Inspirations from the past and opportunities for the future

Part 1: Cross-flow filtration and flotation

This article is the first in a three-part series by AWRI Senior Engineer **Simon Nordestgaard** discussing the history of selected wine industry technologies, current adoption levels and opportunities. It is based on material originally presented at the Australian Wine Industry Technical Conference in July 2019 and published in the proceedings of that conference, reproduced with permission of the AWITC.

Introduction

This series of articles draws on data from the AWRI Vineyard and Winery Practices Survey (Nordestgaard 2019) and research on the history of winery equipment and practices (Nordestgaard 2020). This first article focuses on the adoption of cross-flow filtration and flotation in the wine sector - techniques that have led to significant efficiency and quality improvements. The second and third articles to be published in the following editions will focus on technologies where adoption is still low and opportunities remain.

Cross-flow filtration – the most important practice change in wineries

The AWRI Vineyard and Winery Practices Survey results for wine filtration technologies used in Australia in 2016 are presented in Figure 1. Cross-flow filtration has now been widely adopted by the Australian wine sector, particularly by larger wineries, with 95% of wineries crushing 10,000 tonnes of grapes or more a year using this technology. In the survey, cross-flow filtration was nominated more than any other newer winery practice as having had a positive impact in the last five years. One prominent winemaker described it as: "the single biggest advance that we have made in quality improvement in the last 25 years". Wine producers also mentioned health and safety benefits of replacing diatomaceous earth, reduced numbers of filtration stages and/or refiltrations and lower product dilution and wine losses. Automation is another major benefit of this technology—systems can run for long periods unsupervised, including overnight.

However, cross-flow filtration is not new for the wine industry and it was not always so popular. Systems were available as early as the 1980s and numerous studies were performed. For example, in 1985 in France, the Institut Technique de La Vigne et du Vin held a seminar on cross-flow filtration featuring multiple manufacturers and researchers and published a 250-page set of proceedings (ITV 1985). There was also interest in Australia from multiple companies and Bryce Rankine reports that the first system was used in 1986 (Gibson 1986; Rankine 1996).

Uptake of cross-flow filtration in the 1980s was limited. Adoption did not really accelerate in Australia until the mid-2000s when a couple of big wine companies installed systems and put large quantities of wine through them. This likely illustrated the benefits of the technology and gradually gave others the confidence to adopt it. Prior to that, industry opinions of cross-flow filtration were typically negative. There were concerns about possible stripping of colloidal compounds and of wine warming and oxidation. The technology was also considered to be too expensive given that flow rates were much lower than with pressure leaf diatomaceous earth filtration. (This is still a criticism from some wineries and pressure leaf diatomaceous earth filtration is still used to some extent, Figure 1.)

Technical improvements in membranes and system design have addressed the initial quality concerns with cross-flow filtration. However, there remains ongoing industry interest in more robust cross-flow filtration membranes capable of higher flow rates and the most suitable membranes and systems for filtering lees. Adoption of cross-flow filtration for lees re-processing is currently much lower than it is for wine.

The adoption path of cross-flow filtration should serve as inspiration for other advanced technologies that industry sentiments can change. This technology has gone from being dismissed in the 1980s to being one that wineries have nominated as the best change that they have made.

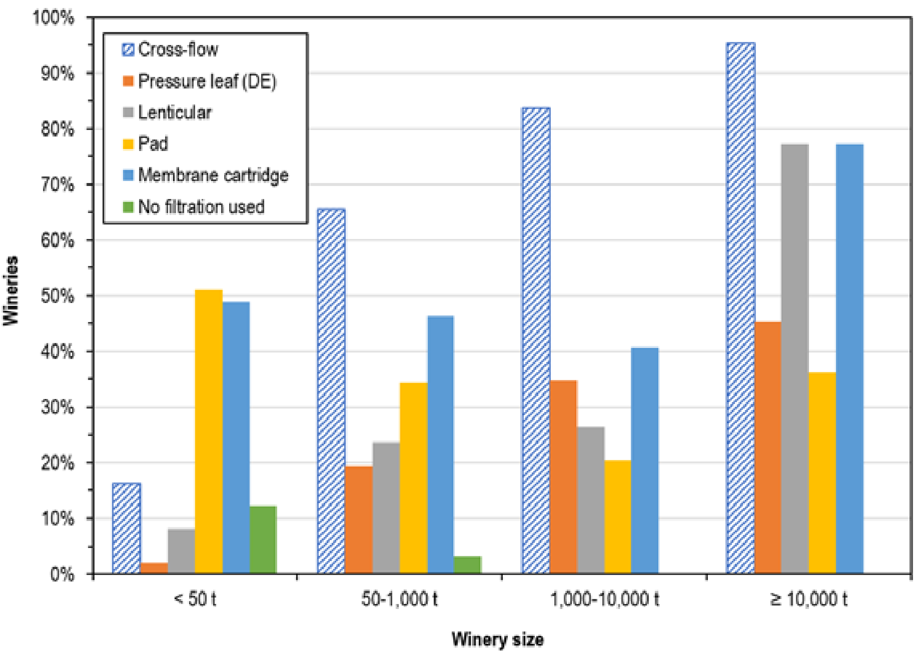


Figure 1. Wine filtration techniques used by Australian wineries in 2016

One interesting aspect of the early days of cross-flow filtration in the wine industry was that there was also interest in ultrafiltration, not just the microfiltration that has now been so successful. Ultrafiltration uses membranes with smaller pores and can remove haze-forming proteins from white wine, negating the need for bentonite (Wucherpfennig 1978; Miller *et al*. 1985). However, it also strips out other desirable macromolecules and there were sometimes issues with incomplete protein removal by the membrane types/porosities used at the time (Hsu *et al.* 1987). Ultrafiltration has received relatively little attention in this application since and may be worth revisiting using new membranes in a multi-stage format to retain desirable macromolecules. Ultrafiltration has the potential to be integrated with microfiltration into a single clarification and protein stabilisation system. While it would take some development, this style of technology is desirable since it could be automated and would be at lower risk from future regulatory changes than most alternatives since it would not use additives or processing aids.

Flotation – the second most important practice change in wineries (and a history across multiple industries)

In the AWRI Vineyard and Winery Practices Survey, flotation was the next most important practice change nominated by wineries. The 2016 adoption levels of flotation either as a single-stage juice clarification process or as a secondary stage technique following centrifugation are shown in Figure 2. Single-stage flotation is now used by around half of wineries that crush more than 1,000 tonnes of grapes per year.

Flotation has many benefits. It is faster than settling, requires less cooling and less juice is generally lost in float lees than settled lees. Flotation systems are also cheaper than centrifuges. The uptake of single-stage flotation is still relatively new for the Australian wine industry, having happened predominantly in the last decade. However, flotation has been used in other industries for much longer, including for more than a century in the minerals industry.

While flotation has resulted in important efficiency improvements in wineries, it had an even bigger impact on minerals processing. Fuerstenau (2007) reports

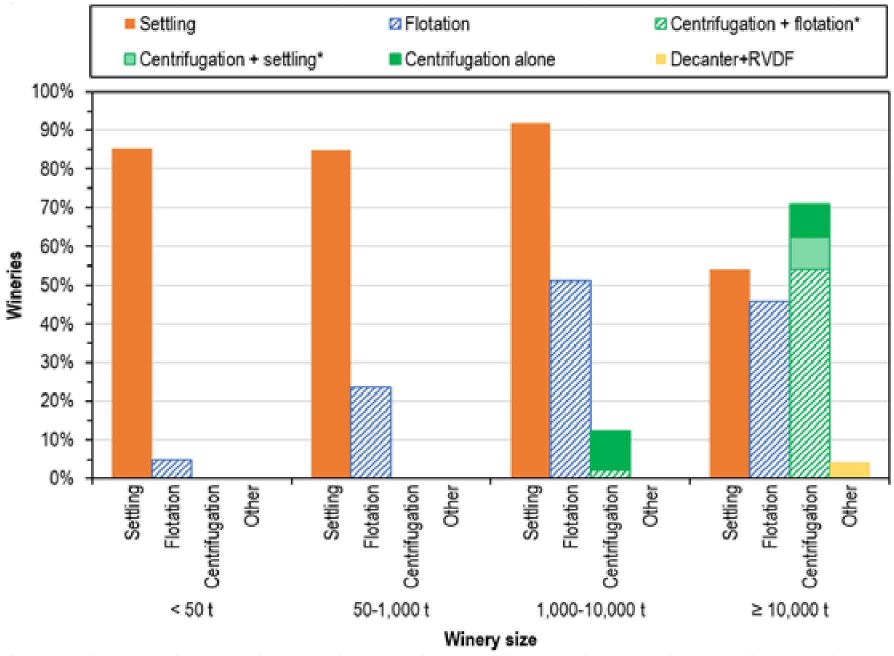


Figure 2. Juice clarification techniques used by Australian wineries in 2016 (*Second clarification step is usually but not always applied)

that "no metallurgical process developed in the 20th century compares with that of froth flotation and the profound effect it had on the minerals industry". Earlier, Milliken (1962) expressed similar sentiments saying: "Without the development of froth flotation there would be no mining industry as we know it today. This is because virtually the entire world supply of copper, lead, zinc, and silver is first collected in the froth of the flotation process". Prior to its use in wine production, flotation also made major contributions to wastewater clarification and potable water clarification (Wang *et al.* 2005; Edzwald and Haarhoff 2011), and it is from these applications rather than from mining that single-stage flotation technology likely crossed into the wine industry and evolved to its current state.

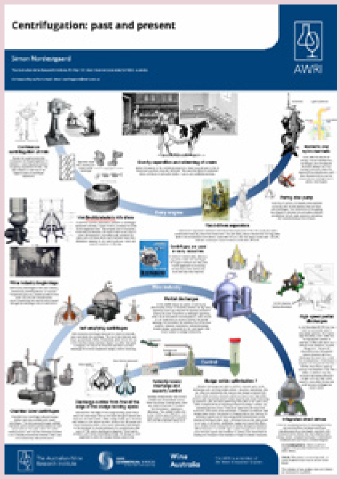
While flotation processes currently use gas bubbles, early flotation applications relied on oil, with the desirable hydrophobic mineral constituents being attracted to the oil. The Bessel brothers used oil for flotation of graphite particles but reported in their 1877 patent that the bubbles produced by boiling made the process more efficient (Fuerstenau 2007; Edzwald and Haarhoff 2011). They followed up with a patent that relied on acid reaction with carbonates to produce gas bubbles, but their work was abandoned and forgotten for many years, following the discovery of higher-grade graphite reserves.

ASSOCIATED WEB RESOURCES

AUSTRALIAN WINE INDUSTRY Technical Conference & Trade Exhibition

Proceedings of the 17th Australian Wine Industry Technical Conference
awitc.com.au/program/proceedings

AWRI Vineyard & Winery Practices Survey – Final Report
awri.com.au/survey



Winery Equipment/Practices History Posters
wea.org.au/archives/wine-history-posters

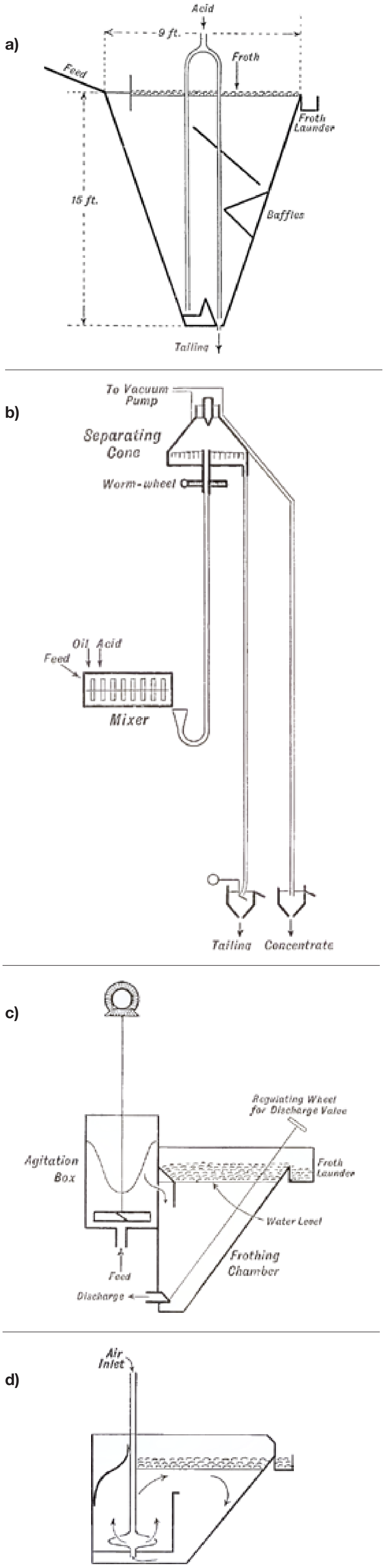


Figure 3. Some early mineral flotations equipment: (a) Potter-Delprat acid-carbonate flotation process, (b) Elmore oil-vacuum flotation process, (c) Minerals Separation cell with agitation box, (d) Ruth sub-aeration mechanical dispersion cell (adapted from Truscott 1923)

Australia played a key role in the development of minerals froth flotation technology in the early 20th century (Fuerstenau 2007). One early Australian process was the Potter-Delprat process (Figure 3a) used at Broken Hill (Truscott 1923; BHP 2015). As with one of the Bessel patents, it relied on the generation of carbon dioxide gas from the reaction of acid with carbonates. The feed material naturally contained carbonates and therefore only the acid needed to be added (Truscott 1923).

Another method that was used to generate bubbles in some early flotation equipment was application of a vacuum, such as in the Elmore vacuum process (Figure 3b). Bubble generation/dispersion by mechanical aeration also came to be used. The early Minerals Separations cells (Figure 3c) relied on agitation for frothing, while later equipment such as the Ruth cell (Figure 3d) specifically introduced air below the surface of the liquid and then mechanically dispersed it. While less sophisticated, this last design is conceptually not dissimilar from many modern minerals flotation cells that rely on air introduction (via natural aspiration or using compressed air) followed by mechanical dispersion of this air using an agitator (e.g. Figure 4). In minerals flotation, an array of different chemicals can be used to suit the specific separation application – frothers, collectors, activators, depressants, modifiers and flocculants (Fuerstenau 2007). The use of chemicals is much more restrictive in juice clarification since the end product is for human consumption. Also, unlike juice clarification, in minerals processing the valuable material is generally in the froth/floats rather than in the phase below them.

Flotation for wastewater and water clarification has generally relied on dissolved gas bubble generation, in contrast to the mechanical dispersion techniques used in minerals processing. In this technique gas (usually air) is dissolved under pressure and that pressure is then released, producing bubbles that are usually smaller and more uniform than achieved with mechanical dispersion processes (Pedersen 1921; Shammas and Bennett 2010; Edzwald and Haarhoff 2011). The small bubbles provide more surface area for collisions with solids and the lack of an agitator means that they are less likely to be sheared. Wastewater and water solids typically have low densities compared with many minerals, so large bubbles are

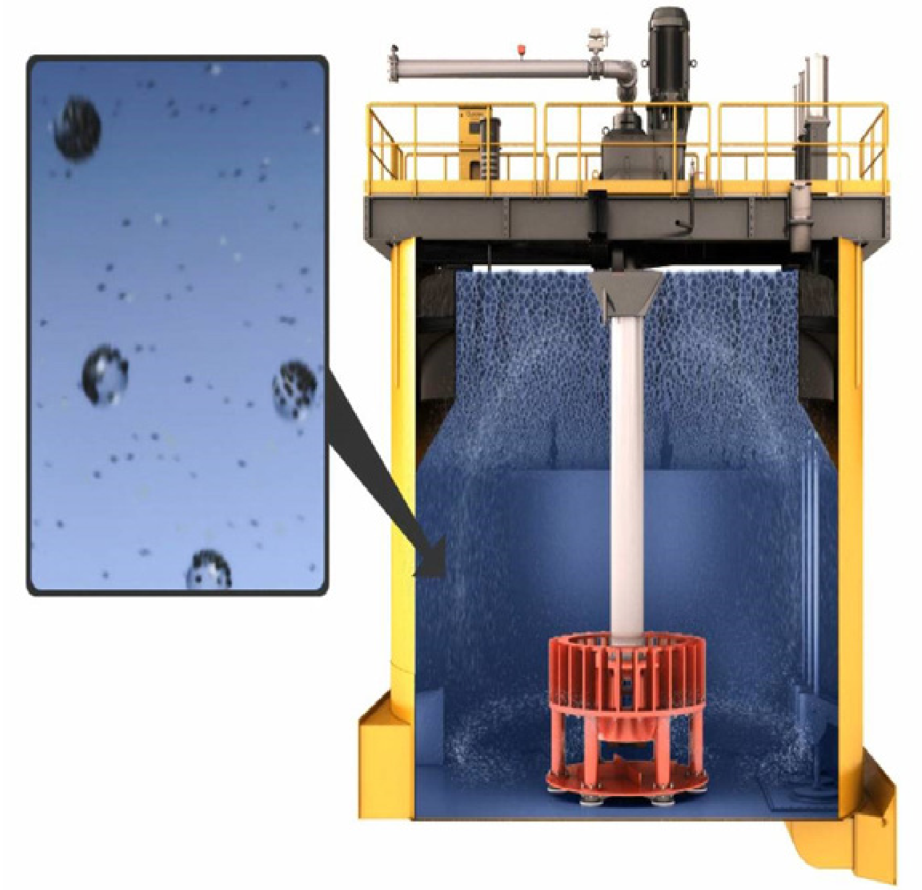


Figure 4. A modern mechanical dispersion flotation cell (Outotec, supplied)

not required to lift them (Edzwald and Haarhoff 2011).

The first use of flotation in water processing was in the 1920s for clarifying wastewater from the Scandinavian paper industry. The original Sveen-Pedersen process (Figure 5) used dissolved air flotation. It is referred to as the Sveen-Pedersen process because Pedersen designed the equipment, but it was only successful once Sveen's 'glue' was dosed to enhance flocculation (Pedersen and Sveen 1930; Klinger 1958). This dosing principle is amazingly similar to current wine industry flotation practices since the 'glue' was mainly protein, like the gelatine which is still used today in juice clarification (although gelatine is gradually being substituted with other non-animal and non-allergenic additives like pea and potato proteins and fungally derived chitosan). Flotation was later adopted for other industrial wastewater treatment and finally for potable water clarification. There were various advances along the way including dissolving air in a small part of a recycle stream instead of in the entire feed to save power, different configurations of flotation basin (e.g. Figure 6) and dissolved air flotation-filtration (DAFF) whereby depth filtration is integrated at the bottom of the flotation basin.

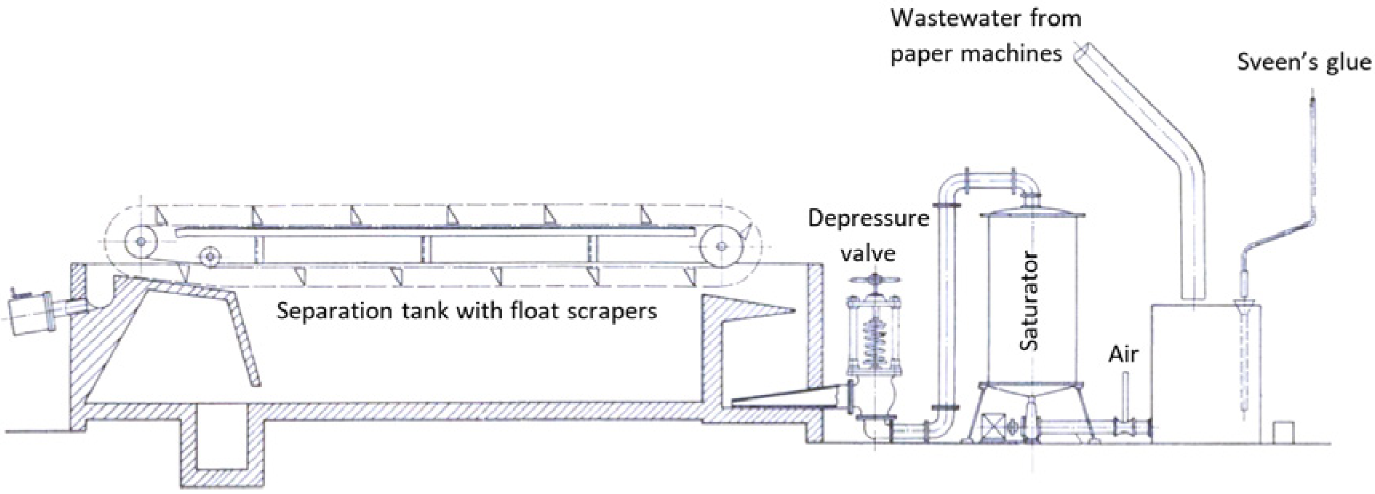


Figure 5. Sveen-Pedersen flotation cell (adapted from Brecht and Scheufelen 1938)

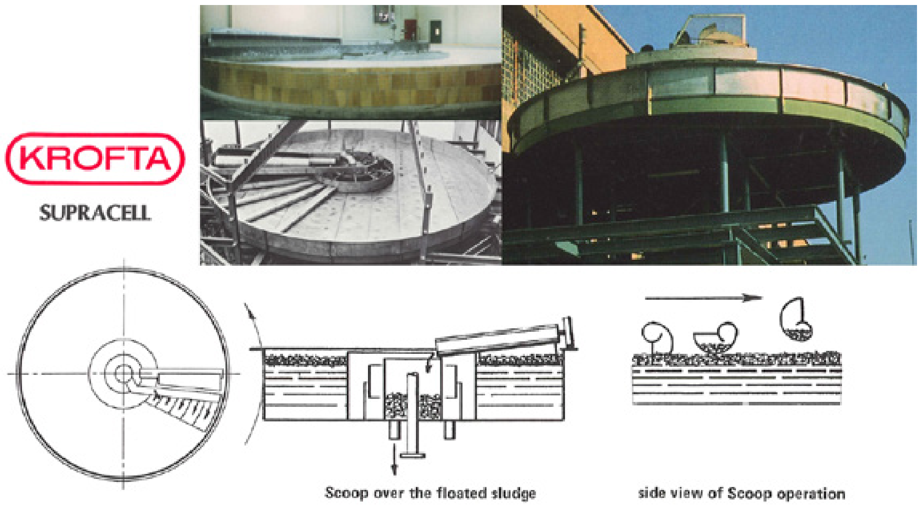


Figure 6. High capacity shallow circular flotation separation basin, c. 1970s (Krofta, supplied)

Figure 7. Mobile recirculation flotation pump (Juclas, supplied)

Single-stage flotation in the wine industry has been experimented with since the 1970s (e.g. Boulton and Green 1977). The first widespread application of flotation, however, appears to have been in Australia as a secondary stage after centrifugation and this technique is still widely practiced today (Figure 2). When centrifuges started to be used for juice clarification it was found that air was being dissolved under pressure and when released the air bubbles floated fine particles in the product tank (Heinz Eibner, pers. comm.). Systems were later refined to use nitrogen instead of air and to specifically take advantage of this phenomena (Chan 1984). By using a flotation step, much higher flow rates through the centrifuge could be used and/or a secondary settling stage prior to fermentation avoided.

Modern-day winery single-stage flotation originated in Italy around 1990 with the work of Ferrarini *et al.* (1991, 1992, 1995). The systems trialled were continuous and have clear similarities to those that were already being used for wastewater clarification (e.g. Figure 6). There appears to have been good uptake of this technology in some countries, but the uptake in Australia was very limited, with only one winery seeming to have installed a system (Falkenberg 1997). At the time a lot of installations appear to have used air for flotation in order to hyperoxidise juice, instead of the nitrogen that now dominates wine industry flotation (at least in Australia). The dosing of processing aids like gelatine and bentonite was also a key aspect of the new process, in contrast with the Australian centrifugation-flotation process that was not quite so reliant on perfect flocculation because it had a centrifugation step as well.

Large continuous flotation systems are cheaper than centrifuges, but still reasonably expensive. Apparently to make the process more affordable, systems were also sold without the continuous separation basin, with existing winery tanks being used for separation. As a next step to reduce cost, the large tank saturator was also removed, and small mobile units were developed in which gas and processing aids were injected during pumping between valves on the same winery tank (Figure 7). More than one full pump-over volume is generally used to try and counteract the inferior gas-liquid contacting from not using a large saturator. It could be argued that this arrangement is less sophisticated than the flotation systems that had been used in the wine industry 20 years earlier; however, they are a true wine industry adaptation of flotation. These systems allow many small batches to be processed (not a consideration in water treatment), cause no extra product movements compared with juice settling and importantly systems are relatively cheap, facilitating more rapid adoption. Interestingly, after some significant adoption of these recirculation flotation pumps, many large Australian wineries are now installing continuous flotation systems, similar to those introduced to the wine industry around 1990. While these continuous systems are relatively expensive, have a large hold-up volume and are less flexible, they can be more efficient when large volumes of the same juice need to be clarified because they are more automated and centralise float lees accumulation for reprocessing.

Flotation is already an effective process but perhaps it may be improved further in the future. For any new flotation technology development to be successful in the wine industry, it would likely have to be continuous but have a much smaller separation basin than existing continuous systems. It would also likely need to be able to handle intermittent flow such that it could be attached directly to the outlet of a batch press and clarify the juice as it produced and send it directly to the fermenter. Technology that can achieve this has not yet been demonstrated.

Jameson flotation cells (Figure 8) have sometimes been advocated as a technology that should be adopted by the wine industry. Jameson cells were developed in Australia in the 1980s for the mining industry and have been very successful. Bubbles for flotation are created in the downcomers as the feed is jetted in, entraining air and vigorously mixing it in. Atkinson *et al.* (1993) reports that Jameson cells produce much smaller bubbles than traditional mechanical dispersion flotation cells. However, while no explicit comparisons exist, it seems unlikely that this technology produces as small and consistent bubbles as dissolved gas flotation where gas is dissolved under pressure and then released from solution. Therefore, the clarification performance with a Jameson cell is likely to be lower and/or the juice occlusion in the float lees higher than with current wine industry systems.

Conclusions

Cross-flow filtration and flotation were initially slow to be adopted in the wine sector but have now successfully been used in many wineries. Some tweaking was required to adapt them to the specifics of wine production. The next article in this series will discuss the use of in-tank fermentation monitoring in

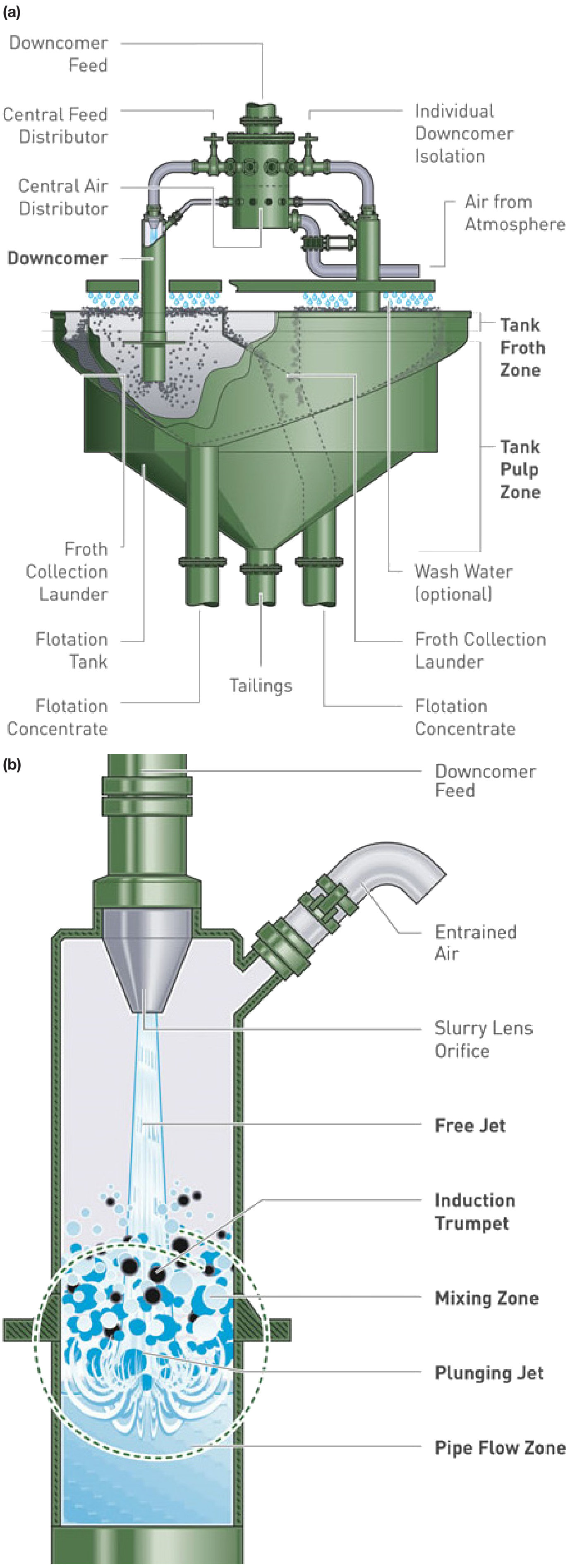


Figure 8. (a) Jameson flotation cell, with (b) close-up of downcomer operation (Xstrata Technology, Wikipedia, CC-BY-SA-3.0)

the wine industry - something that has been adopted to a much lesser extent than cross-flow filtration and flotation despite being around for just as long. It will also discuss the history of continuous processes in the wine sector - continuous fermentation in particular. Engineers generally favour continuous processes over batch processes and have developed some fascinating winery equipment with this philosophy in mind, but it has not always proven to be the best approach.

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Disclaimer

Readers should undertake their own specific investigations before purchasing equipment or making major process changes. This article should not be interpreted as an endorsement of any of the products described. Manufacturers should be consulted on correct operational conditions for their equipment.

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