# Beyond Baumé rounds and tank dips

In this first of two articles on tank instrumentation, AWRI Senior Engineer **Simon Nordestgaard** presents results from 2021 winery trials of tank pressure and radar sensors for automatic measurement of ferment density and liquid volume.

## Introduction

In wineries, ferments are usually tracked by manually collecting samples from tanks and testing them in the laboratory. The volume of juice or wine in tanks is also usually measured manually. A tape measure with a floating weight on the end is used to measure the distance from the top of the tank to the liquid, and a corresponding volume for that tank is then read from a 'dip table'. These processes for ferment and volume tracking work but are not optimal. Live data from in-tank sensors would improve oversight of operations, allow fermentation to be controlled based on fermentation rate, and could facilitate enhanced automation of other winery operations in the future. It would also reduce vintage labour requirements.

The concept of using in-tank sensors for tracking fermentations and volume is not new. It has been trialled for decades but only adopted to a very limited extent (see Nordestgaard 2020 a,b). Now though, there is more interest from wineries, sensor suppliers and start-ups than ever before. It is just a matter of time before in-tank measurements of ferment density and volume become routine in large wineries.

## Technology options

### Level and volume

The two main options for level measurement in tanks are pressure sensors and radar. Pressure sensors work on the principle that higher liquid levels exert a greater pressure at the bottom of the tank (the pressure exerted also depends on the density). Radar works by measuring the time of flight of a radar beam from the top of the tank down to the liquid and up again. For both techniques, the level can then be automatically converted to a volume using an electronic dip table.

### Density

Decreasing density is used to track the conversion of grape sugars to ethanol and carbon dioxide during fermentation, since higher sugar solutions have a higher density. It is typically measured with laboratory hydrometers or hand-held density meters and is commonly expressed in Australia in units of °Baumé.

There are several techniques that can be used to determine density directly in-tank. Some work by measuring a different parameter (e.g. carbon dioxide flow) and then back-calculating the current density based on the initial density measured in the laboratory and the fermentation equation. Others use equipment such as tuning forks, tilt and pressure sensors to determine the current density without needing to know the initial density. Tuning-fork style sensors work on the principle that liquid density is related to the liquid's natural frequency. Free floating tilt hydrometers are an option that has been quite successful in the home-brewing market. They have a centre of mass not aligned with their centre of gravity and therefore tilt to differing extents depending on the density of the liquid they are floating on (Baron and Bryant 2016). A pressure sensor allows the determination of the density if the level is known, since $P = \rho gh$ (where P is pressure, $\rho$ is density, g is gravity and h is level). If two pressure sensors are used, the density can be determined without even knowing the liquid level, since the difference in pressure between the two sensors relates to the known difference in sensor installation heights. Furthermore, since the density is now known, the liquid level can then be calculated using the pressure measured by one of the pressure sensors. This is a convenient arrangement that has long been used in other industries (e.g. minerals processing).

## Technologies trialled in 2021

Pressure sensors were the primary technology trialled in 2021. One 228 kL dual purpose white fermenter/wine storage tank was fitted with

Endress+Hauser FMB50 diaphragm pressure sensors (1.2 bar-g range, with ±0.1% high accuracy calibration and a flush-mount installation) at three different heights. While only two pressure sensors are needed to determine both density and level, three sensors allowed some investigation of the influence of installation location. An Endress+Hauser FMR62 radar was also fitted to this tank to allow a comparison of level measurements made by pressure and radar.

Multiple white and red fermenters and yeast culture tanks were also fitted with Winegrid WP1100 fermentation monitors. These devices also calculate density and level based on dual pressure measurement. They measure the pressure at two different heights by blowing a very small amount of air through two tubes of different lengths. A similar approach is used on small fermenters at UC Davis (Clos de la Tech 2013).

The general formulas used for density and height calculation from pressure measurement are shown in Figure 1. Density measurements were corrected to a standard temperature of 20°C based on tables for the density of water at different temperatures, as is commonly performed for laboratory measurements.

## White ferments

White ferment density and level were accurately measured using two diaphragm pressure sensors or the two-tube bubbler-type pressure sensor. Diaphragm pressure sensors installed 2-5 m apart gave accurate density data (Figure 2), with readings very similar to each other and to laboratory density measurements.

## Why you need two sensors even if you are not interested in level

Measuring level might not be seen as critical while tracking fermentation. Therefore, some suppliers have tried to track fermentation progress with a single pressure sensor after an initial measurement of level. The problem with this strategy (along with those that attempt to back-calculate density from $CO_2$ flow or refractive index) is that it assumes that there are no major volume additions or removals during ferments. In large logistically complex wineries this is often not the case. For example, fresh juice was added towards the end

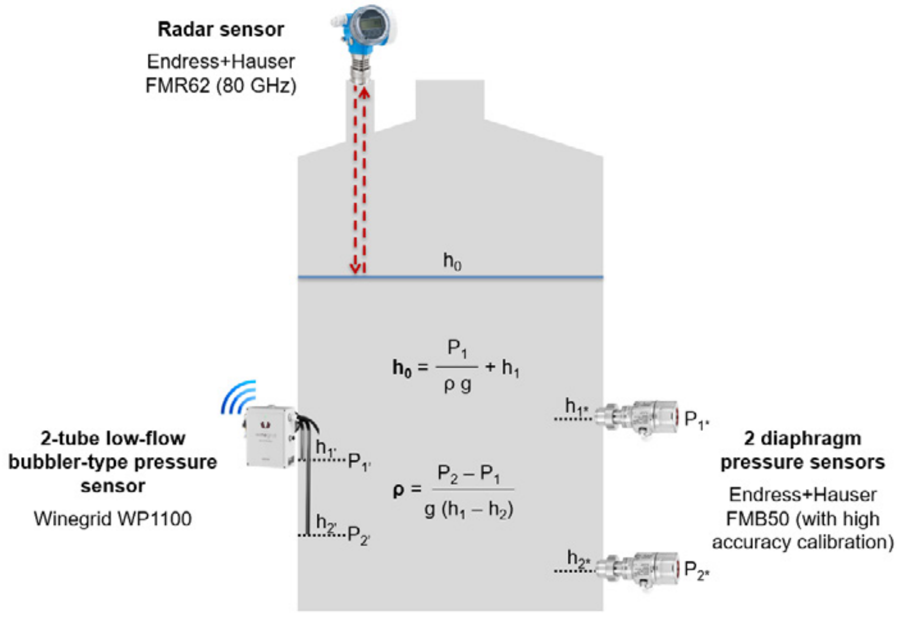


Figure 1. Density and level measurement technologies trialled in 2021

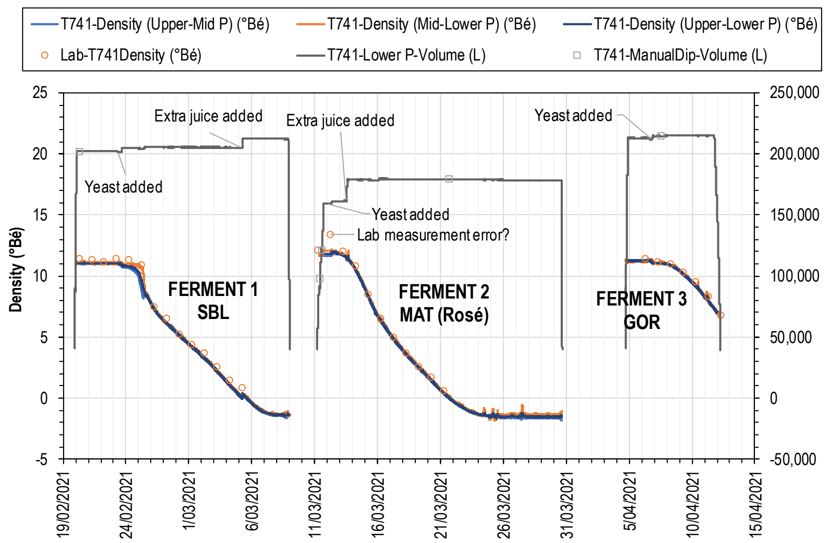


Figure 2. Fermentation density and volume tracking for three different ferments, with dual diaphragm pressure sensors compared with laboratory density measurements and manual dips (228 kL tanks, Lower P is 1 m, Mid P is 3 m and Upper P is 6 m off the rear floor, see Figure 6) (SBL – Sauvignon Blanc, MAT – Mataro, GOR – Muscat Gordo Blanco)

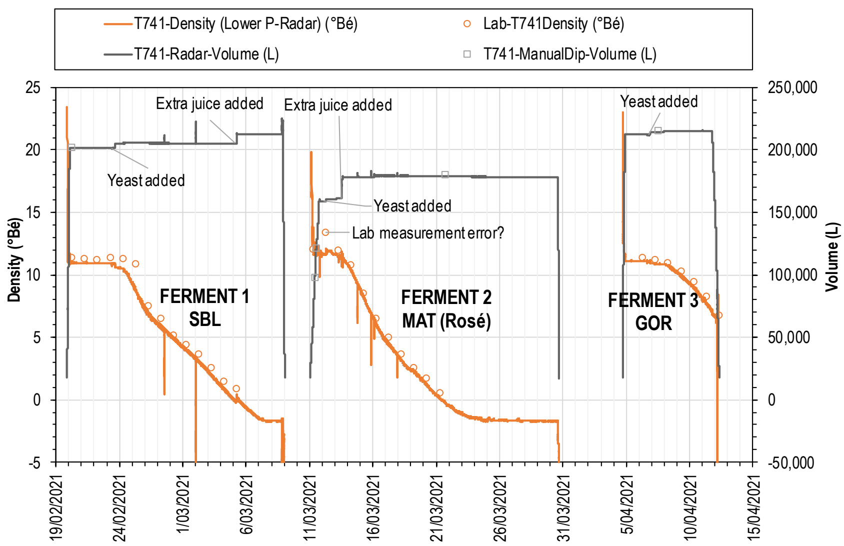


Figure 3. Tracking ferments using a combination of radar and a single pressure sensor compared with laboratory density and manual dips

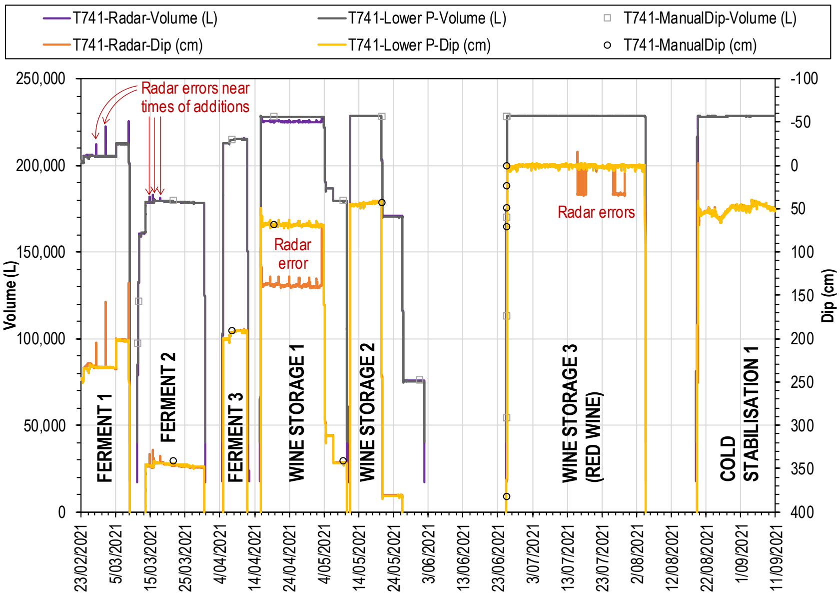


**Figure 4. Comparison of level and volume measurement using two pressure sensors, radar and manual dips**

**Figure 5. Radar positioned on an extension tube to allow level measurement up to tank brim without obstructing the tank lid**

of Ferment 1 (Figure 2). This occurred because a small batch of grapes were processed and this tank was the best option to put the resulting juice. With the two pressure sensors it was possible to independently track both the increase in level and density resulting from the addition of this fresh juice. With a single pressure sensor, the apparent result would have just been a larger increase in density, unless a manual correction for volume was made. Similarly, in Ferment 2, extra juice was added after the ferment had already been inoculated with yeast and therefore likely after any initial measure of volume or density would have been made. A single pressure sensor is therefore not a robust approach and could often lead to confusion.

An alternative to using two pressure sensors is to use a combination of a single pressure sensor and a radar level sensor. This option was also trialled, and while it allowed accurate independent tracking of density and level, there were some short-term disturbances associated with errors in radar level measurement (Figure 3).

## Radar vs two pressure sensors for level/volume measurement

Pressure sensors and radar were trialled for level measurement during both ferments and wine storage (Figure 4). Both worked reasonably well, but as mentioned earlier, there were some erroneous spikes in radar measurements that did not occur with the pressure measurements. The timing of these spikes corresponds with the timing of addition of ferment nutrients. These were added into the top of the tank and may have interrupted the radar beam and/or induced foaming that interfered with the radar. There were also some other more sustained radar errors after vintage during wine storage. For example, during Wine Storage 1, the radar was measuring the second reflection off the liquid surface rather than the first. These errors could likely be managed by refining the radar instrument settings. As the wine went into the tank for Wine Storage 1 it appeared that level based on pressure measurement may have overshot initially, but close inspection of both the radar and pressure data suggests that the pressure-derived level measurements are correct and the drop in level after filling is a consequence of the wine's density increasing slightly due to cooling after it went into the tank.

Level measurement based on pressure sensors has some practical advantages over radar. Pressure sensors can be installed on the side of the tank, while a radar must be on the top of the tank, putting it at risk of being damaged by staff performing operations above the tank. In this trial, an extension tube was fitted to allow radar measurement up to the brim of the tank without obstructing access to the tank lid (Figure 5). This was designed according to the manufacturer's guidelines, but it may still have contributed to some of the radar errors. Radar is also typically more expensive than using pressure sensors – commonly it might be possible to buy two pressure sensors for the same price as one radar unit. In addition, two pressure sensors allow density measurement, not just level. One concern that has been raised about diaphragm pressure sensors is that tartrates may form on them and cause inaccuracies. This issue was not experienced in the trial tank in 2021, even during one cold stabilisation at -4°C. More tests are needed to understand how much of an issue this is. The risk is likely greatest in cool climates, such as New Zealand, that have high tartaric acid levels.

## Pressure sensor location

When using pressure for level measurement, it is only possible to measure down to where the lowest pressure sensor is installed. On that logic, at first glance the best installation point for the lower sensor might be close to the floor at the front of the tank. In addition to the diaphragm pressure sensors installed on the rear of the tank for this trial, the winery already had an existing similar pressure sensor (Endress+Hauser FMB70) at the front of the tank close to the bottom (Figure 6b) that was installed around 15 years earlier. This sensor showed some disturbances in pressure that did not occur for the pressure sensors installed higher in the tank (Figure 7). Like the radar errors (Figure 4), some of these anomalies occurred around the time of ferment nutrient additions. A pump-over is sometimes used to mix in additives. It is possible that the action of pumping liquid out the valve next to the bottom pressure sensor may have caused the

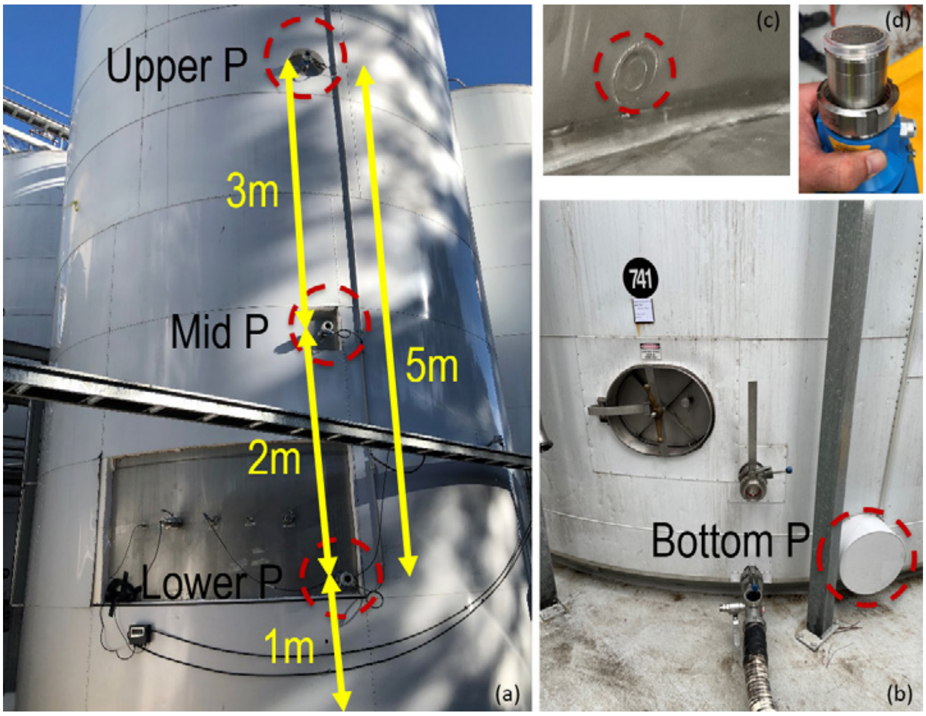


**Figure 6. Pressure sensor installation locations (a) on the rear of the tank for the trial, and (b) existing 15-year-old pressure sensor on the front of the tank near the floor covered by insulation, (c) inside view of the bottom sensor, and (d) view of one of the new pressure sensors prior to installation.**

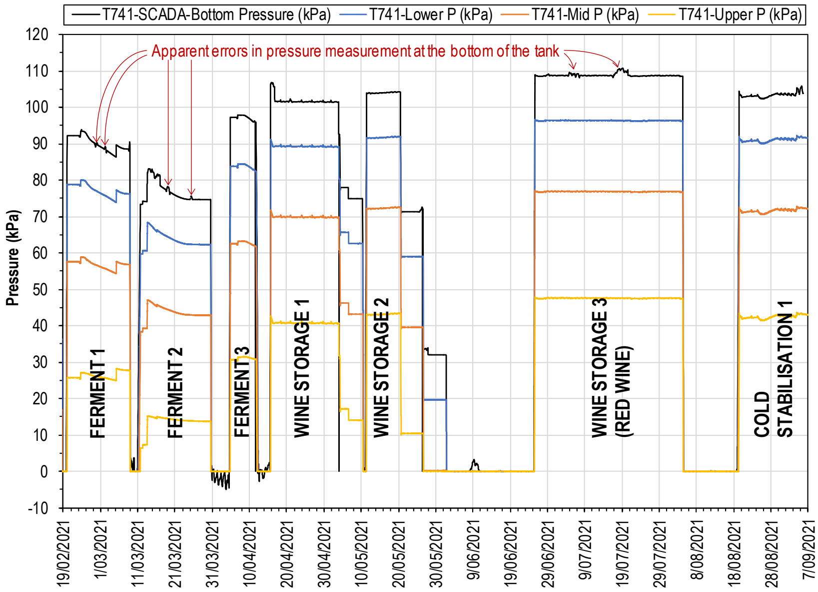


**Figure 7. Raw pressure measurements at different locations in the tank**

disturbances. There were also some unusual results during storage of red wine. On that occasion, no operation was recorded that could have caused the error. Possibly, it may have related to lees or tartrates. Another possibility is that the response of the sensor has declined with age. In 2022 vintage trials a new sensor will be installed at the bottom of the tank to understand whether it is the sensor or the position that is responsible for these discrepancies. The robustness of sensors over long periods of time is an important consideration in the adoption of automation.

For now, the most conservative installation point for sensors is off the floor on the rear of the tank as used in this trial. A 2 m gap between the two pressure sensors was sufficient to obtain accurate results using these pressure sensors with a high accuracy calibration. Further trials in 2022 will investigate if sufficient accuracy can still be achieved

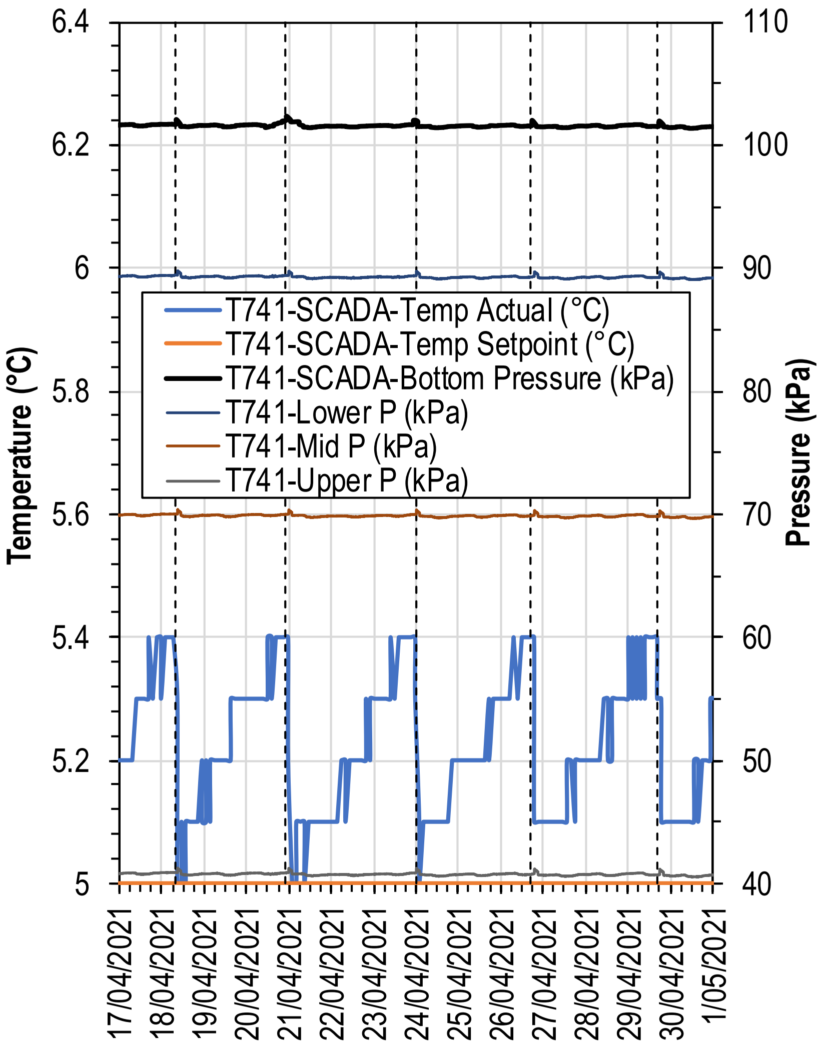


**Figure 8. Influence of agitation during cooling on pressure measurements (dashed line indicates when cooling with agitation is occurring)**

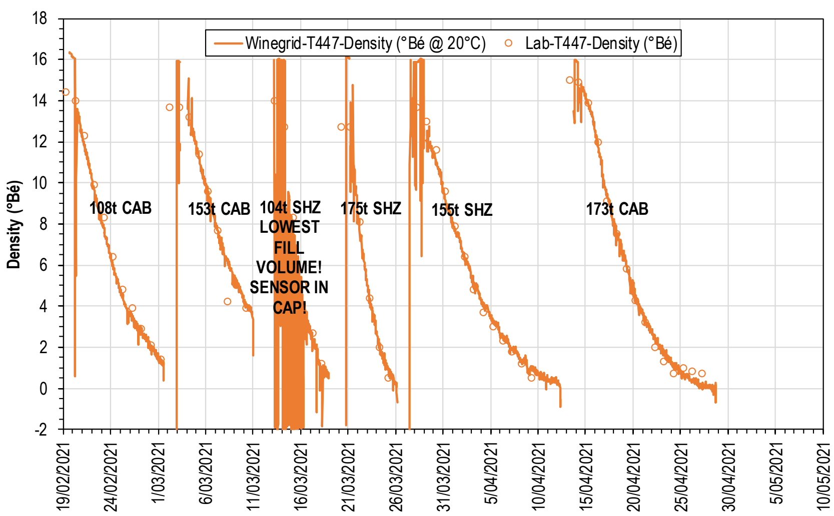


**Figure 9. Density measurements (orange line) of red ferments in a 228 kL tank with Winegrid WP1100 sensor (no screen) located ~3 m from the bottom compared with laboratory density measurements (open circles) (CAB – Cabernet Sauvignon, SHZ – Shiraz)**

if sensors are brought to 1 m apart – installation and maintenance will be easier the lower and closer they can be together.

Irrespective of position, agitation does appear to temporarily affect pressure results. During wine storage at 5°C, the cooling and agitator were set to come on when the temperature increased by 0.5°C. This caused slight temporary increases in pressure at all locations in the tank while the agitator and cooling were running (Figure 8).

## Red ferments and managing skins

In trials of red ferments, Winegrid WP1100 low-flow bubbler-type pressure sensors were installed on several red fermenters and generally worked well. With no screen over the sensor tubes, the data at the very start of the ferment was noisy, but once the cap had risen the density results compared well with laboratory data (Figure 9). With the addition of a well-designed screen, reasonable results were even obtained before the cap had risen (Figure 10).

The ferments that did not work well nevertheless tell a useful technical story. The third ferment in Figure 9 gave poor results because the sensor was partially in the cap – this was the lowest fill volume used for that tank. With a screen fitted, the results for a similarly low fill level for the third ferment in Figure 10 were better but still not excellent. It is therefore important that in red fermenters, sensors are placed relatively low down in tanks, well below where the skin cap may be. The density data for the fifth ferment in Figure 10 is clearly offset downwards from the true density. On inspection, it was found that the sensor had rotated slightly reducing the distance between the two pressure legs and resulted in low density readings. When the problem was identified and the sensor was straightened near the end of the ferment, the density immediately increased to meet the trend of the laboratory data. This sensor rotation also occurred at other sites. It is recommended in the future that the Winegrid WP1100 sensor fitting should include some style of key-way to prevent it from rotating.

A range of different screen designs were used in trials of the Winegrid sensors in red ferments. Screens that had to

be affixed to the inside of the tank had originally been supplied but were impractical because someone needed to get inside the tank to fit or clean them. New screens were therefore designed that could be attached to the sensor and therefore inserted or removed from the tank through a fitting together with the sensor (Figure 11). The narrower screen designs tended to lose accuracy after around two ferments without cleaning, while a larger screen design was able to last more than four ferments without cleaning. Future installations of this style of sensor in red ferments should feature a fitting on the tank approximately four inches in diameter, which should be able to accommodate a relatively large cylindrical screen that may be able to last a whole vintage without specific cleaning.

While trials of the Winegrid WP1100 sensor in red ferments mixed by pump-overs were generally successful, trials at a winery using Pulsair and a narrow sensor screen design (Figure 11a) gave poor results. The errors were not just when the measurement and pulses coincided, and may therefore have been a consequence of screen design and fouling of those screens caused by Pulsair mixing. It is possible that with a larger fitting and a larger screen the issue would be resolved, but this remains to be shown.

So far, no trials have been performed with diaphragm sensors in red fermenters. It is hypothesised that they should work once the cap has risen above both sensors, but this remains to be proven and will be the subject of 2022 trials.

It should also be noted that while dual pressure sensors (whether they be diaphragm or bubbler-type) allow measurement of the level in white

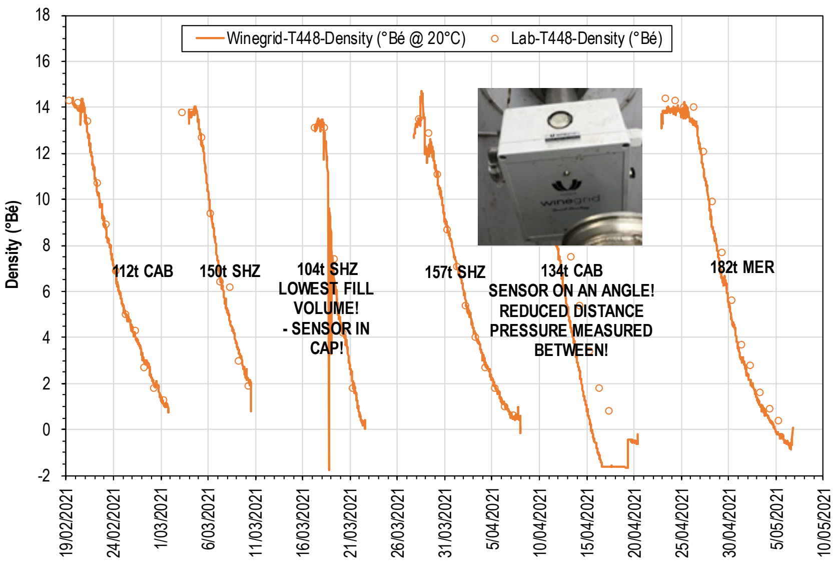


**Figure 10. Density measurements (orange line) for red ferments in a 228 kL tank with a Winegrid WP1100 sensor (with screen) located ~3 m from the bottom compared with laboratory density measurements (open circles) (MER – Merlot)**


**Figure 11. Integrated screens on the Winegrid WP1100 sensor that are able to be installed and removed via the tank fitting: (a) design that fits through a 50 mm DIN fitting, (b) design that fits through a 4-inch BSM fitting and (c) this same design disassembled**

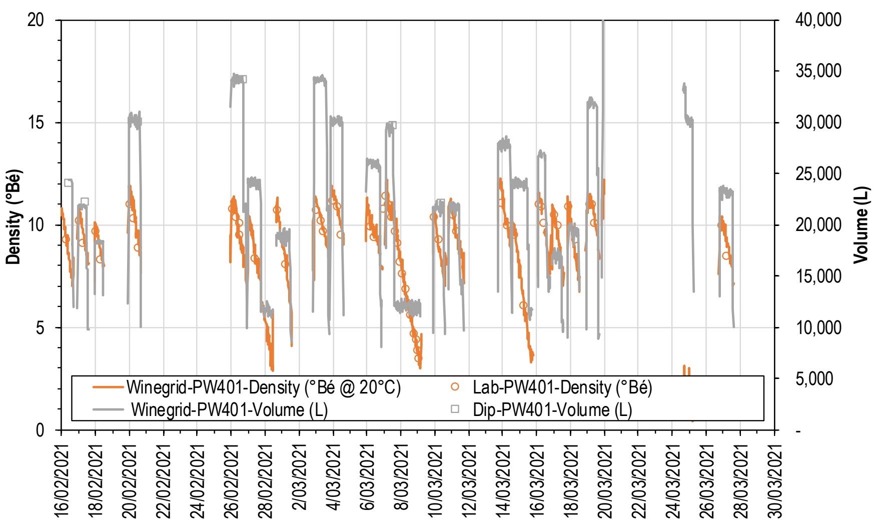


**Figure 12. Comparison of yeast culture tank density and level measurements between Winegrid WP1100 sensor and laboratory density measurements and manual dips**

ferments they cannot measure level in red ferments because the cap has been expanded by carbon dioxide gas and the true level will therefore be higher than the pressure readings suggest it is.

## Yeast culture tanks

In larger wineries, yeast culture tanks are typically sampled and tested very often and they therefore present a good labour-saving opportunity for in-tank sensor adoption. A Winegrid WP1100 sensor was successfully able to track culture density and level in a culture tank (Figure 12), despite the constant air-bubbling and frothing that occurs in these tanks (Figure 13). Some wineries regularly perform yeast counts to track cultures. It is possible that if density is measured often enough by in-tank sensors that the rate of change in density may be a sufficient surrogate for yeast activity and could therefore replace many time-consuming yeast counts. Again, this remains to be proven and further experiments are planned in 2022 to study this hypothesis further.

## Diaphragm vs bubbler pressure sensors and wired vs wireless

The Endress+Hauser diaphragm pressure sensors and the Winegrid low-flow bubbler type sensors both generally worked well in the applications in which they have been trialled so far. They are both installed via fittings on the side of the tank. This is a more robust installation method than sensors that are installed via the top lid of the tank, float in the tank, or rely on external sampling loops. One downside of the Winegrid sensors was that they could only handle a head of 6 m, so in large tanks they needed to be installed inconveniently high on the tank. However, a model that can handle a larger head will be introduced shortly. These sensors also introduce bubbles of air. The quantity is very small and would have no impact on fermentations, but it may be problematic if it were used too often to measure level during the storage of finished wines. An inert gas could be used instead of air to mitigate this concern but may add complexity to the system. Measurement also takes a few minutes. This is not an issue for ferment control (most people currently only measure density twice per day), but it would be a problem for applications such as measuring level to control pumps

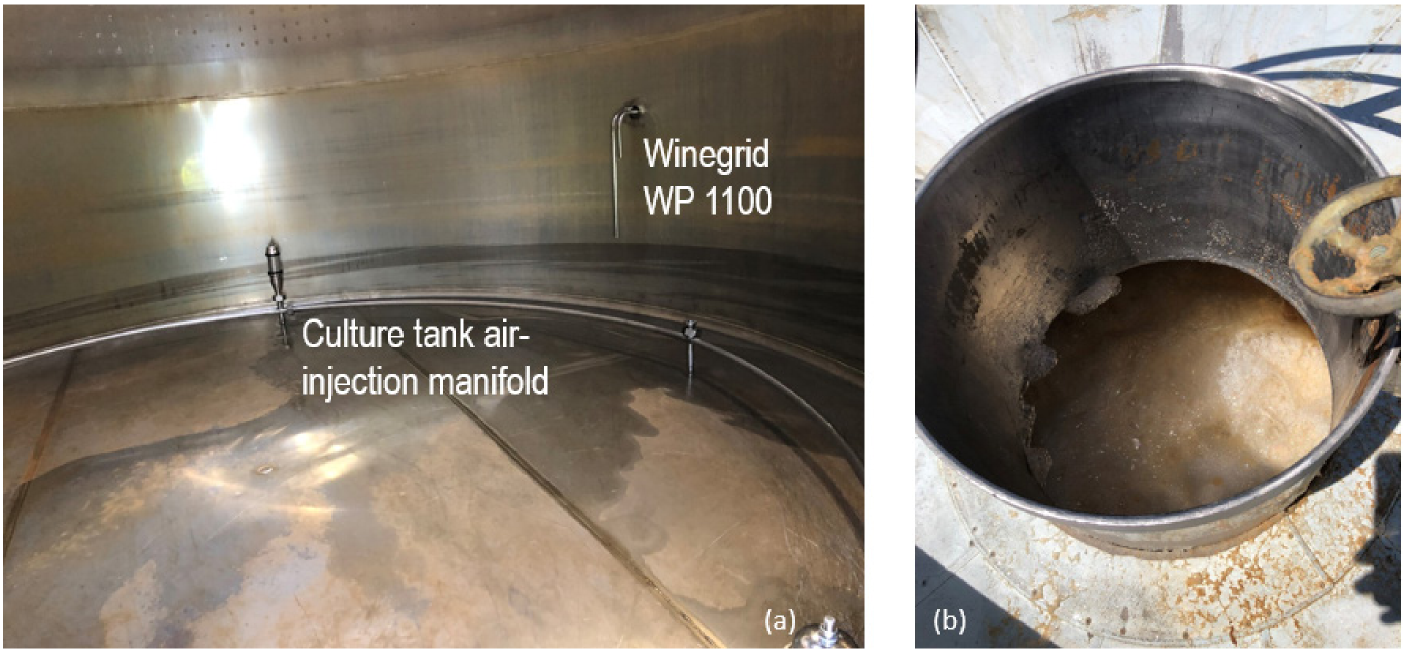


**Figure 13. Yeast culture tanks showing, (a) air-injection manifold and Winegrid WP1100 sensor, and (b) culture tank froth**

during tank topping. For these reasons, two diaphragm pressure sensors would seem to be the best approach for white fermenters that will also be used as storage tanks. The Winegrid sensors do have the advantage that only one hole needs to be cut in the tank, not two. The best solution for red fermenters is still to be determined. While the Winegrid WP1100 sensors have been proven to work in red fermenters, diaphragm pressure sensors have not yet been tested and will only be trialled in this application in vintage 2022.

The Winegrid sensors use LoRa wireless communications. This made them very easy to setup. A Winegrid LoRa gateway was plugged in at the winery and connected to the internet (a 4G modem was used for these trials). The data could then be viewed online. The more traditional diaphragm pressure sensors were more complex to install and needed an industrial electrician and a lot of wiring (IO-link wiring may have been an easier approach and will be pursued in 2022 trials). The disadvantage of a wireless approach using LoRa though is that while it is good for monitoring, the measurements are typically not frequent enough for automated process control. Winegrid may also offer a wired version in the future.

## Conclusions

Ferment density and level were accurately measured by pressure measurement at two heights in tanks using either two pressure sensors or a low-flow bubbler-type pressure sensor with two tubes of different lengths. More trials are planned for 2022 to build on the lessons learned in 2021, including further trials with red fermenters and replication of 2021 white ferment trials to build confidence in the technique. In-tank sensors for measuring density and level have much potential. In addition to automating some manual processes, they will provide wineries with greater oversight of operations and allow them to make faster and better decisions.

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