A Comparative Study on the Evolution of Wine Aged for 24 Months in a Flextank vs. a Two-Year-Old Oak Barrel

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Abstract: The objective of this study was to compare over a 24-month period the performance of an ECO15 standard maturation weight HDPE (high density polyethylene) Flextank to that of a similarly sized two-year-old oak barrel, both equipped with an oak adjunct. Performance was assessed both quantitatively by measuring and analyzing various enological parameters and qualitatively, though subjectively, by tasting and evaluating each wine throughout the study. This report presents the results for the second 12-month period; results for the first 12-month period are presented in Pambianchi (2021).

After a 24-month period, the barrel- and Flextank-aged wines were very similar and had followed in the second 12-month period similar evolution as observed during the first 12-month period from both chemistry and organoleptic perspectives, though with some exceptions. Although there were differences in several measured parameters, most were not noticeable or could not be detected during organoleptic assessments.

Free sulfur dioxide (SO_2) remained relatively flat month over month for both wines, and both measured almost identical free, bound and total SO_2 after 24 months. And since the Flextank wine had experienced less binding in the first 12 months, it was greater in the second 12-month period though there was no trend to support the extra binding.

Volatile acidity (VA) in the barrel wine increased continuously and by a similar amount as observed in the first 12-month period, but it has remained below detection threshold, not impacting organoleptic qualities. VA in the Flextank wine unexpectedly more than doubled in the second 12-month period although still considerably less than in the barrel wine. Other measured parameters do not offer any insights as to this increase in VA in the Flextank wine.

The amount of alcohol, or % ABV, in each wine was similar until 18 months into the study, at which point it started increasing in the barrel wine suggesting that, due to evaporative losses and concentration effects in barrels, the increase in % ABV manifests itself later in smaller barrels than what is experienced in larger barrels.

As was already observed in the first 12-month period, the barrel wine maintained lower turbidity, although this was not noticeable visually. The lower turbidity is likely due to the combined effects of greater amounts of tannins acting as fining agents in the barrel wine and the shape of the barrel. The greater amount of tannins in the barrel wine is likely due to the barrel not being completely neutral yet.

Color analysis shows that both wines aged similarly but that the barrel wine displayed a slightly redder color, as measured by spectrophotometric means, although the differences were not noticeable visually.

This study demonstrates that the standard maturation weight (SMW) ECO15 Flextank mimics a 55-L (14.5-gal) two-year-old oak barrel from both organoleptic and oxygen transfer rate (OTR) perspectives provided that the lid is tightly sealed.

Key words: Flextank, ECO15, HDPE tank, oak barrel, oxygen transfer rate (OTR), WineStix

Introduction: Oak barrels have long been used in winemaking. There exists a natural harmony among oak wood compounds, wine constituents, and the oxygen transferred into barrels that, in general, results in greater wines compared to their non-oak-aged counterparts. The main wine constituents of interest here are polyphenols, and more specifically, tannins, the substances responsible for the drying, puckery sensation in the mouth, and anthocyanins, the red-color pigment molecules.

Aside from the plethora of aromas and flavors that oak and particularly toasted oak impart to wine, the infinitesimally small amount of atmospheric oxygen entering barrels, a phenomenon known as micro-oxidation, improves and stabilizes color, "softens" tannins for a mellower mouthfeel, i.e., the combined sensation of tannins, acids, ethanol, and polysaccharides, and

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Date of publication: February 3, 2022

improves aging potential. Those aromas and flavors also become more concentrated due the slow evaporative loss of ethanol and water — the "angel's share" (Feuillat, 1996).

But oak barrels are a significant investment; acquisition costs are high, they require care and maintenance, and they have a limited lifespan in that they become neutral after several uses and no longer impart those much-desired aromas and flavors.

Oak powder, chips, staves, cubes, balls and spirals — collectively referred to as oak adjuncts — are inexpensive alternatives to oak barrels, driving the cost of "oak-aged" wines down significantly.

Oak adjuncts can be used either in inert vessels, such as stainless steel tanks, or in neutral oak barrels. There is no oxygen ingress into inert vessels and therefore oak adjuncts are only used for imparting oak aromas and flavors. In neutral barrels, micro-oxidation still occurs, albeit at a slower rate, and can therefore better replicate newer barrels when used with adjuncts.

There are other technologies and products that can replicate the benefits of oak-barrel aging. Micro-oxygenation, or MOX, uses a specially designed control unit to inject minuscule amounts of oxygen into stainless steel tanks fitted with oak adjuncts, typically long oak staves.

HDPE (high density polyethylene) vessels can be manufactured to similar oxygen permeation rates, or oxygen transfer rates (OTR), as oak barrels, and can therefore be used with oak adjuncts to mimic micro-oxidation in barrels. HDPE vessels are manufactured from resin into extremely durable polyethylene that can last significantly longer than the useful life of an oak barrel and which does not affect wine aromas and flavors, unlike the first generation of HDPE tanks (Carey 2009).

Some studies have examined the effects of oxygen transfer through HDPE material (Nguyen et al. 2010) and concluded that HDPE tanks in combination with oak adjuncts (Cronje 2020; del Alamo-Sanza et al. 2015) are a viable alternative for maturing wines similarly as in oak barrels. Cronje (2020) interviewed and reported that two South African winemakers found that new-barrel matured wines have sweeter tannins and a long finish but that red wines matured in HDPE tanks have better color extraction.

Flextanks, manufactured by Smak Plastics, Inc. (https://flextank.com/), is one such line of HDPE tank products and the focus of this study. Smak Plastics' standard maturation weight (SMW) HDPE vessels are designed to have an oxygen permeation rate, or OTR, similar to that of a typical second-year barrel when used at a nominal cellar temperature at around 13°C (55°F) (Flextank 2020). "Second-year barrel" is interpreted to mean "2-year-old barrel" (personal communication). Their heavyweight tanks are have thicker walls with oxygen permeation rates about half that of SMW vessels, comparable to "neutral" barrels.

The objective of this 24-month study was to compare the performance of a SMW Flextank to that of a similarly sized two-year-old oak barrel, both equipped with an oak adjunct. Performance was assessed both quantitatively by measuring and analyzing various enological parameters, and qualitatively, though subjectively, by tasting and evaluating the wine throughout the study.

This report presents the results from the second 12-month period of the study; Pambianchi (2021) discusses results from the first 12-month period.

Materials and Methods

Enological Parameters: Several enological parameters that could provide clues as to any potential differences in wine evolution between the barrel and the Flextank wines were measured and monitored throughout this study.

Total Acidity (TA), expressed in g/L as tartaric acid equivalents, is a measure of the concentration of all fixed and volatile acids. Changes in TA would primarily be due to potassium bitartrate (KHT) formation and precipitation during aging, more so if the wines are subjected to colder temperatures, and possibly from any changes in volatile acidity (VA).

Volatile Acidity (VA), expressed in mg/L as acetic acid equivalents, is a measure of the concentration of all volatile (steam-distillable) acids. Increasing VA levels would point to increasing acetic acid amounts that could result from the activity of acetic acid bacteria, which thrive in the presence of oxygen, or from chemical oxidation of ethanol into acetaldehyde then into acetic acid in the absence of sulfur dioxide (SO_2), which would point to excessive oxygen ingress and insufficient SO_2. Acetaldehyde could not be measured as the required instrumentation and reagents were not available.

Free sulfur dioxide (SO_2), or FSO2, is a measure of the concentration of molecular SO_2 (MSO2) and bisulfite ions (HSO_3^-) protecting wine against microbial and chemical spoilages, respectively. Bisulfite ions react with oxygen, more specifically with its radicals, e.g., hydrogen peroxide (H_2O_2), and with oxidized polyphenols, such as brown-colored *o*-quinones, causing them to revert to their colorless forms. These reactions cause FSO2 to be consumed and to drop. FSO2 drops further as bisulfite ions also bind with certain wine compounds, such as acetaldehyde and polyphenols, and cause an increase in bound SO_2 (BSO2). Tannins and anthocyanins are strong SO_2 binders, though acetaldehyde is much stronger (Blouin 2014). Since similar wines are expected to have bisulfite ions bind similarly, any differences in FSO2 measurements between wines could point to differences in oxygen consumption, which would mean oxygen is permeating into vessels at different rates, as well due to evaporative losses in the case of barrel-aged wine. FSO2 could drop further in barrels if not topped up promptly and regularly as molecular SO_2 fills the headspace until equilibrium is re-established; that MSO2 is lost every time the barrel bung is pulled.

Total sulfur dioxide (TSO2) is a measure of the total amount of SO_2; it is the sum of FSO2 and BSO2. By measuring TSO2 and calculating BSO2, the latter can give important clues as to any differences in binding between the two wines. For example, if oak wood from the barrel is still contributing tannins, BSO2 in the barrel wine may be higher than the Flextank wine. Similarly, BSO2 may increase if there is oxidative spoilage with the formation of acetaldehyde.

FSO2, MSO2, BSO2 and TSO2 are all expressed in mg/L (equivalent to ppm).

Dissolved Oxygen (DO), expressed in mg/L, is a measure of the instantaneous amount of oxygen dissolved in wine. Any spikes in DO would point to an oxygen ingress problem. And a low DO coupled with a low FSO2 could mean that oxygen has been consuming FSO2, again pointing to an oxygen ingress problem. The total amount of oxygen consumed in each wine over the course of the study could not be measured as the necessary special instrumentation was not available.

pH is a measure of a wine's microbiological stability; the higher the pH, the greater the risk of microbial deviations. The optimal amount of FSO2 needed to protect wine with sufficient MSO2 is a function of pH. Greater amounts of FSO2 are needed at higher pH since the molecular fraction, i.e., MSO2, is smaller at higher pH. pH changes may also point to changes in acidity, either TA or VA, due to, for example, tartrates or acetic acid forming, respectively. A drop in TA due to KHT forming and dropping as tartrates can cause pH to increase or decrease depending on whether wine pH is above or below 3.65 — the approximate pH at which bitartrate ions (HT^-) are at maximum concentration. Color is also affected by pH: as pH increases, there is a drop in red color and intensity as anthocyanins shift towards their colorless forms.

Ethanol content is a measure of the amount of ethanol in wine, and is expressed as a percentage of ethanol-to-wine volume (% ABV). A decrease in % ABV can result from microbial or chemical transformations to acetaldehyde and acetic acid in the presence of oxygen. There are also evaporative losses of ethanol from the barrel to the external environment, but this is difficult to measure as water too evaporates to the outside of the barrel.

Turbidity is a measure of the degree of turbidity, or clarity, and is expressed in Nephelometric Turbidity Units (NTU). Since the barrel and Flextank have different physical properties — a "bulging" cylindrical shape on the horizontal axis versus a completely cylindrical shape on the vertical axis — it can be expected that precipitable matter could sediment at different rates.

Color evolution is used to assess aging in wines. Young red wines are characterized by a reddish and somewhat purple color. As wine ages, polyphenols oxidize into their brown-colored forms, or *o*-quinones, which, in the absence of FSO2, can be seen by an orange-hued tint at the rim, then to brownish hues as the wine ages and exceeds its ability to preserve red color. A very low FSO2 (below 10 mg/L) or a large FSO2 drop are signs of impending oxidative spoilage, but several color parameters are used to better gauge color evolution and assess a potential browning problem.

Red wines are characterized by three absorbance peaks (A_λ) in the visible spectrum at wavelengths (λ) of 420, 520 and 620 nm, which correspond to the yellow, red and purple/blue components of color, respectively. Absorbance measurements are expressed in absorbance units (a.u.). Young red wines display a red color with some purple hues; quantitatively, that translates into low A_{420} and high A_{520}; A_{620} is relatively much smaller than A_{420} and A_{520}. As wine ages, it slowly sheds some of its red color and its purple hues (A_{520} and A_{620} decrease), and moves progressively towards yellow, orange and brown colors (A_{420} increases). These absorbance measurements are used to calculate several other key parameters for assessing red wines: color intensity, hue, blue index and brilliance of red.

Color Intensity (IC), expressed in absorbance units (a.u.), is a measure of the intensity of color and is calculated here as the sum of A_{420}, A_{520} and A_{620}; there is a variation of this parameter that is the sum of A_{420} and A_{520}, but it is mainly used for older wines. Light-, medium- and deep-colored reds will have IC values in the range 3–5, 5–8, and 8–12 and higher, respectively. Since A_{420} increases and A_{520} decreases (and that A_{620} is small) during wine aging, IC can change either way; color intensity does not necessarily decrease with aging.

Hue (H) is a measure of the degree of color evolution and is calculated as the ratio of the yellow component to the red component, i.e., A_{420}/A_{520}. Young wines will have H values below 0.8, and increasing H values, especially beyond 1.0, are indicative of oxidation and increasing browning.

Blue Index is a calculation of the ratio of the purple/blue component to the red component, i.e., A_{620}/A_{520}, and provides an indication of changes in purple/bluish color during wine aging.

Brilliance of Red (dA), expressed as a percentage, is a measure of red color "brightness," and is calculated from a ratio of yellow and purple to red as $[1 - ((A_{420} + A_{620})/(2 \times A_{520}))] \times 100$ (Ribéreau-Gayon et al. 2012). Young wines have dA values in the range 40–60%.

Total Phenol Index (TPI) is a measure of the amount of polyphenols in wine, and can point to differences in tannin reactions, and possibly further tannin extraction from oak wood of the barrel or oak adjuncts. Light-bodied, low-tannin wines will have TPI values in the range 25–30; medium-bodied wines with good tannic structure will have TPI values in the range 30–50; and full-bodied, tannin-loaded wines will have TPI values over 50.

Study Methodology: Wine from Touriga Nacional grapes from the 2019 vintage from Lodi (CA) was vinified from frozen must purchased from Musto Wine Grape Company (Hartford, CT), and as outlined in Pambianchi (2021).

In the first 12-month period of this study, the wines had been aging in a 15-gal (56.7-L) SMW ECO15 Flextank purchased from Flextank (Vancouver, WA), and a 2-year-old 55-L (14.5-gal) Boutes oak barrel, which had previously and continuously held two wines of the same variety (Sangiovese) for approximately 24 months. A demijohn-sized Allier French Oak, Medium Plus Toast WineStix purchased from Peter DeVivi Productions (Waterloo, NY) was introduced at the start of aging (time T0) into each vessel. Both wines were stored in a temperature-controlled cellar at 13°C (55°F) with relative humidity between 55% and 75%.

Each month of the study in this second 12-month period is labeled as T0+*i*, where *i*=13, 14, …, 24, where T0 represent the start of the study and T0+12 is the starting/reference point for this second part.

WINE	Date	Time + months	TA (g/L)	VA (mg/L)	pH	%ABV	FSO2 (mg/L)	Adjusted FSO2 (mg/L)	TSO2 (mg/L)	DO (µg/L)	NTU	A_{420} (a.u.)	A_{520} (a.u.)	A_{620} (a.u.)	IC	H	Blue Index	dA (%)	TPI
Base Wine	3-Dec-19	T0	6.86	226.9	3.65	13.9	25.3	54.2	54.0	1420	13.0	2.240	3.080	0.640	5.96	0.73	0.21	53.2	44.1
Barrel	**10-Dec-20**	**T0+12**	**5.42**	**364.7**	**3.63**	**14.3**	**27.1**	**39.0**	**128.3**	**80**	**1.18**	**2.450**	**2.920**	**0.576**	**5.95**	**0.84**	**0.20**	**48.2**	**45.6**
Barrel	10-Jan-21	T0+13			3.58		25.5	31.7		75									
Barrel	10-Feb-21	T0+14			3.63		24.5	35.3		70									
Barrel	**10-Mar-21**	**T0+15**	**5.73**	**370.0**	**3.67**	**14.2**	**25.8**	**38.7**	**133.2**	**85**	**1.35**	**2.540**	**2.960**	**0.598**	**6.10**	**0.86**	**0.20**	**47.0**	**46.6**
Barrel	10-Apr-21	T0+16			3.64		25.8	36.3		75									
Barrel	10-May-21	T0+17			3.62		27.2	33.3		75									
Barrel	**10-Jun-21**	**T0+18**	**5.98**	**436.4**	**3.61**	**14.3**	**24.5**	**34.0**	**154.3**	**75**	**1.12**	**2.490**	**2.860**	**0.606**	**5.96**	**0.87**	**0.21**	**45.9**	**45.2**
Barrel	10-Jul-21	T0+19			3.61		26.6	33.7		80									
Barrel	10-Aug-21	T0+20			3.63		25.9	35.5		75									
Barrel	**10-Sep-21**	**T0+21**	**6.01**	**548.2**	**3.63**	**14.4**	**26.5**	**34.0**	**170.5**	**78**	**1.15**	**2.690**	**3.070**	**0.630**	**6.39**	**0.88**	**0.21**	**45.9**	**47.2**
Barrel	10-Oct-21	T0+22			3.64		25.8	35.0		75									
Barrel	7-Nov-21	T0+23			3.65		25.6	34.9		90									
Barrel	**10-Dec-21**	**T0+24**	**6.21**	**595.6**	**3.61**	**14.5**	**27.0**	**31.9**	**182.2**	**85**	**1.15**	**2.630**	**2.980**	**0.630**	**6.24**	**0.88**	**0.21**	**45.3**	**47.2**
Flextank	**10-Dec-20**	**T0+12**	**5.02**	**258.3**	**3.69**	**14.2**	**31.0**	**44.4**	**120.3**	**70**	**1.59**	**2.180**	**2.580**	**0.518**	**5.28**	**0.84**	**0.20**	**47.7**	**43.6**
Flextank	10-Jan-21	T0+13			3.67		29.6	38.9		70									
Flextank	10-Feb-21	T0+14			3.67		29.4	38.9		65									
Flextank	**10-Mar-21**	**T0+15**	**5.30**	**279.7**	**3.71**	**14.2**	**29.6**	**42.6**	**141.4**	**70**	**1.62**	**2.230**	**2.600**	**0.508**	**5.34**	**0.86**	**0.20**	**47.3**	**42.7**
Flextank	10-Apr-21	T0+16			3.64		29.8	36.3		70									
Flextank	10-May-21	T0+17			3.64		29.7	33.4		70									
Flextank	**10-Jun-21**	**T0+18**	**5.69**	**315.0**	**3.66**	**13.9**	**28.4**	**35.7**	**164.3**	**65**	**1.55**	**2.340**	**2.720**	**0.520**	**5.58**	**0.86**	**0.19**	**47.4**	**43.3**
Flextank	10-Jul-21	T0+19			3.65		29.3	35.6		75									
Flextank	10-Aug-21	T0+20			3.68		29.6	40.3		65									
Flextank	**10-Sep-21**	**T0+21**	**5.67**	**338.0**	**3.65**	**14.0**	**29.6**	**35.5**	**175.8**	**75**	**1.55**	**2.300**	**2.650**	**0.528**	**5.48**	**0.87**	**0.20**	**46.6**	**44.4**
Flextank	10-Oct-21	T0+22			3.66		28.9	36.5		65									
Flextank	7-Nov-21	T0+23			3.67		28.4	37.9		80									
Flextank	**10-Dec-21**	**T0+24**	**5.86**	**342.2**	**3.63**	**14.0**	**29.8**	**34.1**	**185.6**	**65**	**1.76**	**2.300**	**2.760**	**0.528**	**5.69**	**0.87**	**0.19**	**47.0**	**45.2**

Table 1 Data collected over the second 12-month period for a same wine aged in a 2-year-old oak barrel and in a standard maturation weight (SMW) HDPE ECO15 Flextank. Measurements for T0 and T0+12 are included for reference purposes.

At one-month intervals (i.e., T0+13, T0+14, T0+15, etc.), pH, FSO2 and DO were measured in each wine to determine FSO2 consumption and losses and instantaneous oxygen levels, then FSO2 was adjusted back to the proper level based on pH and DO with an MSO2 of 0.5 mg/L and no binding factor using the SO2 CALCULATOR (https://techniquesinhomewinemaking.com/attachments/File/SO2%20CALCULATOR%20v6.0.xlsm).

To reflect the average FSO2 consumption reported in studies and the literature (Pascal et al. 2019; Schneider 2008), FSO2 was adjusted for DO using a factor of 2.5 instead of the stoichiometric factor of 4, i.e., theoretically, 4 mg FSO2 are consumed for every 1 mg DO.

At three-month intervals (i.e., T0+15, T0+18, etc.), in addition to the parameters measured at one-month intervals, TA, VA, TSO2, % ABV, turbidity, color parameters and TPI were measured. Sensory evaluations were also performed to assess evolution of each wine using qualifiers of appearance, aroma and bouquet, taste, aftertaste and overall impression. The tastings were conducted by the author and not blind.

All parameters were measured once only, and repeated only to confirm what may possibly have been perceived as an erroneous measurement. Data for the measured parameters for the barrel and Flextank wines over the second 12-month period from T0+13 to T0+24 are presented in Table 1.

The barrel was topped up every two weeks and after taking samples for analysis, and the Flextank every month after taking samples for analysis. The same wine reserved in a separate vessel was used for topping.

Test Equipment: TA, pH, FSO2 and TSO2 were measured using a Hanna HI 902 Automatic Potentiometric Titration System. The pH electrode was calibrated at 3.00, 4.01, 7.01 and 10.01 using Hanna buffer solutions. Samples were degassed prior to TA and pH analysis; TA was measured to a fixed endpoint of pH 8.2.

For VA analysis, samples were steam-distilled into 100 mL of distillate using a Cash Still to collect volatile acids. The distillate was then titrated similarly as TA using the Hanna HI 902 unit.

FSO2 and TSO2 were measured using the Ripper method with an ORP electrode. BSO2 was calculated as the difference between TSO2 and FSO2 measurements.

% ABV was measured using a Dujardin-Salleron ebulliometer with calibration against distilled water.

DO was measured using a NomaSense O_2 P300 Analyzer and dipping probe equipped with an optical sensor calibrated to ambient air.

NTU was measured using a Hach 2100P Turbidimeter calibrated using Formazin standards.

Color and polyphenol analyses were carried out using a Thermo Scientific Genesys 10S UV-Vis spectrophotometer with all calibrations done against distilled water. A_{420} and A_{520} measurements were made without dilution using 1-mm (pathlength) quartz cuvettes; A_{620} measurements were made without dilution using 5-mm quartz cuvettes. All reported

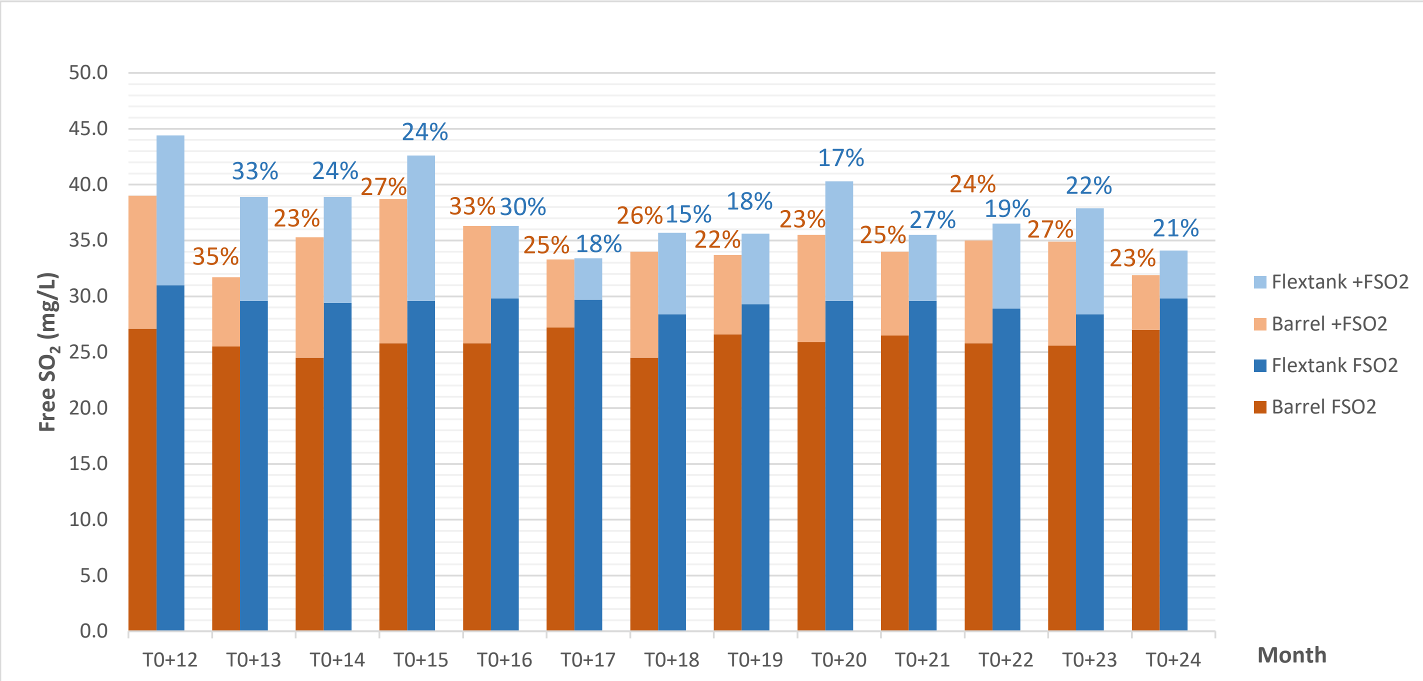

Figure 1 FSO2 changes in wines aged in barrel and Flextank over the second 12-month period. The solid bars represent FSO2 measured; lighter-colored bars on top of solid bars represent the amount of FSO2 added to bring FSO2 back up to the required levels according to pH and DO.

measurements have been normalized to 10 mm, the standard pathlength for reporting absorbance measurements. TPI was measured using the Folin-Ciocalteu method and absorbance at 750 nm as per Method OIV-MA-AS2-10 using 10-mm quartz cuvettes (OIV 2013). All samples were degassed and filtered down to 0.45 µm using 25-mm syringe filters.

Barrel and Flextank samples were retrieved using a glass wine thief from as close to the center of wine volume as possible from each vessel to avoid taking samples too close to the edge of vessels or closures.

Results and Discussion

SO$_2$ and DO Analyses: Refer to Figures 1, 2 and 3, and Tables 2 and 3.

In Figure 1, the solid-colored bars represent the measured FSO2 for a month; the lighter-colored bars represent the amount of FSO2 added to achieve the required target based on pH and DO for each wine. For example, at T0+13, the barrel wine measured 25.5 mg/L FSO2, and potassium metabisulfite was added to bring that up to 31.7 mg/L — the target determined based on pH 3.58 and 75 µg DO/L. The drop in FSO2 is then calculated based on the FSO2 measured in the following month, i.e., solid-colored bars of the following month. For example, at T0+14, FSO2 in the barrel wine dropped by 7.2 mg/L, the difference between the adjusted FSO2 of 31.7 mg/L at T0+13 and the measured FSO2 of 24.5 mg/L at T0+14. Since FSO2 was adjusted based on pH to maintain the same MSO2 level in each wine and not the same FSO2 level, this FSO2 analysis is based on percent change.

FSO2, as measured at the end of each period, remained relatively flat from T0+13 to T0+24 for the barrel wine, ranging from 24.5 mg/L to 27.2 mg/L, as well as the Flextank wine, ranging from 28.4 mg/L to 29.8 mg/L; it had also been flat for the barrel wine, ranging from 25.9 mg/L to 28.4 mg/L, from T0+6 to T0+12. Monthly FSO2 drops in the barrel wine were in the range 22–35% while in the Flextank wine they were in the range 15–33%.

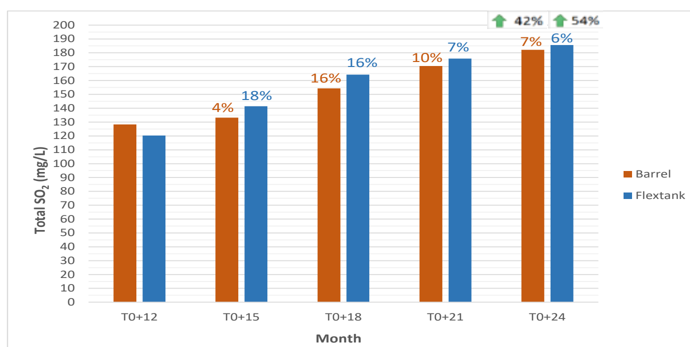

Figure 2 TSO2 changes in wines aged in barrel and Flextank over the second 12-month period.

Figure 2 compares measured TSO2 in each wine at 3-month intervals. Although there were differences in TSO2 increases in the two wines at T0+15 but with a small reversal at T0+21, both wines ended within instrumentation error at the same final TSO2 at T0+24 at 182 mg/L in the barrel wine, which represents a 42% increase (i.e., from T0+12) in the second 12-month period, and at 186 mg/L in the Flextank wine, which represents a 54% increase over the same 12-month period. And examining the amount of FSO2 added each month and the extent of binding in each wine, Tables 2 and 3 show that after an additional 12 months both wines had almost identical FSO2, BSO2 and TSO2 with approximately

15% FSO2 and 85% BSO2. And since the barrel wine had a higher percentage of BSO2 compared to the Flextank wine at T0+12 (79% vs. 74%), this means that the Flextank wine had more binding in the second 12-month period, confirmed by the lower SO_2 loss of 36% compared to 51% in the barrel. These results suggest that there was greater FSO2 consumption or evaporative losses in the barrel wine in the second 12-month period.

BARREL

	MEASURED				EXPECTED			
	FSO2	BSO2	TSO2	+FSO2	FSO2	BSO2	TSO2	SO2 LOSS
T0+12	27.1	101.2	128.3	11.9	39.0	101.2	140.2	
T0+13	25.5			6.2	31.7	114.7	146.4	
T0+14	24.5			10.8	35.3	121.9	157.2	
T0+15	25.8	107.4	133.2	12.9	38.7	107.4	146.1	24.0
T0+16	25.8			10.5	36.3	120.3	156.6	
T0+17	27.2			6.1	33.3	129.4	162.7	
T0+18	24.5	129.8	154.3	9.5	34.0	129.8	163.8	8.4
T0+12 to T0+18				***67.9***				***32.4***
%	***16%***	***84%***						
T0+19	26.6			7.1	33.7	137.2	170.9	
T0+20	25.9			9.6	35.5	145.0	180.5	
T0+21	26.5	144.0	170.5	7.5	34.0	144.0	178.0	10.0
T0+22	25.8			9.2	35.0	152.2	187.2	
T0+23	25.6			9.3	34.9	161.6	196.5	
T0+24	27.0	155.2	182.2					14.3
TOTAL T0+19 to T0+24				***42.7***				***24.3***
TOTAL T0+12 to T0+24				***110.6***				***56.7***
%	***15%***	***85%***						***51%***

Table 2 12-month analysis of FSO2, BSO2 and TSO2 of the barrel wine.

FLEXTANK

	MEASURED				EXPECTED			
	FSO2	BSO2	TSO2	+FSO2	FSO2	BSO2	TSO2	SO2 LOSS
T0+12	31.0	89.3	120.3	13.4	44.4	89.3	133.7	
T0+13	29.6			9.3	38.9	104.1	143.0	
T0+14	29.4			9.5	38.9	113.6	152.5	
T0+15	29.6	111.8	141.4	13.0	42.6	111.8	154.4	11.1
T0+16	29.8			6.5	36.3	124.6	160.9	
T0+17	29.7			3.7	33.4	131.2	164.6	
T0+18	28.4	135.9	164.3	7.3	35.7	135.9	171.6	0.3
T0+12 to T0+18				***62.7***				***11.4***
%	***17%***	***83%***						
T0+19	29.3			6.3	35.6	142.3	177.9	
T0+20	29.6			10.7	40.3	148.3	188.6	
T0+21	29.6	146.2	175.8	5.9	35.5	146.2	181.7	12.8
T0+22	28.9			7.6	36.5	152.8	189.3	
T0+23	28.4			9.5	37.9	160.9	198.8	
T0+24	29.8	155.8	185.6					13.2
TOTAL T0+19 to T0+24				***40.0***				***26.0***
TOTAL T0+12 to T0+24				***102.7***				***37.4***
%	***16%***	***84%***						***36%***

Table 3 12-month analysis of FSO2, BSO2 and TSO2 of the Flextank wine.

The DO analysis in Figure 3 does not show any irregularities that could explain any correlation between FSO2 consumption by oxygen. The Flextank wine measured slightly lower DO but the differences are insignificant at DO levels below 100 µg/L and which are beyond instrumentation error.

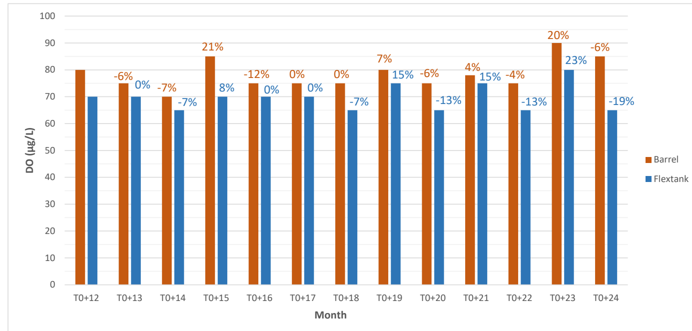

Figure 3 DO changes in wines aged in barrel and Flextank over the second 12-month period.

TA, VA and pH Analyses: Figures 4, 5 and 6.

From Figure 4, there were similar, small changes in TA in both the barrel and Flextank wines. Although TA had been mostly decreasing between T0 and T0+12, it has slowly increased every period in both barrel and Flextank wines during T0+13 to T0+24, with an increase of 15–17% at T0+24 compared to T0+12 and an overall decrease of 9–15% at T0+24 compared to T0. These increases in the second 12-month period are attributed to instrumentation error as no significant TA changes would be expected during this second 12-month period, except for VA increases but which were much smaller than TA increases.

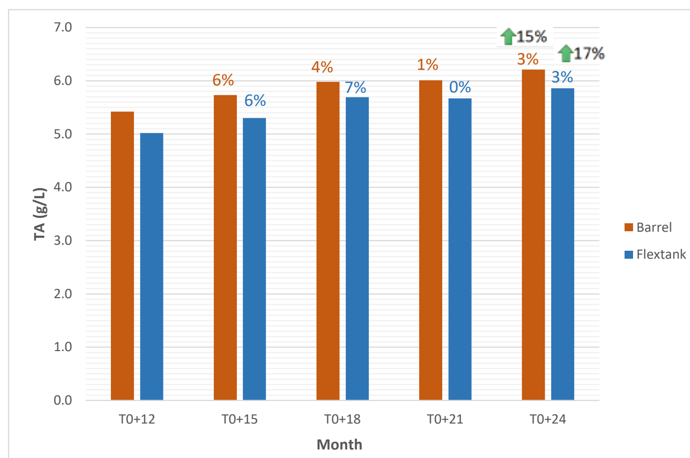

Figure 4 TA changes in wines aged in barrel and Flextank over the second 12-month period.

In Figure 5, consistent with results from T0 to T0+12, pH continued showing small changes in the range 3.58–3.67 for the barrel wine and 3.63–3.71 for the Flextank wine. These small changes, not consistent with TA changes, are believed to be due to instrumentation error as no significant pH would be expected. pH in the barrel wine has as in the previous 12 months been lower in the barrel wine due to the slightly higher TA due to less KHT precipitation compared to the Flextank wine.

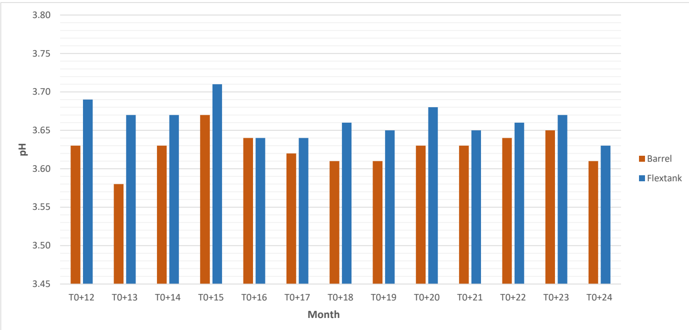

Figure 5 pH changes in wines aged in barrel and Flextank over the second 12-month period.

Figure 6 shows a continuous and steady increase in VA in the barrel wine, as would be expected, due to the headspace formed resulting from wine being absorbed into the wood and some lost to evaporation, but still below the detection threshold of 600–700 mg/L after 24 months of barrel aging. VA after 24 months of barrel aging was 596 mg/L. The increase after 24 months was similar to that after 12 months, 63% vs. 61%, for an overall increase of 162% between T0 and T0+24. But whereas VA in the Flextank wine was relatively steady between 258 and 270 mg/L from T0+3 to T0+12 and only a 51% increase over the 24-month period, there was a 32% increase to 342 mg/L from T0+12 to T0+24, which is greater than the instrumentation error ±50 mg/L. There was no significant changes in DO or % ABV and there was no headspace in the Flextank that could explain this increase in the second 12-month period.

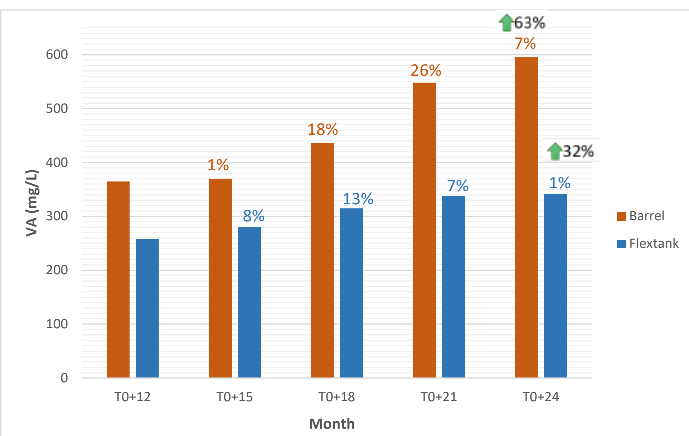

Figure 6 VA changes in wines aged in barrel and Flextank over the second 12-month period.

% ABV Analysis: Figure 7.

Accounting for instrumentation error, % ABV has been the same in both barrel and Flextank wines at around 14% with never more than a difference of 0.1% until T0+18. It has remained essentially the same in the Flextank wine but it started increasing in the barrel wine to reach a peak of 14.5% vs. 14.0% in the Flextank wine at T0+24. It is surmised that the concentration effect manifests itself later in smaller barrels than which is expected in large, standard-size barrels. The difference of 0.5% at T0+24 is significant and beyond instrumentation error. The increase in the barrel wine from T0 to T0+24 is 4%, which is greater than instrumentation error, while only 1% and within instrumentation error in the Flextank wine.

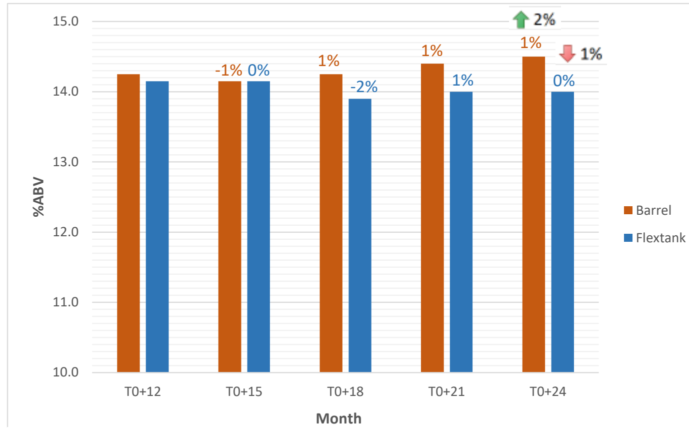

Figure 7 % ABV changes in wines aged in barrel and Flextank over the second 12-month period.

Turbidity Analysis: Figure 8.

Except for measurement anomalies in the barrel wine at T0+15 and in the Flextank wine at T0+24, turbidity has remained fairly constant in both wines and in the range 1.12–1.15 in the barrel wine compared to 1.55–1.62 in the Flextank wine, and relatively unchanged from T0+12 and therefore no further clearing occurred in the second 12-month period. Although the quantitative differences are significant, even considering the 1.76 value for the Flextank at T0+24, the difference was almost imperceptible visually. At turbidity levels below 2 NTU, a 10% difference is already significant although not necessarily observable by visual examination in a glass. The barrel wine is clearing faster likely due to the barrel shape; it is shorter and longer than the Flextank.

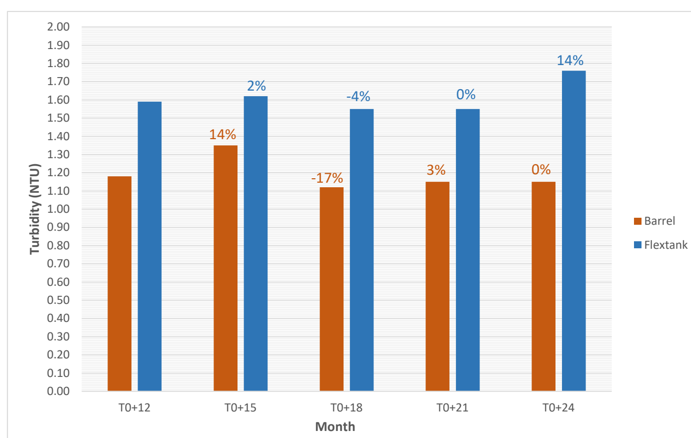

Figure 8 Turbidity (NTU) changes in wines aged in barrel and Flextank over the second 12-month period.

Color and Polyphenol Analyses: Figures 9, 10, 11, 12, 13, 14, 15 and 16.

The yellow/orange component (A_{420}) (Figure 9) increased similarly in both wines, 7% in the barrel wine vs. 6% in the Flextank wine, compared to T0+12, but the barrel wine having experienced an overall increase of 17% compared to 3% in the Flextank wine since T0. An increase in A_{420} typically results from the oxidation of polyphenols into their brown-colored *o*-quinones. The results suggest that the wines aged similarly between T0+12 and T0+24; however, the barrel wine experienced a smaller overall loss of red color in the same period.

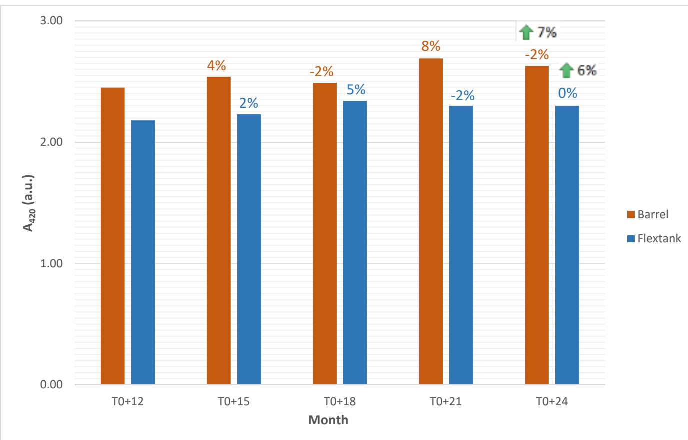

Figure 9 A_{420} changes in wines aged in barrel and Flextank over the second 12-month period.

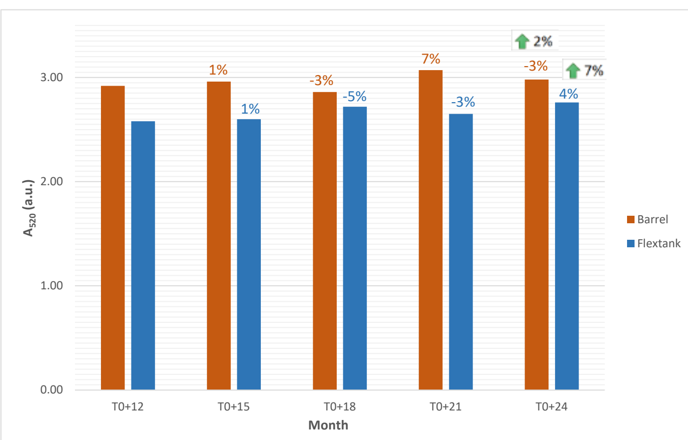

Figure 10 A_{520} changes in wines aged in barrel and Flextank over the second 12-month period.

The extraction of more tannins would support the hypothesis that they are contributing to a more stable and greater red color based on A_{520} measurements (Figure 10). There were small increases in A_{520} measurements, 2% in the barrel wine vs. 7% in the Flextank wine, in the second 12-month period, with overall decreases of 3% vs. 10% in the 24-month period. The barrel wine was 8% "more red" than the Flextank wine by T0+24, in part also due to the lower pH in the barrel wine. These small differences were however not visible in the glass.

The brilliance of red (dA) (Figure 15) was similar in both wines until T0+15, but then at T0+18 dA dropped in the barrel wine for a decrease of 6% vs. 1% in the Flextank wine at T0+24. This is due to the greater change in the yellow/orange component (A_{420}) relative to the red component (A_{520}) in the barrel wine.

The blue/purple component (A_{620}) (Figure 11) remained unchanged, within instrumentation error, in both wines with the barrel wine having a greater blue/purple component and an overall decrease of only 2% compared to 18% in the Flextank wine at T0+24. However, the Blue Index (Figure 14) remained unchanged in both wines, and having similar values, throughout the 24 months.

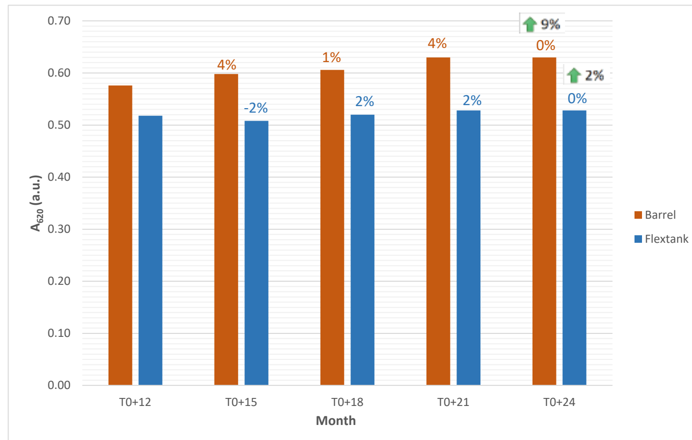

Figure 11 A_{620} changes in wines aged in barrel and Flextank over the second 12-month period.

Looking at the components collectively by calculating color intensity (IC) from A_{420}, A_{520} and A_{620}, IC (Figure 12) increased in both wines in the second 12-month period, 5% in the barrel wine and 8% in the Flextank wine although the barrel wine had an overall increase of 5% compared to a decrease of 5% in the Flextank wine during the 24-month period, but again, these differences in IC were not observable in the glass.

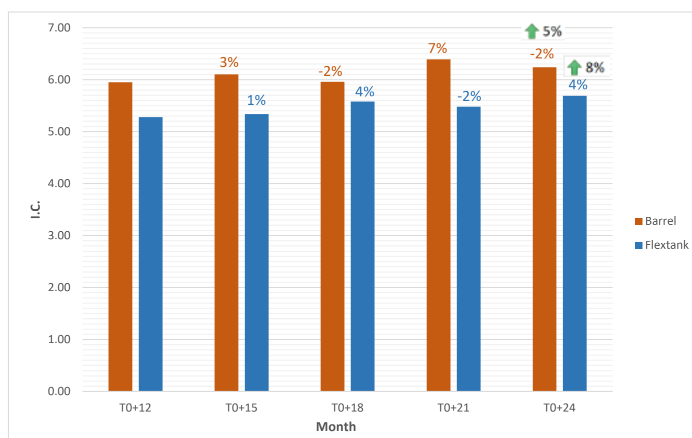

Figure 12 Color intensity (IC) changes in wines aged in barrel and Flextank over the second 12-month period.

Hue (H) (Figure 13) has increased similarly in both wines during T0+13 to T0+24 and were essentially the same at T0+24, 0.88 vs. 0.87, just around the 0.8 threshold, indicative that both wines have started their oxidative evolution and at a similar rate.

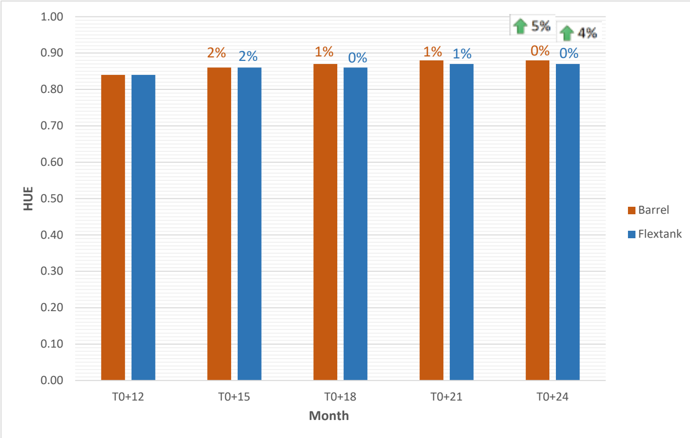

Figure 13 Hue (H) changes in wines aged in barrel and Flextank over the second 12-month period.

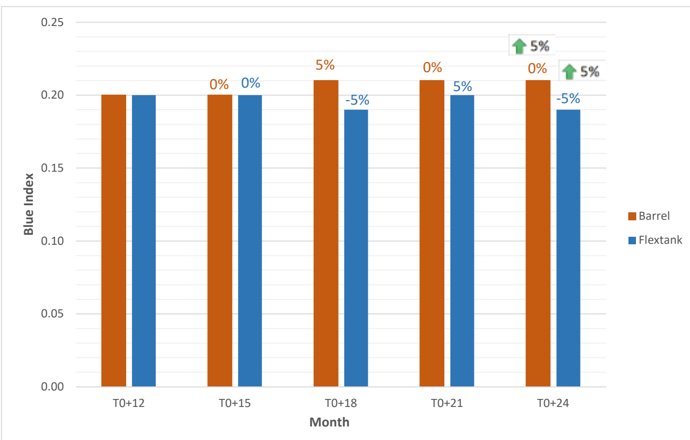

Figure 14 Blue Index changes in wines aged in barrel and Flextank over the second 12-month period.

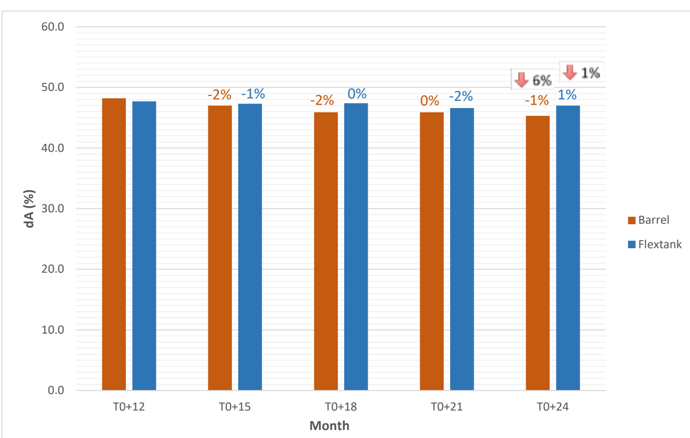

Figure 15 Brilliance of red (dA) changes in wines aged in barrel and Flextank over the second 12-month period.

Total phenols analysis (Figure 16) shows relatively constant TPI measurements in both wines throughout the second 12-month period with an overall increase of 7% in barrel wine vs. 2% in the Flextank wine, suggesting that the barrel may have become neutral and that the WineStix too may have become neutral in both wines. By T0+24, TPI in the barrel wine was 47.2 vs 45.2 in the Flextank wine, a small difference, but given the sensitivity of TPI measurements, these small changes are significant and can be detected by taste.

The higher TPI in the barrel wine may also explain the lower turbidity (NTU) in the barrel wine as tannins are known to act as fining agents.

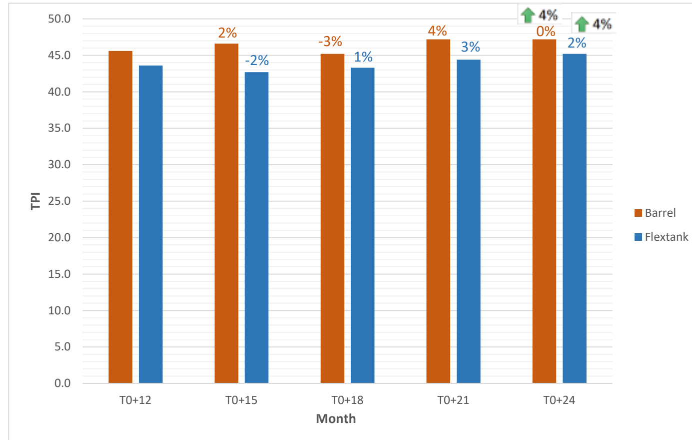

Figure 15 Total Phenol Index (TPI) changes in wines aged in barrel and Flextank over the second 12-month period.

Sensory Evaluations: Although both wines appeared and tasted very similarly after 12 months (at T0+12) of aging, as described in Pambianchi (2021), with the Flextank wine having a slight edge, tasting slightly smoother, the barrel wine seemed to have developed more favorably in the second 12-month period. At T0+24, the barrel wine seemed to have a slight edge; it tasted slightly fuller on the palate with more structure, consistent with the TPI results.

Both wines displayed a limpid, medium-light red color, though the differences in absorbance measurements were not observable, and with very pleasant oak aromas and subtle oak flavors on the palate with good persistence. The green character detected in both wines in the first 12-month period have disappeared; this is one benefit of extended aging.

The higher VA in the barrel wine has not had any perceptible impact on aromas and flavors.

Readers are reminded that sensory evaluations were performed by the author and not carried out blindly, and so the assessments are subjective.

Conclusions

The second part of this 24-month study demonstrated that the standard maturation weight (SMW) ECO15 Flextank mimics a 55-L (14.5-gal) two-year-old oak barrel from an oxygen transfer rate (OTR) perspective provided that the lid is tightly sealed, consistent with the conclusions from the first 12 months.

The wines had almost identical FSO2, BSO2, and TSO2 by the conclusion of the study, suggesting that they behaved similarly in terms of oxygen consumption and reactivity with polyphenols, and consistent with observations and results from the first 12-month study period. There were some differences in other enological parameters, primarily VA, % ABV, NTU, color indicators and TPI, which, except for TPI, were not observable or detectable. As expected, VA continued to increase in the barrel wine due to the headspace created during aging. And the difference in % ABV had reached 0.5% by the end of the 24-month period, a difference that is beyond instrumentation error. We can conclude that barrel aging does indeed create a concentration effect but that this occurs over a longer period of time as compared to larger barrels.

Organoleptic characteristics were very similar for both wines. The higher TPI in the barrel wine seemed to enhance its structure slightly. The greater amounts of tannins, based on TPI results, and barrel shape may have also contributed to greater fining in the barrel wine based on NTU measurements but, again, there were no observable differences in turbidity/clarity by visual inspection between the two wines.

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