Reducing CO_2 use during tank sparkling wine production

While the CO_2 bubbles in sparkling wines are produced by secondary yeast fermentation, management of tank headspaces during processing can consume large amounts of purchased CO_2. Recently, there have been periods where this CO_2 has been difficult to get and/or very expensive. Costs of purchased CO_2 are also likely to increase as the economy decarbonises, given its production is closely linked to fossil fuels. In this article, AWRI Principal Engineer **Simon Nordestgaard**, discusses where CO_2 is used during the production of tank sparkling wine and opportunities to reduce this. This work forms part of a Wine Australia-funded impact project on CO_2 re-use in wineries.

Introduction

Carbon dioxide (CO_2) is added to tank headspaces during processing of sparkling wines that are fermented in-tank (i.e. Charmat method) or in-bottle but with subsequent tank processing (i.e. transfer method). The counter-pressure exerted by the headspace CO_2 ensures that the CO_2 generated during secondary fermentation remains in solution. For sparkling wines fermented in-tank, CO_2 is typically added in three stages. Firstly, the empty filtrate tank is pressurised with CO_2 to match the ferment tank pressure. Next, during isobaric filtration, CO_2 is added to the ferment tank to replace the wine as it is filtered. Finally, CO_2 is added to the filtrate tank to replace the wine as it is bottled (some wineries may not bottle directly from the filtrate tank, in which case there would be an additional movement of wine and associated CO_2 requirements).

The extent of CO_2 recovery during these processes varies between sites. In the worst-case three-stage scenario illustrated in Figure 1, all the CO_2 is eventually vented, meaning at least 3 litres of CO_2 is consumed for every 1 litre of sparkling wine produced. The processing pressure may be around 270 kPa-g and temperature around 0°C, so the density of CO_2 is around four times higher than at atmospheric conditions, meaning that the equivalent of 12 litres of CO_2 at atmospheric conditions is being used for each litre of wine.

A winery processing 5 million litres of sparkling wine annually under these conditions would consume around 100 tonnes of CO_2, costing approximately $50,000 at typical historical CO_2 prices, or over $100,000 at the elevated prices experienced during shortages in 2023, when gas suppliers needed to import CO_2 from overseas. Much of this CO_2 use can be avoided, including by connecting headspaces during cross-flow filtration and by cleaning filtrate tanks under CO_2 pressure, as discussed in subsequent sections.

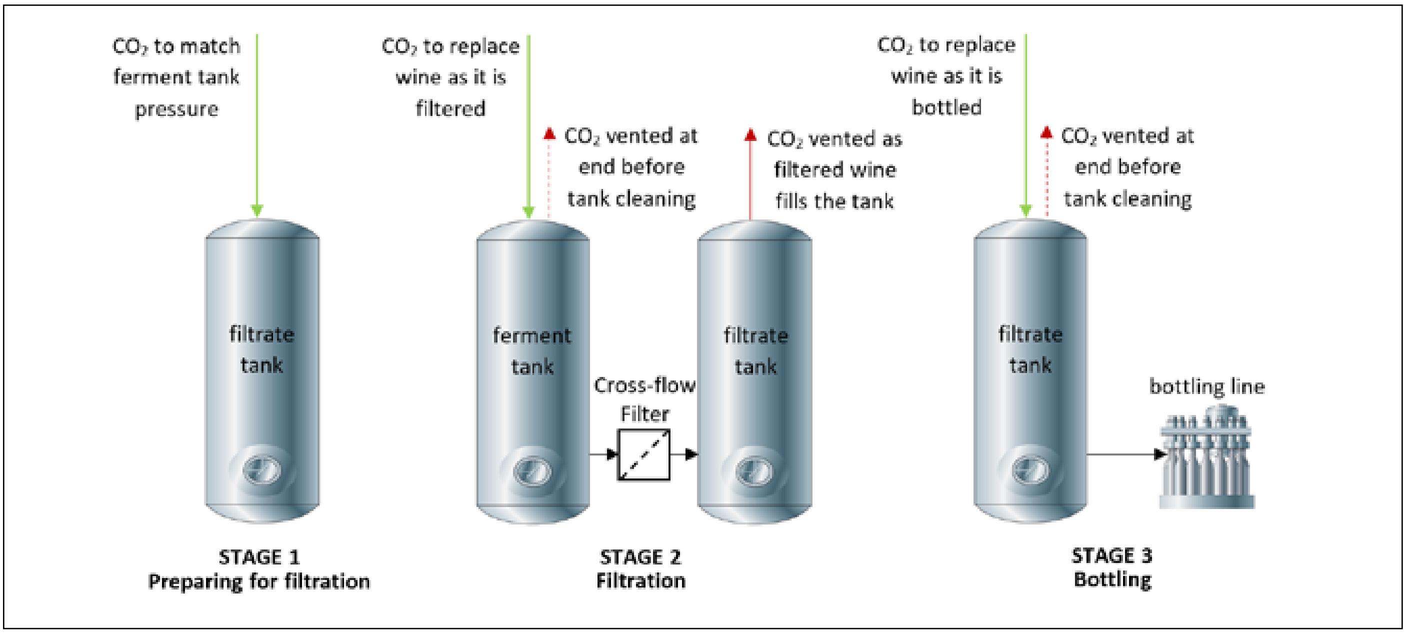

Figure 1. Carbon dioxide (CO_2) use during processing of tank-fermented sparkling wine (assuming no CO_2 recovery)

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Connecting tank headspaces during filtration

If the headspaces of the ferment and filtrate tanks are connected, when wine is filtered into the filtrate tank, a corresponding volume of CO_2 from the filtrate tank headspace passes back into the ferment tank headspace, avoiding the need to add CO_2. Of four wineries visited in researching this article, two were connecting headspaces during filtration and two were not. In the past, connecting headspaces was standard practice. Classic textbooks such as Troost and Haushofer (1980) discuss and show pressure equalisation return lines (e.g. Figures 2 and 3). At that time, pad filters with or without pre-centrifugation were

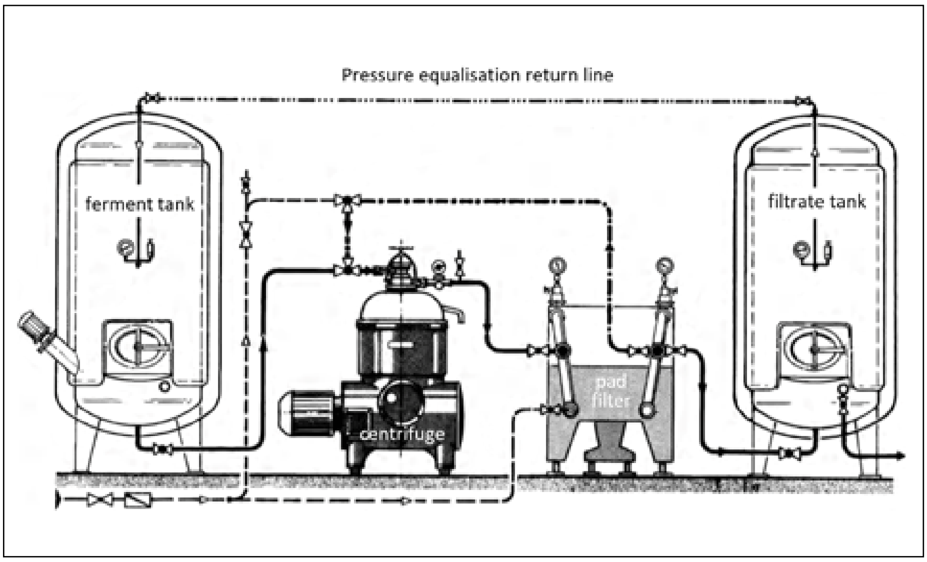

Figure 2. Historical pressure clarification arrangement using a centrifuge and pad filter, including a pressure equalisation return line (adapted and translated from Troost and Haushofer 1980)

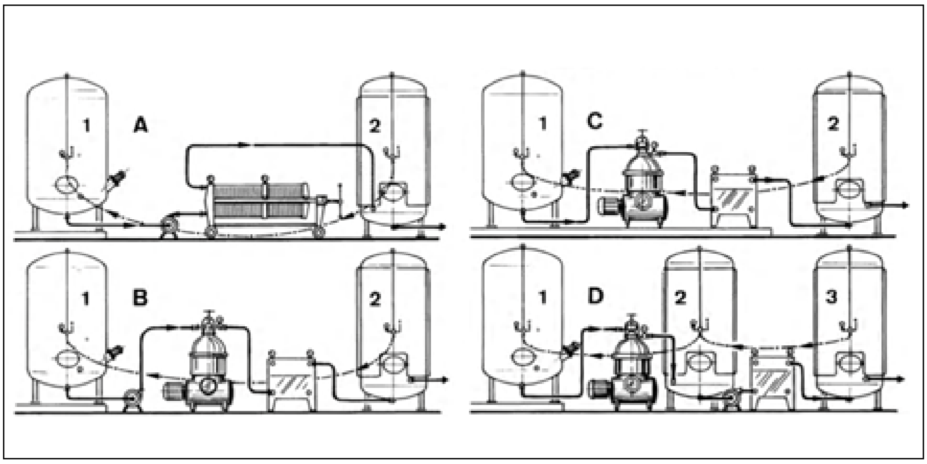

Figure 3. Historical pressure clarification options using centrifuges and pad filters, with or without a buffer tank, all with pressure equalisation return lines shown in the background (adapted and translated from Troost and Haushofer 1980)

Figure 4. Cross-flow filter for isobaric sparkling wine clarification at a winery

Figure 5. Headspace key station at another winery

the clarification method of choice for tank sparkling wines. Now, cross-flow filtration is the standard method (Figure 4), but this should not be an impediment to connecting tank headspaces.

One possible reason why headspaces are not connected in some newer installations is that it would require additional pipework and key stations where the connections can be made (e.g. Figure 5), which would increase plant cost. However, CO_2 use is not insignificant and prices are likely to increase as the world transitions away from fossil fuels, so connecting headspaces is probably now worth doing. Another reason that headspaces may not have been connected is that technology has made the use of purchased CO_2 easier. Newer installations often have pressure sensors, automated valves and tank control systems that add or vent CO_2 as needed to maintain pressure set-points automatically. In the past, where these processes had to be managed more manually, it was little extra effort to connect headspaces. Contamination concerns may also have been a factor in not wanting to connect the headspace of a 'dirty' ferment tank and a 'clean' filtrate tank. However, the main flow of CO_2 should be from the filtrate tank to the ferment tank, so this should be manageable. It is impossible to say that there is zero risk, but the two wineries visited that are connecting headspaces have been doing it for many years without issue and it is suspected that this technique has been practiced extensively around the world. No non-return valves or in-line gas filtration are generally employed. One of the wineries visited does set the filtrate tank 50 kPa higher than the ferment tank before filtration, so that the first gas flow will be from the filtrate tank back to the ferment tank.

There are different ways that the headspace networks can be set up. Even when CO_2 is not being recovered, Pall filtration units generally have a connection between the winery ferment tank headspace and a feed balance line on the cross-flow filtration skid, and between the winery filtrate tank headspace and a filtrate balance line on the cross-flow filtration skid. However, one of the sites visited not currently recovering CO_2 does just use a controlled CO_2 gas supply to the feed and filtrate balance lines to avoid the need to manually change headspace paths when changing tanks. The cheapest way of retrofitting a recovery system at a winery that already has balance lines, could be to make an additional connection between the CO_2 feed and filtrate headspace balance lines. A challenge with this is that during the filtration cycle there can be backwashing or other level adjustments on the cross-flow filter that would cause 'dirty' headspace gas to flow from the cross-flow filter's on-board feed tank to the 'clean' on-board filtrate tank. Similarly, depending on the winery tank gas addition/venting control systems, there could conceivably be periods of headspace gases flowing from the ferment tank headspace to the filtrate tank headspace. Pall recommends that a separate headspace network be

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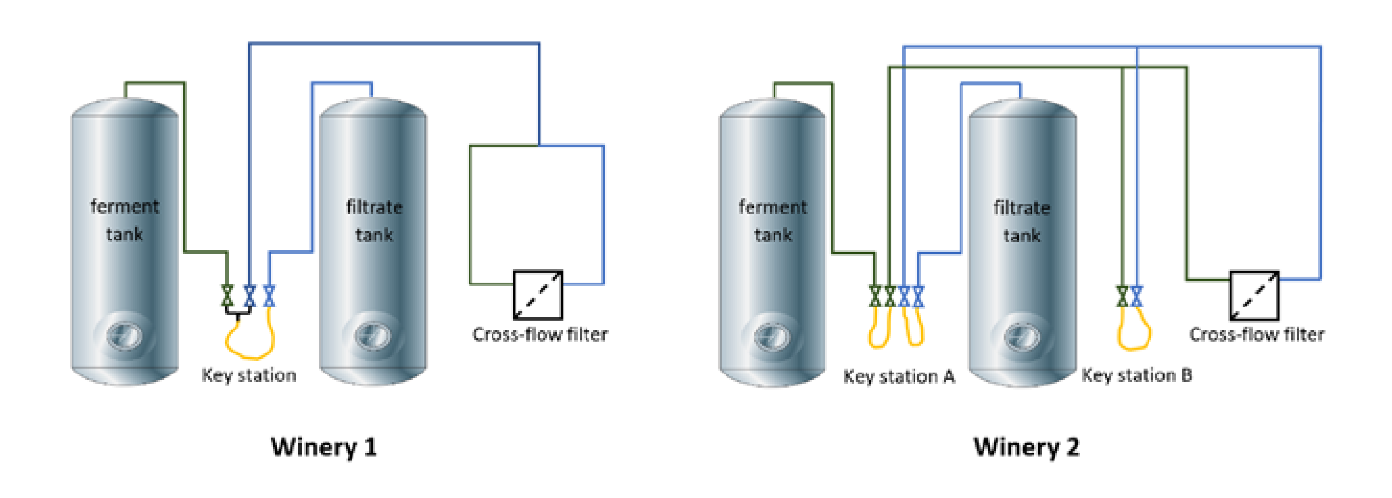

Figure 6. Simplified illustration of headspace connections during pressure filtration at two wineries (only headspace connections are shown, and the real installations include multiple tanks in varying locations with corresponding headspace networks and key station connection points)

used to connect the headspaces of the tanks for CO_2 recovery to that used for filter balance lines to avoid the risk of gas backflows around the filter. However, both wineries visited that had successfully recovered CO_2 over a long period, did not have additional tank headspace take-off points, just a network that did provide some length of piping in between the headspaces of the feed and filtrate sides of the cross-flow filter (Figure 6). A similar approach could be suitable if retrofitting a system at a winery not already recovering CO_2 during filtration; that is, having an amount of piping between the feed and filtrate balance lines of sufficient volume to counter potential undesirable headspace gas flows from the ferment to filtrate sides. For the winery that is not currently connecting the headspaces to the filter and relying purely on external CO_2 supply for balancing, the key station should just be linked directly to the tank headspaces. Specific arrangements for individual wineries should be designed on a case-by-case basis in conjunction with the site engineer and filter manufacturer.

Cleaning filtrate tanks under CO_2 pressure

Another opportunity to reduce CO_2 use is to maintain the filtrate tank under full CO_2 pressure after bottling, ready for the next batch of filtrate (i.e. the CO_2 added in Stage 3 of Figure 1 is kept so that CO_2 no longer needs to be added at Stage 1 for the next batch). This means that filtrate tank cleaning needs to be performed under pressure. The filtrate is relatively clean, so in some cases where there is not a change of product colour and sweet products are not being processed, a water rinse of the tank may suffice. Thorough cleaning of open still tanks at wineries is often performed using caustic solutions; however, with closed tanks there is some risk of tank implosion (Lewis 2019), as caustic can rapidly consume a large volume of CO_2 gas as it reacts to form a much smaller volume of carbonate/bicarbonate solution. Non-caustic cleaners are available that can allow safe cleaning of closed tanks under CO_2 pressure. Some wineries already do this to an extent, as do breweries who often use acid cleaners in similar circumstances (Johnson 2011, Thomas 2010). Apart from reducing CO_2 purchases, keeping tanks at pressure saves time venting and avoids potential oxygen pick-up for the next filtrate batch.

There are a few considerations in implementing this strategy. The water supply, cleaning pumps and pipework bracing all need to be able to operate at higher pressures. Some care may be needed to avoid squirting cleaning chemicals when opening valves at higher pressures. Compromise options can also be adopted where tanks are partially vented so as to retain some CO_2, and many wineries already do this, partly as a means of avoiding getting oxygen in the tanks that can take a lot of water/CO_2/time to evacuate. Another consideration in adopting cleaning under pressure is whether tanks at a site are used interchangeably for ferments and filtrate. Of the four wineries visited, three had dedicated tanks for ferments and filtrate. For these wineries there would be no scheduling issues from storing empty filtrate tanks under pressure, since these tanks have to be at pressure before the next filtration anyway. The one winery that currently uses tanks interchangeably thought that holding tanks under pressure might be problematic because if a filtrate tank was to be used next for a ferment, the CO_2 would have to be vented and would be wasted.

Ferment tank CO_2 recovery

Approximately two-thirds of the worst-case scenario CO_2 use illustrated in Figure 1 can be saved by adopting the strategies outlined in the two sections above. The other one-third will still be lost if the ferment tank is vented and caustic cleaned. This is likely the most difficult CO_2 to recover and use.

The ferment tank is the dirtier tank and probably does need to be caustic cleaned on a regular basis. The CO_2 that has been in that tank likely presents a higher microbial risk, and also needs to be stored somewhere else if the tank is being vented for caustic cleaning. Some filtration of the gas is likely to be needed before it is stored to prevent carry-over of microbes and removal of moisture is also important if CO_2 is to be stored in vessels that are not made from stainless steel. Arguably, removal of any aroma from the CO_2 could also be needed if this CO_2 is to be re-used perpetually. This should all be possible using adaptations of brewery-style CO_2 recovery systems and other systems that are starting to be proposed for winery use.

The recovered CO_2 could be stored either as a pressurised gas or as a liquid. If we consider the example of storing the CO_2 from a 60,000L Charmat tank that was at 270 kPa-g (2.7 bar-g), to pressurise and store this CO_2 as a gas at 10 bar-g, a 20,000L tank rated for that pressure would be needed. If it was to be liquefied, the CO_2 would occupy a volume of around 600L. This liquid CO_2 could potentially be stored in a 12-pack of G-size cylinders.

One benefit of recovering and reusing CO_2 from tank sparkling wine headspaces compared to recovering CO_2 from primary winery ferments is that sparkling wine production occurs all year round, not just during vintage. However, this type of production represents a much smaller market. Exact numbers are not available, but in Australia there are likely fewer than 10 wineries that combined make less than 30 million L of tank sparkling wine, and the quantities of CO_2 involved are smaller than those released from fermentation of grape juice. The CO_2 being recovered is also not biogenic, as it is originally added as purchased CO_2.

Significant volumes of CO_2 may also be consumed on bottling lines during the packaging of sparkling wine, but this was not evaluated in this current study.

Conclusions

Some wineries producing tank-fermented sparkling wine purchase significant quantities of CO_2 for managing tank headspaces. There are relatively simple opportunities to reduce this use of CO_2 in many of these facilities - the most common being to ensure that CO_2 is immediately reused during pressure filtration.

Acknowledgements

This work was supported by Wine Australia, with levies from Australia's grapegrowers and winemakers and matching funds from the Australian Government. The author thanks the wineries, suppliers and their staff that have contributed to this project. AWRI is a member of the Wine Innovation Cluster in Adelaide, SA.

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