

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.

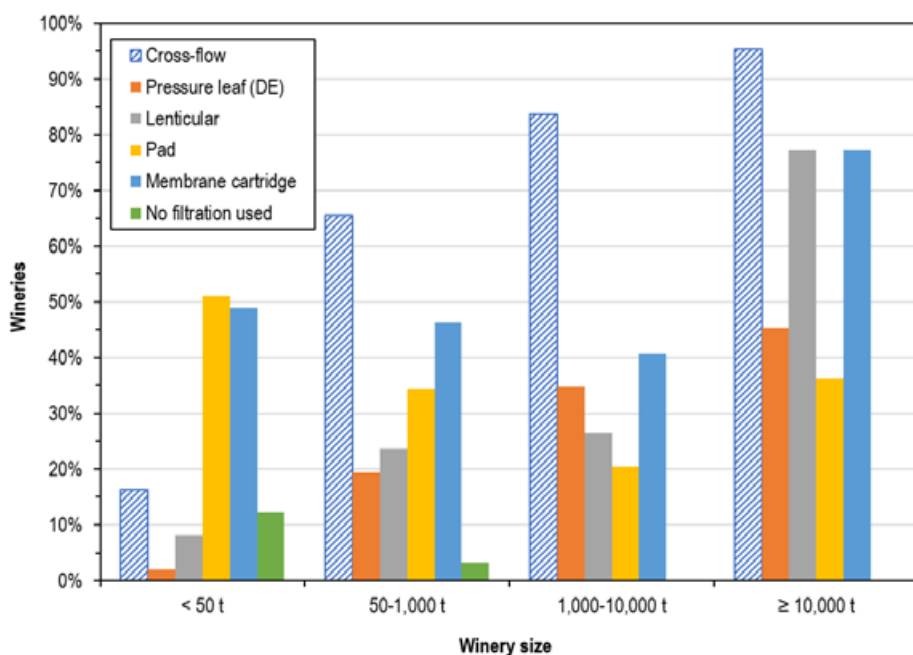


Figure 1. Wine filtration techniques used by Australian wineries in 2016

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

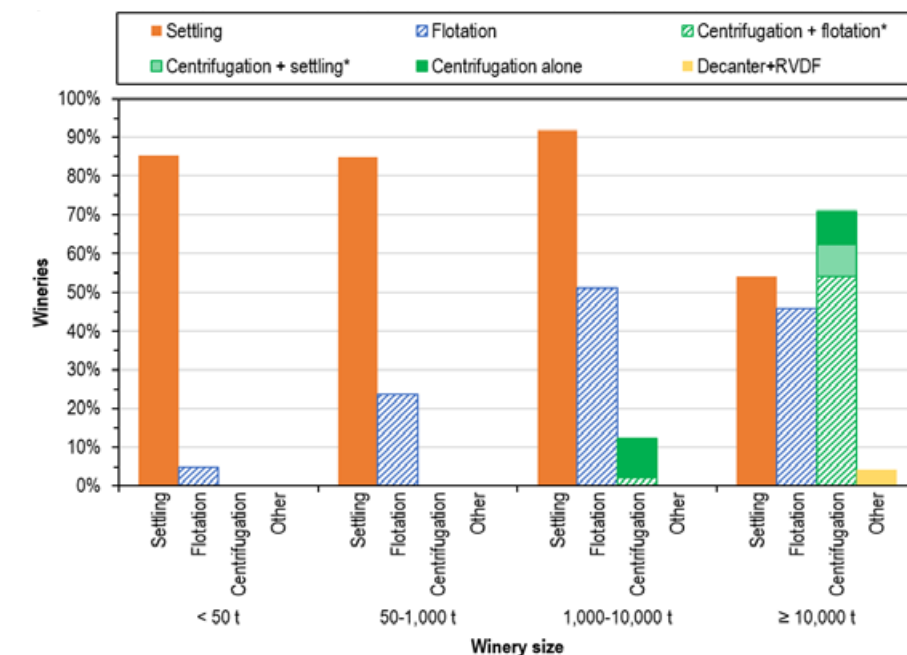


Figure 2. Juice clarification techniques used by Australian wineries in 2016 (*Second clarification step is usually but not always applied)

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.

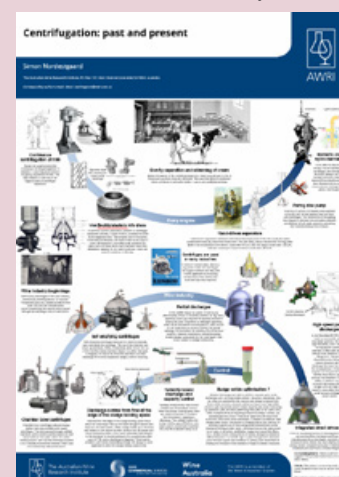
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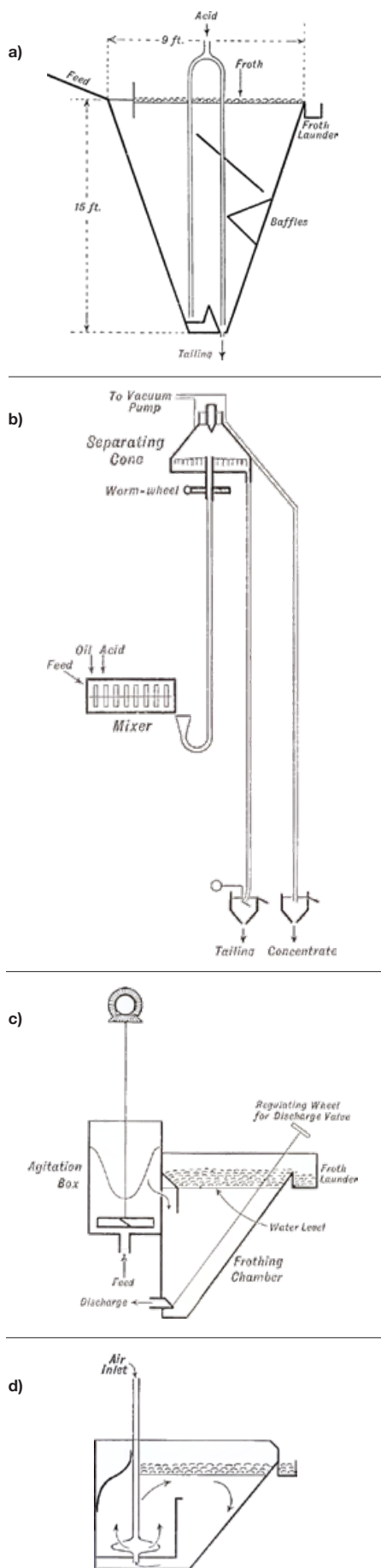


Figure 3. Some early mineral flotations equipment: (a) Potter-Delprat acid-carbonate flotation process, (b) Elmore oil-vacuum flotation process, (c) Minerals Separation cell with agitation box, (d) Ruth sub-aeration mechanical dispersion cell (adapted from Truscott 1923)

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

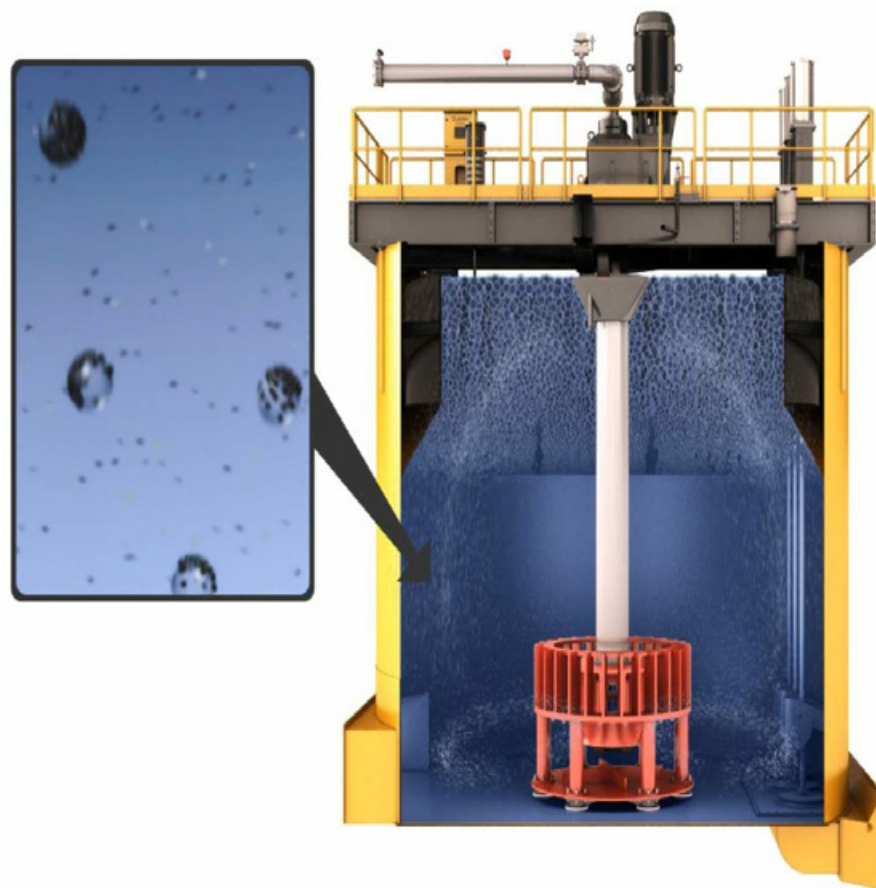


Figure 4. A modern mechanical dispersion flotation cell (Outotec, supplied)

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. ▶

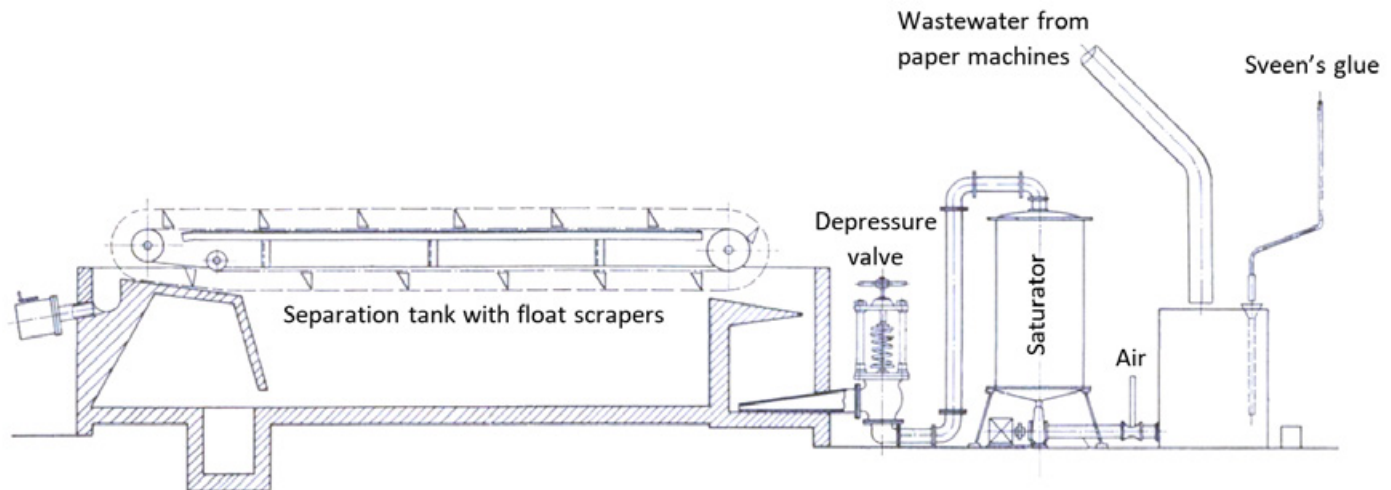


Figure 5. Sveen-Pedersen flotation cell (adapted from Brecht and Scheufelen 1938)

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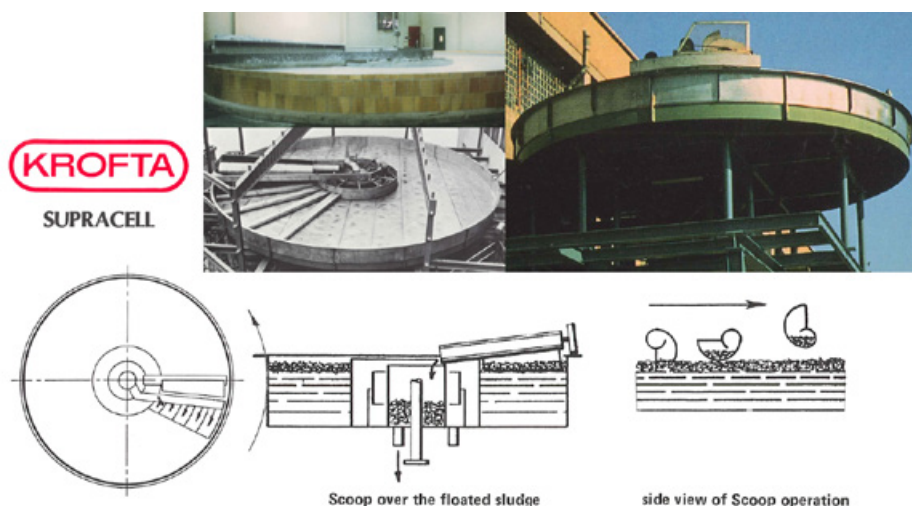


Figure 6. High capacity shallow circular flotation separation basin, c. 1970s (Krofta, supplied)

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



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

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



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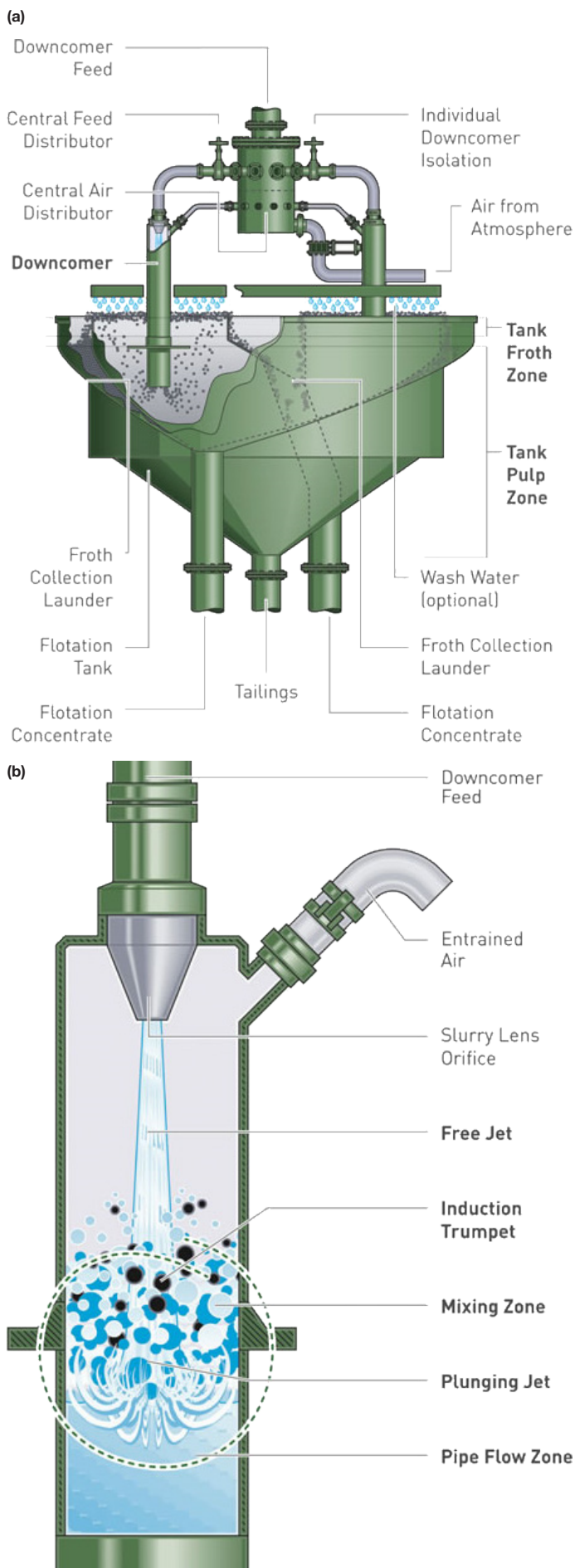


Figure 8. (a) Jameson flotation cell, with (b) close-up of downcomer operation (Xstrata Technology, Wikipedia, CC-BY-SA-3.0)

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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Inspirations from the past and opportunities for the future

Part 2: In-tank fermentation monitoring and continuous processes

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Introduction

The first article in this series discussed cross-flow filtration and flotation, technologies that have been quite widely adopted in the wine sector. This article will discuss in-tank fermentation progress sensors - something that has only been adopted to a much more limited extent. It will also consider the use of continuous processes in the wine sector and some of the challenges involved with these. Continuous fermentation is discussed in some detail, both because fermentation is at the heart of wine production and because while this interesting technique was once not uncommon in mass wine production overseas, it is now almost extinct.

In-tank monitoring of fermentation progress

While in-tank measurement of temperature is common, only one Australian winery currently uses sensors to monitor the conversion of sugar to ethanol during fermentation (Figure 1), and only in a small number of their tanks. It is instead standard practice at wineries to regularly manually collect samples and measure their density with a laboratory hydrometer or density meter. The low uptake of in-tank sensors for monitoring fermentation progress is similar in other wine-producing countries.

While there are some technical challenges to measuring fermentation progress in-tank (e.g. sensor fouling), the real barrier to adoption is price. The seasonal nature of wine production means that many tanks are needed to vinify grapes in the short time available and the cost of fitting all these tanks with sophisticated instrumentation is not insignificant. It is sometimes reasoned that it is cheaper just to get a

vintage casual to collect samples and for them to be tested in a laboratory, since samples are needed for regular sensory analysis during fermentation anyway. However, an opposing argument is that an in-tank sensor is more than just a substitute for a manually collected sample later analysed in a laboratory. If ferment progress is measured in-tank it can feed into process control to optimise each fermentation (e.g. temperature, nutrients, agitation). If data is measured and recorded automatically it is also likely to better facilitate continual improvement. Ideally, wineries would have set programs for different types of fermentation with appropriate control parameters surrounding at least fermentation speed and temperature for different stages of the ferment (instead of just having a current temperature setting for the tank, which is common). At the end of vintage, the data could be reviewed and programs continually

refined year after year in conjunction with sensory and chemical data. This strategy would likely be most useful in large wineries.

The concept of in-tank fermentation progress sensors is not new. Many different techniques have been trialled and adopted to a limited extent in wine and beer production:

- Pressure transducers to monitor ferment density were one of the first techniques to be used. In this approach two pressure diaphragms connected to a transducer or to two separate pressure transducers are installed, allowing the product density to be calculated based on the difference in pressure at different heights in the tank. Moller (1975) and later Cumberland *et al.* (1984) investigated this technique in breweries and similar techniques have since also been trialled to a limited extent in wineries.

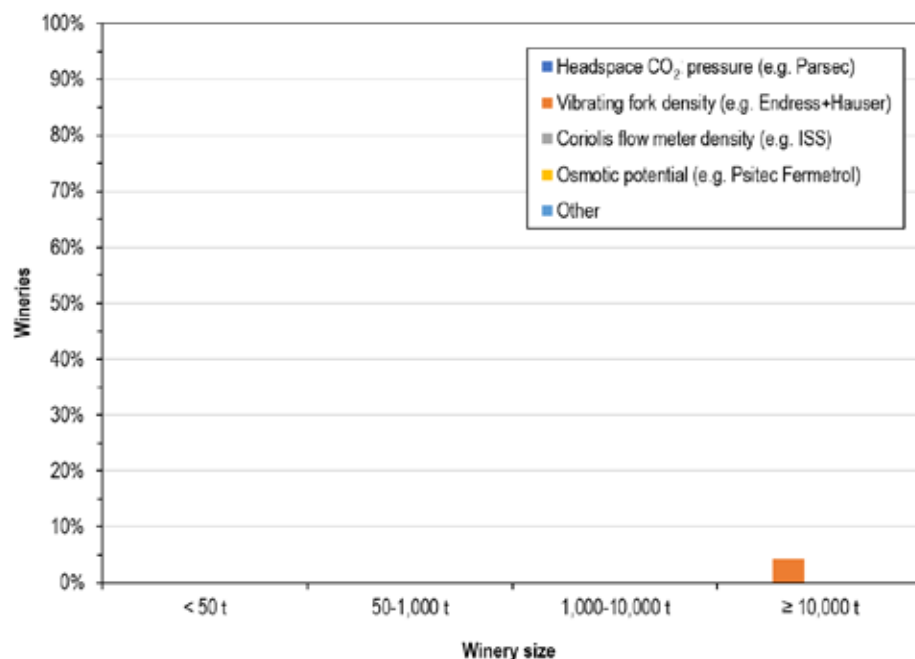


Figure 1. In-tank fermentation progress sensor use by Australian wineries in 2016

- Tuning-fork style density sensors have also received some recent attention (Endress+Hauser 2014; Zimmeroff 2016). These calculate density based on the resonant frequency of the liquid (Emerson 2018).
- Coriolis flow meters can also be used for analysis of density using similar principles, during pump-overs or using sample loops (Emerson 2015).
- Another approach to monitoring ferment progress has been to constantly measure the flow rate of gas (principally carbon dioxide) coming out of the fermenter. The sugar concentration/liquid density can then be back-calculated based on the stoichiometry of the fermentation reaction and the initial sugar level. In a forerunner to this approach, Saller (1958) used a device that monitored the carbon dioxide flow rate and controlled cooling to maintain a constant fermentation rate. Modern wine industry incarnations assessing carbon dioxide flow rate sold by Vivelys and Parsec appear to have their roots in French research during the late 1980s and early 1990s (El Haloui *et al.* 1988; Sablayrolles and Barre 1989; Bely *et al.* 1990; Sablayrolles 2009). While carbon dioxide flow rate can theoretically be used to back-calculate density, a major use of these systems seems to be for timing additions of oxygen to ferments to help avoid sluggish or stuck ferments (for example, oxygen addition at the time of peak carbon dioxide flow rate). Breweries have also used carbon dioxide flow rate as a means of tracking fermentation (Daoud *et al.* 1989; Daoud and Searle 1990; Stassi *et al.* 1987, 1991). A major advantage of ferment monitoring by carbon dioxide flow rate is that the sensor is not in direct contact with the liquid or ferment solids; however, it will not work if the tank/lid is opened and the initial sugar level does need to be known.
- Other in-tank sensors that have been trialled in the wine industry include osmotic potential sensors (Abbott 2016) and in-tank refractometers (VinPilot 2019). Refractometers are widely used in the wine industry for assessing juice sugar

content, but during fermentation the measurement is complicated by the contribution of ethanol to refractive index. This can, however, be approximately corrected for based on the known initial sugar content (i.e. when there was no ethanol), fermentation stoichiometry and known relationships for the impact of sugar and ethanol on refractive index.

Other in-tank fermentation measurements

In addition to the above techniques, methods for directly assessing yeast health and nutrient/aeration requirements beyond what is possible from just tracking the fermentation speed may also be useful. Redox probes are one technique that has been trialled (Boulton 2016; Killeen *et al.* 2018; Wilson 2018). Another approach has been to measure the hydrogen sulfide concentration in the gas from the fermenter, using relatively cheap electrochemical gas sensors (AEB's Ctrl-Ferm). These sorts of techniques may prove important to the successful adoption of fermentation progress sensors, because if winemakers still need to perform sensory analysis once or twice a day on ferments to determine nutrient additions and these same samples could be tested for density in the laboratory, then the argument against installing in-tank ferment progress sensors is stronger. For high-end products, winemakers will likely always still want to taste the wine as a check, but in large wineries with large batch sizes where the technology would be most applicable, tasting as regularly as is currently performed is probably not necessary and could be limited to only when a problem is identified by sensors.

Breweries have also used other technologies to monitor yeast, particularly in relation to pitching control. In-line turbidity measurement before and after yeast dosage has been quite widely used in breweries (Boulton and Quain 2006; Kunze 2014). A problem with techniques like turbidity measurement for monitoring yeast is that they do not distinguish between viable and non-viable yeast cells. However, an alternative technique has been developed that detects only viable cells, based on their dielectric properties, and it appears that this may have had some commercial

success (Harris *et al.* 1987; Boulton *et al.* 1989; Carvell 1997; Boulton and Quain 2006; Aber 2020).

In-tank colour/phenolic/tannin measurements may also be of value for red ferments to control decisions about fermenter mixing regimes, but this is not currently practised. Shrake *et al.* (2014) developed one system with a sample loop to analyse ferments using UV/Vis spectroscopy. The system provided valuable data; however, it worked based on light transmission through a 100 µm flow cell and therefore needed an in-line pre-filtration system. Unfortunately, the need for sample filtration means that this style of system is less likely to be adopted by wineries. The need for sample clarification has long been a major practical problem for immediate

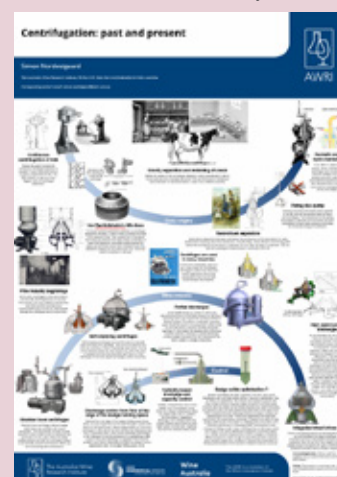
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phenolic/colour measurements needed for in-line or at-line process control and has likely contributed to very low adoption levels of phenolic/colour measurements during fermentation. One interesting development that has achieved some commercial uptake is voltammetry using disposable electrodes, which requires no sample clarification (Lagarde-Pascal *et al.* 2019). However, the disposable electrodes mean that this is still a manual at-line process rather than an in-line technique. Another approach that is being developed is a UV/Vis spectrometer that uses an 'integrating sphere' to separate scattered and absorbed light and which can therefore be used with turbid samples (Darby *et al.* 2016, 2019).

Continuous processes in the wine industry

Continuous processes are generally seen by engineers as being preferable to batch processes. Among other advantages, they usually have a smaller footprint and lower operating costs; however, there are some important aspects to consider in the adoption of a continuous process:

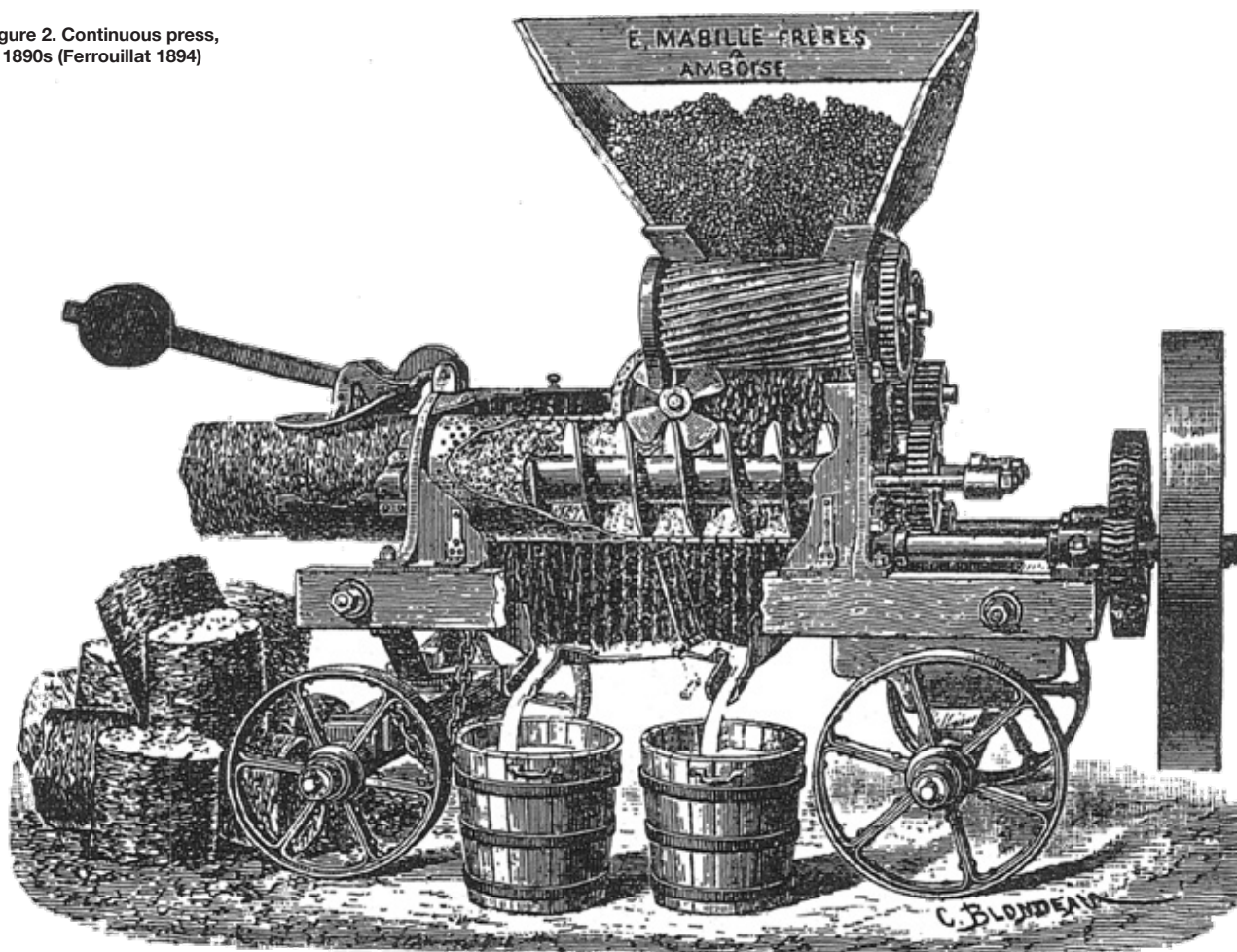
- What is the hold-up volume of the continuous process?
- How long does it take to start up and reach steady-state?
- If it is an operation that can currently be performed in many tanks simultaneously, would adopting a continuous process with a single piece of equipment create a process bottleneck?
- What is the impact on wine quality?
- Does it involve purchase of an additional piece of equipment?
- Is it appropriate across the range of different products being made?

The answers to some of these questions can make continuous processes not as easily applicable to wineries as they are in other industries. However, there have been many efforts at continuous processes in the wine industry because of the potential benefits.

An early example of continuous winery equipment was the continuous press. Batch basket presses were labour intensive

and a typical process bottleneck. To address this, many different types of continuous press were developed in France in the late 19th century (Ferrouillat 1894). The continuous screw press (e.g. Figure 2) quickly became the most popular continuous press design. Continuous screw presses are still used today in wineries following many improvements; for example, more hygienic materials, improved feeding systems, larger screw diameters, lower speeds and better automation. Even with these improvements, continuous screw presses generally produce juice with higher solids levels than batch press designs. The advent of large automated axial filling membrane presses that produce juice with relatively low solids levels has gradually led to the decline in use of continuous screw presses; however, they remain an important part of pressing operations in many large wineries around the world. While superior to earlier batch processes, membrane presses are still slow and there is therefore intermittent interest in other continuous alternatives like decanter centrifuges (Nordestgaard 2015).

Figure 2. Continuous press, c. 1890s (Ferrouillat 1894)



Continuous fermentation

One fascinating continuous process that has been used in the wine industry, but which is now almost extinct, is continuous fermentation. This was a prominent technology in France in the 1960s and 1970s. One of the earliest systematic attempts at continuous wine fermentation was performed by Semichon (1926). Fresh juice was added to fermenting juice containing around 4% alcohol. This alcohol facilitated the selection of *Saccharomyces* yeast over other species (sometimes referred to as the 'Super 4' principal) and the continued addition of fresh juice also served to cool the ferment. A conically bottomed tank was used to allow for yeast removal. Juice removed from the tank at 4% alcohol completed the remainder of its fermentation in other tanks. For red wines, drained juice was put through the process and then added back to the skins. The first commercial implementation of continuous wine fermentation was by Victor Cremaschi in Argentina in the 1940s (Nègre 1949; ▶

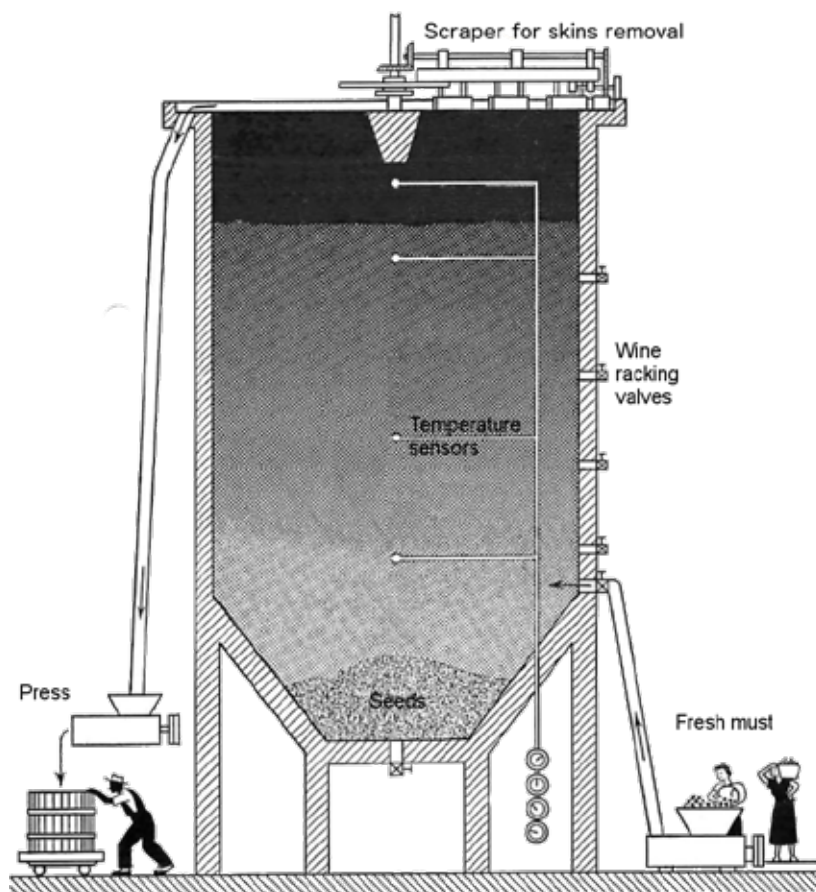


Figure 3. Cremaschi continuous fermenter (adapted from Anon 1953)

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Willig 1950). Cremaschi's continuous fermenter (Figure 3) used the 'Super 4' principal, but also incorporated a means to manage skins. The automatic removal of skins was a key consideration in this and many later designs of continuous wine fermenter because the standard practice at the time of digging skins out of fermenters was labour-intensive and there were risks of carbon dioxide asphyxiation. The largest adoption of continuous fermentation was ultimately in Southern France (Ladousse 1962; Nègre 1967; Peynaud and Guimberteau 1967; Fages-Bonnery 1968; Roubert 1970). Continuous fermenters lack the flexibility of batch fermenters since large volumes over multiple days are mixed in the same tank and bacterial contamination is also a risk given the large volume of wine and long use of each tank. There were also debates about how cost-effective these devices really were. Claims that continuous fermenters greatly reduced the overall winery tank capacity needed were contested by others since the often only partially fermented wines from these devices still needed to be stored in other tanks to complete fermentation. Continuous fermenters ultimately fell from favour. The availability of improved designs of batch fermenter that facilitated easy skin removal and that were built from steel and stainless steel likely also contributed to the decline of continuous fermenters.

As already mentioned, winery technology choices are heavily affected by the seasonal nature of wine production, and this also applies to the use of continuous processes. Attempts have been made to try to 'de-vintage' wine production. For example, in the late 1970s large quantities of juice used to be stored heavily sulfited and at low pH and used for year-round fermentations (after de-sulfiting and pH adjustment) for bag-in-box wine production. Continuous fermentation would have coupled well with this process since fermenters could have been run for many months and even years without stopping, but this did not happen (Potter 1984). The method of storing and processing juice in this manner, always controversial, fell out of favour in the 1980s.

Continuous fermentation is more easily applicable to sparkling wine production since it could be performed all year round using base wine, a much more

stable feedstock than juice. Continuous sparkling wine production was pioneered in the Soviet Union (Amerine 1959) and it may have been quite widely used there. Continuous fermentation has also been used in beer production, which, like sparkling wine production and unlike still wine production, can easily be performed all year round. Continuous beer fermentation was pioneered in New Zealand by Morton Coutts in the 1950s (Campbell 2017) and for a long time it was used to produce most of the beer in New Zealand. Its use in New Zealand is much lower than it once was, but at least one brewery in New Zealand still uses this approach. Continuous fermentation has also been used for periods by other breweries around the world but has since been abandoned (Bud 1989). Interestingly at the time when the technique was widely adopted in New Zealand there were some restrictive building regulations and taxation arrangements that made it desirable to minimise plant footprint and beer volume on-site, which further contributed to the merit of the technology (Kennedy 1996).

Continuous cold stabilisation

Another area of wine production for which continuous processes are often proposed is cold stabilisation; for example, continuous tartrate contact and electrodialysis systems. These technologies were first used in the late 1960s (Caputi 1967; Vialatte 1979) and exist in improved forms today. Both techniques can work, but the economics can be difficult to justify (Low *et al.* 2008) for wineries that already have refrigeration and insulated jacketed tanks to manage ferments that can be used for cold stabilisation outside vintage. While slow, the standard batch arrangement gives the ability to cold stabilise many different batches of wine at the same time, whereas adopting a single piece of equipment might create a process bottleneck.

Is it a continuous or a batch process?

It should also be noted that the line between what is a continuous process and what is a batch process can be somewhat blurred. For example, multiple batch presses used in sequence can process a continuous intake of grapes. Even processes like continuous fermentation

were not generally continuously fed with fresh grapes and wine and skins continuously removed. Instead enough wine was removed each day so that there was space to add that day's grapes.

Conclusions

The wider application of sensors for monitoring fermentation progress is an improvement opportunity for the wine sector – large wineries in particular – that may lead to not just improvements in efficiency but also improvements in product quality and consistency. It can be more than just a substitute for a vintage cellar-hand collecting samples. Continuous processes have a place in wine production, but it is important to not be governed by the simplistic philosophy that a continuous process is always better than a batch process. The next article in this series will consider automated alternatives for some winery practices that are currently very manual.

Acknowledgements

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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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- Aging:** The final stage before bottling.

Inspirations from the past and opportunities for the future

Part 3: Volume measurement, product movements and gas adjustment

This article is the final 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

Prior articles in this series covered the widespread adoption of cross-flow filtration and flotation, the limited adoption of in-tank fermentation progress sensors and the history of continuous fermentation. This final

article reviews some winery operations that are currently performed very manually even in large wineries and presents some of the alternative technology options available.

Volume measurement – is there a better option than a dip tape?

Most Australian wineries currently measure the volume of liquid in tanks using a tape measure with a floating weight on the end (Figure 1). The ullaged distance from the surface of the wine to the top of the tank is measured and the corresponding volume of liquid in the tank is read from a table. This technique is relatively cheap, simple and hygienic. However, it requires somebody to go above the tank to perform the measurement, relies on them performing it accurately and it is not a live measurement. Small differences in level can make quite a big difference in volume measurement (e.g. a 2 cm dip error in a 5 m diameter tank is a 400 L error). Another potential source of error in this (and most of the other techniques discussed below) is any inaccuracies in the tank dip tables, since tanks that are nominally the same often

have slightly different volumes.

External tubes next to a graduated scale are another basic level measurement technique that has sometimes been employed by wineries (Figure 2). While these do not require access to the top of the tank, the level would be difficult to view on taller tanks, and it is likely a less hygienic solution than a dip since there is a thin tube containing wine that is at risk of not being properly cleaned.

Hydrostatic pressure at the bottom of tanks has also been used to measure levels in winery tanks. Both mechanical pressure gauges and electronic pressure sensors have been employed (Figure 3). An advantage of electronic sensors is that they can be connected to a Supervisory Control and Data Acquisition (SCADA) system and monitored remotely. Measurement errors increase with height. For example, in the electronic pressure sensor shown, the error in pressure measurement is $\pm 0.2\%$, so assuming a constant and known liquid density, at 2 m height the error is ± 4 mm, while at 10 m it is ± 20 mm. A major disadvantage of level and volume



Figure 1. A dip tape used for level measurement.

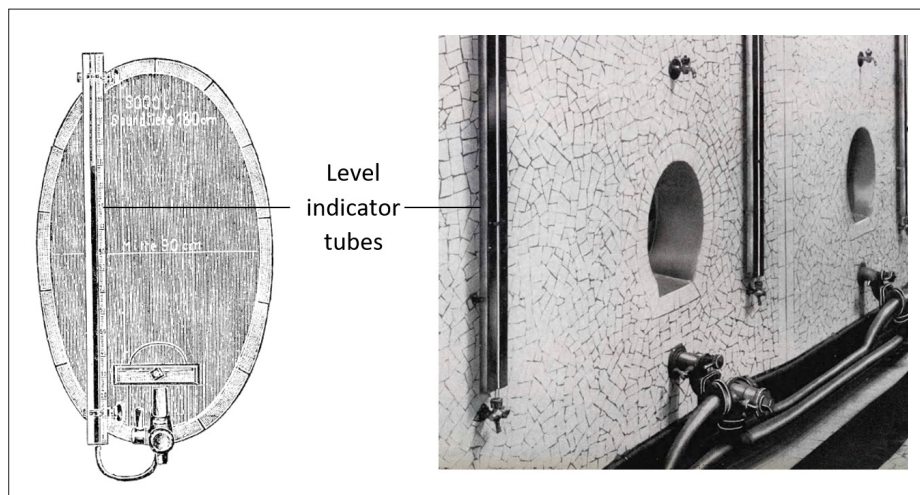


Figure 2. External level indicator tubes (Meißner 1920; Gasquet c. 1950s)

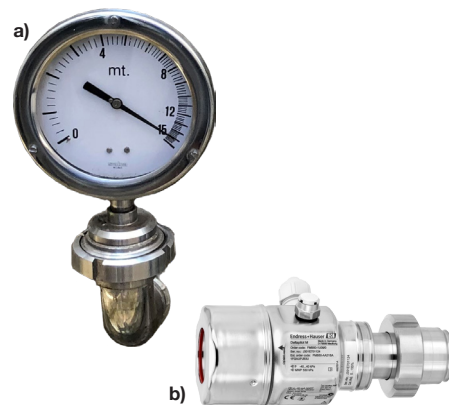


Figure 3. (a) Mechanical pressure gauge (reports in metres based on an assumed liquid density, photo from an Italian winery) and (b) electronic pressure sensor (Endress+Hauser, supplied)

measurement based on hydrostatic pressure is that the results are dependent on density, which can vary with product type and temperature. For example, a density difference of 0.4% between dry red and dry white wine would regularly be encountered (40 mm for a 10 m liquid level) and, more significantly, sweet and fortified wines can often be 7% more dense than dry wines (700 mm for a 10 m liquid level). This issue might necessitate having a second pressure transducer on the same tank so that the real density can be calculated based on the difference in hydrostatic pressure between the transducers (similarly to when using pressure transducers to monitor ferment progress – see prior article in this series).



Radar is another technique for level measurement (Figure 4). This works based on the time of flight of a radar pulse reflected off the surface of the liquid. Radar should generally be more accurate than hydrostatic pressure transducers and the result is not dependent on liquid density. The device shown has an error of ± 1 mm across most of its range, increasing up to ± 4 mm right next to the sensor. These devices are already used to a small extent in wineries, mainly for sparkling wine pressure tanks where it is not possible to access the inside of the tank to take a manual dip measurement.

Trials have not been performed by the author using these technologies but based on discussions with suppliers it seems likely that they could be very useful. Electronic level sensors will be more expensive than dip measurements

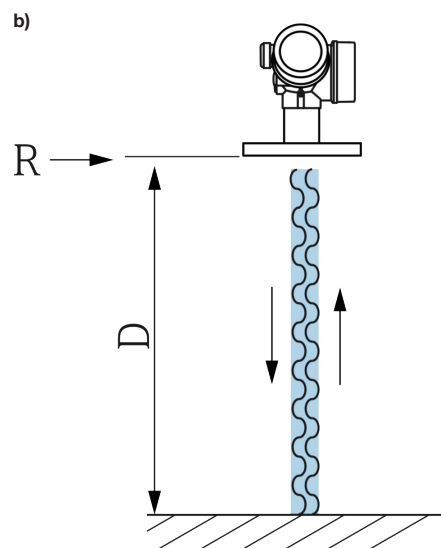


Figure 4. (a) Radar level measurement sensor (80 GHz with a narrow beam) and (b) radar measurement principle (Endress+Hauser, supplied)

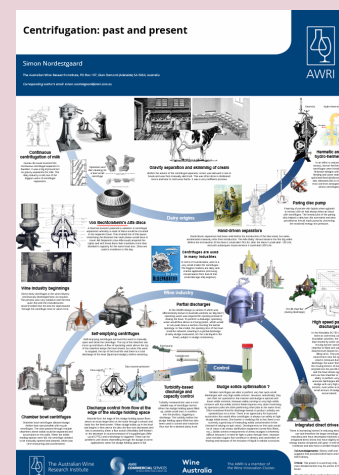
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in the short term. While the cost would be significant, it is likely to be only around 5% of the cost of a 250 kL tank and less for larger tanks and large multi-tank installations (the exact costs would vary depending on the specific circumstances). The installation position would need to be carefully considered to ensure that systems collect the correct

data and do not get in the way of other operations or create cleaning problems.

More sensors would lead to some different skills requirements in wineries; for example, likely more instrumentation maintenance staff and less general labour. At some point, individual sensors will inevitably give incorrect readings and some clever system design is likely to

be required to identify and manage these issues. For example, automatic cross-checking between levels measured in feed and product tanks and flow meters in-between during transfers.

The live nature of automated level measurements is likely to provide greater centralised process oversight and can ultimately facilitate greater process automation for product movements. As a basic example, some wineries that installed electronic level sensors many years ago and have them integrated with their SCADA have commented how useful they are for tracking jobs and scheduling which tanks the next batch should go into during the peak of vintage.

Eliminating hoses and automating product movements

Hoses are widely used in wineries because they facilitate the movement of product between any two points. They are a trip hazard, require manual handling and their use is a barrier to improved winery automation (for example they are problematic to 'pig').

Some old winery design catalogues (e.g. Daubron 1931; Gasquet c. 1950s) contain fascinating examples of wineries with very few hoses. These wineries had pipework that went all the way to tanks fitted with multi-way valves (Figure 2) and used centralised distribution boards (e.g. Daubron's 'Centralisateur', Figure 5). One driver in these designs was the need

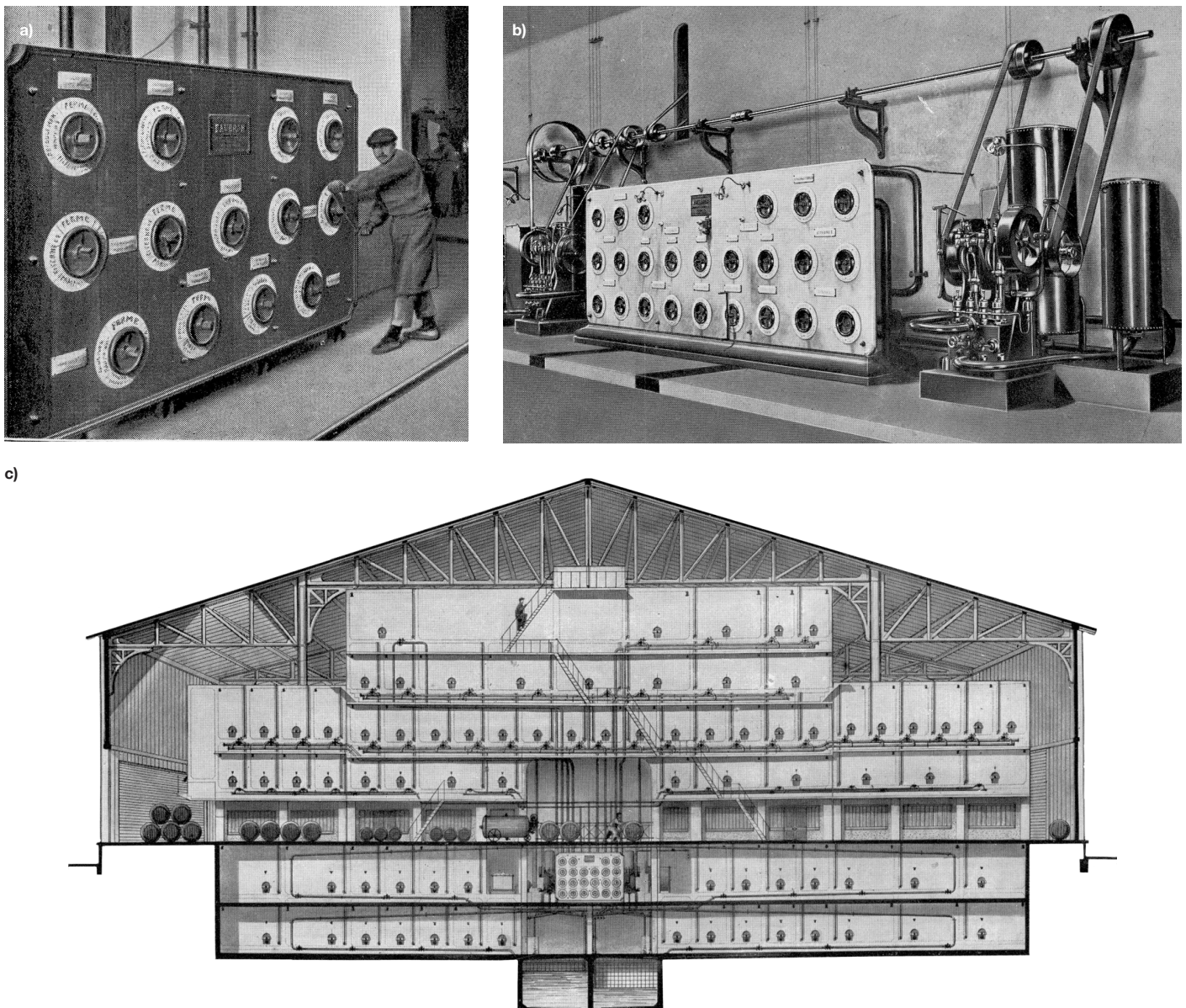


Figure 5. (a,b) Centralisateur distribution boards and (c) a winery built around this principle (adapted from Daubron 1931)

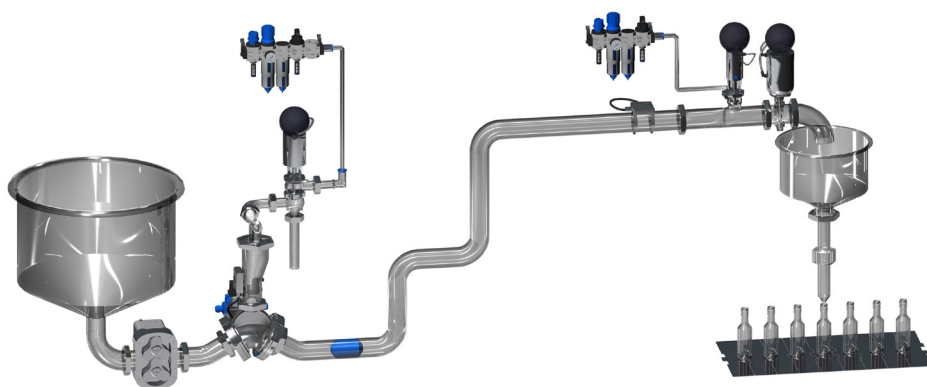


Figure 6. Illustration of a pigging system (Hygienic Pigging Solutions, supplied)

to use fixed steam-powered pumps; they probably fell out of favour following the advent of electrification and mobile electric pumps, and because of issues with hygiene and metal leaching.

However, in some respect these designs are more advanced than many modern wineries despite the much more limited technology available at the time of their construction. They should serve as some inspiration for designers of modern automated wineries. Designers now have at their disposal stainless steel, hygienic pumps and valves, and computers.

Pigging would likely form a part of a modern automated winery. Pigging uses mobile plugs (pigs) to clean, inspect or push products through pipelines (Figure 6). Advanced automated pigging systems are already used at some wineries for key fixed transfer lines, particularly in bottling facilities for key transfer lines between the main winery and bottling

tanks and between bottling tanks and bottling lines, and on some winery must lines. The use of pigging could potentially be expanded in wineries to all stages of production. Pigging loops around tank farms might be used in addition to the point-to-point systems that are now most common. Increased use of pigging would be expensive but would allow significant process automation and would help with reducing winery water use.

There are other technologies that may also assist with automation, beyond the electronic level sensors discussed and flow meters that are already common in wineries (electromagnetic flow meters are common, but more accurate Coriolis flow meters may be useful in some applications). For example, equipment using electrical impedance spectroscopy to automatically detect interfaces between different liquid types and stop a pump is now commercially available (Figure 7; Cozbel 2015; Pellenc 2019) and

cheaper but less sophisticated electrical conductivity and turbidity sensors may also be useful for interface detection in some applications.

In-line dissolved gas management using membrane contactors

One newer technology that is starting to gain traction in the wine sector is membrane contactors for dissolved gas adjustment (Figure 8). When combined with appropriate control systems these can be used to adjust carbon dioxide levels up or down to a set level, while simultaneously removing some oxygen, all in the same pass. They are a viable alternative to sparging for gas adjustment in the later stages of wine production and potentially allow for looser winery carbon dioxide specifications with adjustments being made automatically during bottling. Membrane contactors can be used for both minor adjustments to carbon dioxide levels and for full carbonation. The ‘bubbleless’ method of gas addition can also allow for carbonation at warmer temperatures than might currently be practised (Nordestgaard 2018).

Conclusions

This series of articles has outlined a range of technologies that have been used in wineries, including some that have become very successful (such as cross-flow filtration and flotation) and others where adoption has been lower. Something that stands out even in large wineries is that many practices are still very manual. The costs for some of the more automated approaches discussed in these articles may be higher in the short term but they may also be a path to continued improvements in quality and cost reduction in the longer term.

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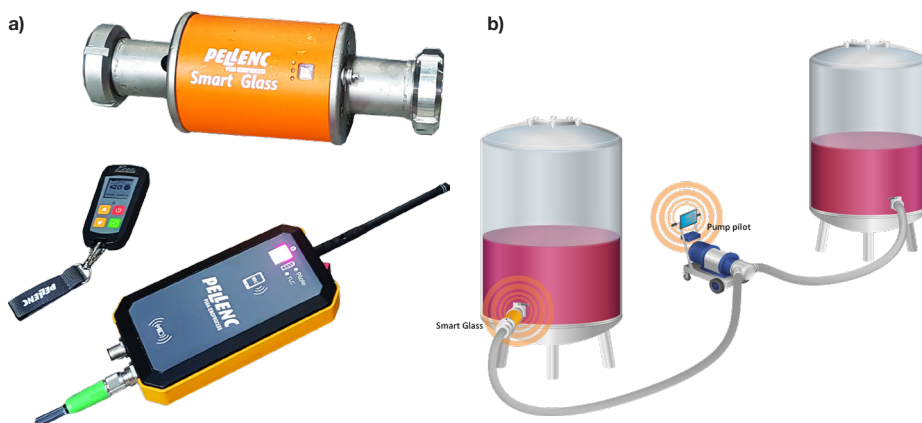


Figure 7. Smart Glass system for interface detection: (a) key components, (b) example implementation (Pera-Pellenc, supplied)

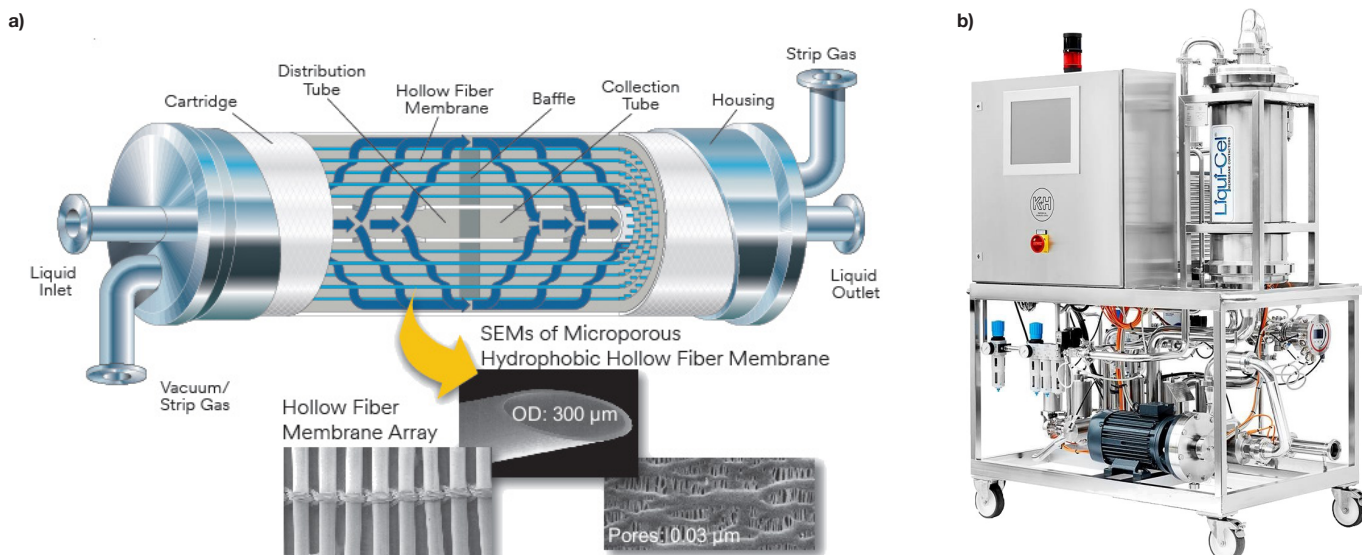


Figure 8. Membrane contactor: (a) module, (b) automated dissolved gas management system incorporating a membrane contactor module (3M and K+H, supplied)

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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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