Inspirations from the past and opportunities for the future

Part 2: In-tank fermentation monitoring and continuous processes

This article is the second 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

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.

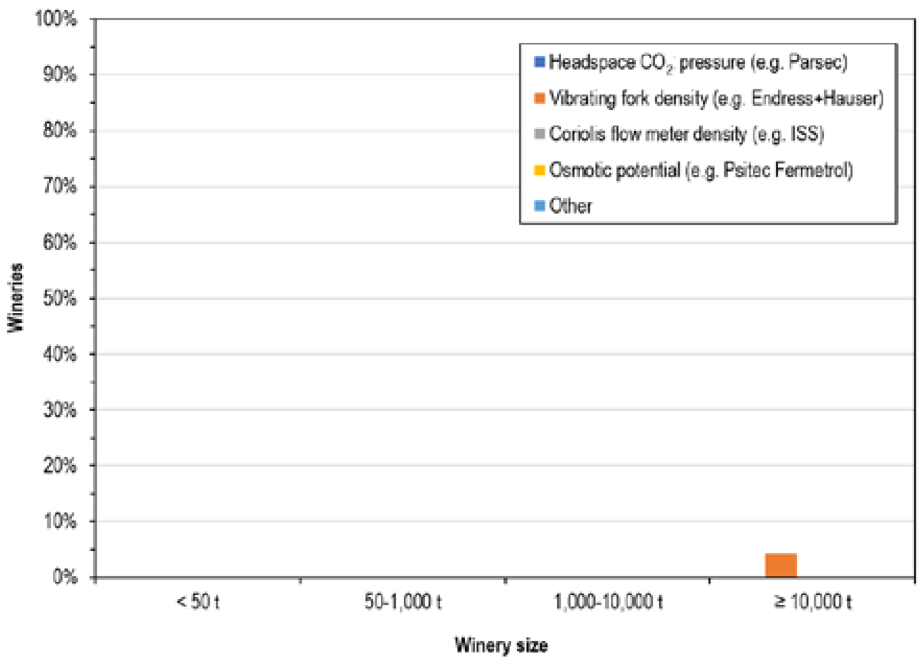

Figure 1. In-tank fermentation progress sensor use by Australian wineries in 2016

- Tuning-fork style density sensors have also received some recent attention (Endress+Hauser 2014; Zimberoff 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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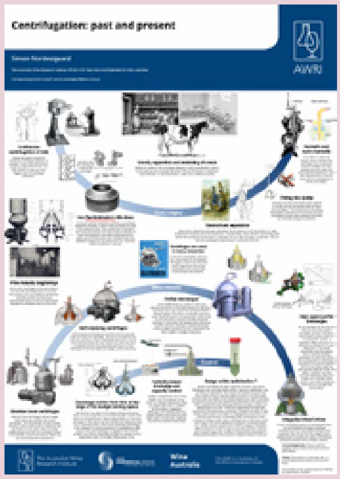

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phenolic/colour measurements needed for in-line or at-line process control and has likely contributed to very low adoption levels of phenolic/colour measurements during fermentation. One interesting development that has achieved some commercial uptake 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).

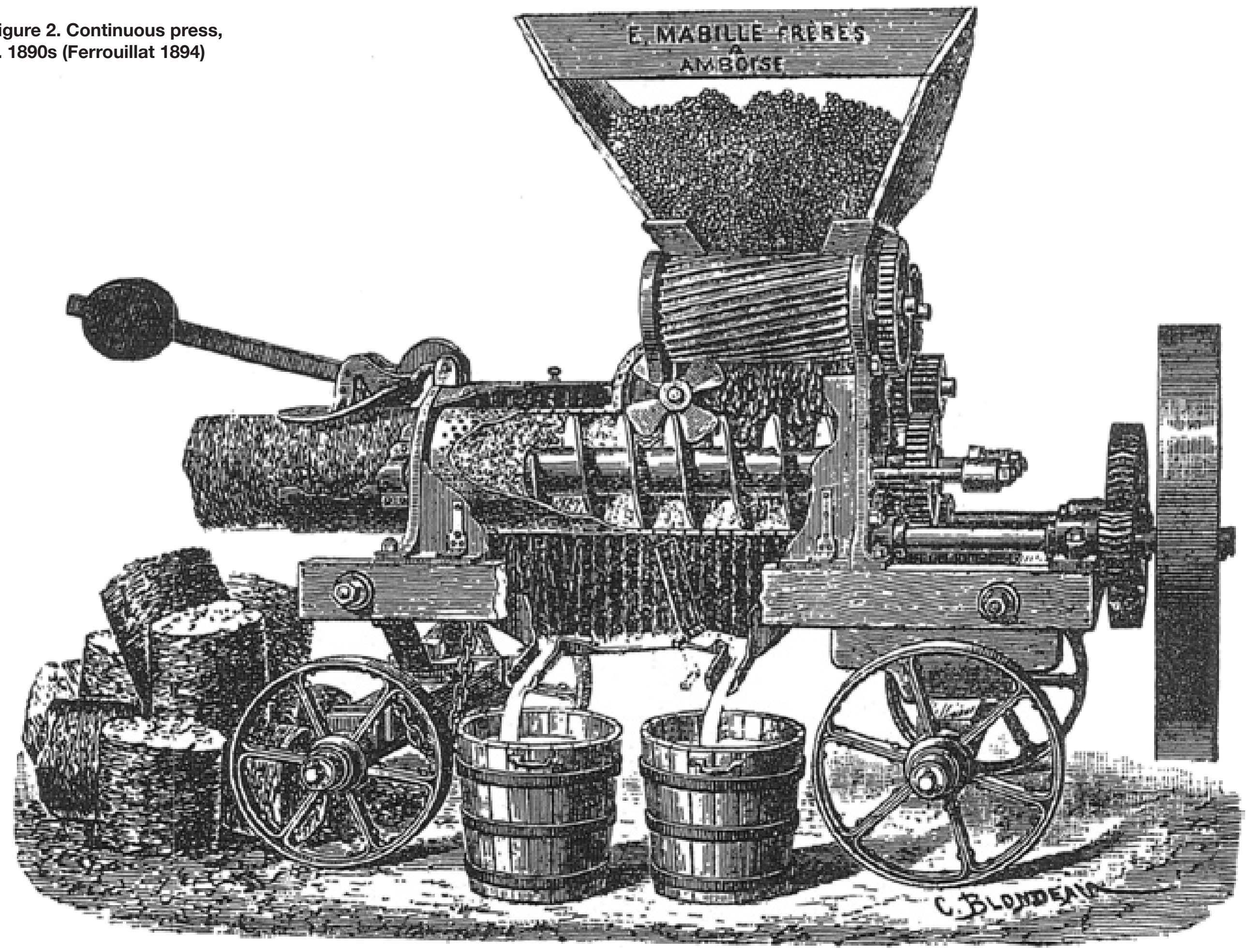

Figure 2. Continuous press, c. 1890s (Ferrouillat 1894)

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; ▸

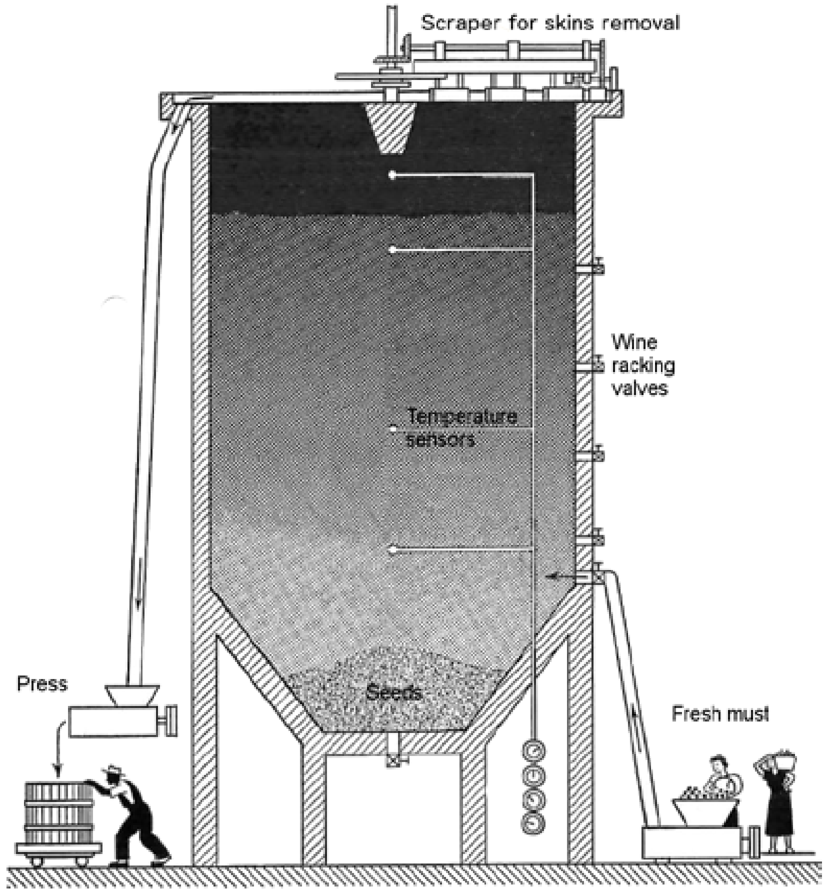

Figure 3. Cremaschi continuous fermenter (adapted from Anon 1953)

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.

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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.

References

Abbott, T. 2016. Using sensors to monitor sugar levels during fermentation. Urrbrae, SA: The Australian Wine Research Institute Ltd: https://s3.amazonaws.com/wea-website-files/2016+SA+Presentation+McLaren+Vale/AWRI+-+Tadro+Abbott+Ferment+Monitoring+presentation.pdf

Aber 2020. Compact Yeast Monitors. Aberystwyth, UK: Aber Instruments Ltd: https://www.aberinstruments.com/productscategories/view/online-compact-yeast-monitors

Amerine, M.A. 1959. Continuous flow production of still and sparkling wines. Wines Vines 40(6):41–42.

Anon 1953. Prácticas modernas en la gran industria del vino. Revista de la Cámara Argentina de Comercio: p. 109.

Bely, M.; Sablayrolles, J.M.; Barre, P. 1990. Description of alcoholic fermentation kinetics: Its variability and significance. Am. J. Enol. Vitic. 41: 319–324.

Boulton, C.A.; Maryan, P.S.; Loveridge, D.; Kell, D.B. 1989. the application of a novel biomass sensor to the control of yeast pitching rate. European Brewing Convention. Proceedings of the 22nd congress: Zurich: 653–661.

Boulton, C.; Quain, D. 2006. Brewing yeast and fermentation. Oxford, UK: Blackwell Science Ltd.

Boulton, R. 2016. Controlling redox potential during wine fermentations. 9 December: RAVE: https://lecture.ucanr.edu/Mediasite/Play/0bcd2d15875c466cac572b08297450921d

Bud, R. 1989. Biotechnology and the chemical engineer: a case study in the history of continuous brewing. Int. Ind. Biotechnol. 9(6): 17–20.

Campbell, S.L. 2017. The continuous brewing of beer. DB Breweries Ltd: https://nzic.org.nz/app/uploads/2017/10/6A.pdf.

Caputi, A. 1967. Wine stabilization by electrodialysis. Report to Wine Institute Technical Advisory Committee Meeting, 8 December.

Carvell, J.P. 1997. Developments in on-line monitoring of viable yeast in the brewery process. Paper presented at the Institute of Brewing (Asia Pacific Section) Regional Technical Symposia, April.

Cumberland, W.G.; MacDonald, D.M.; Skinner, E.D. 1984. Automated fermenter control at Moosehead Breweries Limited. MBAA Tech. Quart. 21(1): 39–44.

Daoud, I.; Dyson, R.; Irvine, J.; Cuthbertson, R.C. 1989) Practical experiences of on-line monitoring of evolved CO2 from production fermenters. European Brewing Convention. Proceedings of the 22nd congress: Zurich: 323–330.

Daoud, I.S.; Searle, B.A. 1990. On-line monitoring of brewery fermentation by measurement of CO2 evolution rate. J. Inst. Brew. 96: 297–302.

Darby, B.L.; Auguié, B.; Meyer, M.; Pantoja, A.E.; Le Ru, E.C. 2016. Modified optical absorption of molecules on metallic nanoparticles at sub-monolayer coverage. Nat. Photonics 10: 40–45

Darby, B.; Setford, P.; Robinson, A.; Miles, J. 2019. The CloudSpec - A new spectroscopic tool for analysis of unfiltered ferments. Poster presented at the 17th Australian wine industry technical conference, 21-24 July, Adelaide, SA:https://awitc.com.au/wp-content/uploads/2019/07/163-MARAMALABS_POSTER_FINAL.pdf

El Haloui, N.; Picque, D.; Corrieu, G. 1988. Alcoholic fermentation in winemaking: On-line measurement of density and carbon dioxide evolution. J. Food Eng. 8: 17–30.

Emerson 2015. Coriolis flow meter theory of operation: https://www.youtube.com/watch?v=31jYXlnu-hU

Emerson 2018. Liquid density meter from Emerson micro motion: https://www.youtube.com/watch?v=0d5XG8l6g2g

Endress+Hauser 2014. Density measurement in wine fermentation process: https://portal.endress.com/wa001/dla/5001070/7403/000/00/CS01410F00EN0114.pdf

Fages-Bonnery, A. 1968. Procédés de vinification continue. Fermentations et vinifications. Proceedings of 2nd Symposium International d'Œnologie, Bordeaux-Cognac, 13-17 June 1967. INRA Volume 2: 553–583.

Ferrouillat, P. 1894. Les pressoirs continus. Rev. de Vitic. 1(25): 597–601, 1(27): 645–654, 1(28): 671–674, 2(29): 14–17, 2(30): 33–38, 2(32): 91–93.

Harris, C.M.; Todd, R.W.; Bungard, S.J.; Lovitt, R.W.; Morris, J.G.; Kell, D.B. 1987. Dielectric permittivity of microbial suspensions at radio frequencies: a novel method for the real-time estimation of microbial biomass. Enzyme Microb. Technol. 9: 181–186.

Kennedy, M.J. 1996. The World's first brewery exclusively designed to use continuous fermentation: Biotechnology history made in New Zealand. Aust. Biotechnol. 6(1): 13–18.

Killeen, D.J.; Boulton, R.; Knoesen, A. 2018. Advanced monitoring and control of redox potential in wine fermentation. Am. J. Enol. Vitic. 69: 394–399.

Kunze, W. 2014. Technology Brewing and Malting. 5th revised English ed. (translated by Pratt, S.) VLB Berlin: 960 p.

Ladousse, G. 1962. Vinification continue et automatique. Vignes et Vins 115: 11–13.

Lagarde-Pascal, C.; Charpentier, E.; Diéval, J.-B.; Vidal, S. 2019. Méthode électrochimique pour la mesure en temps réel des polyphénols au cours de la vinification. Rev. des Œnologues 173: 41–44.

Low, L.L.; O'Neill, B.; Ford, C.; Godden, J.; Gishen, M.; Colby, C. 2008. Economic evaluation of alternative technologies for tartrate stabilisation of wines. Int. J. Food Sci. Tech. 43: 1202–1216.

Moller, N.C. 1975. Continuous measurement of wort/beer extract in a fermenter. MBAA Tech. Quart. 12(1): 41–45.

Nègre, E. 1949. Procédé original de fermentation continue. Le Progrès Agr. et Vit. 132: 313–325.

Nègre, E. 1967. Le point actuel sur la vinification continue. Le Progrès Agr. et Vit. 84: 511–524.

Nordestgaard, S. 2015. SIMEI 2015 – Wine, olive oil and decanters. Aust. N.Z. Grapegrower Winemaker 624: 66–68: https://www.awri.com.au/wp-content/uploads/2019/02/Nordestgaard2016-SIMEI.pdf

Nordestgaard, S. 2019. AWRI Vineyard & Winery Practices Survey, May: www.awri.com.au/survey

Nordestgaard, S. 2020. Wine History Posters: https://wea.org.au/archives/wine-history-posters

Peynaud, E.; Guimberteau, G. 1967. Vinification continue mise au point oenologique. Connaissance de la Vigne et du Vin 3: 128–157.

Potter, R.A. 1984. The Brimstone process - past, present and future - Part I. Lee, T.H. (ed.) Proceedings of the 5th Australian wine industry technical conference, Perth, WA, 29 November – 1 December 1983. Urrbrae, SA: The Australian Wine Research Institute: 293-298.

Roubert, J. 1970. In: Équipement viticole. Vignes et Vins 196: 9–23.

Sablayrolles, J.M.; Barre, P. 1989. Pilotage automatique de la temperature de fermentation en conditions œnologiques. Sci. Aliments 9(2): 239–251.

Sablayrolles, J.M. 2009. Control of alcoholic fermentation in winemaking: Current situation and prospect. Food Res. Int. 42: 418–424.

Saller, W. 1958. Control of cold fermentation. Am. J. Enol. Vitic. 9: 41–48.

Semichon, L. 1926. Nouveau procede de vinification par fermentation continue. Rev. de Vitic. 65(1671): 21–27, (1672): 41–43, (1673): 53–59, (1674): 71–79.

Shrake, N.L.; Amirtharajah, R.; Brenneman, C.; Boulton, R.; Knoesen, A. 2014. In-line measurement of color and total phenolics during red wine fermentations using a light-emitting diode sensor. Am. J. Enol. Vitic. 65(4): 463–470.

Stassi, P.; Rice, J.F.; Munroe, J.H.; Chicoye, E. 1987. Use of CO2 evolution rate for the study and control of fermentation. MBAA Tech. Quart. 24: 44–50.

Stassi, P.; Goetzke, G.P.; Fehring, J.F. 1991. Evaluation of an insertion thermal mass flowmeter to monitor CO2 evolution rate in plant scale fermentations. MBAA Tech. Quart.28: 84–88.

Vialatte, G. 1979. Stabilisation des vins en continu vis à vis du bitartrate de potassium. Rev. Française d'Œnologie 16(73): 67–71

VinPilot 2019. VinPilot Brix: https://vinpilot.com/en/vinpilot-brix-en

Willig, M. 1950. Wine now made continuously. Food Ind. 22: 1184–1185.

Wilson, L. 2018. Practical oxygen management in the winery: https://s3.amazonaws.com/wea-website-files/2018_WineEng_SA/Yalumba+-+Luke+Wilson+-+Practical+Oygen+Management+in+the+Winery+-+Oxygen+Management+Forum.pdf

Zimberoff, L. 2016. Napa's fermenting your wine with submarine technology: https://wired.com/2016/01/how-to-make-wine

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