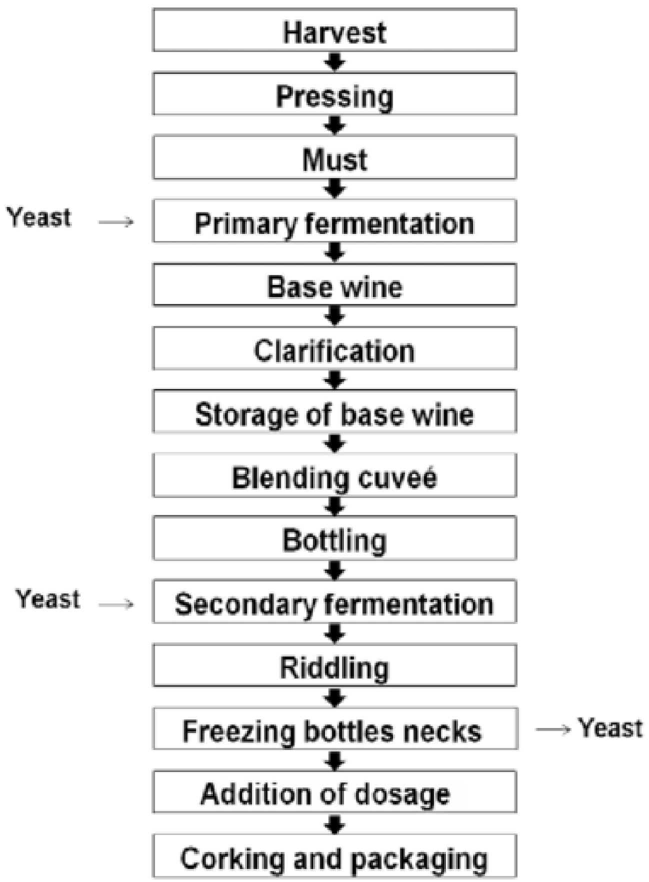


Figure 5. Flow diagram of the manufacturing process of Sparkling wine.

3.2 STEPS OF THE MANUFACTURING PROCESS OF SPARKLING WINE

Harvesting: The first step is harvesting the grape from the vineyards. The harvesting is done when the grape achieves the perfect conditions such as sugars, acidity, volume and so on. It can be done by hand or by machine, but both are usually done in the early morning when the low temperatures on summer months produce less oxidation to the grape before arriving to the winery.

Pressing: The pressing is the next step where it is obtained the grape juice fundamental for the process. This step basically consists of stripping the branch and squeeze with low pressure in order not to damage the seed which could produce unpleasant bitter tastes.

Sulphurated: the addition of SO_2 provides the control to the microorganisms in the grape juice, inhibiting the growth of the non-fermenter yeast and enabling the fermenter yeast alive. Besides, the SO_2 protect the grape juice from the oxidation by oxygen from the air who could damage the properties and features of the grape juice. The quantity added is around 5-7 g/hL because the excess can become a risk for human intake and the default would not do its performance. It is also used to stop the fermentation due to the limiting factor to the conditions required for the microorganisms [12].

Clarification: the clarification is where the solid substances in suspension such as earthy debris, pieces of leaves, branches and even precipitated proteins. The natural clarification is done letting the grape juice inside the tank for 12-24 hours and let the effect of the gravity do their work to take to the bottom of the tank all the undesired solids, as well as, cooled around 10ºC to facilitate the precipitation. Then, the liquid is separated to the solid precipitated by filtration of diatomaceous earth and mesh [13].

The image below, the glass of the left, it shows the grape juice just pressed with all the insoluble solids before the clarification, on the right, it is shown the grape juice after the clarification.

Figure 6. Grape juice pre and post clarification step.

Fermentation: the fermentation is one of the most important steps in the process. It is based on transforming the sugars of the grape juice into ethanol, CO_2 and other substances without the presence of oxygen. The fermentation is done basically by yeast from the genus of Saccharomyces cerevisiae which is the yeast that gather the features to produce the fermentation of the wine. The alcoholic fermentation has many variables that have to be under controlled like temperature, biomass concentration or sugar concentration and so. The fermentation usually last around 10 days between 14-20ºC depending on the variety and the type of the wine is wanted to obtain [14].

Cold stabilization: the cold act on the wine causing the insolubilize and the precipitation of the salts, principally the potassium bitartrate, because its solubility decreases with the temperature. The presence of this molecule can appear as crystals in the in the final product and have a bad visual impact. This step is done by cooling the tank where the base wine is within and let it inside for 6-7 days in temperatures below 0ºC, usually -4ºC. The precipitation is helped by adding a clarifier called Bentonite whose molecule has a negative charge whereas the proteins have positive and are attracted each other and form colloids and joined with the cold stabilization precipitate as solid on the bottom of the tank. Then, the wine needs to be separated throw a filter again and finally, the base wine is obtained and ready to go on the procedure of cava-making [15].

Figure 7. Potassium bitartate crystals in the cork.

The blending cuveé: the blending cuveé is the mixture of the different types of base wine coming from the different types of grapes which has distinct properties, aromas, bouquets and features. The blending cuveé is made by the oenologist whose experience and knowledge can mix in different percentages the composition of each base wine in order to get the desired aroma, bouquet, colour and taste in the palate and have a more structure and complexity wine. The blending cuvée of Cavamaking has not many varieties to work on, so, the main role is to find out the percentage of each variety and get an equilibrated blending cuvée for the second fermentation.

The "Tiratge": the "tiratge" consist of putting the blending cuvée wine inside the bottle and adding a mixture called "liquor of dosage" which is made of sugar, yeast and few clarifier (Bentonita). The sugar and the yeast in this mixture are the responsible for the second fermentation that will be inside the bottle. In order to obtain the typically bubbles of Cava, the second fermentation must be in the closed bottle. That is why it is put a crown cap which resist the pressure obtained in the second fermentation and do not allow the entry of the oxygen and neither the exit of the CO_2. Besides, this have to be easy to remove in the disgorging step.

Aging: the aging in the cave is when the second fermentation takes place. The bottles rest in horizontal position along minimum 9 months where the second fermentation takes place inside the closed bottle where the CO_2 cannot escape, and this gas gets dissolved in the liquid making the typical Cava's bubble. Furthermore, the bouquet and the aromas are equilibrated and smoothed providing complexity, structure and body to the taste. The aging zone is underground for atmospherically conditions such as stable temperature, the air's humidity and little light there [16].

To remove the yeast responsible for the second fermentation inside the closed bottle, it is required to open the bottle to expel the death yeast. As the bottles rest in the cave in a horizontal position, the yeast is compacted in the body of the bottle, but it is required to be on the neck of the bottle in order to be as close as possible on the hole of the bottle. To do so, the bottle needs to be rotated in a very slow speed because not to mix again the yeast in the liquid. In the past, the bottles were put in a desk and each determinate time, were turned and leant a little bit more in a vertical position upside down. Nowadays, in order to save time and space, the bottles are put in a metallic cage which includes around 720 bottles and a machine called "Giropallet" turns the bottles constantly in a very low speed to the vertical position. This way, the yeasts are compacted by the gravity in the neck of the bottle when in the next step is where the yeast is going to be expelled by the pressure achieved in during the aging and the second fermentation inside the bottle known as "Traditional Method".

The Disgorging: the disgorging is the step where the bottles are taken out from the cave and put in the line production. The disgorging begins with the freeze of the neck because it solidifies the yeast died and it makes sure that, by the pressure achieved inside the bottle because of the fermentation, all the residue will be expelled by the disgorging machine

The disgorging machine expel the residue and fills the liquid lost with the liquor of expedition. The liquor of expedition is made by a mixture of Cava and sugars. Depending on the quantity of sugars added, the Cava is classified in sugar's range list [17].

Corking: the corking machine puts the cork in the neck of the bottle and fasten it with metallic helmet which ensure that the cork will not get fired due to the pressure inside the bottle. Besides, it is also put the bottle cap distinctive of each winery and brand. Then, the bottle is cleaned and dried in water and air respectively in order to take any dirt out.

Labelling: there are some labels that have be put in the bottle. First of all, the front label indicates mainly the brand, and the back label the features of the Cava. Secondly, the collar that protect the neck and the cork. Lastly, a sticky that indicates that it is Cava and the month of ageing. The figure below shows the three types of sticky. The grey sticky indicates that the aging is over 9-month and under 15-month whereas the green sticky is from 15-month to 30 months in aging, and the black indicates that the aging is from 30 month [18].

Boxing and Stock: Finally, the bottles are ready to be on stock and be sold to the customers. The product can be sold individually, in a case or even in boxes of 6 unities.

4. LAYOUT

The distribution of the equipment in the winery is very important to take advantage of the whole space available. As the winey will be settled in a familiar garage, the space is very reduced and the positions of the equipment, machinery and space for the aging of the bottles has to be very organised and planed in order to be able to produce the objective's number of bottles in the less space possible and the properly performance of the workers.

The Layout below shows the ubication of the elements that forms the winery. The winery is divided in the zones: the fermentation zone, the aging zone, and the automatic production line zone. The division of the winery is to differentiate the zones and their conditions to produce Cava. Furthermore, the winery is designed in the way that the process goes in a single direction, that's to say, the first step is the reception of the grape which is on one site of the winery and the last step, the expedition of the bottles, is on the other side of the winery.

Firstly, the fermentation zone consists of the tanks where is received the grape juice and where is will be made the clarifications. Besides, the fermentation zone will be the fermenter as close as possible to the tanks to reduce the distances of the pipes, the power of the pumps and, in the end, the space in this zone because the tanks take up a lot of space. The filters and the water tank, for cleaning the tanks and other equipment in the cellar, are situated as close as possible to the tanks for the same reason.

There is another little tank to do the reactivation of the yeast where it is added water and yeast to do the hydration and some grape juice to provide some sugars and acclimate and prepare the yeast to transfer into the fermenter. The cooling system is the equipment responsible for the cool the tank to do the static precipitation and cooling the fermenter during the fermentation. So, this system is near to the tanks. Besides, there are more space destinated to store all the materials such as bottles, corks, labels and so on and the store of the stock of the final product.

The next zone is the aging zone where the bottles rest for minimum 9 month according to the D.O. Cava in the adequate environmental conditions. Usually, the temperature in the caves are between 12-15ºC, the relative humidity needs to be around 70% and the light has to be the lowest possible as well as the noise. As the cellar is well-isolated these conditions are kept along the year, however, in hotter months, an air-conditioning will make sure that the conditions are regular and adequate for the whole season of the year. The bottles rest in a horizontal position, for the yeast can have the major contact surface to do the second fermentation and are stacked up one over the other alternated to reduce the space.

The aging can be done in trays or without but in our winery, the bottles are going the aged in trays which can include 36 bottles each tray and there are 20 trays one over the other in a metallic cages which can accumulate 720 bottles per cage in a total of 70 metallic cages to store all the bottles at the same time. The disposition of the cages is thought to save as many spaces as possible in the cave and the comfortable operating. The capacity of the cave can store 34 cages on the ground but, there are another level on these first floor of cages. The two last cages are store on the removing machine.

The aging zone also includes the removing machine at the corner called “Giropallet”. This machine makes possible to remove the yeast of the second fermentation which is inside the fermentation turning around the bottles in a vertical position. This machine is needed to be as close as possible to the frozen machine in order to not shake the yeast concentrated in the neck of the bottle. However, once the neck of the bottle is frozen, the bottles can be turned upside because the yeast are solidified in a block of ice which cannot be mixed in the liquid.

Finally, the last zone is the automatic production line. This line is the responsible for some steps that prepares the bottle to be ready to be sold. The automatizing of this lines has enabled to achieve higher productions in less time and workers. The line consists of six machines that begins with the frozen machine which, as said before, it freezes the neck of the bottles to solidify the yeast and make easier to remove it at the next machine, the “disgorging machine”. This machine does two steps, the first is to expel the yeast helped by the internal pressure although some liquid can escape too, and the second step is to refill the bottle with the liquor of expedition which is made depending on the content of the sugars added to provide the final product more or sweetness.

Next, the capper machine puts a cork and the metallic helmet to make sure that the pressure does not expel the cork. Furthermore, the bottle cap that identifies the brand is also put in this machine. Following, the bottles go throw a shower tunnel and a dryer to clean all the dirt that could be due to the aging in the cave and clean the glass for the next step which is the labelling machine. This machine puts the front label, the back label and the collar label too. Finally, at the end of the line, there is an accumulation table because the las step, the boxing machine is a semi-automatic machine, has to be done by a worker.

According to the automatic line, each machine has his own cadence. The cadence is the quantity of bottles worked on divided by the time spend on dealing these number of bottles. Finding the slowest machine involve knowing the velocity of the line because this retard the velocity of the fastest machines. All these machines have an operation range cadence compressed between 500-1,000bottles/hour. However, the bottle neck in this automatic line is the disgorging machine, which can run at 500 bottles/hour, because the fact that expel the yeast and can originate foam and, the subsequent step, fulfilling the bottles with the liquor of expedition takes a little bit more time.

According to the target of the bottles produced per year, 50,000 bottles, it is required the total of the 37,500 litres of grape juice. The presence of different varieties of grape provide to the Cava its particulary taste and bouquet, that is why, the importance of selecting by the oenologist to obtain the desired percentage of mixture of each variety. The recommendation by an oenologist is to produce a Cava freshly, pleasant in bouquet and easy to drink made by the following percentages of each variety: 50% Parellada, 35% Macabeu, 15% Xarel·lo.

Resulting that it means a quantity of 18,750 m^3 of Parellada, 13,125 m^3 of Macabeu, 5,625 m^3 of Xarel·lo. However, the size of the store tank is selected to be 20m^3, 15m^3, 6m^3, respectively. There is a lung tank where it is produced the blending cuvée when is doing the tiratge. Furthermore, in this tank is used as a temporal store tank to permit us to transfer and filtrate besides cleaning the tank used. This tank will have a capacity of 15 m^3 to store the batches of the fermented base wine and to be able to have a capacity to produce 20,000 bottles every time it is done the tirage. The fermenter will have a 7m^3 and its dimensions are described in the fermenter chapter.

Finally, it is indicated with the red line the first part of the process, from the reception of the grape juice to the line of tirage, which is done in the fermentation zone. The blue line in the layout indicates the second part of the process which begins in the line of tirage and takes place at the aging zone and the disgorging zone where it is the automatic line. As it is said, the procedure of manufacturing runs from the one site to the other in just one direction.

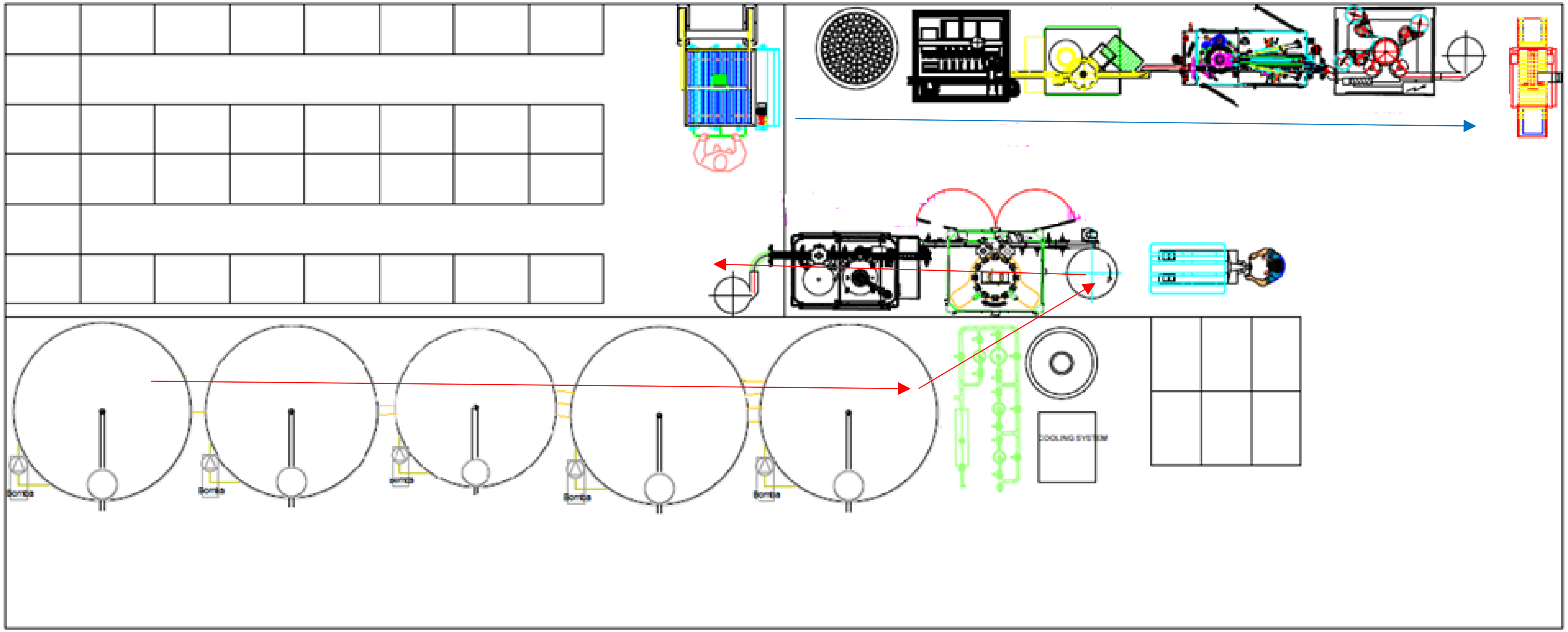


Figure 8. Layout proposal for the manufacturing plant.

The working time in the winery will be around 1,750 hours distributed depending on the season of the year. The table blow indicates the time spend on each step of the process and the season of the year which is done. The process begins on August with the reception of the grape and finishes on September. Then, the first fermentation is done to produce the base wine. After that, the wine is prepared, mixed with other varieties ready for the next step, the "Tiratge" which consist of putting the yeast for the second fermentation. Then the aging in the caves provide the Cava their bubbles and their characteristic aroma and bouquet. Finally, the "Disgorging" consists of removing the yeast and getting ready the bottle for the customers refilling the bottles, putting the labels, boxing and store them as a stock. The disgorging is made by pack depending on the demand of the markets, that is why, it is done almost along the year.

Table 2. Distribution of the tasks during the year in the winery.

ACTIVITY	J	F	M	A	M	J	J	A	S	O	N	D
GRAPE HARVEST AND RECEPTION												
1st FERMENTATION												
PREPARING THE BASE WINE												
TIRATGE												
AGING IN THE CAVE				FROM 9 TO 30 MONTHS								
DESGORJAT												

5. EDGE OF DRUMMER

The process for Cava productions in not extremely complicated process but, it is not simple due to the demanding conditions of the biomass, the yeast, who are the responsible for the proper fermentation of the grape juice. To produce Cava there are two fermentations which the second one is done inside the bottle. However, the first one is done in an atmospheric tank with some parameters under control that ensure the reaction is running correctly. For this reason, this project will focus on the design of the fermenter, a bioreactor, because this device is one of the most important of the whole process because it is where most of the parameters and the base wine's characteristics are obtained.

The fermenter produces the alcohol from the sugars of the grape juice by the yeast who need restrictive environmental condition of the culture medium. To design the fermenter is necessary study the working conditions, the quantity to produce, the cooling system and so on. Besides, it is also selected the material of the fermenter taking into account the corrosion and the specified conditions. To do so, a study of the fermentation reaction and the mass balance and the energy balance will provide the calculations to determinate its features and specifications. Furthermore, the design of a control system will be implemented to ensure that the fermenter is working on the correct conditions, depending on the variables that must be controlled.

The image below shows the edge of drummer's project. The edge of drummer begins with the entrance of the raw material, the grape juice and the yeast, and finishes to the exit of fermented wine. However, the mode operation is a Batch so, there are no entrance and exits during the fermentation. The design of the fermenter is about decide the capacity, the volume of the reactor and its characteristics such as the time of operation, the evolution of the concentration of the components inside the reactor, the dimension of the elements of the fermenter like the agitator.

Besides, it is included the cooling system service that will be required to make the reaction's performance but, it is not contemplated other equipment such as pipes, pumps or valves.

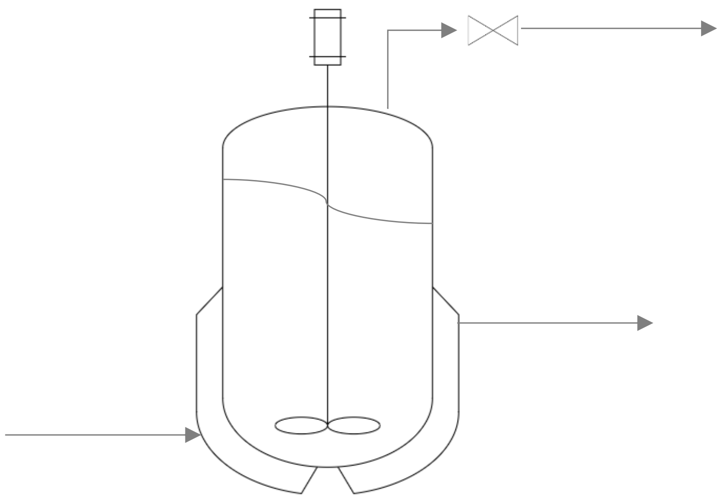


Figure 9. Edge of drummer for the fermenter

5.1 THE FERMENTATION REACTION

The alcoholic fermentation is a biological process without the presence of the oxygen originated by the activity of the microorganisms that processes the carbon hydrates (sugars such as glucose, fructose, sucrose…) in order to obtain final products like alcohol (its empirical form is an ethanol) , carbon dioxide in gas phase and adenosine triphosphate molecules (ATP) that consume the own microorganisms in its metabolism cellular energetically anaerobic [19].

The alcoholic fermentation has to biological finality provide anaerobically energy to the microorganisms (yeast) in absence of oxygen from the glucose. In the process, the yeast obtain energy dissociating the glucose molecules producing waste alcohol and the CO_2. However, during the fermentation not only is produced alcohol and CO_2, it is also produced secondary products which provide to the wine its organoleptic properties, its characteristics such as colour, and the quality of the wine.

The process of obtaining alcohol by fermentation consists of two parts, the first is glycolysis, while the second is alcoholic fermentation. Glycolysis which usually takes place in two phases; in the first, energy is consumed and in the second, energy is obtained. The chemical reaction is described as the reduction of two NAD $^+$ molecules from NADH (reduced form of NAD +) with a final balance of two molecules of ADP that are eventually converted to ATP. Other compounds in smaller proportions that are present after fermentation are: succinic acid, glycerol, fumaric acid. The reaction of fermentation is:

$$C_6H_{12}O_6 \rightarrow 2\, C_2H_6O + 2\, CO_2 \quad \text{(Eq. 1)}$$

In more detail during the alcoholic fermentation within the yeasts, the glycolysis pathway is identical to that produced in the erythrocyte (except for pyruvate which is transformed into ethanol). First, pyruvate is decarboxylated by the action of the enzyme pyruvate decarboxylase to give as final product acetaldehyde releasing carbon dioxide (CO_2) from hydrogen ions (H^+) and NADH electrons. After that the NADH synthesized in the biochemical reaction catalysed by GADHP is re-oxidized by the enzyme alcohol dehydrogenase, regenerating NAD^+ to continue glycolysis and at the same time synthesizing ethanol.

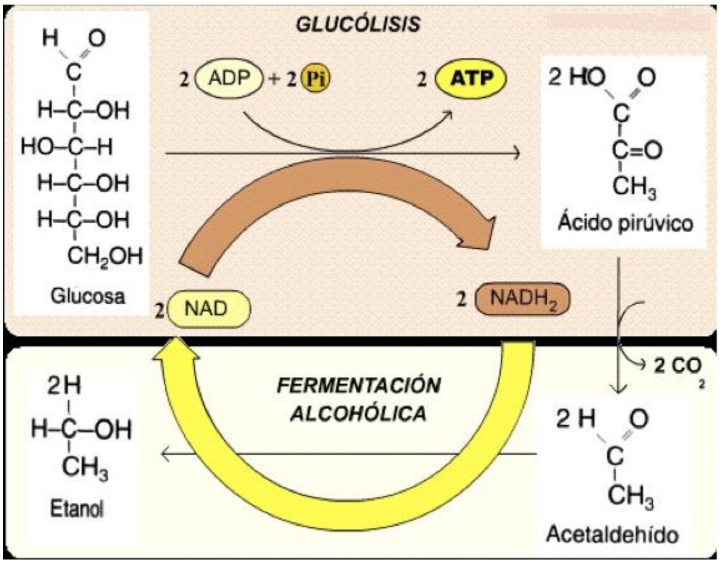


Figure 10. Image of the fermentation's reaction

During the fermentation, the concentration of alcohol increases up to a limit because as the alcohol is a toxic product, the yeast tends to die when is achieved a concentration of alcohol around 12%. This is the reason why the fermented beverages do not have values above 15% of ethanol. There are other limitations in the fermentation reaction, for instance:

- The acidity of the substrate because the yeast is affected by the environmental conditions and the pH must be between 3.5 and 5.5 to have a properly performance. Sometimes, it is added a base or an acid to correct this parameter.
- Another limiting factor is the concentration of sugar available in the medium, because an excess or the lack of sugar can stop the fermentation due to the sugar concentration affect the osmose throw the cellular membrane.
- The presence of oxygen stops immediately the process because of the Pasteur effect. This effect distinguishes the metabolic route when the presence of oxygen. The solution is to close hermetically the fermenter and use a system called "airlock" to allow the CO_2 escape and forbid the entrance of oxygen.
- One of the most important limiting in the fermentation reaction is the temperature. As the process is exothermic, the yeast has an optimal range of temperature between 12-20ºC, that means the fermenter need to be cooled in order to keep the temperature constant and in the optimal range.

- The quantity of yeast reproduced during the fermentation has an important role in the fermentation when the yeast increases the number of yeast but, if there are too much cellules, they kill themselves in order to survive, it is “called killer factor”.

The alcoholic fermentation is an exothermic anaerobically process that liberates energy and ATP molecules necessaries for the metabolic performance of the yeast. Due to the lack of oxygen conditions during the process, the chain from the ADP to ATP became completely blocked, being the only source of energy for the yeast to the glycolysis of the glucose for the formation of ATP molecules throw the phospholyrification of the substrate. The balance of the process generates 2 molecules of ATP per each molecule of glucose. Despite this balance, it seems to be enough for the anaerobic organisms to carry on the reaction. The Gibb’s energy is -234.6 kJ/mol which indicates that thermodynamically the alcoholic fermentation is a spontaneous process [20].

5.2 THE FERMENTER

As said previously, the scope of this project is the design of the fermenter where the sugars of the juice grape are transformed into the base wine that later will be transformed into Cava in a winery production plant. The raw materials are principally the sugars of the juice grape and the yeast that will make the fermentation.

The fermenter is a vertical vessel where a chemical reaction is done inside. In this case, the type of the fermenter is a bath, that means it works in non-steady state for loads. The total mass inside the fermenter is constant because there are any entry flow and any exit flow, however, the variables such as temperature and concentrations changes as the reaction progress.

Due to the exothermically reaction, the fermenter needs a cooling shirt to reduce the production of heat by the reaction. The shirt consists of pipes around the lateral wall and the bottom which is flowing a cooling fluid in a closed circle. The cooling liquid is usually water or thermal oils.

This fermentation is done in absence of oxygen although it has to be done in atmospherically pressure. That is why, the fermenter needs an open exit to let escape the CO_2 but guarantee the absence of oxygen inside the fermenter because it would stop the reaction. This system is called “Airlock” which permits the exit of the CO_2 and forbid the entrance of the oxygen that could stop the fermentation [21].

Besides, the fermenter is provided by an agitator to ensure the homogeneity of the liquid, the release of the gas CO_2, and the properly contact between the sugars and the yeast. However, the agitation needs to be soft because the shear stress could damage the yeast. The agitation of the reactor must be very soft because it has to take care about the yeast. If the agitation is high, the shear stress could damage the membrane of the cells and cause the lyses and killing the cells. According to the heuristics, the fermenter must have the following relations to a properly performance. These equations and the tables of this heuristics are shown in figure 12 and in the appendix 3 although the result is shown in the chapter of the design of the fermenter.

Inside the fermenter takes place the growth of the yeast. This step is not considered in this project although it is worth take notice of this information in the appendices.

5.3 THE EVOLUTION OF THE COMPOSITION OF THE COMPONENTS

The plot below shows the evolution of the components of the fermentation inside the fermenter. Firstly, as can be seen, the yeast follows the growth of the microorganisms in the fermenter. Secondly, the substrate (sugars) begins with a high concentration around the 18% of sugars in the grape juice. This is the feed of the microorganisms to eat and produce their waste, the alcohol and the CO_2. When the substrate is over, it is easily to see that the yeast begins to die. The ratio of the yeast introduced in the beginning is around 1g of yeast for 1 litre of grape juice but, in the end, the biomass has increased due to the exponential stage of growth, according to the experience of an oenologist.

According to the alcohol, the ethanol, raise as the number of yeast increases, however, when the substrate is no longer available, the ethanol decreases the speed of being transformed and remain in the medium. Besides, the high concentration of the ethanol, is another factor for the yeast to die.

According to the fermentation's reaction, the productions of the CO_2 is very close to the ethanol production although it is produced in the gas phase. The ratio of the production of the CO_2 is two transformed into CO_2 per mol of glucose. The production of the CO_2 provides the fermentation be anaerobic although it has to be removed and sometimes it can be a danger for the people who is near the fermenter.

On the other hand, the pH is practically the same. It remains constant because the acidity components liberated in the medium by the microorganisms are wake acids and the correction of the pH in order to keep in the optimal interval permits that not to be a limiting factor according to the biochemistry and the regulations by the Cava's council.

The equations that predict the evolution of the growth of the yeast and the creation of the products of them, the alcohol and the CO_2, are estimated by the models of growing and the performance parameters applicated on the reaction of the fermentation. In this project the calculations of the growing models are out of the edge of drummer, but it is used to estimate the period that lasts the fermentation. Nevertheless, in winery sector, it is commonly used a predeterminate period obtained by the experience of the cava makers. That is why this project contain in the appendices the equations that should be used to calculate the performance of the yeast.

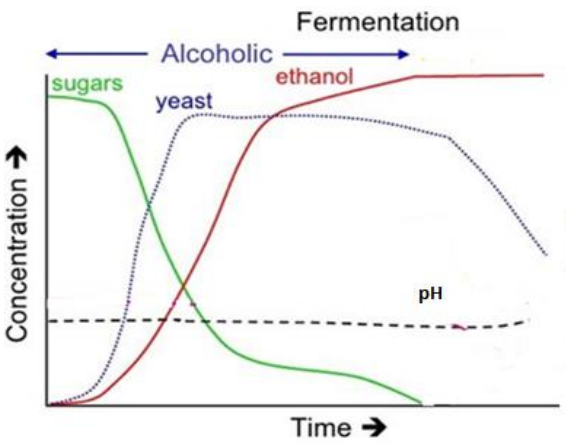


Figure 11. plot of the evolution of the components during the fermentation's reaction and the pH.

5.4 THE DESIGN

The design of the fermenter is done according to the requirements of the fermentation and the variables that need to be controlled and under control to make sure that the reaction in running properly. Referring to the growing model of the microorganisms, the production of the products, the alcohol and the yeast, and the type of mode of operation, a batch, discontinuous, exothermic, the fermenter is designed to fulfil the quality and the characteristics desired for the base wine due to its importance for the second fermentation inside the bottle [22] [23].

5.4.1 MACROSCOPIC MASS BALANCE

Firstly, the design of the fermenter is done according to the objective production of base wine and the availability of the space in the winery. As the smallest quantity of one grape juice to be fermented is the variety of "Xarel·lo", a total of 5.625m^3, the volume of the breeding ground in the fermenter is going to be the same because in just one batch can be fermented all the quantity of this variety. Making the same size of the fermenter, will optimize the volume of the lung tank, which will save more space and time while the batch is made. However, the fermenter needs a "hold-up" space. This space is for the gases originated for the reaction and security features. The heuristics models recommend around 20% space for the "hold-up".

Furthermore, after a research in the fermenter vessels, the dimension that requires the fermenter is commonly manufactured. So, the fermenter is going to have a volume of 7 m^3 or the total volume of the reactor. The height of the reactor will be calculated according to the heuristics which considers that the diameter of the fermenter has to be the same as the height. The volume of the culture is 5.625 m^3, where the reaction of fermentation is going to take place. So, the height as the diameter is calculated as an unique variable in the next equation:

$$V = 5.625\ m^3 = \frac{\pi\ D^2}{4}\ H\ \rightarrow D = H = 2m \quad \text{(Eq. 2)}$$

However, the fermenter has a "hold-up" of 20% of the height. So, the real height is going to be:

$$Hreal = Hculture + 0{,}2H = 2.4\ m \quad \text{(Eq. 3)}$$

Once the volume of the reactor is defined as well as the total quantity of grape juice to be fermented, the number of batches to ferment all the quantity of each variety are: 1.5 batches for "Macabeu" variety, just 1 batch for "Xarel·lo" variety and batches for the 3.5 "Parellada" variety. The lung tank used also to do the Bending Cuvée and permits the transfer, filtration and cleaning the tanks, will store the fermented base wine meanwhile it is done the other fermentations.

To know how long the fermentation will be, it is required a macroscopic mass balance. As the fermenter operates in a batch mode, there is no mass input, neither mass output. So, the mass remains constant although the number of moles changes. The design of the fermenter is considered as an ideal reactor in order to create the mathematic model. The mathematic model provides the equation to calculate how operates the reactor depending on the mode of operation of the fermenter which are: discontinued agitated tank reactor, operating by charges, in a batch where the discontinuous mode and homogeneous phase. It follows the perfect mix flow which means that the composition and the temperature are unique in the system but varies along the progression of the reaction. So, the equation of the BMM become the following one [24]:

$$\frac{dn_a}{dt} = R_a = \sum_i v_{ai}\, R_i \qquad \text{(Eq. 4)}$$

According to the percentual conversion of the limiting reactant, the extensive velocity reaction, R, and the intensive, r, and integrating of the equation above, provides the *design equation of the perfect mixing batch reactor:*

$$t = n_a^0 \int_0^{x_a} \frac{dX_a}{-r_a V} \qquad \text{(Eq. 5)}$$

Which making the corresponding substitutions with some parameters, becomes:

$$t = -\frac{1}{k} \ln\,(1 - X_a) \qquad \text{(Eq. 6)}$$

This equation provides us the information of the time to be fermented per batch. A research has been done in order to know the value of the parameters in this equation which will permit to calculate it. On the one hand, the conversation of the reactant, the glucose, is almost the 100% because the yeast can consume all the sugar transforming into alcohol. However, due to the limiting factors explained before, it usually remains some residual sugars in the culture medium. The sugars at the beginning is around 182 grams of sugar / litre of must, and to the end, it is only 2 g of sugar/litre. It means that, the conversion of sugars is around 98%. On the other hand, the velocity constant kinetic is taken from some experimental research. In this case, the value of this constant is 0,032 h^{-1} (according to a cava maker experienced and database). Thus, the fermentation last:

$$t = -\frac{1}{k}\ln(1 - X_a) = -\frac{1}{0.032}\ln(1 - 0{,}98) = 122.25\ h$$

$$122.25h \cdot \frac{1\ day}{24h} \approx 5\ days$$

As the fermentation runs 24 hour per day, the process of fermentation is done in around 5 days per batch. However, the yeasts have an accommodation period that it usually takes at least 24 hours. At the end, the process of fermentation is calculated to lasts 6 days per batch. As the fermenter has a capacity, for the culture liquid, of 5.625 m^3, it takes at least 7 batch to ferment all the grape juice.

5.4.2 MACROSCOPIC ENTHALPIC BALANCE

As the alcoholic fermentation reaction is exothermic, in order to take place in an isothermally conditions at the 14ºC, the fermenter has to be cooled. The fermenter is provided by a cooling jacked which circulates the refrigerant fluid. The refrigerant fluid is usually water because the range of temperatures of exchanging are on the liquid phase of the water. The fluid runs in a closed circuit that goes throw a cooling machine.

The heat that produce the alcoholic fermentation can be calculated by the enthalpic macroscopic balance applicated to the reaction system with temperature and composition uniform. The equation for this system is [24]:

$$\frac{d(H - H^*)}{dt} = \sum_m (\hat{H} - \hat{H}^*)_m w_m - \sum_i \Delta\hat{H}^* R_i + \dot{Q} + \dot{W} + \frac{d(PV)}{dt} \qquad \text{(Eq. 7)}$$

As the condition of the system is a closed system, without inputs neither outputs, the first term becomes null. The fluid is a liquid (taken as incompressible) that means that the two-last term of the equation also becomes null because there is no expansion work. The fermentation has to be done in the same temperature, in isothermal conditions, the term on the left of the equality, also becomes zero. Finally, the equation of the enthalpic macroscopic balance can be developed to obtain a more workable equation. Developing the extensive reaction velocity, R, and integrating for all the reaction time, the equation to calculate the total heat exchanged is:

$$\dot{Q} = \sum_i \Delta\hat{H}^* R_i = -\frac{\Delta\hat{H}^* \ k\, n_a^0 \ (1 - X_a)}{v_a} \qquad \text{(Eq. 8)}$$

To calculate the need of this service, it has to be known the quantity of heat that produces the fermentation per mol, which is 57 kcal/mol, although not all of this energy is transformed into heat. The 25% of this energy liberated per mol of glucose, is retained in the energetic bonds of the ATP, the rest, is lost in the form of heat. So, finally, the energy liberated by the reaction is 42.75 kcal/mol. Of glucose. As the maximum capacity of the culture liquid in the fermenter is 5,625 m^3 and the quantity of sugars is 180 g/litre, that means the total quantity of sugars that would be transformed into alcohol is;

$$n_a^0 = \frac{5625\, l\ grape\ juice}{batch} \cdot \frac{180g\ glucose}{1\ l} \cdot \frac{1\ mol\ glucose}{182g\ glucose} = 5560 \frac{mols\ glucose}{batch}$$

The conversion from kcal to kJ is:

$$\Delta\hat{H}^* = -42.75\frac{kcal}{mol} \cdot \frac{4{,}18\ kJ}{1\ kcal} = -179\frac{kJ}{mol}$$

So, the total heat produced during the fermentation is, as a result, the heat that have to be removed per batch, can be calculated using the above values:

$$\dot{Q} = -\frac{\Delta\hat{H}^*\ n_a^0\ \ X_a}{v_a} = -\frac{(-178.99) \cdot\ 5.563{,}19\ \cdot (0.98)}{-1} = -976000\frac{kJ}{batch} \qquad \text{(Eq. 9)}$$

In kilowatts:

$$\dot{Q} = -976000\frac{kJ}{batch} \cdot \frac{1\ batch}{7h} \cdot \frac{1h}{3600s} = -39\ kW$$

Once known the heat produced by the reaction of fermentation, to keep designing the surface of cooling jacket, *A*, it is required to know the global heat transfer coefficient, *U*. *Tr* is the temperature of the refrigerant responsible for the thermic exchange and the *T* is the temperature of the system, the temperature of the fermentation. The equation to calculate the surface of heat exchange is the next:

$$\dot{Q} = U\ A\ (Tr - T) \qquad \text{(Eq. 10)}$$

The value of the *U* is going to be used a value of 450 W/(m^2 ºC) obtained from bibliography. The *Tr* will be calculated in order to make possible the exchange of the heat. In other words, as the dimensions of the reactor are settled down, the lateral surface and the bottom surface provides an area of 15m^2, from the lateral and the bottom surface, and this is a restriction. So, the fluid has to be able to do its task in this area of exchange. It is taken the maxim surface of exchange, 15m^2, and it is calculated by the equation above:

$$Tr = \frac{\dot{Q}}{U\ A} + T = \frac{-38.72\ kW}{0.450\ \frac{kW}{m^2\ ºC}\ 15\ m^2} + 14ºC = 8.3\ ºC \qquad \text{(Eq. 11)}$$

On the other hand, to know how much the cooling fluid flow will be circulating in the cooling jacked, it is required to know the heat capacity of the coolant. The value of this variable depends on the fluid and the working temperature. As it is used water as a cooling fluid at 8.3ºC, the value of this variable is 4.18 kJ/ (kg ºC).

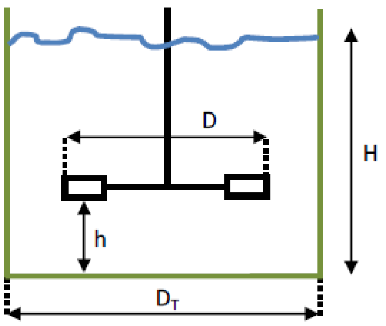
$$w_r = \frac{\dot{Q}}{Cp\ (T_r - T)} = \frac{-38.72\frac{kJ}{s}}{4.18\frac{kJ}{(kg\ ºC)}(8.3-14)} = \frac{1.63kg}{s} \qquad \text{(Eq. 11)}$$

$$wr = 1.63\frac{kg}{s}\cdot\frac{3600s}{1h}\cdot\frac{7h}{bath} = 41000\ kg/batch$$

So, the water consumed per batch is 41000 kg which are recirculated in a closed circuit to reduce the use of water and reduce the power by the cooling system to decrease the temperature of the water responsible for exchange the heat.

5.5 THE STIRRING SYSTEM

According to the heuristics to design the fermenter, the agitator is designed following these rules. The outstanding relations are in shown in the figure below. Then, it is calculated the power that must be provided to the stirrer [25].



$H = D_T$

$D \sim (1/2 - 1/3)\ D_T$

$h \sim (1/2 - 1/3)\ H$

Figure 12. Relations between distances of the stirrer of the fermenter.

As the viscosity is very low, 10^{-3}–10^{-1} Pa·s, the agitator usually is between turbine and helix. Depending on the kind of the pales, the model of the flux is tangential or axial, respectively. So, deflectors help to achieve the perfect mixture with radial and axial mixing because add radial component to the tangential velocity due to the turbine. Our fermenter is provided by conventional turbine because it is the most used in fermentations.

To calculate the power of agitation in non-air agitated systems, is used the heuristics and the equations to estimate the Reynolds and the number of power, N_P. Next are the Reynolds equation and the N_P:

$$Re = \frac{\rho \, N \, D^2}{\mu} \qquad \text{(Eq. 12)}$$

$$N_P = b \, Re^x \qquad \text{(Eq. 13)}$$

Where:

ρ = density of the liquid
μ = viscosity of the liquid
D = diameter of the pale
N = number of the revolutions

The parameters *b* and *x* are obtained depending on the agitator and the Reynolds. According to the table and the graphic shown in the appendix 3, the values of the parameters and the equation to use according to the type of regime can be selected.

To calculate the Reynolds, it is supposed that the liquid in the reactor have approximately the viscosity of the water due to the high percentage of water in the grape juice. So, the viscosity is μ (20ºC) = $1.009 \cdot 10^{-3}$ Pa·s. To the density, approximating the average of the liquid from the beginning to the end. So, the density is estimated to be $\bar{\rho}$ = 1040 kg/l. The N indicates the revolutions of the pale, which is usually settled to be slow. In this case, *N*= 250 r.p.m. The value of the *D* is estimated as *D = T/3* where T is the diameter of the fermenter. So, $D = \frac{2}{3} = 0.66$. Thus, the Reynolds value is:

$$Re = \frac{1040 \frac{kg}{m^3} \; 250rpm \frac{2\pi \, rad}{1 \, rev} \frac{1 \, min}{60s} (0.66)^2}{1.009 \cdot 10^{-3}} = 11.75 \cdot 10^6 \qquad \text{(Eq. 14)}$$

The Reynolds obtained is in turbulent regime and, according to the graphic and the type of the turbine agitator, it is selected the value of x = 0 and b = 2 to calculate the number of powers, N_P. As the regime of floe is turbulent, the equation *Np* to use is

$$N_P = b = 2$$

Finally, the power consumed by the agitator of the fermenter is calculated by the following expression:

$$P = N_P \, \rho \, N^3 \, D^5 = 2 \cdot 1040 \, \frac{kg}{m^3} \cdot (250rpm \cdot \frac{2\pi \, rad}{60s})^3 (\frac{2}{3})^5 \approx 5 \, MW \qquad \text{(Eq. 15)}$$

The power consumed by the agitator is 5 MW.

6. THE CONTROLLING SYSTEM REACTOR

Although the purpose of this project is to design the fermenter where is it going to take place the fermentation, controlling the conditions of the fermentation is important to be sure that the reaction is running properly. The main variables to control are the density, temperature, and the pH. The pH is controlled thanks to a sensor "*in situ*" which provide us the lecture of the culture mix. The pH is corrected adding an acid or a base depending on the deviation.

The density is an indicator of the evolution and the state of the fermentation. At the beginning of the fermentation process, the density is around 1.090 kg/l due to the presence of sugars and the lack of alcohol. However, at the end of the fermentation, the density is around 0.980 kg/l. The control of the density provides information about the alcoholic volume achieved in the base wine by the fermentation.

As to produce Cava is required to a second fermentation, and the presence of alcohol in a determinising concentration can stop the fermentation inhibiting the yeast, the fermentation is usually stopped adding SO_2 or let the temperature increase and stop the fermentation process in order not to achieve this limiting factor and let some margin for the second fermentation can be done. So, the density variable is an interesting parameter that provides useful information.

The "airlock" is a device that permits to escape the CO_2 out of the vessel but forbids the input of oxygen. This device operates like a one direction valve. The reaction is done in atmospherically pressure although a little overpressure makes ensures the no presence of oxygen in the vessel.

The most important variable to control is the temperature because it is the responsible for the reaction can keep going. As the reaction is exothermic, the heat has to be removed by thermic exchange by a cooling system. This cooling system acts when the temperature inside the fermenter rises to keep the temperature between the around 14ºC. So, the temperature control consists of measuring the temperature in the vessel and answering to control this variable increasing or reducing the flow of the cooling fluid. The cooling fluid entry for the highest point of the cooling jacket and go around and down and up the body of the vessel up to the other point of the cooling jacked situated on the other site. Then, the cooling fluid is recirculated in a closed circuit to the cooler machine.

The image below shows the controlling system of the fermenter. As said before, the most important variable is the temperature. So, the temperature detector measures the temperature inside and send a signal to the temperature controller who regulates the cooling liquid's flow which is the responsible for keep the reactor in an isothermal and stable temperature condition

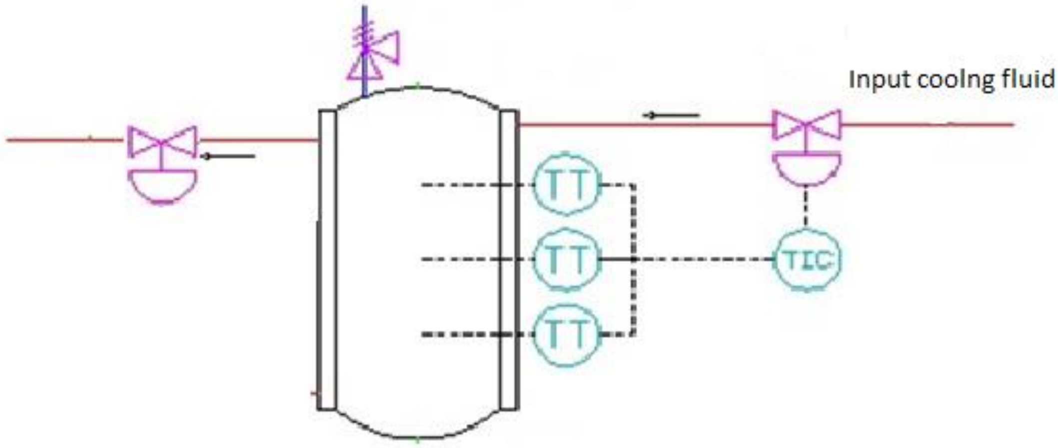


Figure 13. Controlling fermenter system proposal.

7. MATERIAL

In the past, the most used material in the winery to produce wine and Cava was the wood. However, nowadays it is used more developed materials which can resist better different conditions such as temperatures, corrosion, and be inert for the alimentary products. Furthermore, the material must be able to be washed with ease with cleaning products that are not dangerous for the human health.

After a research, the most used material is the stainless steel due to its properties. Although there are many types of steel, the most commonly in the industry are the steel AISI 304 and the AISI 316. The AISI 316 is known as to be classified in the family of 300 which have an austenitic structure achieved by the addition of nickel. Specially, the stainless steel is popular known as being added some Molybdenum which provides the advantage of having a better response to the corrosion rather than the AISI 304. Thus, the majority of the equipment in the industry of winemaking is made of steel 316, such as the fermenter, the tanks, the pumps, the "tirage" and disgorging machinery [26].

8. CONCLUSION

Once finishing the project, having done the researching, talking with specialists in this area and having done the study and calculations about the preliminary design of the reactor, the fermenter, to transform the quantity of grape juice into base wine proposed as objective to produce 50,000 bottles of Cava per year, this project reaches the conclusion that to make the production suitable it is required the following aspects:

- It is required as raw materials 37,500 litres of grape juice divided in three types of grape according to the blending cuveé and 37 kg of yeast in total. As a result, it will be produced the desired quantity of 37,500 litres of base wine that will be fermented in the bottle achieving the objective of 50,000 bottles of Cava per year.
- According to the fermenter, it will operate in batch which will have to do a total amount of 7 batches to transform all the grape wine. The main characteristics of the fermenter would be a volume of 7 m^3 and the reaction would last 6 days in relation of the data obtained by experts in the Cava making. In order to be more precisely and reaffirm these data of kinetics variables, a study of the kinetics variables of the fermentation reaction would be required.
- As the exothermicity of the fermentation reaction, the fermenter is provided by a cooling jacked in order to remove the heat generated. Therefore, the surface required is limited by the surface of the fermenter which is 15 m^2. So, the solution founded to remove the heat is adapt the temperature of the cooling fluid to do the proper exchange. Finally, the temperature of the cooling fluid is 8.3ºC. Besides, the cooling fluid's flow total consumed in a closed circuit is around 41000 kg of water.
- To make possible the properly performance of the fermentation's reaction, in terms of temperature, the fermenter is provided by a controlling system. This system is the responsible for adjusting the flow of the cooling system according to the temperature of the culture liquid. If the temperature increases, the controlling system increases the cooling liquid to keep the temperature inside the optimal range for the performance of the reaction.
- The materials for the tanks, the fermenter and other equipment requires a material that resist the corrosion of the sugars, the different temperatures from below zero to around 25ºC, and permits the proper transference of heat exchange. Finally, after the research, the material selected is the stainless steel AISI 316 according to the manufacturers of the cava's equipment because provide the desired conditions satisfactorily.

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APPENDICES

APPENDIX 1

CHAPTER 1: Generalities.

Article 1.- In accordance with the provisions of the EEC Regulation. 823/87, by which establishes specific provisions regarding quality wines produced in certain regions and in the order of the Ministry of Agriculture, Fishing and Food 27.02.86, are protected with the name "CAVA" quality sparkling wines produced by bottle fermentation according to the traditional method in the determinated regions contemplated in the Regulations and that they comply with its production, elaborating, designation and marketing, the requirements of this provision and others current legislation.

CHAPTER 2: About the production

Article 5: Authorized grape varieties intended for the Cava's production.

- Whites grape varieties: Macabeu, Xarel·lo, Parellada, Malvasia and Chardonnay.
- Red grape varieties: Garnatxa, Monastrell, Pinot Noir, Trepat.

About the above varieties, the white ones: Macabeu, Xarel·lo and Parellada will be the only ones destinated to the production of Cava. Regargding the red ones, the variety of Trepat, is the only destinated to produce Cava Rosé.

CHAPTER 3: The production of base wine.

Article 9: The base wine to produce Cava will fulfil the following analytical characteristics:

Table 2: Analytical characteristics of base wine.

Alcoholic graduation achieved	Minimum	9,5%
	Maximum	11,5%
Total acidity minimum (in tartaric acid)		5,5 g/L
Dry extract non-reductor	Minimum	13 g/L
	Maximum	22g/L
Real volatile acidity (in acetic acid)	Less than	0,60 g/L
Total anhydride sulphate		140 mg/L
Ash	Minimum	0,70 g/L
	Maximum	2 g/L
pH	Minimum	2,8
	Maximum	3,3

CHAPTER 4: The production of Cava.

ARTICLE 11.9: The incorporation of the liquor of expedition cannot increase the alcoholic grade above 0,5% vol/vol.

Article 11.10: All the elaboration process, from the "Tiratge" to the disgorging, both included, must happen in the same bottle.

Article 12: The duration of the Cava's elaboration process, included from the "Tiratge" to the disgorging, cannot be less than 9 months.

Article

Article 15: terminated its elaboration, Cava must have the following analytical characteristics:

Table 3: Analytical characteristics of Cava.

Alcoholic graduation achieved	Minimum	10.8%
	Maximum	12.8%
Total acidity minimum (in tartaric acid)		5.5 g/L
Dry extract non-reductor	Minimum	13 g/L
	Maximum	22g/L
Real volatile acidity (in acetic acid)	Less than	0.65 g/L
Total anhydride sulphate		160 mg/L
Ash	Minimum	0.70 g/L
	Maximum	2 g/L
pH	Minimum	2.8
	Maximum	3.3
Overpressure		~ 3.5 bar (20ºC)

Article 16: Depending on the sugars added with the liquor of expedition, the different kinds of Cava will be classified as:

Table 4: Classification of Cava according to the sugars added

BRUT NATURE	0-3 g/L
EXTRA BRUT	3-6 g/L
BRUT	6-15 g/L
EXTRA-SEC	15- 35 g/L
SEC	35-50 g/L
SEMI-SEC	35- 50 g/L
DOLÇ	>50 g/L

These are ones of the most remarkable articles to produce Cava. In the bibliography, there is the link to access directly to the Cava's Regulation Council.

APPENDIX 2

MODELS OF GROWING:

The cellular behaviour is described in simple equations that predict the parameters of the reaction. One of the most used is the Monod's Equation which describes the microorganism growth according to the substrate available in the culture liquid. It is expressed below:

$$\boldsymbol{Substrate\ (S) + Cells\ (X) \rightarrow more\ cells\ (X) + Product\ (P)} \qquad \text{(Eq. 16)}$$

$$\boldsymbol{r_x = dX/dt = \mu_m (S \cdot X)/(K_s + S)} \qquad \text{(Eq. 17)}$$

Where:

r_x : cellular growth velocity, [mol/ (L·s)].
μ_m : specific maximum velocity growth rate, [h^{-1}].
K_S: Monod's constant, [g/L].

Ks is the value of the concentration of the nutrient limiting where the specific velocity growth rate is the half of the maximum. When values of S are under Ks, the growth velocity depends on lineally for S, whereas values of S over Ks, the value of μ is independent of S.

However, using the Monod's equation do not enable the right determination of Ks due to the Monod's equation only represents the region of exponential growth and the stationary region.

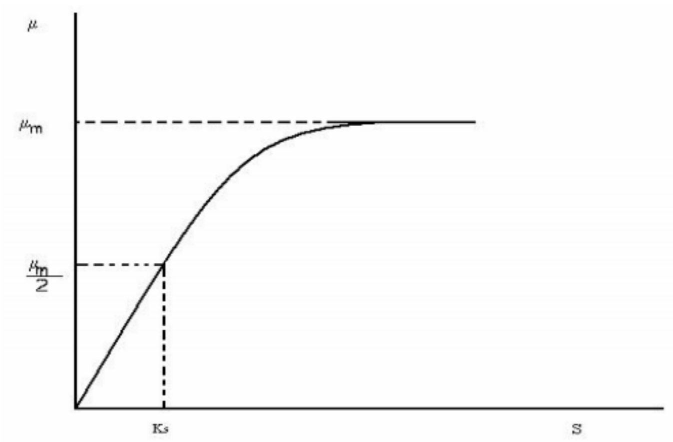

Figure 14. Velocity growth rate

Another equation that is used is the logistic equation. This model considers the growth velocity of cells is only referred to the concentration of cells but, besides, it includes a term that describes the inhibition of the concentration of the biomass:

$$dX/dt = kX - \beta X2 \quad \text{(Eq. 18)}$$

Where:

k: term analogous to that of the Malthus equation
β: constant of the inhibition term

There are 4 stage according to the microorganism growth during the fermentation:

Stage I: Latency stage. Also known as adaption period because in this period the cells are getting comfortable in the liquid but there is no growing.

Stage II: Exponential stage. In this step the microorganism reproduces themselves in an accelerated way. The cells are consuming oxygen and nutrients to Split them up into new microorganism. This slope goes according to the maxim velocity of growth.

Stage III: Stationary stage. In this period, the rhythm of the cellular reproduction is the same of the old cells dying. So, the number of cells keeps constantly.

Stage IV: Cell death stage. In this step, the reproduction of cell is no longer possible. The number of cells in the culture liquid is decreasing due to the accumulation of toxics in the culture liquid or the no longer substrate available.

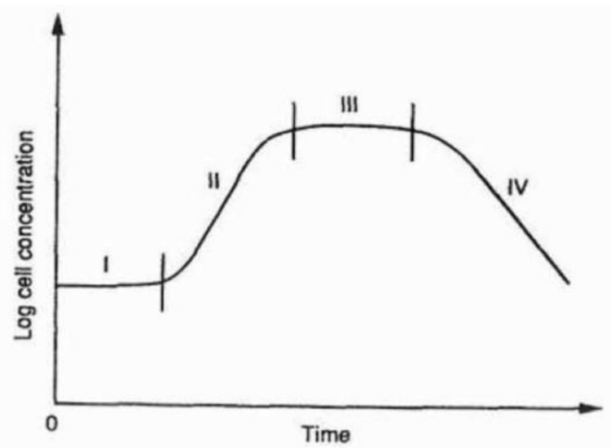

Figure 15. stages of the cell concentration expressed in log in front of time

PERFORMANCE PARAMETERS:

The performance is defined by the product obtained and the Substrate consumed. The microorganism performance is related to the substrate limiting which is the controller of the reaction because it is the first to be consumed.

The reaction produces more microorganism and the product according to the reaction below:

$$\textbf{Substrate }(S) + \textbf{Cells }(X_0) \rightarrow Y_{P/S} \cdot \textbf{Product }(P) + Y_{X/S} \cdot \textbf{more cells }(X) \qquad \text{(Eq. 19)}$$

The performance can be referred by the following's elements:

$Y_{X/S}$ =Product $Produc$ed /Substrate consumed

$Y_{P/S}$ =$Product\ produc$ed / Substrate consumed

Now, the velocity of the consumption of the substrate according to the performance of the product and the cells growth velocity can be defined as:

$$r_S = -(1/Y_{X/S}) \cdot r_X \qquad \text{(Eq. 20)}$$

$$r_S = -(1/Y_{P/S}) \cdot r_P \qquad \text{(Eq. 21)}$$

Finally, both can be related as:

$$r_P = (Y_{P/S} / Y_{X/S}) \cdot r_X \qquad \text{(Eq. 22)}$$

So, the quantity of the substrate, the product and the cells in every instant can be calculated by the next equations and plot the graphic below which indicates the production of new cells and the product but the decrease of the substrate.

APPENDIX 3:

There are shown the table and the plot used for estimating the parameters for calculating the variables which provide the power used by the stirrer. Thanks to the table 5, it is obtained the parameter *b* and the parameter *x* according to the value of Reynolds.

Table 5. Provide the information for the parameter b according to some variables

Agitador	b	
	Laminar Re<10 (x=-1)	Turbulent Re>10^3 (x=0)
Turbina de disc	70	5-6
Turbina de pales	35	2
Hélix	40	0.35

In the figure 16 , it is obtained the equations to calculate the power consumed by the stirrer according to the value of Reynolds, the parameter *b* and the parameter *x*, finally, it can be calculated the value of the power used by the stirrer depending on the type of pales. The value of the Reynolds determinates the equation that it is calculated the power consumed by the stirrer.

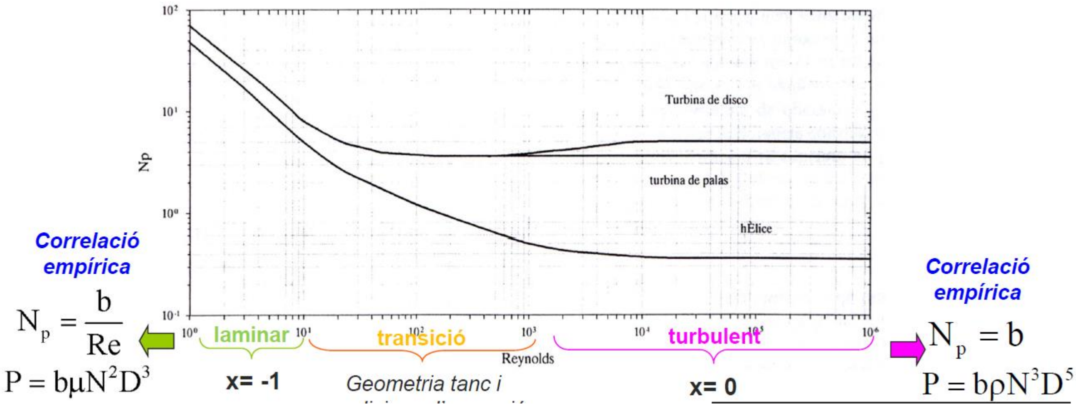

Figure 16. Provide the equation for the Power according to some variables