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A Study to Determine the Oxygen Status

In Ohio Commercial Wines at Bottling

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Abstract

Commercial wines (2014) from 14 Ohio wineries were selected to determine their dissolved oxygen (DO) status. Oxygen is an important substance that can alter the chemical and sensory properties of a wine through oxidation. For each winery, 12 bottles were collected during the middle of the bottling process. Using a NomaSense™ oxygen analyzer, the DO and headspace oxygen (HSO) were measured at several storage times, ending in 126 days. In addition, the free and total sulfur dioxide and pH were analyzed in triplicate. Most levels of DO (85%) at bottling were above the industry guideline (1.0 ppm). For the HSO, results showed that 58% were above the recommended limit (2.0 ppm) with 6 wines being extremely high, 3.2 to 4.9 ppm. The greatest decline in free sulfur dioxide during bottle storage occurred in the wines with the highest DO level, which HSO was the main contributor to the DO levels. If this study represents a majority of the Ohio wine industry, our winemakers have a serious issue maintaining appropriate dissolved oxygen and headspace oxygen levels in their wines. Results indicated that significant improvements should be made in reducing wine oxygen at certain steps of vinification: holding tanks, filling bottles, and applying closures.

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Introduction

The amount of oxygen that a wine acquires during vinification has an impact on its sensory quality. Typically, wines exposed to high levels of oxygen often result in the loss of fruitiness and freshness, and develop a brown color. These responses are unwanted in most wines, particularly white wines. Since red wines contain high levels of polyphenols (color and astringency), some beneficial chemical reactions may develop with small amounts of dissolved oxygen. The main substrates for wine oxidation are phenolic compounds. These molecules are connected with two mechanisms of wine oxidation, enzymatic and nonenzymatic (chemical). Enzymatic oxidation occurs very fast and early in the winemaking operation. During crushing and pressing, polyphenolic oxidase activity leads to brown coloration. Also, the resulting wine may have less varietal character. Winemakers often prevent enzymatic oxidation by using inert gases (N_2 or CO_2), adding sulfur dioxide, and settling the juice prior to alcoholic fermentation. Studies have indicated that enzyme activity decreased some 90% with the addition of 50 ppm SO_2. Since enzyme activity is inhibited, the most important oxidation mechanism is nonenzymatic, chemical oxidation in wines. Phenolic molecules, along with ascorbic and tartaric acids, are substrates for this unwanted oxidation process, a slow reaction. Through a series of several pathways and reactions, chemical oxidation leads to the formation of several compounds including: quinones, acetaldehyde, and hydrogen peroxide (H_2O_2), a strong oxidizing agent. Often, the aroma and flavor of an oxidized wine are described as being caramel, sherry-like, bruised banana and rancid, to name a few descriptors.

To control dissolved oxygen (DO), winemakers frequently minimize oxygen pickup during vinification steps and prevent its oxidizing effect by adding appropriate amounts of sulfur dioxide. For the latter, attention is given to specific winemaking operations which include: racking, pumping, filtration, tartrate stabilization, and bottling. Studies indicate that bottle filling is a main source of oxygen exposure, with DO levels from 0.2 to 7.0 ppm, and may be responsible for a 70% increase. Other contributors (steps) are racking (uptake to 5 ppm) and filtration (uptake to 7 ppm).

Besides the above unit operations, two other aspects also influence oxygen enrichment, wine temperature and volume. Temperature has an important effect on the O_2 level in wines. It is well known that decreasing wine temperature accelerates oxygen uptake. To illustrate, the solubility of O_2 in water at 50^o F is 15.4 ppm, while at a higher temperature (68^o F), O_2 solubility is 9.1 ppm. This relationship is decisive in tartrate stabilization where low temperatures approach 32^o F and DO levels may reach 2.7 ppm or higher in wine. For wine volumes during bottling, oxygen contents are less when large volumes are used in comparison to smaller volumes. Studies have found that the beginning and end of a bottling run add higher DO levels. These increases are caused by the filtration system, dead volume, oxygen content near the wine surface, and turbulence in the final bottles.

The guideline for maximum dissolved oxygen in the bottle has been established at 1.0 ppm. To achieve this level, winemakers must employ several measures to lessen the exposure of wines to air (O_2). First, all cooperage must be filled to capacity or covered with inert gas (N_2, CO_2, Ar) and hoses must be as short as possible with tight coupling links.

The "Holding Tank" needs special attention such as establishing a desirable wine temperature, using inert gas in wine transfer, avoiding turbulence and stirring without inert gas. Wine bottling is particularly important in controlling oxygen enrichment. Wine turbulence should be kept at a minimum, and filling levels maintained at certain guidelines. Also, bottles need to be flushed with N_2, usually 2 to 3 bottle volumes, and a vacuum provided during filling. In conclusion, wines before bottling should contain less than 0.5 ppm DO.

The DO level in bottled wine is extremely important. However, headspace oxygen (HSO), contained in the volume from the top of the wine to the bottom of the closure, is also critical to the DO level. This HS oxygen is an additional source and moves into the wine. The HS volume (oxygen amount) depends upon the closure type, cylindrical, such as cork, synthetic, and screwcap. A screwcap has the greatest HS, 14 ml, while corks vary between 3 to 7 ml. Also, the recommended HS height is 15 mm which avoids cylindrical ejection and leakage after HS gas compression at "corking". Excessive pressures are often caused by low temperature wines, small HS volumes, high storage temperatures and bottling without HS sparging and vacuum. Studies have found that HS oxygen may increase the DO as much as 60%. Also, the DO in wine bottles with screwcaps generally experience a DO increase of three times greater than cylindrical closures. Another aspect that increases DO in bottled wines concerns the passing of internal gas (air) within the cylindrical closure pores to the HS at the sealing process. However, the amount of O_2 escaping to the bottled wine depends upon the internal pressure, storage time and bottle orientation during bottle aging.

The third source that affects the DO level relates to the closure type used in bottling. The oxygen transfer rate (OTR) varies widely among closures. Because of this variation, types of closures influence the chemical and sensory properties of bottled wines. Example: research findings have indicated that screwcaps maintain higher levels of Free SO_2 and result in less browning in comparison to natural, synthetic and technical corks in certain white varietal wines. However, screwcaps may offer reduced characters at extended storage periods. In another instance, synthetic closures may bring about oxidized flavor during prolonged storage. Also, performance studies of natural corks have shown variability in OTR which may lead to sensory differences in wine. Certainly, this response depends on composition and wine precursors.

Although wines may be vinified within the guideline levels for DO (<1.0 ppm) and HSO (<2.0 ppm), this does not excuse winemakers from adding SO_2. This chemical is unique, because it offers both antioxidant and antimicrobial properties. In wine, SO_2 prevents unwelcomed browning and oxidation processes. These responses are due to chemical reactions which are much slower than enzymatic oxidation. The use of SO_2 and its interaction with O_2 is complex, involving several pathways and reactions. The ability of SO_2 to react with wine oxidants and prevent spoilage makes it indispensable in producing high quality wines. Sulfur dioxide reacts with many wine compounds such as acetaldehyde, pyruvic acid, glutaric acid, glucose and phenols, just to name a few. One main oxidant in wines is H_2O_2 (hydrogen peroxide) which is produced from phenolic compounds. This powerful oxidant reacts with SO_2 eliminating its effect in wine, and prevents oxidation. Keep in mind that SO_2 in wines consists of two forms: free and bound. The former is the most active and is responsible for its antioxidant and antimicrobial properties. Also, the effectiveness of SO_2 is influenced by such factors as: pH, temperature, oxygen, phenolics, and SO_2 levels. It is often reported that white wine should maintain a free sulfur dioxide content to achieve .8 ppm molecular SO_2 based on wine pH with red wines being maintained at 0.6 ppm molecular relative to wine pH prior to bottling. Some general recommendations for free SO_2 levels are: dry white wine (30-40 ppm) and dry red wine (20-30 ppm). It is important to remember that 4 ppm SO_2 reacts with 1 ppm O_2, and the free SO_2 should not fall below 10-12 ppm during the life of the wine.

Materials and Methods

Winery Description - The descriptions of the 14 Ohio commercial wineries with their unit operations are shown in Table 1. The size of wineries varied from small to large with most in the small category, less than 10,000 gallons. Only 7 wineries were separated between medium (4) and large (3), over 50,000 gallons. For the filling operations, just over half of the filler types were gravity hand operated units which were used by mostly small wineries. The other wineries employed some type of an automated system. Most closure operations (10) were accomplished by semi-automatic or automatic machines, while the others were manual. A majority of the automated lines (7) used some pre-evacuation process to reduce the oxygen level in the bottled wines. These bottle pre-evacuation practices include: flushing with inert gas (N_2 or CO_2) and/or vacuum filling. Within this category, one (1) failed to employ any pre-evacuation treatment. Similar results (2) were found for the critical headspace (HS) evacuation practice (Table 1). However, just five (5) wineries utilized an evacuation technique to remove headspace oxygen. Although several closure types are available to the winemaker, Table 1 shows that the synthetic "cork" was the most popular, 7 wineries. For the remaining closures: 1+1, screw cap and natural cork, were used by two wineries for each type, and one winery with a technical cork. It is important to keep in mind that the type of closure used may depend on the type or style of wine the winery happened to be bottling the day of the study.

Table1. Description and Bottling Operations of 14 Commercial Wineries used to Study the Oxygen Status in Ohio Commercial Wines

Winery	Winery Size	Filler type	Closure operation	Bottle evacuation	Headspace treatment	Closure type
A	Medium	Auto	Auto.	Vac./N_2	Vac./N_2	Syn.
B	Large	Auto	Auto.	N_2	Vac.	Syn.
C	Large	Auto	Auto.	Vac./N_2	Vac./N_2	Syn.
D	Small	Gravity	Manual	None	None	Syn.
E	Medium	Gravity	Semi. Auto.	None	None	Syn.
F	Small	Gravity	Auto.	N_2	Vac.	1+1
G	Small	Gravity	Manual	None	None	Screw Cap
H	Small	Gravity	Semi. Auto.	None	None	1+1
I	Small	Gravity	Semi. Auto.	CO_2	None	Natural
J	Small	Gravity	Manual	None	None	Tech.
K	Medium	Auto.	Auto.	N_2	Vac./N_2	Natural
L	Large	Auto.	Auto.	Vac.	None	Screw Cap
M	Small	Gravity	Manual	None	None	Syn.
N	Medium	Auto	Auto.	None	None	Syn.

Wines and Analyses – Commercial wines from 14 Ohio wineries were selected from 3 different regions: North (4), Central (6), and South (4). Also, they were chosen according to their size in Ohio: small, medium and large. For each wine, temperature and dissolved oxygen (DO) measurements were taken at the "Holding Tank". Then, twelve (12) bottles were collected during the middle of the bottling process. Several measurements were taken at various storage times: 0, 7, 21, 63 and 126 days. At each time interval, three bottles were sacrificed for analyses, except at bottling (0 time interval) when only 1 bottle was examined for sulfur dioxide and pH. The dissolved oxygen (DO) and headspace (HS) oxygen levels were determined by using a NomaSense™ oxygen analyzer. For the free and total sulfur dioxide contents, the aeration-oxidation method was used. A pH meter, Fisher-Scientific, Accumet-Basic Model AG-15 was employed for all pH readings. Also, all results were recorded as averages of three replications.

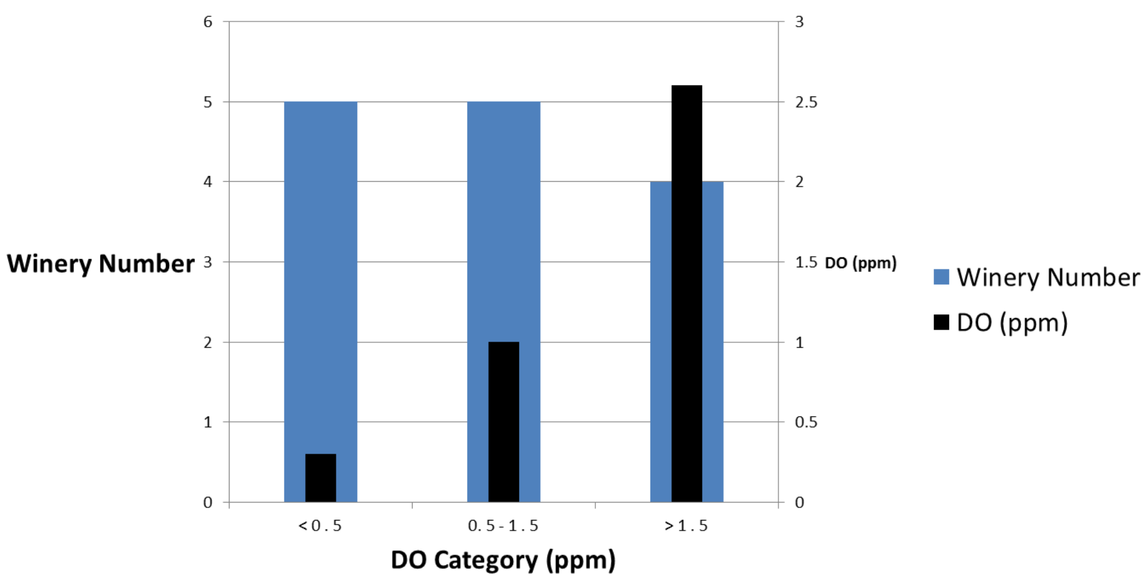
Results and Discussion

Dissolved Oxygen at Holding Tank and Bottling – In order to control the dissolved oxygen (DO) level in wines, every effort should be used to avoid oxygen enrichment at each step of vinification. If high O_2 values are detected, measures need to be used to correct the winemaking errors. The suggested guideline level for DO at the "Holding Tank", just prior to the "Filler" and "Bottling", is less than 0.5 ppm. Table 2 summarizes the DO results for all the Ohio wines at the "Holding Tank" location. For illustration, Figure 1 showed that 5 wines at this site were found below the acceptable level, 0.5 ppm. The DO levels for the other 9 wineries were well above the guideline value. These wines were categorized as medium and high, averaging 1.0 ppm and 2.6 ppm, respectively. From this data, it is obvious that the majority of the wineries have difficulty in limiting the O_2 uptake in their wines. Later in this report, a strong relationship will be shown between the O_2 level in the "Holding Tank" and the DO amount in the bottled wine. Certainly, more attention should be given to the various winemaking steps leading up to the Holding Tank. These include: pumping, filtration, fining, blending and cooling, just to name a few.

Table 2. Temperature and Average Dissolved Oxygen (DO) Levels for Wines at the Holding Tank and Bottling

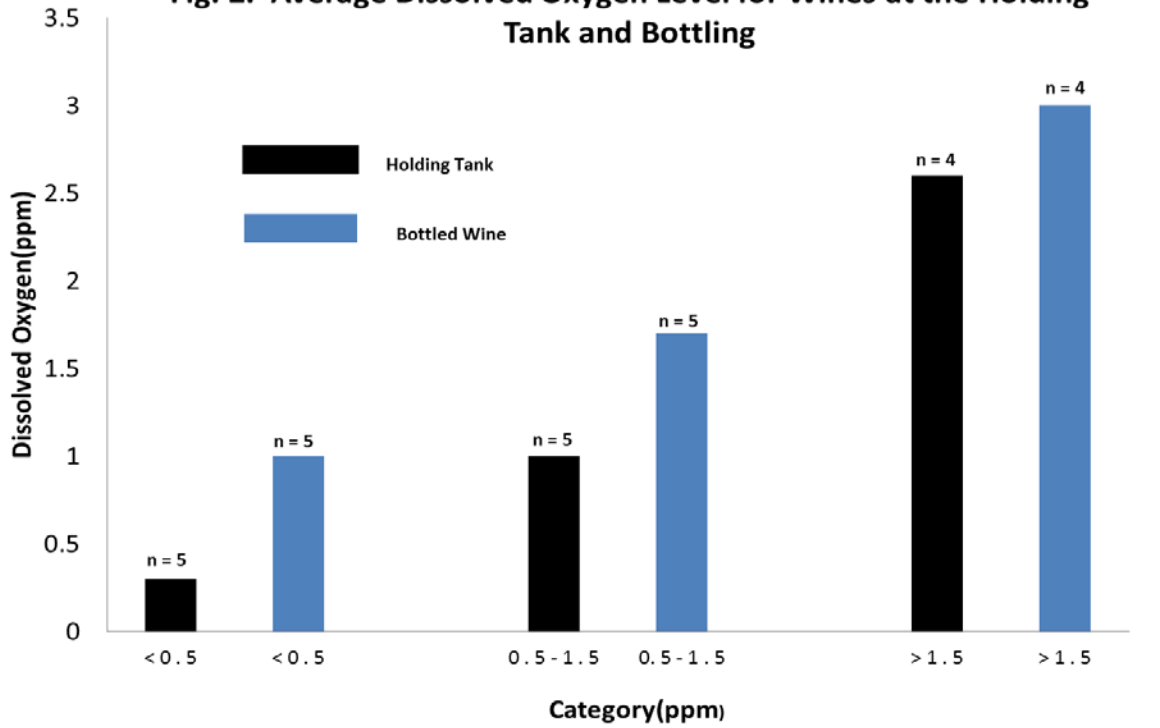
	Holding Tank		**Bottled Wine**
Winery	Temperature ^{0}F	DO Level (ppm)	DO Level (ppm)
A	64	1.6	1.4
B	54	1.2	2.1
C	64	1.3	1.4
D	69	3.0	3.9
E	71	0.5	1.1
F	72	1.1	1.4
G	71	2.7	3.3
H	71	0.8	2.5
I	71	0.1	0.7
J	68	0.8	1.3
K	58	0.2	0.5
L	68	0.5	1.5
M	71	0.3	1.3
N	60	2.2	3.7

Figure 1. Average Dissolved Oxygen Levels Divided into Three Categories for Wines Held in Holding Tanks at 14 Ohio Wineries



As mentioned in the previous section, there appears to be a strong connection between the level of dissolved oxygen (DO) in the holding tank (HT) and the resultant amount in the bottled wine. Figure 2 shows this relationship for three (3) DO categories, each indicating an increase in DO from the Holding Tank to the bottled wine. For the five (5) wines within the first category (< 0.5 ppm), the DO level was 0.3 ppm, which increased to 1.0 ppm at bottling. All other wines and their respective categories showed the same direct correlation. The recommended DO level (1.0 ppm) at bottling was exceeded for these two categories. Certainly, wine temperature, number of bottling stops, and wine level in the holding tank with inert gas protection are issues that need to be addressed to control wine oxygen levels at this critical stage.

Fig. 2. Average Dissolved Oxygen Level for Wines at the Holding Tank and Bottling

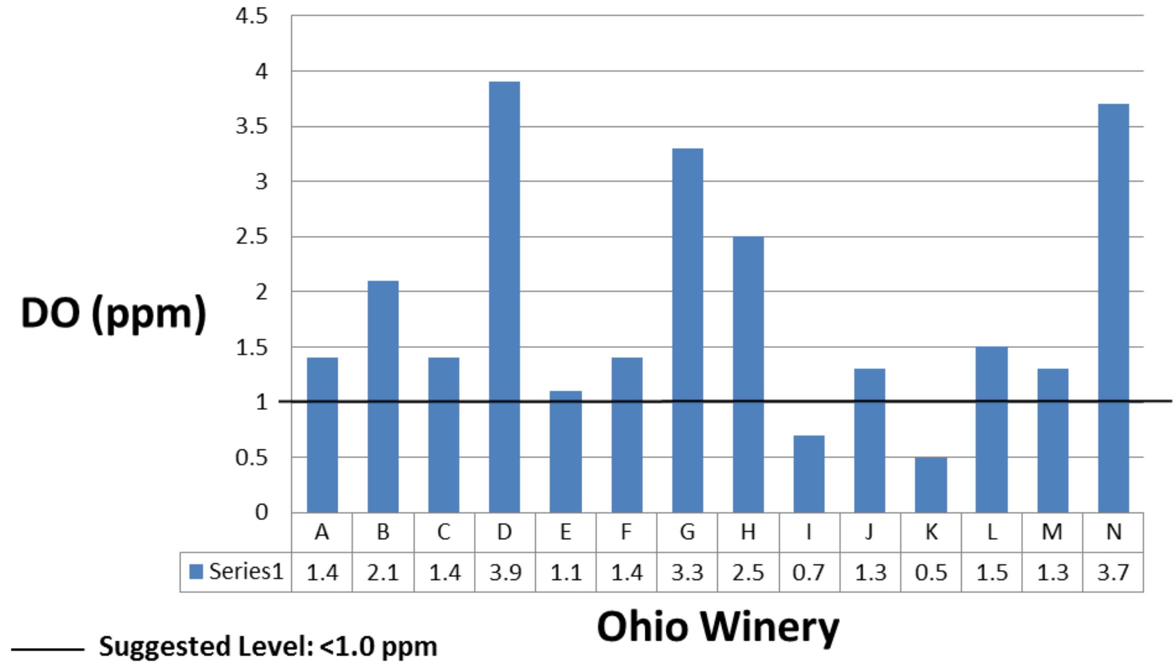


Lastly, there are some comments about wine temperatures at the Holding Tank site. The oxygen amounts in wines are highly dependent on temperature. Wines at lower temperatures contain more oxygen than at higher temperatures. The recommended temperature at bottling is between 60^o to 70^o F. Only 6 wines out of 14 were within these limits. In this study, Ohio wine temperatures were quite variable, ranging from 54^o to 72^o F (Table 2). Of course, some temperature changes will occur from the tank to the bottled wine. Keep in mind that several important issues are influenced by temperatures, including fill height at bottling, headspace volume, and headspace pressure.

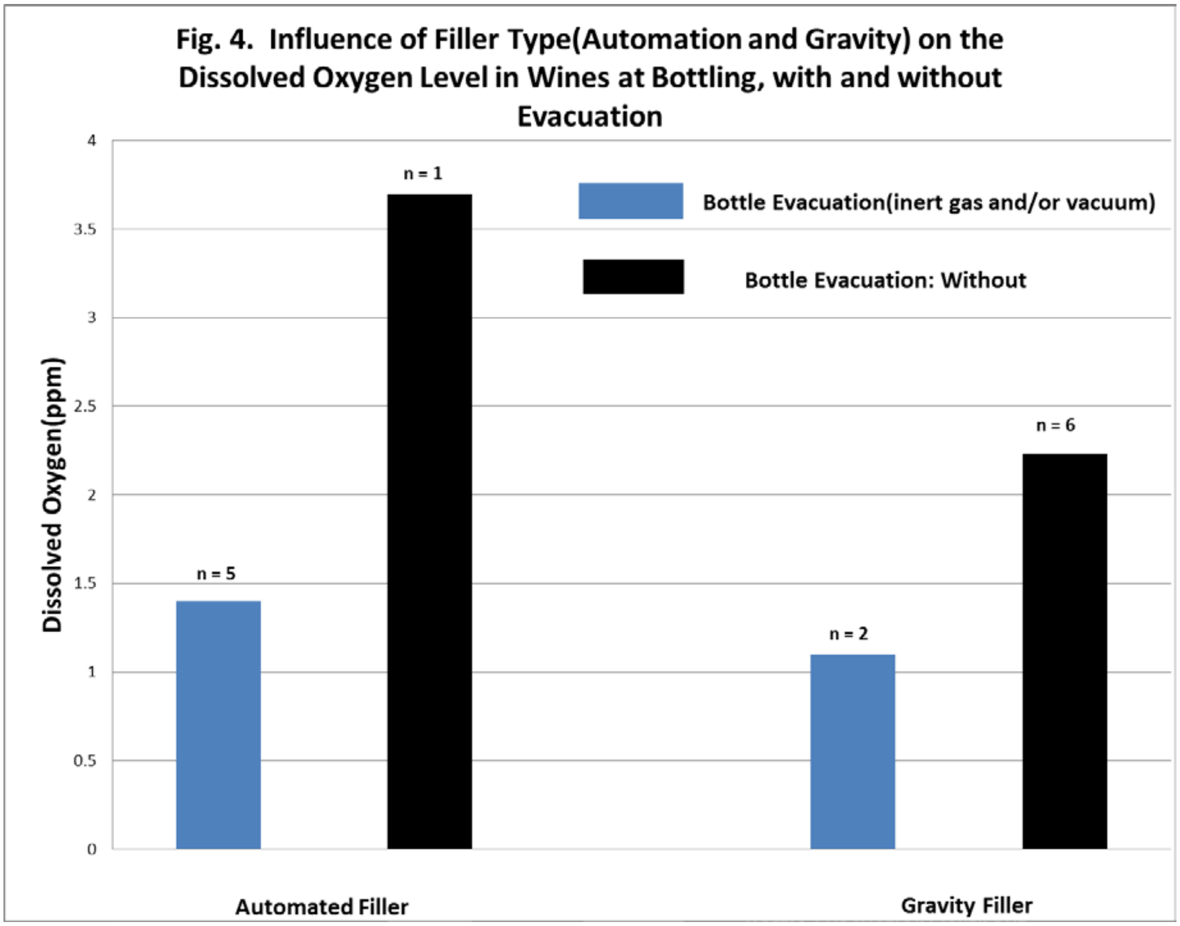
After obtaining a responsible amount of oxygen (< 0.5 ppm) in the Holding Tank, the winemakers' next concern is controlling O_2 enrichment at bottling. The common wine bottle contains 750 ml of air and exceeds 200 mg of oxygen. This presents a problem for the winemaker, because bottling involves turbulence and pumping conditions that lead to high DO values, if not managed correctly. To minimize the O_2 impact, an inert gas needs to be used in transferring wine and covering unfilled tanks, flushing and also using a vacuum prior to filling. Of course, the wine must be in the right condition: proper FSO_2 content, temperature, and DO content, less than 0.5 ppm.

As previously reported most Ohio wineries included in this study were not able to stay below the suggested guideline (Table 2). The analyses for DO levels are summarized in Figure 3. These data illustrate the DO variability among the wines at bottling (0 days storage). Just 2 wineries produced wines that were below the recommended DO value, < 1.0 ppm. However, 7 wines were slightly above the guideline, ranging from 1.1 to 1.5 ppm, while 5 wines were not satisfactory. Also, the evolution of DO for the storage intervals, 0 to 126 days, is shown in Appendix Table 1. The majority of the measurements indicated a rapid decrease by 7 days and most were consumed by 63 days. The rate of decrease was illustrated among the results. A higher DO level at bottling (0 days) took longer to be completely consumed, meaning more time for chemical reactions to occur.

Figure 3.
Average Concentration of DO in each of 14 Ohio Commercial Wines at Bottling



A real pattern was found concerning bottle evacuation effects on the DO content in bottled wine. Figure 4 provides DO results (averages) of wines from two filling operations, with and without inert gas and/or vacuum evacuation. For each bottling operation, automation and gravity, bottle evacuation was critical in reducing DO contents. Although gravity filling without evacuation leads to undesirable DO levels (6 wines), two gravity filled wines were near the DO guideline, < 1.0 ppm. Surprisingly, these wines contained less DO than the wines (5) from the automated operations.



Headspace Oxygen - Although the importance of DO content in wine at bottling is obvious, the second factor, headspace, is considered the main source of oxygen pickup in bottled wine. This factor is often overlooked or ignored by many winemakers. At bottling and sealing, wine comes into contact with headspace gas and oxygen dissolves into the wine. Different closure types have an effect on headspace volume; therefore impacting the oxygen content in the bottled wine. For example, screw capped bottles may have 3 times the headspace volume than bottles finished with cylindrical closures (corks). As mentioned earlier, the use of vacuum and flushing with inert gases (CO_2, N_2 or Ar) is often employed to minimize HSO. The recommended level for HSO is 2.0 ppm to resist oxidation.

The headspace oxygen levels at bottling were variable and ranged from 0.6 to 4.9 ppm (Figure 5). Over 65% of the wines exceeded the HSO guideline (2.0 ppm) for controlling oxidation and preserving sensory properties. The most striking observation was the extremely high HSO values for 6 wines (3.7 to 4.9 ppm). Another interesting find was the HSO measurements within the suggested guideline. Six wines were found in this category and 3 of these wines were filled with gravity fillers (Figure 5). Literature has reported that gravity filling systems have the tendency to deliver high oxygen level wines. However, results showed that wines D, E and F were handled properly and contained acceptable HSO values, below 2 ppm.

Fig. 5. Average Concentration of HSO in each of 14 Ohio Commercial Wines at Bottling

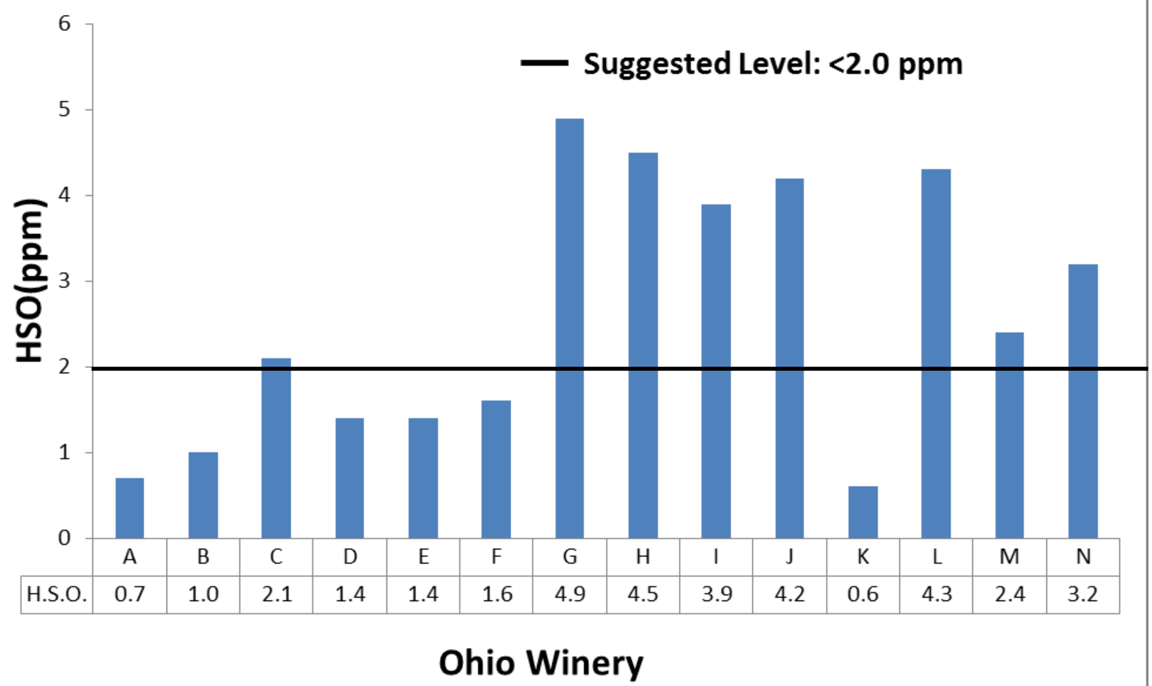
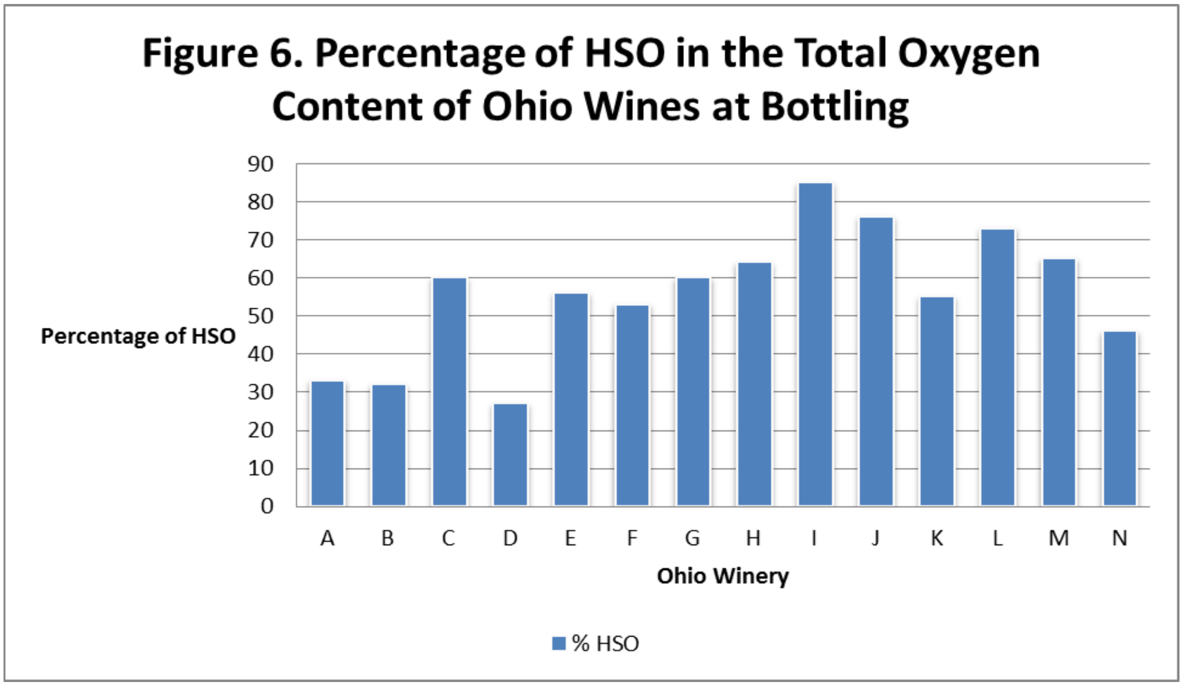
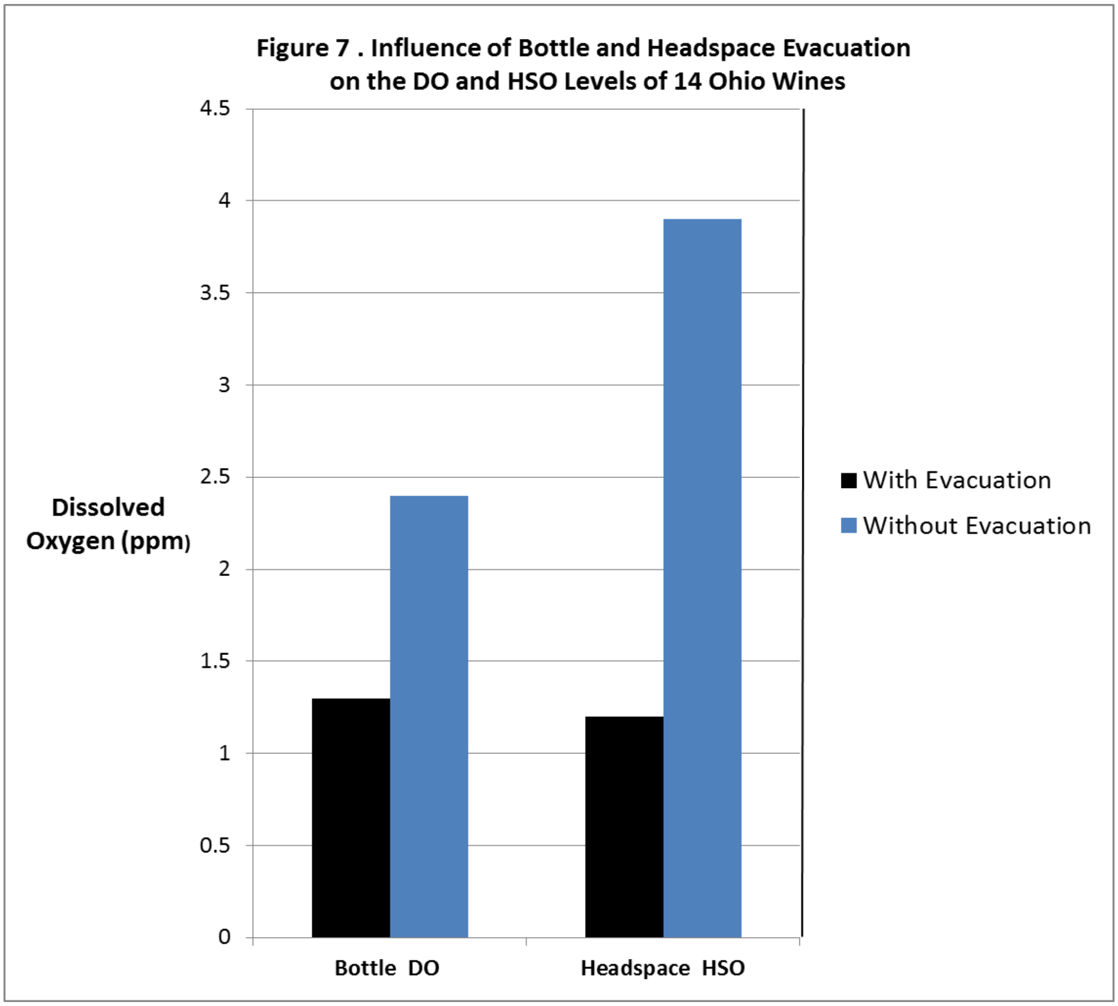


Figure 6 illustrates the proportion of HSO to the total oxygen amount, as percentages, in wines at bottling. Literature has shown that the HSO should be less than 67% to be acceptable. Three wineries (I, J and L) experienced very high HSO percentages, 73 to 85%, and did not exercise head space evacuation. It is interesting to note that one winery within this group (3) utilized an automated filling line. In contrast, the lowest HSO percentage (27%) was from a gravity filling operation (D) with no evacuation. However, this particular wine contained a very high DO level (3.9 ppm) which reduced the percentage HSO to 27%. Overall, it is essential to use evacuation to remove oxygen from the bottle and headspace weather automated or gravity filling is used. Figure 7 demonstrates the success of evacuation in reducing DO and HSO oxygen, 2.4 to 1.3 ppm and 3.9 to 1.2 ppm respectively.



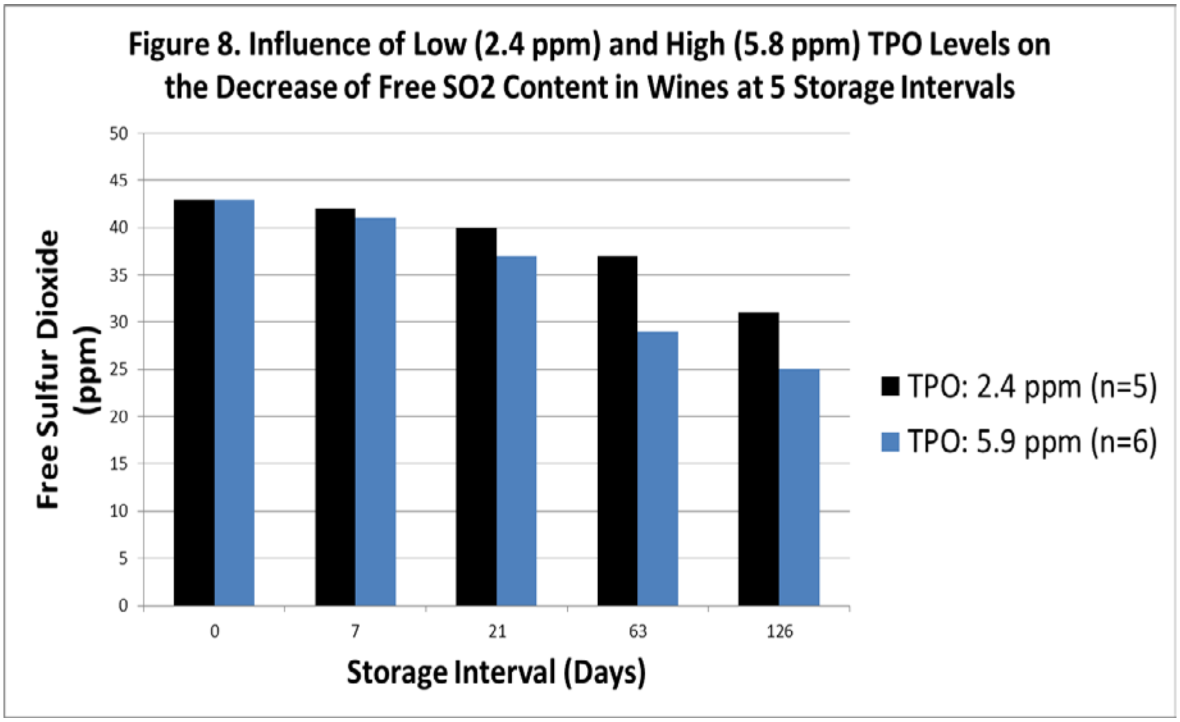


Total Package Oxygen -Total package oxygen (TPO) is the sum of dissolved oxygen (DO) and headspace oxygen (HSO) contents. Although the DO level is important, HSO measurements are equally decisive in monitoring oxygen during the winemaking process. The final TPO value after bottling should be near 3.0 ppm. In this study, TPO levels decreased rather rapidly during bottle storage (Appendix Table 1). Most TPO readings indicated that the oxygen consumption was completed in 63 days. However, some wines high in TPO extended oxygen loss to 126 days. It should be emphasized that high headspace oxygen was significant in delaying oxygen consumption.

Sulfur Dioxide - In addition, FSO_2 levels were measured at each storage interval (Appendix Table 2). The results showed that most wines at bottling contained adequate amounts of FSO_2. However, one wine was considered unacceptable (< 2 ppm) at bottling. It should also be noted that two wines (B and J) did not follow the usual decrease during bottle storage. This inconsistency was most likely due to a sampling error or lack of thoroughly mixing the wine at SO_2 addition.

This study showed that the rate for FSO_2 decline over time was related to the initial oxygen content. For illustration, the TPO data were grouped into two categories (low and high) and were compared to their respective FSO_2 levels at each storage interval (Figure 8). Wines with the lowest TPO value (2.4 ppm) decreased to 31 ppm FSO_2 in 126 days, a 28% drop. In contrast, the highest TPO amount (5.9 ppm) had a 42% decline in FSO_2 at the same storage times. Overall, these results showed that TPO has a primary role in FSO_2 decrease in 4 months. The same conclusion was found in earlier studies which also observed a gradual decline after 4 months. Their findings stated that another loss of 5 to 10 ppm will take place from 4 to 12 months storage. Much of this loss depends on the closure type, which influences the oxygen transfer rate (OTR). Keep in mind that 1 ppm O_2 consumes 4 ppm SO_2. This ratio (O_2: SO_2) can be used to estimate the decline of FSO_2 during storage. For example, the lowest TPO level (2.4 ppm O_2) in Figure 8 is multiplied by 4 (SO_2) to calculate the drop of 10 ppm FSO_2 at 4 months (126 days). Our actual reading (33 ppm) was close to the estimated value of 31 ppm. It is important to remember that the FSO_2 should not fall below 10 to 15 ppm during bottle aging. Levels less than this will result in wine oxidation and sensory property faults in addition to potential microbial instability concerns.

In general, most Ohio winemakers seem to overlook the importance of TSO_2 in controlling oxidation. In this study, there was a noticeable trend among the TSO_2 levels with



storage time (Appendix Table 2). Although some inconsistency was observed, results indicated a decrease during storage (0 to 126 days). An explanation for this variability may relate to the forms of SO_2 in wine, particularly the bound species. These species include, of course FSO_2, but also two bound forms with degrees of binding. One form has a lasting bound while the other dissociates and releases FSO_2. This occurs when the initial wine FSO_2 drops to a certain level and lasts until the supply disappears. All forms depend upon the wine type and composition.

A recent article from the Australian Wine Research Institute stated that SO_2 addition to wines should yield about 35 to 40% FSO_2. Failure to reach these percentages is related to small SO_2 additions during vinification. It is best to treat wines with large amounts, but less frequently. This practice yields higher levels of FSO_2, because a high TSO_2 ratio to bound was established. They (AWRI) also mentioned that many problem wines were related to small SO_2 additions. Their FSO_2 percentages to the total SO_2 were less than 25%. This outcome was evident due to oxidation and spoilage products binding with FSO_2. For this study, calculating the percentage of FSO_2 concentration to TSO_2 revealed that 5 Ohio wines were near 25%. Another important aspect of TSO_2 involves its influence upon wine sensory properties. Past literature has suggested that wines approaching 200 ppm TSO_2 possess certain sensory faults.

pH Values - The pH of wines has an important influence on many phases of the winemaking process. With regard to this study, low pH values are less susceptible to oxidation and more responsive to SO_2. Wine pH levels between 3.1 to 3.6 are generally recommended.

The pH measurements found in this study are summarized in Appendix Table 2. The majority of the pH values at bottling were within the acceptable range. However, wines from B and D wineries were somewhat low, 3.05 and 2.98, respectively. In contrast, winery N was slightly above the suggested limit, 3.72. Also, a trend was observed for pH levels at the various storage intervals. These data showed a modest increase in pH from bottling to the last storage period, 126 days. An average pH rise near 0.2 with a range between 0.4 and 0.19 occurred in 13 wines of this study. Explanations for this pH increase may include: sulfur dioxide loss and extent of potassium exchange with wine acids during bottle storage.

Also, the slight pH increase may suggest to the winemakers to add an extra amount of SO_2 before bottling. However, most Ohio wineries are small and usually store their wines for a short time, 3 to 4 months. Thus, the SO_2 results of this study indicate that SO_2 levels were adequate for brief storage times. On the other hand, prolonged bottle storage may experience a significant FSO_2 decrease with levels approaching the minimum guideline, 10 ppm.

Conclusion

Management of DO can affect the wine quality during bottle aging. It was demonstrated that Ohio wines varied considerably with respect to their DO levels in the "Holding Tank" and at "Bottling". Most wines at these locations were above industry guidelines for DO. For example, only 2 wines of 14 measured were below the recommended level, 1.0 ppm. The same trend was found for HSO, with only 6 wines below the proposed level of 2.0 ppm. Also, the HSO percentage in the total wine oxygen content indicated that HS was an important source of oxygen in the wines. Most wines showed HSO percentages were above 50% which may have a significant impact on the wine shelf life. It is evident that most wineries in this study need to employ techniques to better manage their oxygen levels. One specific issue that needs special attention is utilizing inert gas to remove wine oxygen at various vinification steps. Another meaningful observation showed that the FSO_2 decreased during wine storage and was related to the oxygen content at bottling. Wines with high O_2 amounts experienced the greatest loss in FSO_2. With this in mind, a future study may answer the question "Can winemakers compensate for high oxygen wines with FSO_2 without diminishing wine quality during bottle aging?"

We have no reason to believe that the results of this study do not correlate with the rest of the Ohio commercial wine industry in addition to most of the Midwest and Eastern section of the U.S. This provides a good source to review our winemaking and bottling protocols in providing Best Management Practices to limit unwanted oxygen pickup in addition to appropriate sulfur dioxide use at critical times. This will help put us on the right track of producing premium quality wines with longer shelf life potential on a more consistent basis.

Appendix Table 1: Average Concentration of Oxygen (DO), Headspace Oxygen (HSO) and Total Oxygen Package (TPO) in each of 14 Ohio Commercial Wineries at Five Storage Intervals.

Winery		Average DO (ppm) Storage Days						Average HSO (ppm) Storage Days						TPO (ppm) Storage Days				
		0	7	21	63	126		0	7	21	63	126		0	7	21	63	126
A		1.4	0.5	0.2	0.1	0.0		0.7	1.0	1.0	0.5	0.3		2.1	1.6	1.1	0.6	0.3
B		2.1	1.5	1.0	0.1	0.0		1.0	0.8	0.4	0.1	0.0		3.1	2.3	1.4	0.1	0.1
C		1.4	0.8	0.5	0.2	0.0		2.1	1.8	1.3	0.6	0.2		3.5	2.6	1.8	0.7	0.3
D		3.9	1.5	0.0	0.0	0.0		1.4	1.0	0.8	0.3	0.1		5.3	2.5	0.8	0.3	0.1
E		1.1	0.2	0.0	0.1	0.0		1.4	1.0	0.7	0.2	0.1		2.5	1.2	0.7	0.2	0.1
F		1.4	0.2	0.2	0.0	0.0		1.6	1.0	0.5	0.1	0.0		3.0	1.2	0.6	0.1	0.1
G		3.3	0.6	0.5	0.4	0.0		4.9	4.0	3.4	2.3	2.6		8.0	4.6	3.9	2.7	2.6
H		2.5	4.4	3.9	1.1	0.0		4.5	1.9	1.0	0.3	0.0		7.0	6.2	4.8	1.5	0.1
I		0.7	0.1	0.0	0.0	0.0		3.9	1.5	0.4	0.1	0.0		4.6	1.6	0.5	0.1	0.0
J		1.3	0.7	0.7	0.1	0.1		4.2	2.8	1.6	0.2	0.0		5.5	3.5	2.3	0.3	0.1
K		0.5	0.2	0.2	0.1	0.1		0.6	0.2	0.2	0.1	0.1		1.1	1.6	0.5	0.1	0.0
L		1.5	0.4	0.0	0.0	0.0		4.3	3.9	3.3	1.6	0.5		5.8	3.9	3.3	1.6	0.5
M		1.3	0.3	0.2	0.0	0.0		2.4	1.6	0.5	0.3	0.2		3.7	1.9	0.7	0.3	0.2
N		3.7	1.7	1.5	0.0	0.0		3.2	3.0	1.4	0.8	0.2		6.9	4.7	2.8	0.8	0.2

Appendix Table 2: Average Concentration of Free SO_2, Total SO_2 and pH in Commercial Wines from each of 14 Ohio Wineries at Five Storage Intervals.

Winery		Average FSO_2 (ppm) Storage Days						Average TSO_2 (ppm) Storage Days						Average pH Storage Days				
		0	7	21	63	126		0	7	21	63	126		0	7	21	63	126
A		43	41	41	41	32		172	170	173	187	162		3.41	3.42	3.41	3.47	3.62
B		38	56	48	42	50		152	159	144	150	148		3.05	3.03	3.06	3.10	3.32
C		50	48	45	39	36		114	119	111	112	104		3.10	3.00	3.22	3.20	3.39
D		46	45	38	35	26		131	143	142	155	127		2.98	3.08	3.01	3.11	3.27
E		44	44	38	38	33		114	125	120	123	112		3.11	3.19	3.19	3.10	3.25
F		37	34	36	29	26		93	93	102	84	78		3.29	3.24	3.25	3.38	3.39
G		43	45	43	30	25		121	127	141	114	96		3.53	3.55	3.46	3.57	3.57
H		<2	<2	<2	0	0		5	5	31	21	6		3.42	3.44	3.43	3.51	3.55
I		35	33	29	22	19		85	94	82	66	55		3.31	3.27	3.29	3.36	3.43
J		28	43	31	28	23		171	196	181	156	138		3.18	3.23	3.23	3.30	3.35
K		40	43	38	37	31		175	184	174	172	158		3.18	3.19	1.13	3.30	3.34
L		34	36	35	25	25		133	130	125	117	110		3.14	3.12	3.26	3.27	3.31
M		51	46	38	32	30		157	155	146	130	130		3.10	3.07	3.18	3.21	3.29
N		90	87	75	64	61		246	239	231	216	204		3.72	3.35	3.52	3.57	3.61