Venting or leaking? Residual headspace pressure in bottled wines

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Introduction

Headspace pressure is the motive force for all leakage in bottled wines. Moreover, while the cork is in contact with the wine, high headspace pressure accelerates the gradual decline in its sealing ability and thereby increases the susceptibility to leakage. Because air is usually the major component of headspace gas at corking, elevated pressures are accompanied by increased amounts of oxygen in the bottled wine. The additional amounts of oxygen are variable and, in extreme cases, can be as much as 3ml. Thus, high headspace pressure is also associated with post-bottling oxidation, particularly in those wines that contain only marginally adequate levels of sulfur dioxide.

The major cause of headspace pressure is the compression of headspace gases by the piston-like action of the cork as it moves into the neck of the bottle. The use of a vacuum corker can reduce this pressure, depending on how effectively vacuum is applied to each and every bottle. Further contributions to the headspace pressure are made by the vapour pressures of gases dissolved in the wine, mostly air and carbon dioxide, and by expansion of the wine with increases in temperature.

The incidence, magnitude and the effects of headspace pressure are often underestimated. The reasons for this are as follows:

- The volume of the Bourdon tube in a pressure gauge plus that of the hollow needle ranges from 2-7ml, depending on the size of the gauge. Therefore, when the gas in the headspace expands into the Bourdon tube, the pressure shown on the gauge is only some 40-80% of the true headspace pressure.
- Headspace pressure produced at corking decreases over the next few days or so as the compressed headspace gases dissolve in the wine. A further reduction in pressure takes place as oxygen reacts with constituents of the wine.
- There is sometimes a lowering of the wine level in the neck of the bottle caused by condensation of liquid vapour in the cork and by any loss of liquid. The increase in the headspace volume reduces the pressure.

If a bottle that has lost wine only shows a gauge pressure of 30-50 kPa, the problem may mistakenly be attributed to poor performance by a soft cork. However, when appropriate corrections are made for gauge volume, changes in headspace volume and the dissolution of the compressed gas, it becomes apparent that the initial headspace pressure was very much higher, and often high enough to exceed the sealing pressure of a pristine cork. In addition, if the cork was in contact with the wine soon after insertion, it would have been softened prematurely by the increased uptake of liquid vapour. The cork cell walls reach their minimum stiffness when they become saturated with condensed liquid vapour. This is known as the 'Fibre Saturation Point'. Rosa and Fortes (1993) measured a Fibre Saturation Point for cork in water of 55% (dry weight), corresponding roughly to an increase of about 1.5 grams in the weight of a 44mm cork.

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Measurement of headspace pressure

Headspace pressure is usually measured by piercing the closure with a hollow needle attached to a pressure gauge. If the volume of the headspace is of the same order of magnitude as the volume of the Bourdon tube and hollow needle, a correction is made for the drop in pressure which occurs when any gas compressed in the headspace expands into the Bourdon tube.

$$\text{Headspace Pressure} = \frac{\text{Gauge Pressure} \quad (\text{Gauge Vol.} + \text{Headspace Vol}) \quad (1)}{\text{Headspace Vol.}}$$

Headspace volumes in bottled wines range from 2-10ml. The volume of the Bourdon plus hollow needle is about 2-3ml for a 50mm gauge and up to 5-7ml for larger gauges. ▶

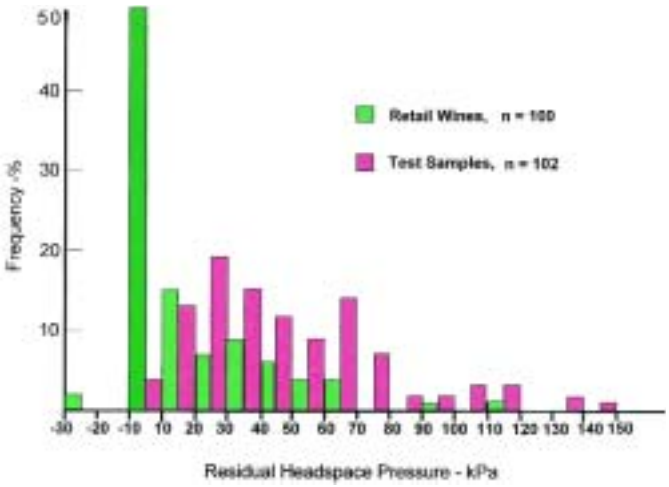

Fig. 1. Residual headspace pressure in bottled wines.

Residual headspace pressures

Over the last several years, the author has measured residual headspace pressures in bottles of wine purchased for domestic consumption. The results, labelled 'Retail Wines', are shown in Figure 1. The wines may not be truly representative of retail wines in Australia as they were selected according to the taste and purse of the author and sundry donors. Additionally, when a bottle shows no sign of headspace pressure, the author is more likely to forgo pressure measurement in the presence of guests. Nevertheless, the results offer some evidence that the major proportion of bottled wines at retail outlets have little or no headspace pressure, and that a significant proportion of bottles have high residual headspace pressures.

The author has also tested residual headspace pressures in a number of bottles submitted for examination to determine the cause of leakage or excessive 'wine travel'. These results are labelled 'Test Samples' in Figure 1. Most of the bottles had high residual pressure and most of the bottles with low pressure had high headspace volumes. The data in Figure 1 do not indicate the full extent of the problems. Many of the bottles had lost more than several millilitres of liquid, and most of the corks had increased in weight by 1-3 grams. Although there can be no absolute proof of the precise causes of loss of wine from a bottle, residual pressure in a bottle that has lost liquid is like a smoking gun at a crime scene.

Estimation of original headspace pressure

If the carbon dioxide content of the wine and the original headspace volume are known, it is possible to estimate the original headspace pressure. This can only be a very crude estimate, as it assumes the applicability of the Ideal Gas Laws, approximate figures for the Solubility Coefficients of carbon dioxide and nitrogen in the wine, that the original wine was 79% saturated with nitrogen, that the wine temperature at bottling was 20°C and that the headspace gas was air. Nevertheless, its main value is that it demonstrates that any residual pressure is only a fraction of the pressure produced at corking.

The estimation is based on the following relationship between absolute headspace pressure and the amounts of nitrogen and carbon dioxide in the bottle.

$$\text{Absolute pressure, } p = \frac{Vn}{(W, Sn + h)} + \frac{Vc}{(W,Sc + h)} \quad (2)$$

where:
Vn = volume of nitrogen
Vc = volume of carbon dioxide
W = volume of wine
h = headspace volume
Sn = solubility coefficient of nitrogen in wine
Sc = solubility coefficient of carbon dioxide in wine






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The calculation is carried out in the following steps:

Gauge reading	45kPa
Headspace volume	8ml
Headspace pressure (Eq 1)	60kPa
Convert to absolute pressure	161kPa
Less contribution of 0.4 g/L CO2 (39 kPa, Eq 2)	122kPa
Total volume of nitrogen (Eq 2)	22.3ml
Less vol of nitrogen dissolved in original wine,(8.3 mL)	14.0kPa
Equivalent volume of air	17.5kPa
Absolute pressure of air in original headspace (6 mL)	290kPa
Original headspace pressure (above atmospheric)	189kPa

At first sight, this result seems extraordinary. However, it is consistent with the results of Jung *et al.* (1993), which show headspace pressure after corking decreasing to 10-50% of the initial value over a period of about 10 days. The same paper also shows greater wine losses and increases in cork weight in those bottles that were stored horizontally immediately after corking.

Venting or leaking?

True leakage is very rare in bottled wines. That is, bottles that leak continuously when inverted. So-called 'leakage' usually involves the expulsion of a few drops of liquid, maybe just the once or maybe on several occasions, until the internal pressure drops below the sealing pressure of the cork. In addition to lowering the internal pressure, the expulsion of liquid enlarges the headspace volume, and this reduces the incidence and magnitude of further losses with any increases in temperature.

The question of whether a cork has leaked or vented depends on whether the sealing pressure was too low or the headspace pressure was too high. In most bottled liquids, a sealing pressure of about 50-60kPa is more than enough to prevent the loss of liquid and the ingress of atmospheric oxygen. The sealing pressure of a freshly-inserted cylindrical cork is in the region of 200kPa, declining gradually over a period of time to about 100kPa. The purpose of the very high sealing pressure is to counteract any pressure produced at corking, and also to resist the greater pressure fluctuations associated with small headspace volumes and changes in temperature. The large safety margin also compensates for variations in the materials and techniques.

Because not all bottles leak/vent, and because the incidence of leakage/venting can vary from one bottling to another, there is a widespread misconception that the differences in performance must be caused by differences in the sealing ability of the individual corks. In fact, the major variable is bottle-to-bottle variations in the headspace pressures. This can be observed during the course of bottling, and also in retail bottles taken from the same carton. The reason for this variation is that different amounts of air are often incorporated in the bottles before sealing. That is, differences in dissolved air at bottling, (Godden *et al.*, 2001), and differences in the amount of air compressed in the headspace by insertion of the cork. The latter is caused by variations in the performance of corking machines, both in the application of vacuum and the length of the compression stroke. The length of the compression stroke varies with the speed of the corking machine and with the rate of recovery of the cork after compression, (Casey, 2001). The recovery rate of a cork depends very much on its moisture content.

Whether or not corks leak or vent is academic. From the practical point of view, it is a matter of balancing all the risks and costs when choosing the type of corking machine, operating techniques, the dimensions, density and moisture content of the corks and the level of control of the overall operations. Sealing wine bottles is an integral part of winemaking, and winemakers cannot distance themselves from the responsibility of ensuring that it is carried out correctly.

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