OXYGEN ADDITIONS DURING VINIFICATION AND THE IMPACT ON WINE. 2ND PART

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In the first part of this article (1) we brought up ideas regarding additions of oxygen during the winemaking process, before the bottling phase.
These additions are quite different from one facility to another since they depend on many factors such as :
- techniques in winemaking (racking, filtering, centrifugation, cold stabilization),
- the size of the tanks, and the volumes of wine being used in the above winemaking procedures,
- the different types of tank transfers : racking from the top of the tank, or from the bottom, overflow tank system and also what kind of pump is used, etc
- also the misuse of some procedures during the movement of wine (2,3) such as the use of too long a hose, air intakes/leaks, too many hose attachments used, unstable pump, transport of wine in tanker trucks not properly filled.

In large Champagne-area units, the average oxygen addition from the end of fermentation to the tirage phase is estimated from 3 et 5 mg/L. This number can increase by two or three-fold when bad winemaking practices (listed above) come into play. Preventative management by using inert or neutral gasses (such as nitrogen) can help diminish the amounts of residual oxygen of the wines in tanks. These are techniques that are not used by wineries enough.

Not all additions of oxygen are limited to the ones added in tanks. Also important to consider are additions that are post-bottling phase, and in the storage and also the degorging of champagne have more weight in the key factors to consider.
This theme has been researched for approximately fifteen years by our group. The production of champagne lends itself well to the analysis of oxygen uptake in wine and the evolution of the wine in bottle. It also illustrates well the comment often made by winemakers but rarely explained; the difference in heterogeneity between bottles for the same bottling run.

Analysis methods used during this study

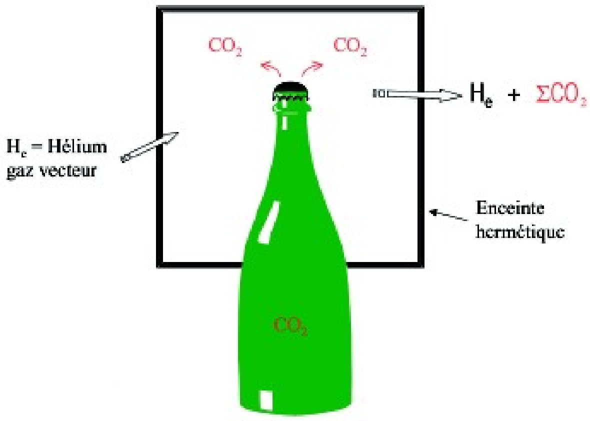
The measurement of oxygen in bottles

These measurements were taken with an Orbisphere, which is composed of a sampler linked to two membrane probes. One probe is polargraphic to measure the amount of oxygen, the other probe is on thermal conductivity to measure the amount of carbon dioxide (CO_2).
This device is already commonly used in breweries on the bottling lines, but is not seen in the enology process. Following a request by the CIVC, the producer of the Orbisphere adapted the unit in 1998 to be able to do trials on champagne. Where the counter-pressure of nitrogen had to be able to withstand 8 bar at 20°C to be able to resist the internal pressure in the bottle and resist the transfer of the wine to the bottle, pass the probes, all without allowing ambiant air to access the wine.
Before the analysis is done, the bottles are acclimated to 18 °C, and also agitated for 15-20 minutes to be able to equilibrate between the gas in the headspace and the gas dissolved in the wine. The measurement can be taken on a bottle with a crown cap or a cork. With a cork, a pre-drilled 3mm hole is used and the lower limit of detection is in the order of µg/L.

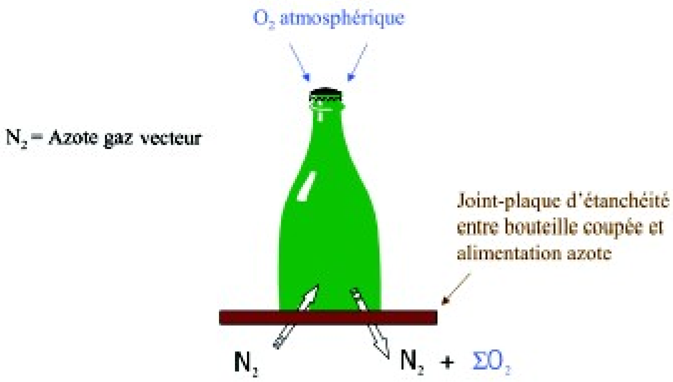
The measurement of the gaseous exchange during bottling

These analyses were done at the National Analysis Lab (LNE) in Paris. It allows for a dynamic analysis of a quantity of O_2 entering or CO_2 leaving the bottle through the existing closure of the bottle (protective cap, capsule, cork, muselet).

For the carbon dioxide (CO_2)
The measurement consists of placing the neck of the bottle after the prise de mousse has been done, in a completely sealed chamber.
This sealed chamber is purged with a neutral gas (helium), and the CO_2 escaping from the bottle can be determined by measuring the gas mixture (helium+CO_2) with liquid phase chromatography. The results measured are in the order of cm3 of CO_2 per 24 heures period.



For the oxygen (O_2)
The bottle is emptied after the prise de mousse, and cut before being attached to a supporting structure. Nitrogen is used to purge the bottle before measuring the amounts of oxygen entering the bottle via the closure.
The mixture (nitrogen+O_2) leaving the bottle is analyzed with a machine called Oxtran. Values are obtained are in the order of 100th of a cm^3 of oxygen per 24 hours (10-2 cm^3/24 heures).



Analysis of sulfur compounds
These analyses were done at the University of Bordeaux II (V. Lavigne, D. Dubourdieu) according to the method described by the authors (4).

Sensorial analysis
The blind tasting was done by a trained jury of judges composed of enologists and cellar masters, winemakers. The panel (10-15 people) was focused on the vocabulary associated with 'oxidation' and 'reduction' of Champgne on a scale of 0 to 5 (0=nothing, 5= strong).
The wines with more sulfur off-flavors, animal, fermentative are in the category of 'tendency to reduced notes'. The aromas qualified under cooked fruit, ripe fruit, stewed fruit, are associated with 'oxidative'

characters. The panel must quickly analyze the evolution of the wines, with 10 bottles per lot, randomly coded and distributed in the tasting stations (maximum 30 bottles, 3 lots of 10 bottles).
The results are shown as colored pie charts or diagrams, grouped as follows :
- yellow for zero= 0, reduction 1 or oxidation 1
- orange for oxidation 2 and 3
- red for oxidation 4 and 5
- light green for reduction 2 and 3
- dark green for reduction 4 and 5

The average marks given by the jury allow us to have an idea of the sensorial profile of the wines judged by the panel.

Additions of oxygen during bottling, aging and disgorging.
Tirage and prise de mousse

Oxygen present in a wine from the bottling process can have three origins :
- the oxygen content of the wine itself after transfers and treatments, but prior to arriving in the holding tank feeding the pump for bottling,
- the oxygen brought to the wine by the bottling process itself : hoses, pump and air pressure etc.,
- the oxygen present in the headspace between the wine and the cork, trapped there while being corked, which will slowly dissolve into the wine.

Vidal et al (6) gives average figures of 1.6 mg/L for bottling lines that are stationary and 1.43 mg/L for mobile bottling lines. Ferrarini (7) gives a figure of 1.2 mg/L.These values appear low as they do not integrate the oxygen in the headspace, unless this was perfectly inert which is not clear in the article.

With a calculation, one can determine that there is approximately 1cL of headspace, and if it is uniquely occupied by air this gives an addition of 2.85 mg of oxygen to the wine. This oxygen will progressively diffuse from a gaseous state, into a liquid one and be consumed by the wine. In a 75 cl Champagne bottle, encapsulated after tirage, the headspace represents 2.5 cl of air and a theoretical addition of 7.1 mg of oxygen, with a maximum of 9.8 g per litre of wine.

In the table below, measurements taken by different Champagne houses during bottling and after the tirage process, for the bottles succeeding each other on a line, the oxygen additions are largely similar (table 1).

Chaîne de tirage	Mode de prélèvement	Nombre de bouteilles	Teneur en oxygène (mg/L)
A	Au même bec	7	4,8 ± 0,06
B	Bouteilles successives	6	5,1 ± 0,07
C	Bouteilles successives	5	4,2 ± 0,03

Table 1. Oxygen amounts in (mg/L) of wines during bottles for the triage mixture.

Variance can be found during the course of the triage operation itself, as we can see in Table 2. These figures were obtained from the bottles themselves (average of 3 bottles per sampling) as a function of how much of the triage mixture was left in the tank.
The bottom of the tank effect was observed visually and also through analyses since there is more turbulence once the liquid reaches the level of the mixer blades, and therefore a greater dissolution of the oxygen into the wine at this stage. Depending on the type of mixer, this effect can be reduced.
The amount of oxygen in the bottled wine is a function of the liquid in the tirage mixture, the transfer and the headspace in each bottle.

Volume de mixtion restant dans la cuve (hl)	Temps (heures)	Teneur en oxygène dans le vin (mg/L) sur 3 bouteilles
175	0,5	2,3 ± 0,06
155	1,0	2,9 ± 0,10
125	1,5	3,2 ± 0,06
90	2,2	4,7 ± 0,06
45	3,0	5,9 ± 0,08
25	3,3	7,2 ± 0,05
< 12	3,5	6,9 ± 0,07

Tableau 2. Amounts of dissolved oxygen (mg/L) in the wine, directly following tirage, bidulage, encapsulation,as a function of the volume of wine left in the triage mixture tank.

Any oxygen closed in to the bottle at the time of triage is effectively used by the yeast within a few days (5). One can therefore consider this addition of oxygen to be heterogeneous from one bottle to the next, and have a limited effect on the evolution of the wine in bottle.

Aging of the wine for tirage

For many years, a bottle during the prise de mousse phase (CO2 developemnt) was considering a completely sealed and closed container with no exchanges with outside gases which would limit the effects of maturation of the wine to the autolysis of the yeast (8).
This point is not valid as no enological closure can be considered immune to the exchange of gases. In the case of sparkling wines, very small quantities of carbonic gas escapes while a small amount of oxygen enters the bottle, despite the internal pressure of CO2 in the bottle. The partial pressures of these two gases tend to equilibrate between interior and exterior of the bottle. These exchanges are very small, but are measureable.
For many years, capsules with synthetic joints of the champenois market have been characterized by their loss of CO2 values based on the measurements to the bottle after tirage (9, 10, 11, 12).
Recently, an additional study was realized at the National Trial Laboratory (LNE) on crown cap closures where the conditions were standardized in terms of force of compression and tightness of the closure. These trials were done in air and in pure oxygen conditions. Within a close margin of error the results correlated (by a factor of 5) between air and oxygen (table 3).

	Pertes en CO_2 (cm^3/24 h)		Entrées d'oxygène (cm^3/24 h)		Rapport PCO_2/PO_2
	Résultats sous 8 bars absolus de CO_2	Calcul sous 1 bar de CO_2	Résultats dans l'air (0,21 bar d'O_2)	Calcul sous 1 bar d'O_2	
Capsule 1	0,12	0,015	0,0006	0,0029	5,2
Capsule 2	0,25	0,031	0,0009	0,0043	7,2
Capsule 3	0,56	0,070	0,0019	0,0090	7,8

Table 3. Loss and entry of CO2 and O2 in cm3/24 h for 3 types of closures used in the Champagne area.

At 1 bar of pressure, the ratio between "loss of CO_2" to "O_2 entry " varies between 5 to 8 depending on the closure. This coefficient to the one normally seen when measuring diffusion of plastics.
These measures of CO2 loss and O2 gain are well within the norm, and the gaseous exchange studied correlates to standard rates of diffusion.

The CO_2 losses measure 0.12 to 0.56 cm^3 per year depending on the closure used. In practice, one can see a loss of 2 bars in 10 years for the most lost closures. Volumes of oxygen entering are 200 times weaker (6 to 19.10-4 cm^3/24 h), with addition rates to the wines from 0.4 mg/L to 1.3 mg/L per year and closures tested here; 0.4 to 1.7 mg/L for closures tested on the market.
For wines being aged 5 to 10 years, oxygen absorption rates can reach several mg/L, which is considerable compared to the results discussed.

Previously, cork capsules were found in the higher end of the results (1.5 mg/L/year), with a great deal of heterogeneity with a given product lot.

Despite these oxygen absorption rates, one never finds, or finds very trace amounts of oxygen in champagne during triage, during the aging process. It is instantly consumed as soon as it enters the bottle.

Influence of the crown cap on the sensory evolution of the wine.

Many experiments have been done since 1989, to demonstrate the effect on the champagne of the gaseous exchange through a crown cap and the evolution during tirage. The example here is the same basewine with three different closures ; A, B and C.
Thanks to the database of knowledge known about these closures, one can estimate that oxygen absorption brought about by the closure will be 0.35, 1.0 and 2.5 mg/L per year.

The results of the tasting (figure 1) are very coherent, even if the difference becomes more perceptible after 2 years of aging during tirage and becomes more obvious over the course of several more years. To be quite rigorous in comparison, it would be inexact to compare the different phases to each other since the judges are not necessarily the same at each tasting, and also a sensorial perception depends on what was tasted in that series of wines. Therefore the wines judged ‘reduced’ at 6 years old will seem more so, when judged with similar wines that are oxidized.

Nevertheless the comments of the tasters are very segmented, particularly those wines with 6 years of tirage. At this stage, capsule A allowed very little oxygen in, but was a very simple wine with some reduced aromas.
With capsule B, the wines seemed more balanced but evolve cooked fruit aromas, but have a good ageing potential.
Wines elaborated with capsule C are distinguished by strong oxidation characteristics. After 10 years in tirage the wines were described as ‘tired’ and ‘finished’.
Capsule C was in fact removed from commercial applications and it was asked that producers of the capsule not sell products with gas exchanges of greater than 0.8 cm^3 of CO_2 per 24 hours (9, 10).

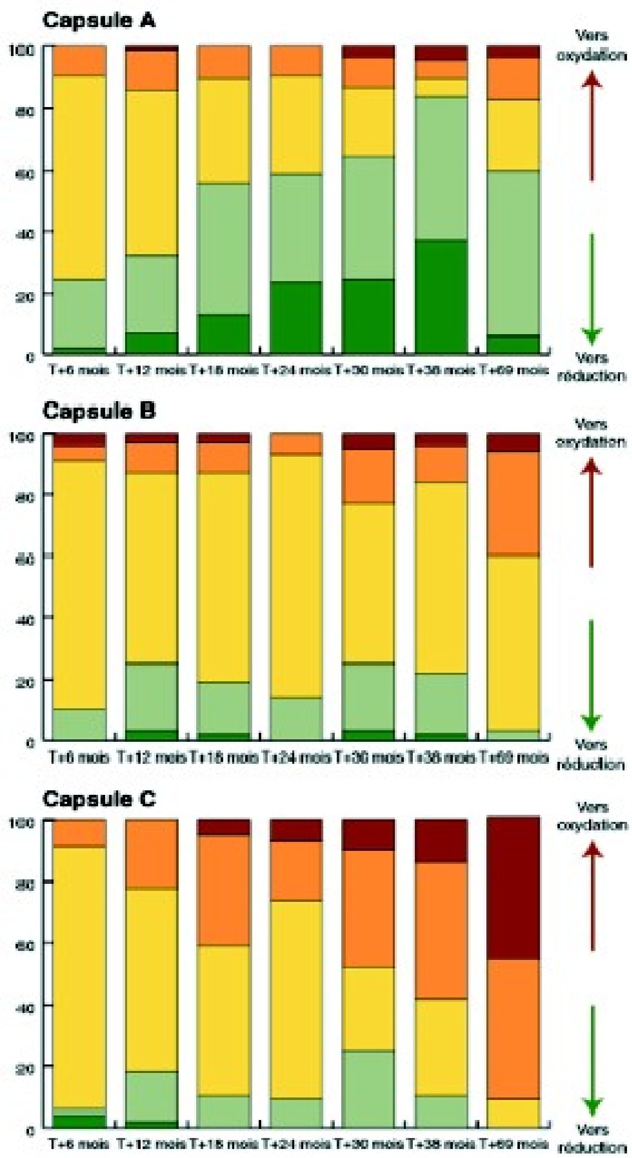


Figure 1. Sensorial profile of the same champagne wine at different times during the ageing in tirage, as a function of the capsule used.

These experiments were repeated several dozens of times during the course of 15 years. The results were systematically similar even if they actual numbers varied, as a function of the base wine used. Hence the difficulty to choose a capsule when one cannot predict the evolution of the wine during aging, nor the date of commercialization and consumption.

The use of the crown caps with reproducible characteristics allows a sensorial from wines in the same tirage lot , as long as the capping machine has well-defined parameters that are maintained throughout the tirage season. Further work is being done on this subject.

Disgorging

During this stage the bottle stays open for a few seconds or up to a minute and a half for longer bottling lines with distance between the topping up and corking stages. Contrary to popular belief, champagne wine is not protected from oxygen during this operation by the degassing of CO_2. Several dozen larger establishments have measured the oxygen in the bottles under cork at the end of the bottling line.
The results (figure 2) show that, after the equilibrium between gas and liquid phase was established, the average oxygen in the wine was 1 mg/L. This value can reach 5 mg/L on some machines, depending on the procedure used to top up the bottles.

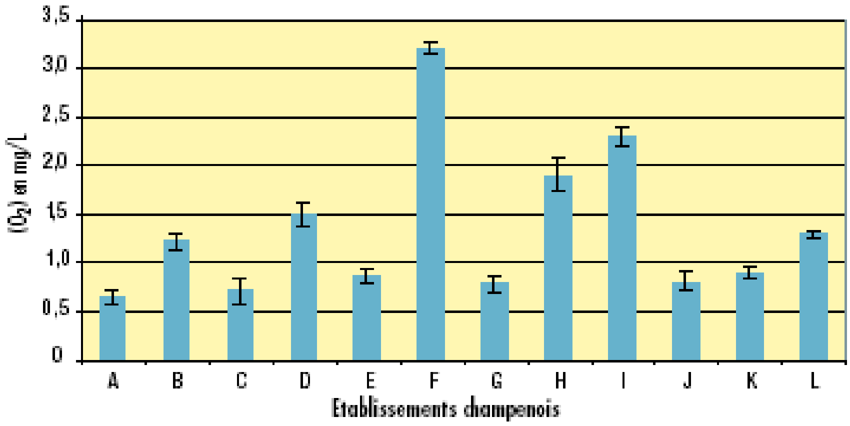


Figure 2. Dissolved oxygen concentration (mg/L) of champagne wines after the cork has been inserted taken at several different larger champagne houses.

Available oxygen in the wine is dissolved, or in the headspace and this will progressively dissolve as the wine consumes the oxygen. In the case of a champagne bottled with a cork closure, a calculation shows that the oxygen added to the wine from the headspace is equal to the oxygen dissolved in the wine, when measured after being corked and given the chance to equilibrate.
The minimum and maximum values measured are 0.7 and 5 mg/L depending on the winery and its bottling line. When one factors the headspace into this, the total amount that can be absorbed by the wine is 1.4 to 10mg/L, but this amount can vary from one bottle to another depending on the wine, the type of cork and the conditions during bottling.

The different gaseous exchanges occurring during the corking phase are actually quite complex. Firstly one does not get the same results with crown caps versus cork.
Thus the champagnes that are disgorged and dosed after being crown-capped have oxygen levels higher than wines that have had a cork during storage. For example, the crown cap method leaves values close to 3 mg/L in the wine, while natural cork will leave values of 1 mg/L.
The insertion of the cork seems to chase some of the gaseous mix above the liquid (13).

This phenomenom during a natural cork insertion is also dependant on the elasticity of the cork and the speed with which it is inserted. In a bottle of a sparkling wine, the oxygen level after disgorging will be influenced by several difficult-to-control factors influencing the volume and the composition of the atmospheric air (% CO_2, N_2, O_2) (figure 3) :
- adjusting of the fill level at the dosage level,
- the time the bottle is open between topping the wine level and inserting the cork,
- the type of cork (which influences elasticity, surface treatment) influences the action of it being able to chase the gas out, as well as that brought by the cork itself.
- the bottling process (cadence, speed of insertion, diameter of the bottle and depth of insertion.
- the reaction of each wine to the process of bottling (14) which can cause a degassing and formation of foam (wine particles or the jostling of the bottles).

Note : By extrapolation, still wines with screw cap involve an increase in dissolved oxygen if the headspace is not an inert gas, due to a larger headspace and no cork to displace some of the headspace gas.

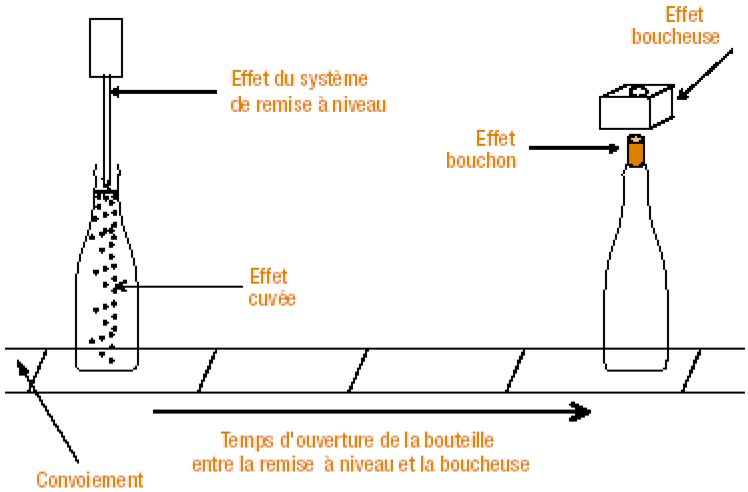


Figure 3. Sources of heterogeneity with oxygen levels during disgorging.

Influence of the disgorging process on the sensorial evolution of champagne

Disgorging constitutes a shock of an oxygen addition compared to the micro-oxygenation occurring via crown caps. To protect the wine, traditionallly and average of 15 à 20 mg/L SO_2 has been added via the topping up liquid.

A series of experiments was conducted during the disgorging-dosage to judge the impact of this exposure of oxygen and SO_2 on the evolution of the sensorial characteristics of the champagne (15).

To avoid the potential aromatic influence of a corked wine in the trial, the wines were re-capped despite the oxygen being slightly more of an influence in this instance.

Four parameters were tested:

- with oxygen, approximately 1.8 mg/L and two variables : without an addition of SO_2 and with an addition of 15 mg/L,
- without oxygen (nitrogen sparge before capping the wine) : and the same two variables of without and with an addition of SO_2 of 15 mg/L.

Following the oxygen levels showed that the oxygen is consumed at the same rate, regardless of whether or not SO_2 was added in the top-up liquid (figure 4).

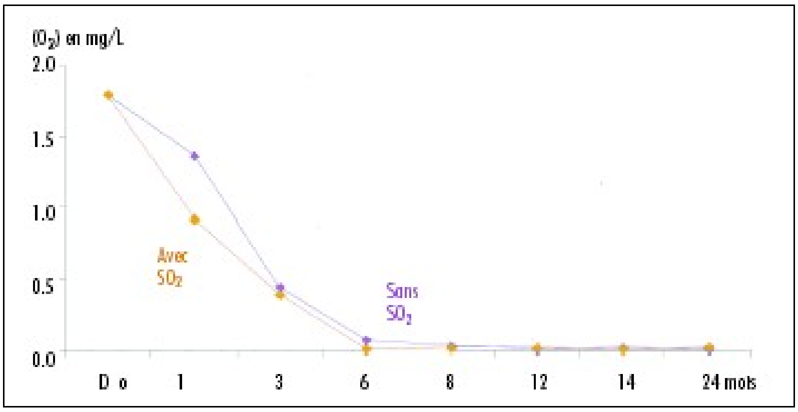


Figure 4. Consumption of oxygen after disgorging.

However during the tasting of the wines, with the same protocol described for the tasting with caps, 15 months after the disgorging the wines were radically different (figure 5). Firstly, with no SO_2, the wines were characterized with oxidative notes and quite orange-colored.

In the presence of SO_2, the wine was protected from oxidation but sometimes had some reduced sulfur off-flavors. As one can note in the lower two pie-charts of figure 5, the wine with no oxygen exposure during disgorging has a low oxidation level, even without an addition of SO_2. In this wine with an addition of inert gasses (air without O_2) an addition of SO_2 induced a very strong reduced note to the wine (predominantly green in the lower, right hand side chart) which was critically noted by the judges. Keeping in mind the different levels of O_2 added during disgorging, there was still a clear trend in the different bottles of the same experimental lot.

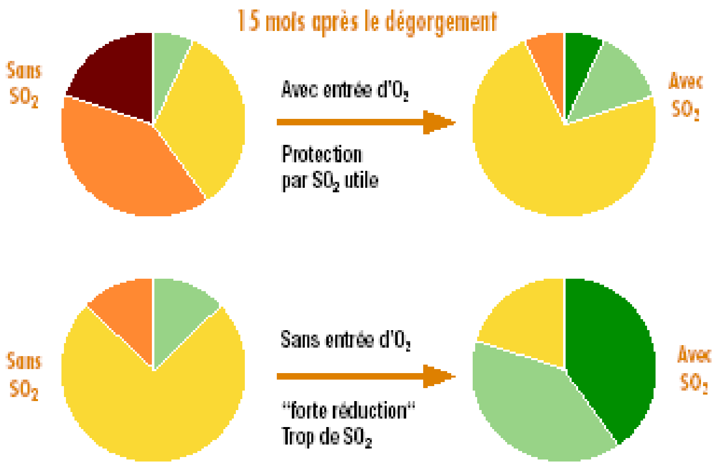


Figure 5. The influence of oxygen and SO2 levels present in the wine after being bottled, and the sensory evolution on the champgane.

The result is also a function of the type of wine and the dose of SO_2 added (figure 6). Thus for champagne A, eight months after disgorging with a dose of 15 mg of SO_2 per liter added in the top-up liquid gave sufficient protection, while champagne B needed 30 mg of SO_2 per liter to have the same effect. By contrast, champagne A had too much reduction when 30 mg of SO_2 par liter was added.

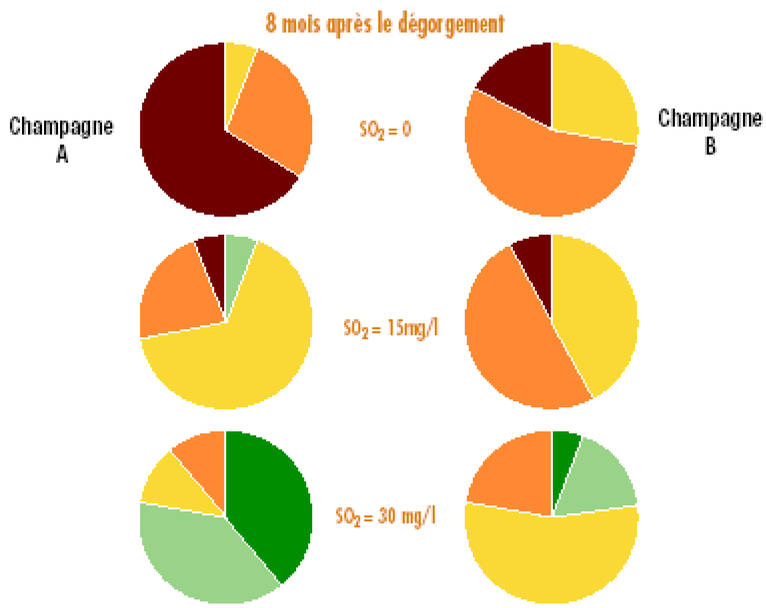


Figure 6. Sensorial evolution after disgorging and sulfiting, depending on the type of wine.

In the case of strong reduced notes in the wine, the first analyses of the wine showed an increase in methanethiol and especially of hydrogen sulfide (figure 7).

The most adapted solution to avoid sensorial deviations and the risk of differences within a lot of bottles, is to sparge with an inert gas between the topping up stage and just before adding the cork. Further research is being done to establish this procedure on an industrial level and be equally careful as in the brewing industry to avoid any introduction of oxygen.

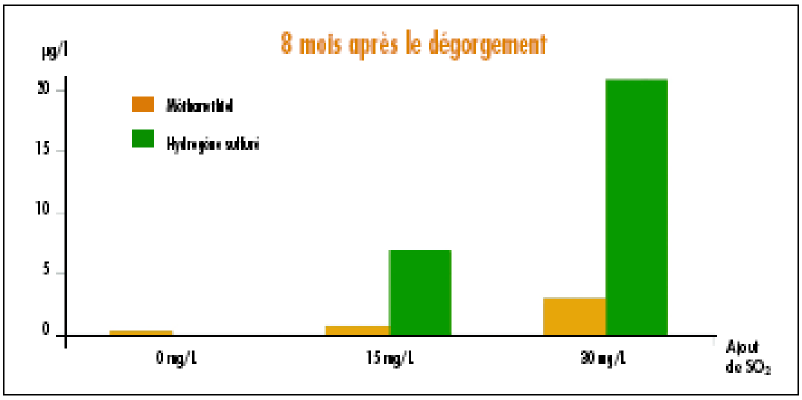


Figure 7. Amount of sulfur compounds as a function of the SO2 levels being adjusted during dosage (Lavigne, Dubourdieu).

The final addition of cork

Similar issues affect cork as affect crown caps, with respect to micro-exchanges of gas around the cork related to the equilibration of the partial pressures of carbonic gas and oxygen between the wine and the atmosphere.
The CIVC had trials done at the National Trial Laboratory (LNE) on different cork closures, such as agglomerated and twin disks.
The results (figure 8) show that within the same lot of corks there is little difference over time from one bottle to the next. These small differences were at least maintained over the 2 year trial (16).

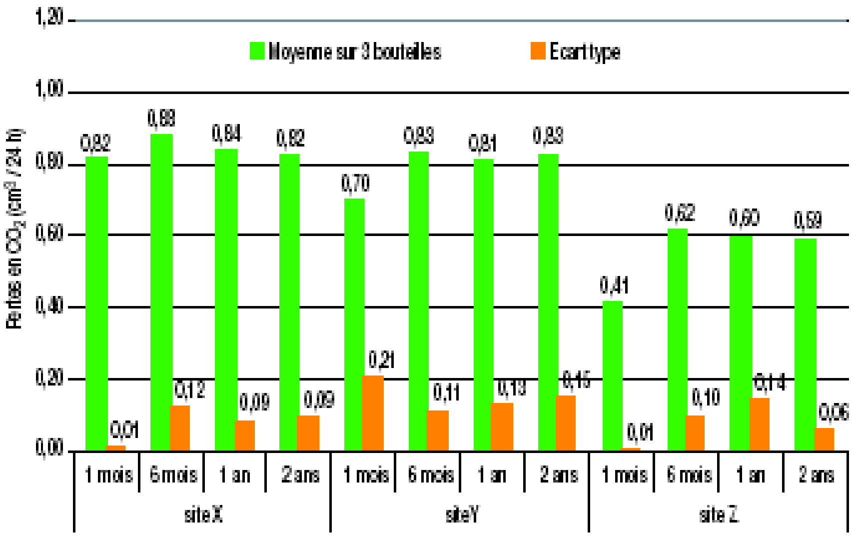


Figure 8. Losses of CO2 (cm3/24 h) of natural cork..

There is a larger difference when completely different lots of cork are considered in the trial (figure 9). The differences range between 1 to 4 on samples taken from different batches of corks from different origins.
Losses of CO_2 vary from 0.5 to more than 2 cm3 per 24 hours.
These results can be compared to the results obtained from crown caps. In these conditions, the average of the cork closures react almost in the same manner as the closure with the least sealing ability. This extrapolation is not a rigorous comparison in the sense that a cork closures' reaction to gaseous exchanges cannot be assimilated to compare to crown caps. Trials are currently being done to confirm this point.

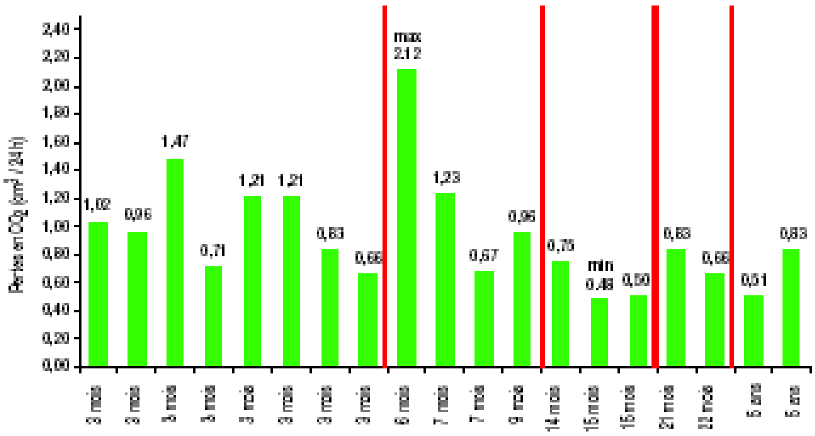


Figure 9. Losses (cm3/24 h) of 19 cork closures (one bottle per lot).

One might expect the final cork closure to contribute as much oxygen (or more) than the crown cap but over shorter amount of time. Wine longevity with the final cork closure is generally inferior to that of the tirage cork. The effect of the oxygen added due to the cork is also greatly masked by the oxygen introduced during disgorging, at least for the first few months

Discussion

The work done over the last 10 years gives the opportunity to conclude on many aspects of how oxygen gets into champagne during its elaboration (table 4), and to weigh which factors during the vinification have the most impact on the final product.
There is still much work to be done, and particularly to understand how much oxygen the wine does use to achieve its optimum maturity. One can estimate that the effects are cumulative, and that a wine having a certain level of oxidation at a certain stage in the process will affect the way that wine is able to resist future exposures to oxygen, or reach its optimum much sooner.

A chronologie of the elaboration of champagne.
In the tank phase, the accumulation of the effect of the different wine transfers, stabilization and clarification can result in an addition of 3 to 5 mg/L, without any particular protection. This oxygen addition can double, if not triple if a racking is done without protection from aeration or after transportation of the finished wines by tanker.

At the bottling stage one can consider an average oxygen accumulation over 2 to 3 years to be in the range of 3 to 5, even if these results need to be re-verified. Exposure to oxygen can be more significant for champagnes where a medium to long-term storage can last 10 years or more.
The other parameter is the homogeneity or heterogeneity of the effects on the finished wine, those wines ready to sold.
In a tank, any addition of oxygen to the tank will be to the whole tank and will not have an individual effect on the bottles. At the bottling stage, oxygen additions are important in volume, and lead to the greatest differences between bottles of the same lot.

Bilan oxygène	Vin tranquille Valeur moyenne (source Vidal et al)	Vin effervescent type champagne Valeur moyenne (source CIVC)
Cuverie		
Soutirage	0,1 à 0,2 mg/L par opération	0,25 mg/L par opération
Filtration sur terre	0,7 mg/L par opération	0,7 mg/L par opération
Centrifugation	0,95 mg/L	0,95 mg/L
Stabilisation tartrique	2,4 mg/L	1,2 mg/L
Bouteille		
Mise en bouteilles	1,4 à 1,6 mg/L beaucoup plus sans inertage	2 à 7 mg/L consommé par les levures
Bouchage couronne		0,4 à 1,7 mg/L par an selon la capsule
Dégorgement		0 à 10 mg/L selon la machine, les arrêts sur chaîne et la mousse
Bouchage d'expédition	quelques mg/L par an ?	quelques mg/L par an selon le bouchon (à confirmer)

Table 4. Overall additions of oxygen (mg/L) during the vinification of a still or sparkling wine.

In the diagram 1 below, one can visualize where the sources of heterogeneity might come from and evaluate their progress thorugh the process, and re-establish the regularity between bottles of the same lot.

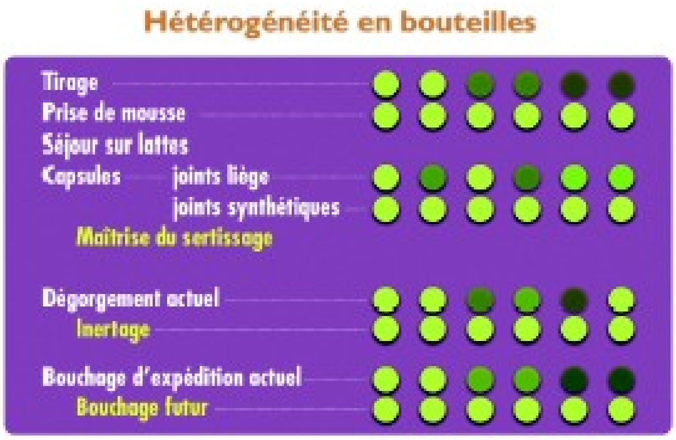


Diagram 1. The colored points schematically represent the heterogeneity during the evolution in bottles, as a function of oxygen entering.

At the tirage stage, the wines will have a varying amounts of oxygen, but the prise de mousse re-establishes homogeneity.
During ageing, the change from natural cork closures to crown cap has considerably improved consistency between the bottles within a lot. The decision on the closure must be carefully considered and the decision taken as a funtion of the wine and its destination in the market.
Another point is the precision and regularity of the crown capping tool must be consistent throughout the bottling season.
Disgorging the wine still represents the point where the most variability can be introduced between bottles, with oxygen additions ranging from 0 to 10 mg/L in extreme cases. Adding an inert mixture of gases to the headspace limits the need to sulfite the wine but is not the ultimate solution, and can in fact add another set of irregularities between bottles by adding sulfure off-flavors.
The ultimate step is the final corking of the wine, where the same set of problems is faced as the triage phase, even if the natural cork closure is a more complex closure than the crown cap. It is not an inert material and can add both positive and negative aspects to the wine as well as evolving as long as it is in

contact with the wine. There is no doubt that the process of bottling must in the future better master the exchange of gasses in this final phase.
If one makes reference to transport in tanker trucks, or wine transfers with the racking returning to the top of the tank, the results in table 4 show that the bottling phase has a critical role to play regarding oxygen additions, namely on sparkling wines who are re-corked twice. This reasoning can be expanded to all wines, particularly those where no inert gas is used or where there is a longer bottle-conditioning phase.

This phase has been neglected for much too long when one considers the additions of oxygen in this field of enology, whereas in long-term aged wines this is just a small, yet difficult part of the winemaking. Over and above the mastering of the ageing process, one must be able to answer the question of the heterogeneity of the wine between bottles and also the potential of this wine to age well.

Variability between bottles from the same lot

This difference between bottles in sparkling wines can also be seen in all wines. The questions that go beyond just the regular cyclical evolution of wine, are: are these cyclical changes related more specifically to sensorial changes brought about b gaseous exchanges in the bottle? Would a total uniformity be possible within a lot? Crown caps have been revealed to havea much better consistency within a lot than have natrual cork closure in the same ageing phases.
Despite this, certain winemakers believe this variety within a lot is part of the 'magic' of the wine. It is the consumer who must pay where one bottle may be phenomenal, the next quite the opposite and extremely disappointing (and expensive!).
The mastery of the gaseous exchange at the bottling and recorking phases is definitely progress towards having better satisfaction for the wine industry overall, and the consumer as well.

The ageability of the wines

One does question the process of bottling for a rosé or white wine the same way as for champagne. These wines would be well-served to maintain freshness and color by paying more attention to the bottling phase and choosing the best possible closure rather than just adjusting the SO_2 levels. New World wineries have already understood and implemented some of these changes (17).

The Swiss white wines made from Chasselas, are very sensitive to oxygen and many have decided to use screw caps since many years.
The terroir and the climate produce the potential of the grape, and the winemaker helps express this potential. Oxygen can moderate this expression of the wine over time.

Bottles at the bottom of the sea

Anecdotally, it has been observed that wine at the bottom of the sea is better conserved than wine aged on land. Not surprisingly, since not only does the colder reaction slow down the oxidation reaction over time, the cork is also kept wet and therefore even with salt water, the seal is maintained and does not allow the salt water to enter the bottle. One can achieve the same in a cool cellar, but the story is not as interesting!

Influence of the bottle size (split, bottle, magnum)

It is observed that smaller bottles do not age as well as larger bottles, where a Magnum is considered the ideal for wine storage. As shown in an article in 1995 in champagne wine, the amount of oxygen added during bottling is equal regardless of the size of the three different bottles (18) due to the size of the neck (ring 29). Therefore over the same time and temperature, the oxidation of the wine will be faster in a split than in a magnum (table 5).

Volume (cl)	Demie	Bouteille	Magnum
Volume total rase-bague	39,0	77,5	153,3
Volume au nominal	37,5	75,0	150,0
Volume gazeux (espace de tête)	1,5	2,5	3,3
Volume gazeux/Volume de vin	4 %	3 %	2 %

Table 5. Liquid and gaseous volumes in differnt bottles sizes used in Champagne with ring opening size 29.

This phenomenon already checked with crown cap closures is similar with natural cork as well. These results must not occur by happenstance, but with the knowledge that there is cause and effect when bottling and changing the closure.

Conclusion

This seeming preoccupation with oxygen allows us to revise the various steps done to elaborate a wine in Champagne, the first steps in tanks, bottling, disgorging, and the final bottling as well. It still needs to be better understood how much oxygen the wine ideally needs in the overall process. Even if opinions still differ on this point, most professionals prefer slight notes of reduction that can be corrected over an excessive oxidation of the wine that is irreversible and often rejected by the consumers.

The ultimate step in knowing the capacity of a wine to absorb oxygen throughout the vinification will be to be able to predict the capacity of the wine, or even must, to resist oxidation. Having a test to determine this will take many more years of work to understand the whole process and the chemistry behind it.

More immediately, and on a practical plan, a simple improvement will be to improve the consistency between bottles of the same lot. This immediately means a better control of the oxygen additions made through bottling and corking. This should be a primary consideration in the choice of bottling lines, and the measuring of the oxygen should be imperative as an enological parameter throughout the vinification process.

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