Australian Government

Australian Grape and Wine Authority

The Australian Wine Research Institute

Evaluating the viability of process sensor technologies for measurement of sugar levels during fermentation

FINAL REPORT to

AUSTRALIAN GRAPE AND WINE AUTHORITY

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1. Abstract

A number of commercially available process sensors for monitoring Baume in wine fermentations were subjected to field trials during 2015. Results show that some sensors can be successfully applied in a process environment, but no single sensor technology can provide reliable and accurate Baume data for white and red ferments. Financial modelling shows that the implementation of in-line sensors could provide a payback period of nine months for very large wineries but up to three years for smaller wineries. Potential benefits of introducing these sensors include reduced labour resources, lower analytical costs, fewer quality downgrades and increased ferment tank capacity.

2. Executive Summary

Commercial winemaking operations devote a significant amount of resources to ferment management. Current management practices are resource intensive and have significant sampling and analysis requirements across the vintage period. In general, this involves at least daily monitoring of Baume levels and subsequent testing and/or tasting of samples.

In-line sensors offer a significant opportunity for the wine industry to reduce labour and analysis costs and exert greater control of ferments, by having immediate access to more ferment data in a more effective manner and in a more accessible form. It is also possible to reduce the frequency and impact of slow or stuck ferments. This should result in improved product consistency, better resource utilisation, greater throughput, reduced risk of quality downgrades and lower costs.

Viable and commercially available sensor options for wine fermentation were investigated, including those trialled successfully in other industries, and the most promising technologies were evaluated through vintage 2015 field trials to assess accuracy, reliability and robustness. A cost benefit analysis was also carried out to determine potential payback for implementation of these technologies in a process setting.

Results show that there is currently no single sensor technology that can provide reliable and accurate Baume data for monitoring both white and red ferments on a commercial scale. There are, however, promising technologies that can be successfully applied in a process environment, if certain considerations are made for their physical integration into existing fermentation infrastructure and for dealing with the challenges of the notoriously heterogeneous fermentation media.

A cost benefit analysis shows that the implementation of these sensors could potentially provide a payback period of nine months for very large wineries but up to three years for smaller wineries. Potential process impacts from the introduction of ferment sensors include reduced labour associated with ferment sampling, lower analytical costs, fewer product downgrades due to minimisation of stuck/sluggish ferments and increased ferment tank capacity.

The AWRI would like to acknowledge the following organisations for their support and resources provided in the undertaking of this trial:

- Petaluma Wines, Woodside (SA)
- De Bortoli Wines, Griffith (NSW)
- St. Hallett Wines, Tanunda (SA)
- Yalumba Wines, Angaston (SA)
- Endress & Hauser Australia
- Psitec/Vinwizard (Australia)
- Integrated Sensing Systems (USA)
- VitalSensors Technologies (USA)/Hach Pacific

3. Background

In-line sensor technologies are commonplace in many industries, especially in the food and beverage sector, such as soft drink and beer production. Various parameters, including sugar, are monitored in-line, typically using refractometry or hydrometry. In wine production, these methods are typically employed off-line in a laboratory, but cannot be easily applied directly in the process environment because of the heterogeneity of the ferment matrix and issues associated with sensor fouling. In addition to this, wine production facilities require a much greater number of fermenters than typically required in other related processing industries, leading to increased up front capital requirements.

Previous investigations carried out by the AWRI identified that red fermentations, in particular, pose a number of problems in relation to in-process measurement; most notably sugar measurement by density, due to the impact of internal pressure that builds underneath the cap due to carbon dioxide evolution. Published studies (Jones, 2002; Mazarevica et al, 2004; Ranasinghe et al., 2013) concerning the use of in-line sensors for monitoring wine ferments have shown that measurement of important parameters in active ferments shows promise, but that effective capture of representative samples and maintenance of sensor cleanliness are key issues that needed to be resolved in a process environment.

Although most of these studies considered direct measurement of the fermentation medium, it is possible to monitor fermentation progress via the production of carbon dioxide gas (CO_2) (Daoud and Searle, 1990; Bendtsen, 2000). However, this brings additional process considerations and challenges and realistically only provides an indicative means of tracking sugar depletion indirectly. Some of the most promising studies have been carried out using amperometric sensors that utilise sugar-sensitive enzymes bound to an inert substrate (Leca and Marty, 1997; Katrlik et al, 1998; Mello and Kubota, 2002). Although the effectiveness of these sensors has only been proven on a small/lab scale, they potentially provide the most interesting and promising application for cost-effective monitoring of the wine fermentation process.

Wine fermentations are variable by their nature and prone to a range of issues that can result in stuck or sluggish ferments, generation of reductive aromas and excessive use of resources. To address this, fermentations are typically monitored through at least daily measurement of a number of parameters, including Baume. The wine industry has had limited success in applying in-line sensors to their production processes, primarily because most measurement technologies cannot cope with the complexities of process environments, such as that found in wine ferments and the capital cost of applying sensors to a large number of fermenters can be prohibitive.

The use of in-line sensors to monitor progress of wine ferments would allow measurements to be taken more frequently, status to be assessed instantly and provide potential for data to be delivered more effectively to winemakers, allowing them to make informed process decisions more frequently and in a much shorter timeframe. This could result in lower resource costs, improved productivity, reduced energy usage and reduced risk of problematic ferments.

In general, equipment suppliers do not invest in generating rigorous technical data on the performance of in-process sensors in wine applications and are unaware of the practical implications and limitations of using these in a winery process setting. This leads to general scepticism of the capabilities of these technologies and low adoption rates across the industry. An independent assessment of the capabilities and reliability of such sensors is required to evaluate their viability for future use in monitoring wine fermentations and the process-related barriers to implementation that producers are likely to face if these technologies are embraced.

4. Project Aims and Performance Targets

The project aimed to identify commercially available sensor technologies for monitoring Baume in white and red ferments and to carry out proof-of-performance testing of the most promising technologies in a commercial process environment. The key objective of the study was to identify those technologies that show the greatest potential for implementation in wine fermentations and evaluate likely benefits and payback for wine producers. The study considered process-related barriers to introduction, technical considerations for effective sampling and methods for maintaining a clean environment for the measurement sensor.

The project had two clear stages:

1. Identify commercially available sensors that have the greatest potential application in wine fermentations. Key criteria included: measurement accuracy, reproducibility, specificity, detection limits (range), physical robustness and proof of effective use in commercial-scale processes.

2. Undertake proof-of-performance testing in commercial-scale ferments and identify key technical considerations for effective implementation of selected sensor technologies.

Performance targets for the study are defined below.

Table 1: Outputs and activities for ferment sensor trial

	Output and Target Date	***Activity***
FY1A	Establish working group and document key technical considerations and barriers. (Dec 2014)	• Establish working group to review scope of sensor application, review performance requirements and address likely barriers to implementation. • Identify effective sample and data capture methods, including engineering considerations and methods to capture and communicate process data. • Consider other process parameters

		which might be measured concurrently by the sensor(s). • Identify ways to maintain cleanliness of the sensors and effective cleaning protocols to protect their shelf-life.
FY1B	Identify suitable sensor technologies for field trials and key assessment criteria for evaluation. (Dec 2014)	• Identify commercially available sensors and identify specifications and process ratings. • Establish evidence of use and commercial performance of sensors in other industries. • Review cost of sensor technologies and associated auxiliary equipment. • Identify up to three sensor technologies for field testing with industry partners. • Define key sensor assessment criteria for field trials, including measurement accuracy, test frequency, effectiveness of sample capture and impact on the process.
FY1C	Complete performance testing on selected sensor technologies. (June 2015)	• Carry out proof of performance testing on commercial-scale ferments with at least two sites during vintage. • Gather and analyse reference analytical data to validate performance of selected sensors. • Document technical barriers and issues associated with use on commercial scale ferments.
FY1D	Technical report issued on sensor evaluations (June 2015)	• Summarise results from field trials and identify key technical considerations for effective implementation of selected sensor technologies. • Identify data communication and transfer methods to effectively capture the process data in a meaningful and immediately usable form. • Identify and prepare suitable communication documents, such as e-Bulletins and fact sheets.

5. Method

5.1 Approach and Methodology

Two individual sites were nominated for field trials. At each trial site, the following approach was used:

- Application of multiple sensors to the same vessel during ferment to obtain direct side-by-side comparisons for performance.
- Capture of representative ferment samples directly from vessels for reference analysis at least one daily.
- Continuous capture of ferment data from both field trial sites from multiple sensors.
- Where possible, collection of sensor data through a local data logging unit or local display, to allow real-time monitoring of ferment data.
- Reference analysis of samples using industry standard defined laboratory methods.

5.2 Collaborators

Initial consultation was carried out with a number of wine producers who indicated a desire to implement in-line ferment sensors. The two individual sites nominated for field trials were:

- Petaluma Wines, Woodside (SA)
- De Bortoli Wines, Griffith (NSW)

Some of the producers consulted have previously invested some time and effort in investigating ferment sensors and offered some insight into some of the technical and process barriers for effective assessment and subsequent implementation. Two of these were included in ongoing communications and consulted regularly throughout the period of the study:

- St. Hallett Wines, Tanunda (SA)
- Yalumba Wines, Angaston (SA).

5.3 Technology equipment supply

Where possible, access to the desired measurement sensors for trial purposes was secured on a short-term loan basis directly with equipment suppliers. Sensor installations were carried out according to supplier guidelines, with the aim of integrating the sensors as closely as possible with available infrastructure, utilities and processing capability. All installations were subject to relevant site safety and inspection tests prior to use. All sensors evaluated are manufactured from food-grade materials and certified as having no measurable impact on wine product quality.

Some suppliers expressed a strong interest to attend the field trial sites to assist with installation and commissioning. During the commissioning process, some equipment suppliers were available to train users on sensor operation and maintenance, prior to the start of vintage 2015.

5.4 Performance criteria

To assess performance during vintage trials, the following aspects were considered, where possible:

- Ease of installation
- Likely cost of installation
- Transportability (between tanks)
- Ease of keeping sensor clean (during and after ferments)
- Ease of keeping tank clean (need to be removed to clean tank)
- Set-up/calibration requirements
- Sensitivity to matrix (solids, bubbles etc.)
- Ease of collecting data
- Integration with a programmable logic controller (PLC), including data correction and/or conversion
- Ongoing costs (maintenance, power etc.)
- Accuracy of measurement (vs reference method)
- Measurement integrity (repeatability, range, etc.)
- Applicability across ferment types/styles
- Additional output parameters (potential)

6. Results/Discussion

6.1 Technology review

The following criteria were considered to identify viable commercial sensors that have the greatest potential application in wine fermentations:

- Measurement accuracy
- Reproducibility
- Specificity
- Detection limits (range)
- Physical robustness
- Proof of effective use in commercial-scale processes

Table 2 below summarises the sensors that were identified as potential candidates for field trials. All of these were deemed to be commercially available at a price-point that could be considered realistic for implementation across multiple tanks in a winery. Of these, the following were removed from consideration for subsequent trials:

- Deltapoint/Micropilot sensor combination – although a combination of hydrostatic pressure and level (volume) indication has merit, the overall complexity of the installation would be high and indicative costs were deemed to be at the high end of the acceptable range.
- Proline t-mass sensor – this sensor is capable of measuring the mass-flow of exhaust gases, but the sensor is not specific to CO_2 and would therefore require additional configuration and/or measurements to be made for integration into the fermentation process.
- The Biosensor identified is not a fully developed commercial product at this stage and is still in the process of being validated for effective use in fermentations.

The remaining four sensors were selected for field trials and the individual equipment suppliers were contacted to arrange access to the sensors.

Table 2: Matrix of potential in-line sensors for 2015 vintage field trials

Sensor	Supplier	Measurement principle	Sampling point	Temp Sensor	Indicative cost (per unit)	Difficulty	Cleaning/ Resistance
Liquiphant Vibrating Fork	Endress & Hauser	Density	In tank	Extra Required	$2-3K	Moderate	High corrosion resistance.
Deltapoint S	Endress & Hauser	Hydrostatic pressure	In tank	None	$3K combined	High	Appears to be corrosion resistant, but need to check.
Micropilot	Endress & Hauser	Volume (level)	Tank header	None		High	No product contact. Need to ensure protection from CIP chemicals.
Fermetrol	Psitec	Osmotic potential	In tank	Integrated	$2K	Moderate	Not suitable for caustic use. Would have to be removed.
MicroLDS	ISSYS	Mass flow (liquid)	By-pass loop	Integrated	$1K	Low	Deionised water, IPA recommended. Likely need removal from vessel for CIP.
VS-3000	Vital Sensors	Mid-IR absorbance	By-pass loop	Integrated	$3K	Moderate	High temp and chemical resistance (caustic).
Proline t-mass	Endress & Hauser	Mass flow (gas)	Tank header	Integrated	$3K	Moderate	No product contact. Need to ensure protection from CIP chemicals.
Biosensor	OptiEnz	Enzyme response	By-pass loop	None	$1-2K	Low	Need to check - likely need removal from vessel for CIP.

CIP: Clean in place

The technologies short-listed for 2015 vintage field trials were:

- Liquiphant M vibrating fork (Endress & Hauser)
- Fermetrol probe (Psitec/Vinwizard)
- Micro-LDS (Issys)
- VS-3000 (Vital Sensors)

6.2 Overview of sensor technologies

6.2.1 Liquiphant M vibrating fork

This sensor measures the density of the fermentation medium it is immersed into. A tuning fork is excited at its resonance frequency and its oscillating frequency changes when immersed into liquids and when the density of that liquid changes. This change is transformed into a signal that is then converted, along with available temperature data, into a direct Baume reading. The conversion is carried out using the attached Density Computer, which can accommodate inputs from up to four different sensors at one time.

6.2.2 Fermetrol probe

This sensor uses a semi-permeable water responsive polymer to determine the osmotic potential due to the concentration of sugar in the grape juice (must). The polymer is permeable to alcohol and responds to increases in alcohol content as it is produced during ferment by expansive pressure in the polymer. The sensor uses a highly stable ceramic membrane to convert the expansive pressure of the polymer to an electrical signal. Generated Baume output can be displayed locally on the unit or fed into a control system.

6.2.3 Micro-LDS

This sensor measures mass-flow using the Coriolis effect. A small hollow silicon tube is the sensing element. Vibrating at very high frequencies, the sensor detects changes in fluid density as a shift in

tube frequency. An integrated platinum Resistance Temperature Detector (RTD) provides direct measurement of fluid temperature. The measured density is converted to Baume, based on published data tables. Output data can be displayed locally or fed into a control system. A solenoid valve and filter mechanism can be attached to the tank sampling port to physically collect the ferment sample for measurement.

6.2.4 VS-3000

The VS-3000 is a solid-state sensor that measures concentrations in fluids directly via a mid-infra-red detector. This measures the absorbance of the liquid medium and this measurement can be translated into a concentration using pre-defined calibration algorithms in the attached VS-300 Sensor Management Station. The unit has the potential to measure the following in fermentations:

- Alcohol
- CO_2
- Specific gravity
- Baume

6.3 Individual site installation: Petaluma

At Petaluma, the following measurement sensor technologies were installed and evaluated:

1. Liquiphant vibrating fork (including Density Computer)
2. Fermetrol probe
3. Micro-LDS mass-flow sensor

The vibrating fork and Fermetrol sensors were located in a 6.5 kL fermenter vessel through a modified fermenter door panel, with the Micro-LDS sensor mounted in a bypass flow-through stream from the same fermenter tank sampling port. The door panel was removed between ferments, to facilitate the cleaning in place (CIP) regime used at Petaluma, which includes a caustic (sodium hydroxide) rinse. This was primarily to protect the integrity of the Fermetrol probe, which is sensitive to caustic and needs to be stored in water when not in use between ferments.

Output signals from the vibrating fork were collected, along with temperature data from an Endress & Hauser temperature probe mounted in the same door panel, with the attached Density Computer and then fed into a local data logger (Hobo U30 Station) and converted to Baume readings.

The Fermetrol probe has in-built temperature adjustment and a local display for inferred Baume data. The probe requires 4-6hrs equilibration time following juice contact, before an accurate Baume measurement can be taken. The initial Baume has to be entered prior to the start of ferment, to allow accurate measurements to be generated through the fermentation.

Measurements using the Micro-LDS sensor were taken every two hours, via the attached sampling valve (solenoid) and filter, with the ferment being sampled directly via the sampling tap on the same fermenter tank and then diverted to the drain following measurement. A local display unit (tablet PC) was used to collect output signals and convert to Baume readings.

During vintage 2015, the aim was to capture comparative data for the three sensors from at least two separate white ferments. Representative samples were collected directly from the fermenters (via the sample tap just above the door) once daily for reference analysis. A summary of the installation details is provided in Appendix 5.

The installation at Petaluma is highlighted in Figure 1 below.

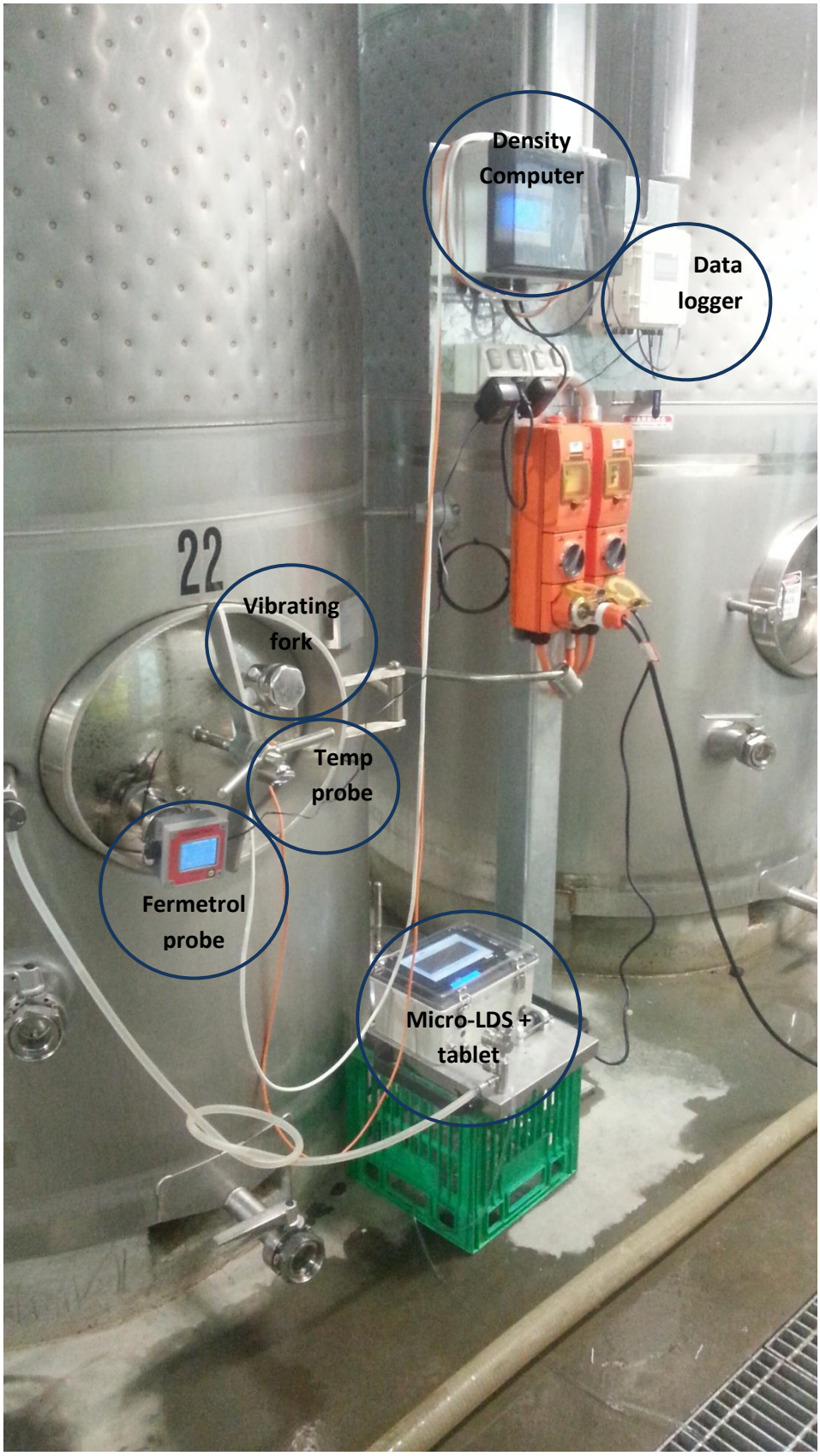


Figure 1. Sensor installations at Petaluma Winery for 2015 vintage trials

6.4 Individual site installation: De Bortoli Wines

The approach at De Bortoli was to install and evaluate the following four measurement sensor technologies in a portable bypass loop configuration (mobile skid):

1. Liquiphant vibrating fork, including Density Computer
2. Micro-LDS mass-flow sensor
3. VS-3000 Mid-IR probe
4. Fermetrol probe

The bypass loop was configured with the following:

- Secure mounting of the sensors in a straight flow-through section of the bypass
- Additional temperature probe to provide local adjustment of ferment outputs
- Positive displacement (mono) pump to control flow rate from fermenter
- Grid-mesh filter (400 micron/40 mesh disk filter) to reduce solids from the flow stream
- Restrictor device (asymmetric pipe reducer), to reduce turbulent flow and bubble incidence in flow stream
- Sampling valve, to remove samples for reference analysis
- Recirculation loop, to return flow stream back to fermenter
- Fixed (local) power source to all sensors
- Local data management station to capture all sensor data and connected display module

The ferment vessel utilised for monitoring was a 200 kL tank fitted with an agitator that was activated on an hourly basis to mix the tank. Pump-overs were also carried out on an hourly basis, providing the process stream for sensor evaluation. The aim with the bypass configuration was to monitor multiple ferments throughout their entirety. Reference samples were designed to be collected twice daily from the bypass stream flow during sensor measurement. It was expected that the pass loop would require flushing with water between ferments, to remove any residual fine solids and maintain clean sensor surfaces. The inlet hose for the bypass loop was initially attached to the upper sampling valve on the fermenter (approx. 3m off the ground), in order to reduce the potential impact from a high loading of grape skins being sucked through the loop.

Baume outputs from the Fermetrol probe, vibrating fork and micro-LDS were fed directly into the local data capture device and displayed through the user interface. The VS-3000 sensor probe has in-built temperature adjustment, with absorbance data fed into the local VS-300 Sensor Management PC to produce real-time outputs for Baume, alcohol and CO_2. These were then fed directly into the local data management device. The VS-3000 sensor needs initial calibration, requiring approximately six data points/samples over at least two ferments (minimum total of twelve samples) prior to use.

Pertinent installation details for the De Bortoli field trial sensors are provided in Appendix 6.

The installation at De Bortoli is highlighted in Figure 2.



Figure 2. Sensor installations at De Bortoli Winery for 2015 vintage trials

6.5 Trial results - Petaluma

6.5.1 Ferment #1

Two ferments were conducted at the Petaluma winery with the three sensor technologies. The first ferment was a Pinot Noir for sparkling base. The ferment volume was 5.7 kL and was conducted in a 6.5 kL tank. The ferment profile is shown in Figure 3, based on the laboratory samples.

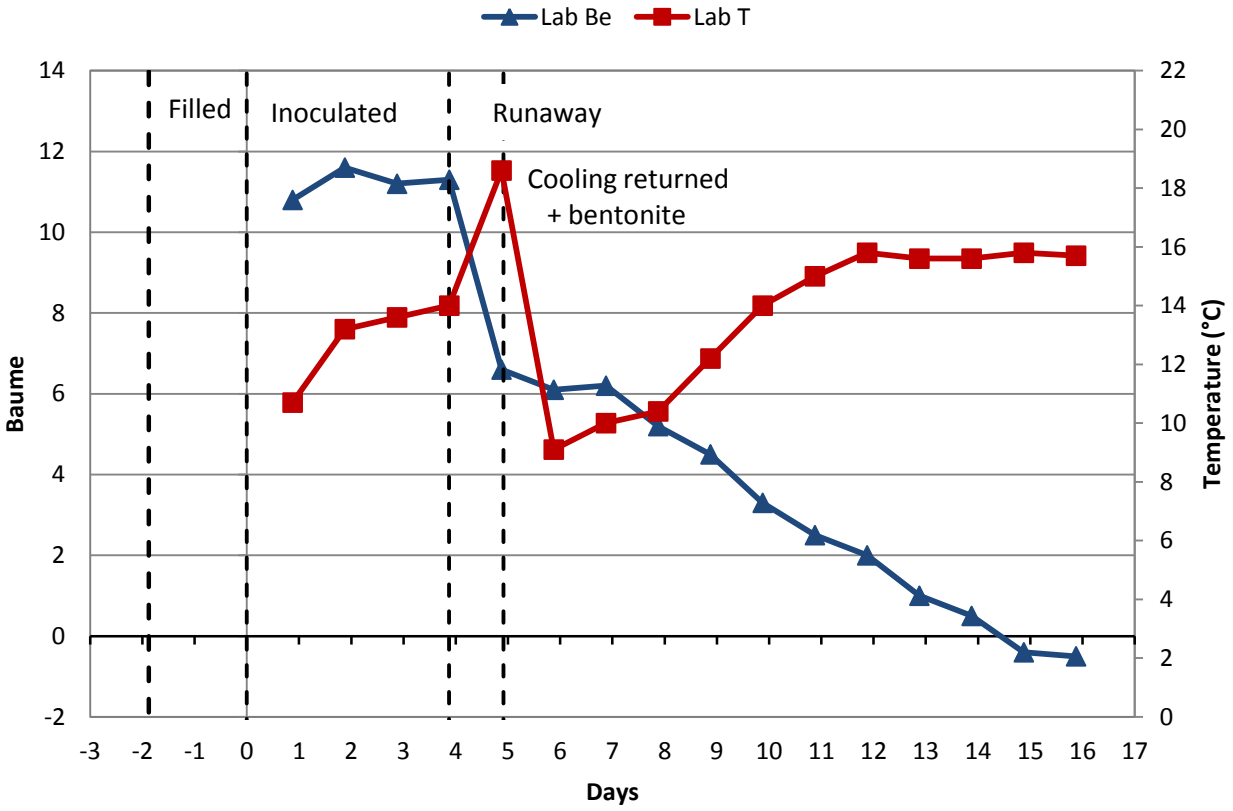


Figure 3. Petaluma ferment #1 reference data

The ferment accelerated out of control for approximately 24 hours due to a faulty solenoid valve on the cooling jacket which was restored on day 5. This accounts for the temperature spike and sudden apparent Baume drop seen on the chart. Bentonite was also added to the tank on day 5, which is standard practice at the winery. This was added through the top of the tank without any mixing. All three sensors experienced different issues with the ferment; each will be discussed individually.

The vibrating fork (Figure 4) exhibited some unusual behaviour at a number of points. Between day 2 and day 4 the reading was quite unstable, oscillating between the high and low defined maxima for the output. After cooling was restored the reading appeared to start tracking the ferment again. Following bentonite addition the reading displayed a constant offset of approximately 4-5 Baume until the end of fermentation.

It was later discovered that the fork had been installed by site staff in the wrong orientation. Correct orientation is for the fork tines to be oriented vertically so that any sediment or grape solids fall through the gap in between. In this instance, the fork had been installed horizontally. It is expected that rising bubbles underneath each of the fork tines caused the unsteady readings seen in the first stage of fermentation, particularly when the ferment was accelerating without any cooling control. The offset seen post-bentonite addition is expected to be the result of dampening due to a small bentonite layer settling on top of the forks.

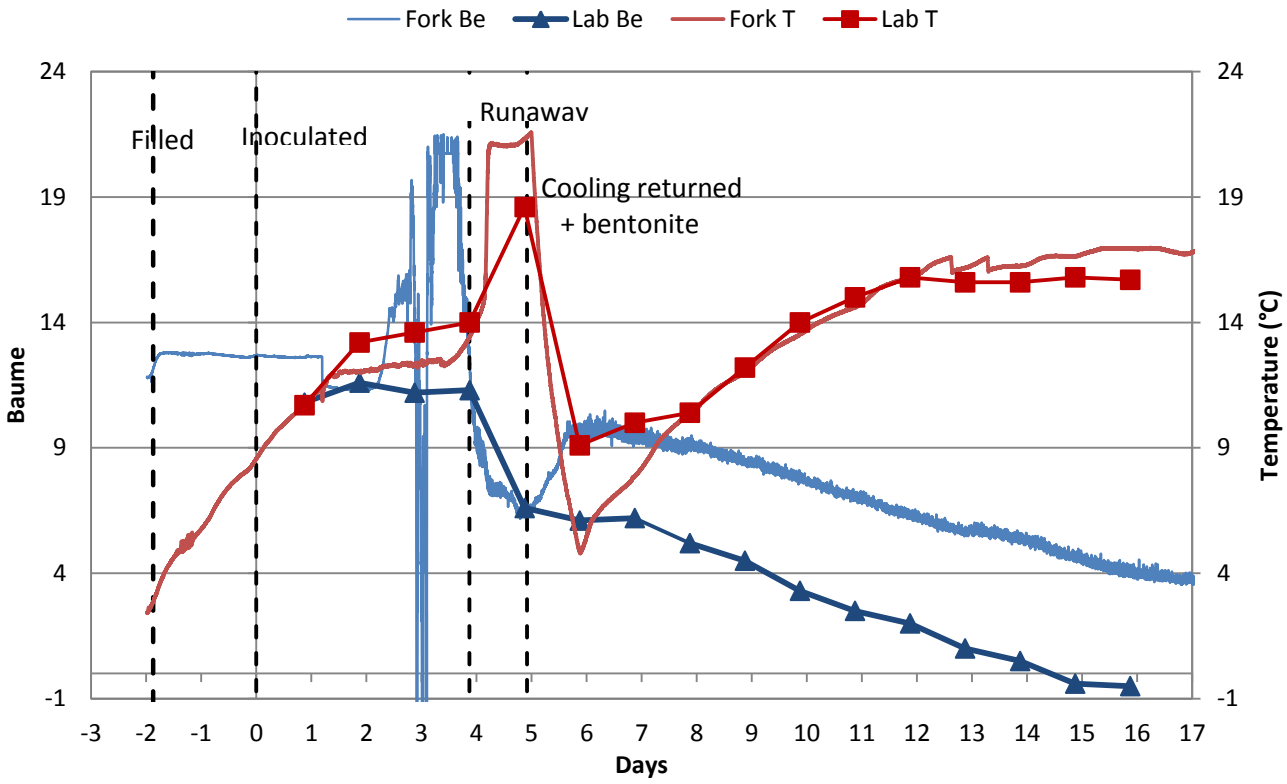


Figure 4. Petaluma ferment #1 vibrating fork

The Fermetrol (Figure 5) suffered from a software issue which prevented the correct storage of data at the correct time intervals. As a result, the sensor did not complete data capture for the first fermentation and the time-spacing of the data is unreliable. The software issues were resolved by the supplier post-ferment.

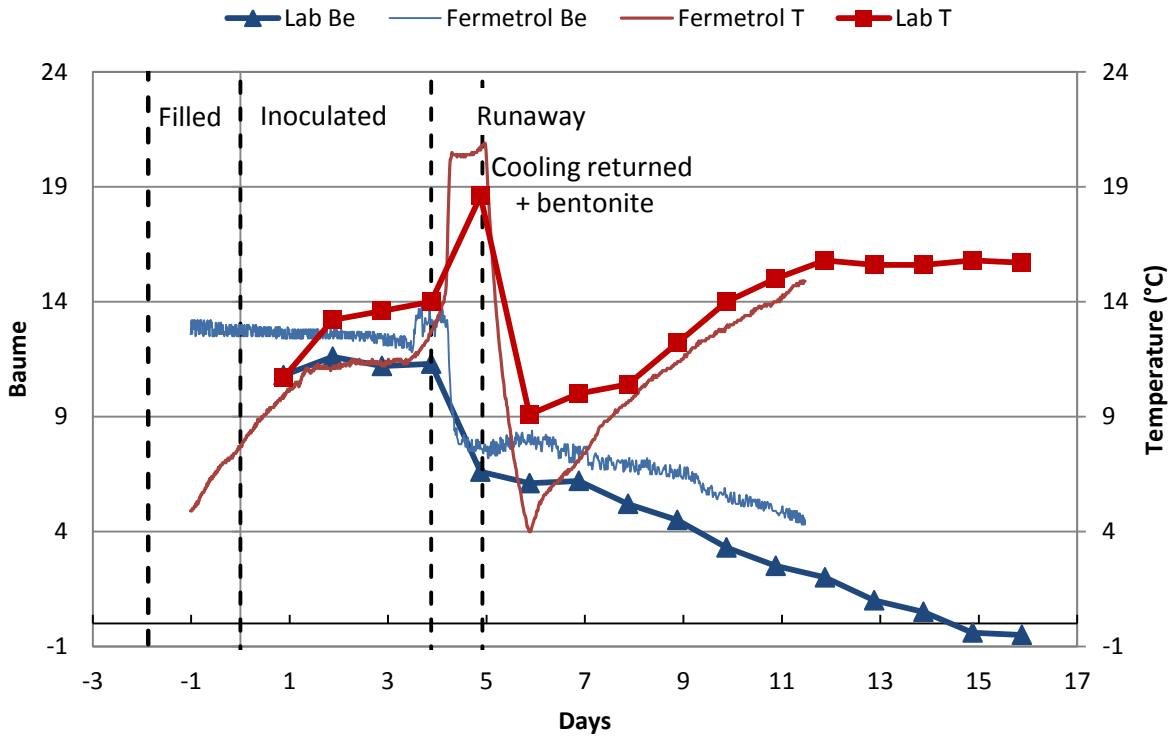


Figure 5. Petaluma ferment #1 Fermetrol

Operation of the Fermetrol was problematic in that it required the user to first input the starting Baume at the beginning of ferment. Any error in this starting Baume, in terms of absolute value or timing, results in the software determining an incorrect endpoint for the ferment, which usually manifests itself as a positive offset after the inflection point on the ferment curve. This can be seen in Figure 5 and has also been seen on a number of ferments from other producers trialling this sensor. This makes the sensor acceptable for measuring the rate of fermentation, but unable to reliably report the actual end point (Baume) of the ferment. Given that one of the key benefits of process sensors in this application is earlier warning of unfinished ferments, this is a significant limitation.

The Micro-LDS (Figure 6) tracked the ferment reasonably well but the reliability of the output data was affected by the long length of tube connecting it to the sample tap. The sensor is configured to open a valve and draw a sample every two hours from the tap. The valve is open for 30 seconds to flush the tube, before sampling for 15 seconds. Under this configuration, it took 3 sampling intervals (6 hours) for wine to travel from the tap to the sensor. While the must was in the tube it was not under the temperature control of the tank and was able to ferment quicker than the must in the tank, which is why the sensor measured a lower result than the tank between day 5 and day 9. An extra sample tap was provided on the unit for cellar hands to take their manual samples, and whenever this was performed, the tube connecting the sensor to the tank was completely flushed, bringing the measured Baume at the sensor more in line with the Baume in the tank. The tube used for this ferment was replaced with one of smaller diameter and shorter length following ferment #1 to alleviate this issue. It should be noted that while the Micro-LDS does record temperature, this is the temperature at the sensor after the sample has passed through the sampling tube and therefore not an accurate representation of the tank temperature.

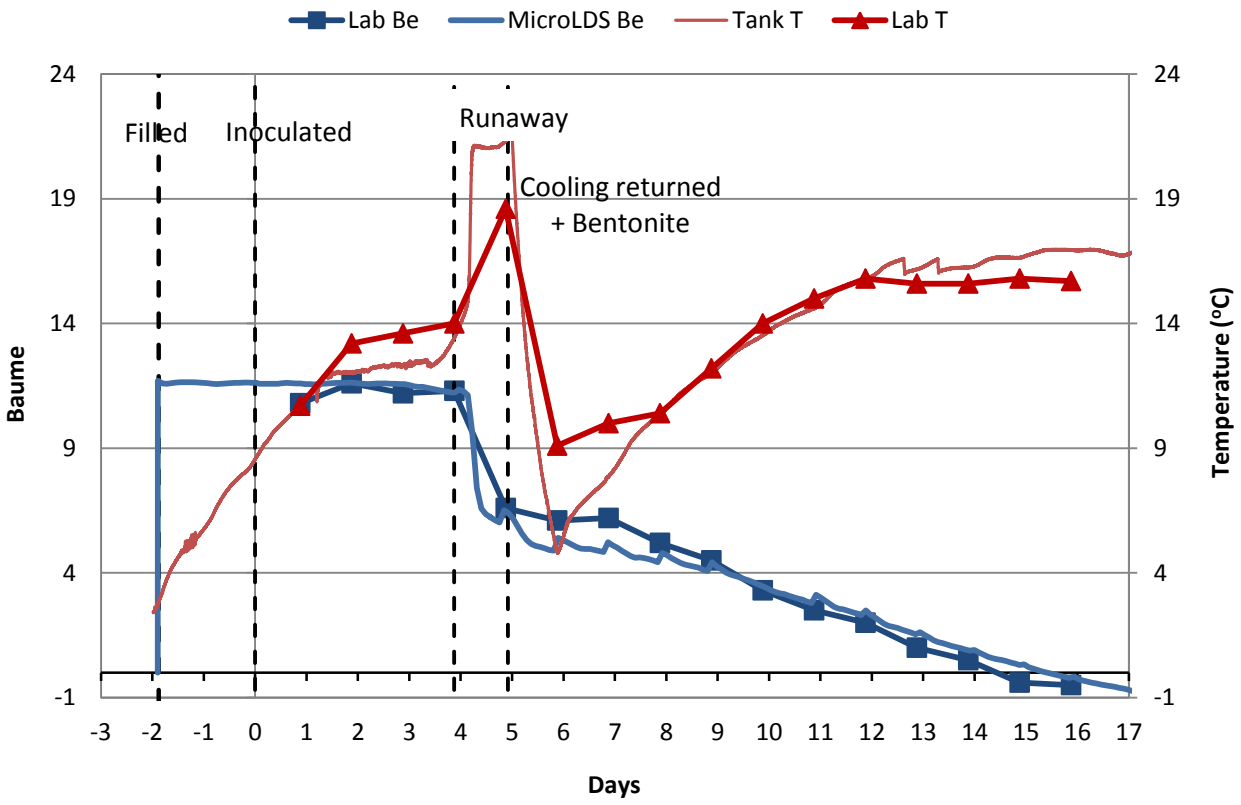


Figure 6. Petaluma ferment #1 Micro-LDS

6.5.2 Ferment #2

The second ferment was a Pinot Gris. The ferment volume was 5.7 kL and was conducted in a 6.5 kL tank. The ferment profile, based on the laboratory reference analysis, is shown in Figure 7. The progression of this ferment was slower than ferment #1. The tank remained on lees for 8 weeks after ferment.

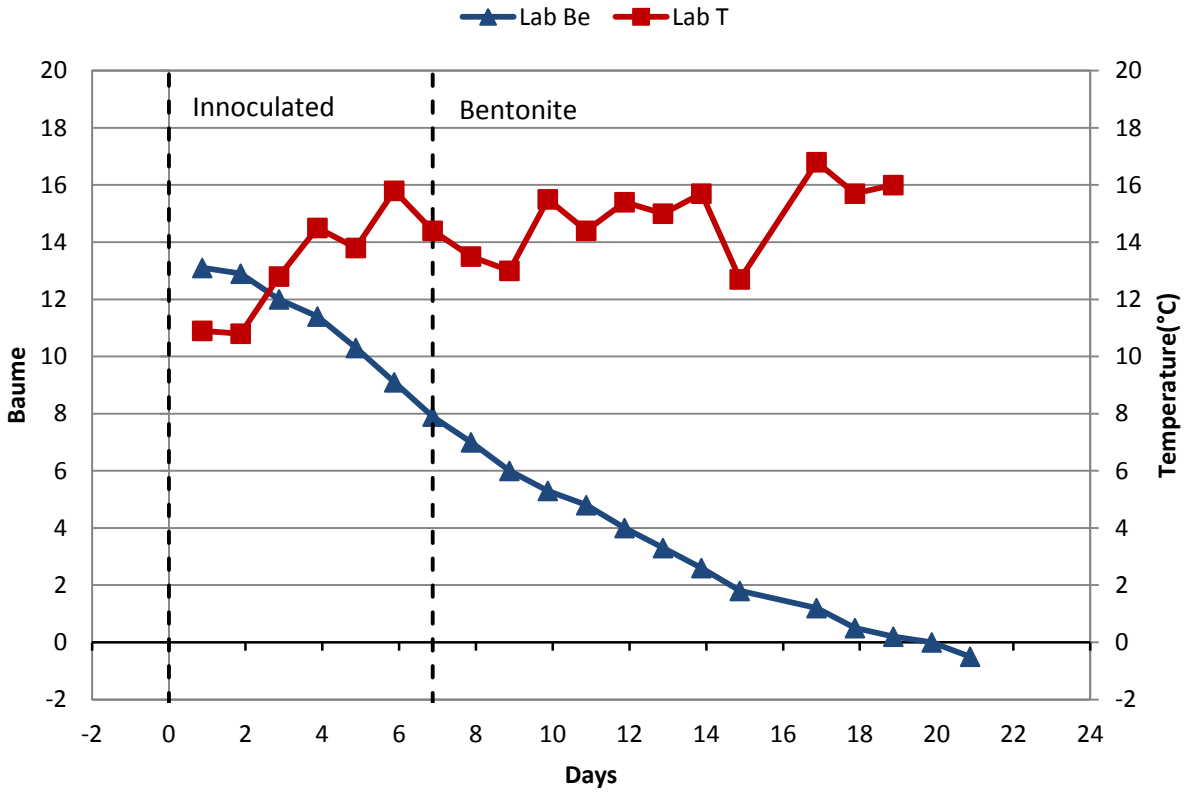


Figure 7. Petaluma ferment #2 reference data

The vibrating fork (Figure 8) again struggled due to the incorrect orientation of the tines. The unstable readings at the beginning of ferment are suggested to be the result of gas build-up under the tines, though it is not known why this did not continue after day 2. The vibration in the fork varied in the order of ~0.5 Be until the addition of bentonite when the signal became more stable. However after bentonite addition, the signal deviated from the lab result and increased exponentially.

It is expected that the increase seen was a combination of bentonite settling on the forks and potentially some tartrate formation during the latter part of the ferment. Significant tartrate build-up was seen on the sensor and all over the tank door when the tank was finally emptied. A layer of bentonite was present under the tartrate crystals which likely provided nucleation sites for the tartrates to form. It is unclear however when the tartrates started to form and whether they impacted on sensor performance during fermentation or only began to grow after completion, during the time on lees. The tartrates were easily washed off of the tank door and sensors with hot water. Images taken of the tank door can be seen in Figure 9.

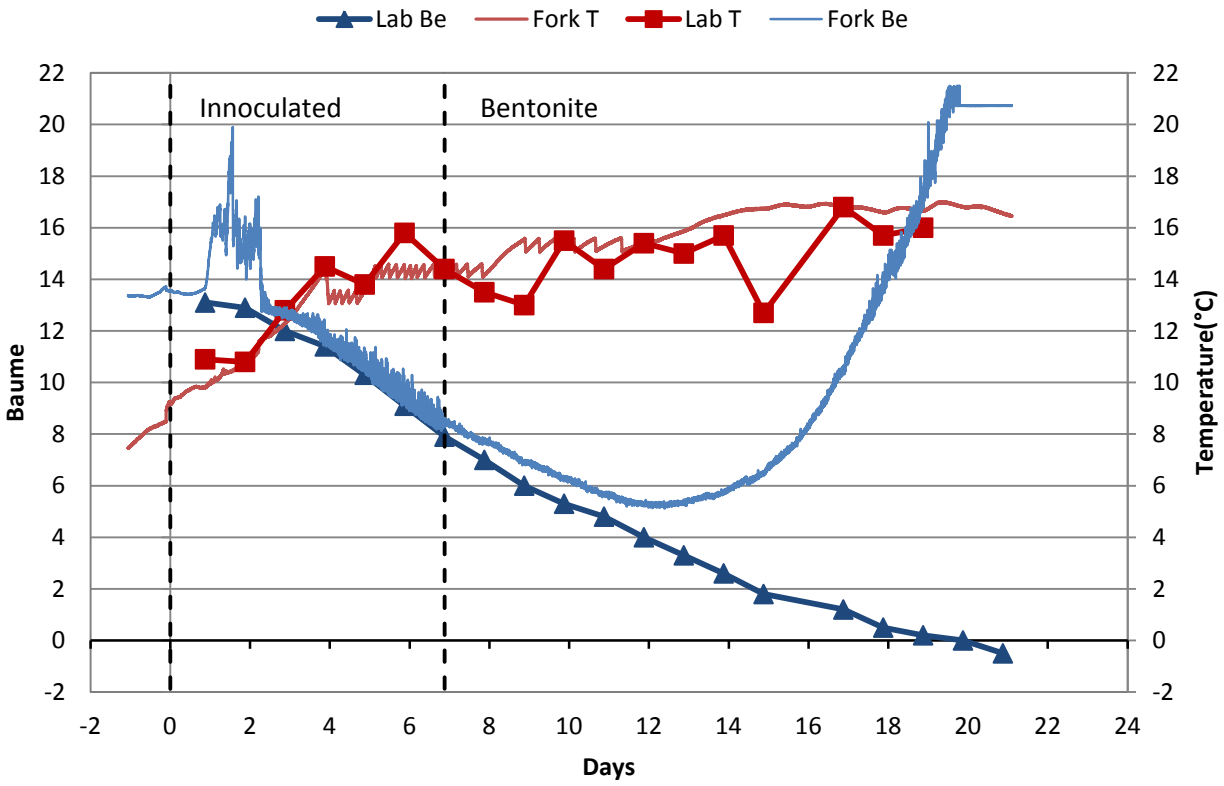


Figure 8. Petaluma ferment #2 vibrating fork



Figure 9. Tartrates on vibrating fork

The Fermetrol (Figure 10) performed much more reliably on ferment #2 following the software update. The sensor tracked the ferment reasonably well, but again failed to measure the exact end-point (Baume) of fermentation, levelling out at around 0.6 Be. In both ferments the Baume entered into the sensor was that measured in the juice by the lab before inoculation. There is some inherent analytical error (uncertainty) in this measurement however, making the operating method of this sensor rather impractical.

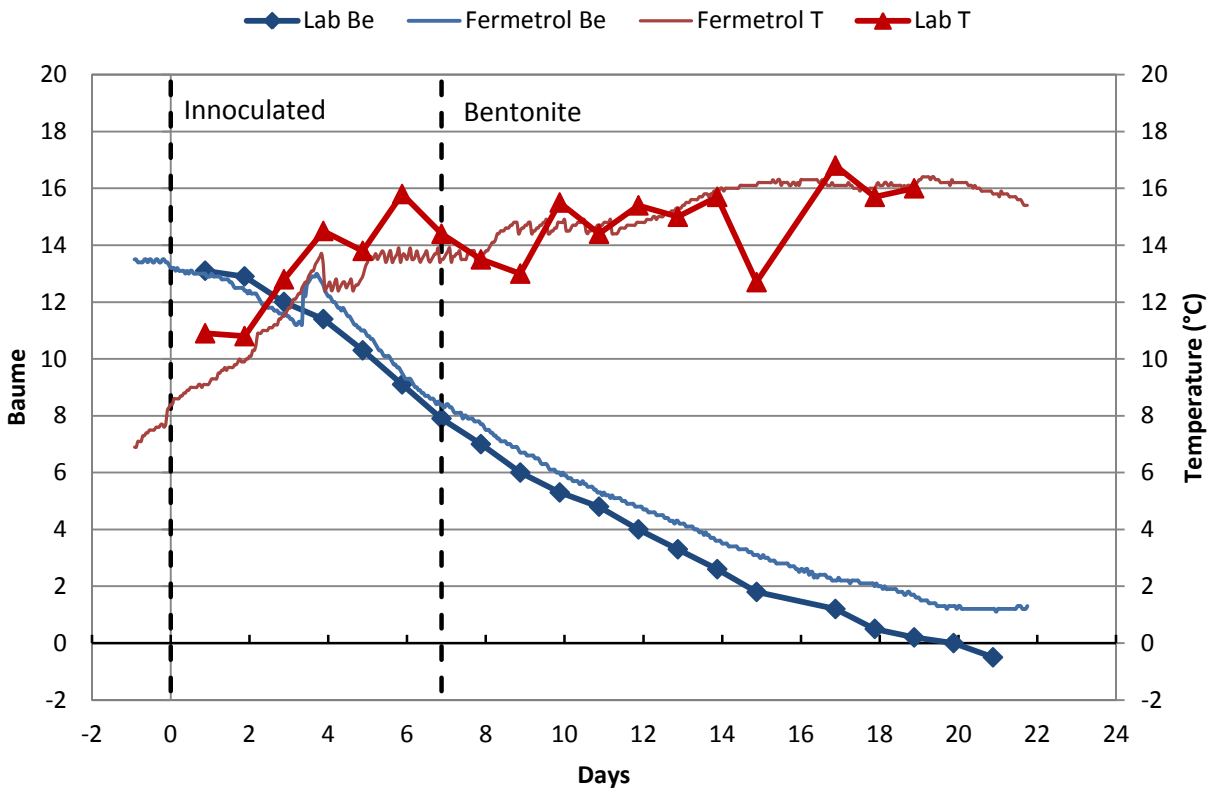


Figure 10. Petaluma ferment #2 Fermetrol

The Micro-LDS (Figure 11) tracked the fermentation much more closely after the tube volume was reduced post ferment #1. This time, however, the sensor suffered from a blockage in the flow path which started around day 12 and blocked completely on day 15. The sensor employs a tiny vibrating silicone tube which draws liquid from a larger bypass loop. A 100 µm filter should exclude any solids which would cause a problem for the sensor; however a blockage still occurred. Both tartrates and microbial growth were found in the filter and sensor flow path after ferment. It is suggested that these crystals/microbes grew inside the sensor rather than breaking through the filter, while flow was stagnant. It is not known which substance grew first and caused the blockage, but once the blockage was formed, it was a good nucleation point for the solids to form. The default sampling interval for the sensor system was set at 2 hours which was, in this case, insufficient to adequately flush the sensor.

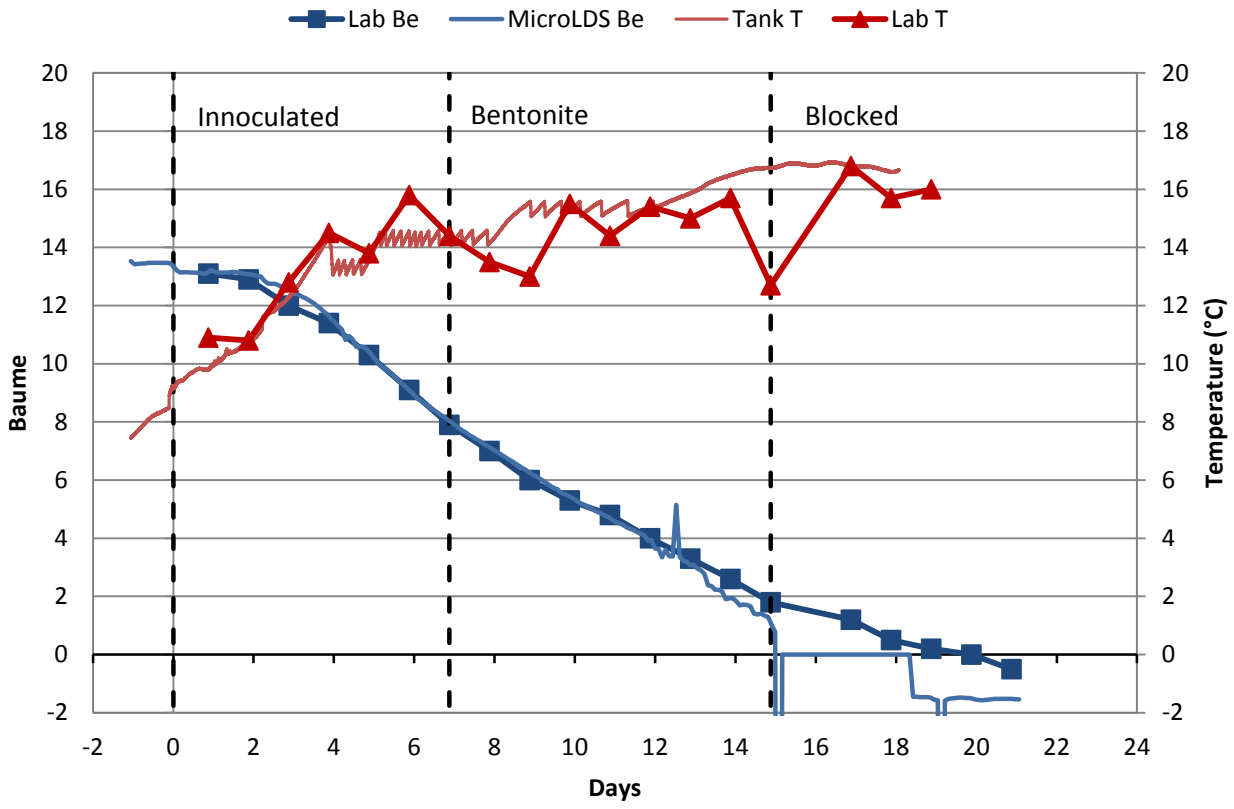


Figure 11. Petaluma ferment #2 Micro-LDS

6.6 Trial results – De Bortoli

The first attempted ferment was on Shiraz must, with a ferment volume of 200 kL. After initial settling, first agitation and yeast addition the bypass flow system was turned on. Initially all devices provided a signal output to the local data management station. Unfortunately, the filter blocked initially as there was a high volume of grape skins coming through the bypass line.

The micro-LDS sensor provided a Baume reading, but it appeared that flow through the sensor had stopped within a few minutes as density became invariant. The pressure at the 5 mm orifice (where the micro-LDS was installed in a secondary loop) was <20 psi, so it was concluded that blockage within the sensor was likely due to the high solids loading (the first filter was already catching skins and seeds).

At this point, the unit was moved to the other interstice of the tank and moved the bypass inlet connection to a lower point on the fermentation tank (below the level in the tank where the skins loading was apparently high) in the hope of reducing the amount of solids coming through the line. The diameter of the orifice plate was increased to 10 mm to reduce the pressure drop over the micro-LDS secondary loop from 35 psi to 2-3 psi and the solenoid valve was adjusted to give 50-75 ml/min through the sensor.

Unfortunately, the issue with grape solids blocking the bypass loop appeared to cause a pressure/flow spike through the micro-LDS and the unit stopped functioning. The relocation of the bypass inlet on the tank did not make a difference to the solids loading and the main filter blocked again. On completion of the first ferment and inspection of the bypass unit, the three remaining sensors were observed to be free from fouling by grape solids. The filter for the sensor was full of a fine residue paste, presumably fine grape particulates.

The micro-LDS sensor and main filter were then removed for a second ferment, to see if the other sensors could operate with a high solids stream coming through the bypass line. The system ran at just over 20 psi on discharge in this configuration initially, with the other three sensors providing Baume signal outputs during operation. However, after several hours, the high grape solids loading in the bypass blocked the inlet line from the fermentation tank and the pump stopped working.

It was concluded that the micro-LDS was not suitable for this type of application. The need to incorporate a small orifice or similar, to minimise the flow through the sensor, rules this device out practically. This sensor did not perform well in this particular trial, although it did perform adequately in the Petaluma trial, where the sensor was exposed to the much cleaner medium of a white wine ferment.

The vibrating fork and VS-3000 sensors were able to continuously provide output signals to the data management station when the bypass loop was functioning correctly, prior to the line blockage, even when the flow stream did contain a reasonably high volume of grape solids. Unfortunately, it was not possible to collect enough process data from these ferments to allow a meaningful evaluation of the sensors to be carried out.

The Fermetrol again suffered from the software issue that prevented the correct storage of data at the correct time intervals, as seen in the Petaluma trial. As a result, the sensor was not able to complete data capture for the first fermentation and no objective assessment of the sensor performance could be made.

6.7 Sensor assessment and ratings

Following completion of the 2015 field trials, an objective assessment was made of the performance of the three sensors trialled at Petaluma. The VS-3000 was not included in this assessment. The categories and ratings utilised for the assessment are listed in Table 3 and the ratings awarded to each sensor are summarised in **Table 4**.

This shows that the micro-LDS was the best performing sensor under the conditions experienced at Petaluma. However, while the micro-LDS is a commercially ready sensor, the filter and valve arrangement, as well as the local tablet PC for data collection, were auxiliary additions that could be improved to provide a more process-robust configuration.

The ratings and overall ranking applied to the individual sensors are solely based on their performance during the 2015 vintage trials at Petaluma, which only included white ferments. For red fermentations, it is likely that the associated performance ratings for the micro-LDS would be lower, given the issues experienced with this sensor at De Bortoli.

The vibrating fork and Fermetrol probe both have the potential to provide reasonably accurate Baume data for red ferments, with the latter also having the benefit of being able to replace a tank temperature probe. However, process issues related to grape solids fouling the fork tines and affecting density measurement have been observed at Yalumba Wines in recent vintages; this has been addressed through the use of mesh screens around the inside of the fermenter tank to shield the vibrating fork from the bulk of the larger diameter grape solids. Several Fermetrol probes have been used with reasonable success on red ferments at St Hallett during vintage 2015; however, the issue of the inferred Baume measurement being offset from the reference Baume measurement towards the end of ferment has again been observed and remains an issue for resolution in future versions of the software.

Table 3: Categories and rating system for sensor performance assessment

RATING	1 (LOW)	2 (MEDIUM)	3 (HIGH)
Ease of installation	Difficult, complex	Moderate	Simple
Cost for installation (incl. mechanical and electrical)	High - needs additional componentry and/or pipework. Needs hard power.	Medium - may need some additional componentry and/or pipework. Can be battery operated.	Low - no additional componentry and/or pipework required. Can be battery operated.
Transportability (between tanks)	None - fixed installation	Some, but needs additional wiring/pipework or reconnection	Easy - minimal wiring/pipework or reconnection required
Ease of keeping sensor clean (during and after ferments)	Has to be removed for CIP, needs careful handling	Can handle CIP, but needs careful handling	Can handle CIP, no careful handling required
Setup/calibration requirements (initially)	Complex and/or requires multiple samples from several ferments	Some, needs initial cal or minimal samples	None
Sensitivity to matrix (solids, bubbles etc.)	High - samples need to be filtered or treated	Medium - may need some filtering/treatment or can be used in vessel with specific ferment types	Low - can be used in vessel or in bypass loop without significant pre-treatment
Ease of collecting data (secondary processing/conversion)	Difficult - data needs transformation and/or processing through secondary PC	Moderate - data may need some transformation and/or processing through secondary PC	Easy - no data transformation required or processing through secondary PC. Supports real-time output display
Integration with PLC	Difficult. Output signals and/or protocol need transformation	Difficult. Output signals and/or protocol need transformation	Easy. Output signals captured directly in PLC. Supports multiple protocols.
Accuracy of measurement (compared to lab reference analysis)	Poor - qualitative at best.	Good/OK - reasonable correlation with reference data.	Very good - high correlation with reference data.
Measurement integrity (repeatability, range, etc.)	Poor repeatability (noise) and/or doesn't reflect range required.	Some measurement noise and/or range not adequately covered.	High repeatability and excellent range
Temperature correction of data (additional T needed)	Required, but not integrated into unit.	Required, and integrated into unit.	Not required.
Ongoing costs (maintenance, power etc.)	High	Medium	Low
Applicability across ferment types/styles	Poor - only applicable for whites	Good - better with whites than reds	Excellent - any
Additional output parameters (potential)	None	Some potential, but needs calibration work	Multiple output parameters possible

CIP: Clean in place; PLC: Programmable logic controller

Table 4: Performance assessment ratings for the three sensors trialled during 2015 vintage

Sensor technology	Vibrating fork	Fermetrol probe	Micro-LDS
Ease of installation	2	2	3
Cost for installation (incl. mechanical and electrical)	2	2	3
Transportability (between tanks)	1	1	3
Ease of keeping sensor clean (during and after ferments)	3	1	2
Setup/calibration requirements	2	2	3
Sensitivity to matrix (solids, bubbles etc.)	1	3	2
Ease of collecting data (secondary processing/conversion)	2	2	3
Integration with PLC	3	2	2
Accuracy of measurement (compared to reference)	1	2	3
Measurement integrity (repeatability, range, etc.)	1	2	2
Temperature correction of data (additional correction needed)	1	2	2
Ongoing costs (maintenance, power etc.)	2	2	2
Applicability across ferment types/styles	2	3	3
Additional output parameters (potential)	1	1	1
Overall rating	23	26	33
Performance ranking	1	2	3

PLC: Programmable logic controller

6.8 Cost-benefit analysis

Current ferment management regimes are responsible for significant labour costs and poor resource utilisation. Use of in-line sensors for continuous Baume measurement could provide the following benefits:

- Reduced analysis costs and resources associated with manual sampling of ferments
- Improved quality and consistency of ferments by reducing incidence of stuck or sluggish ferments
- Improved fermentation throughput and increased tank capacity

Additional benefits may also include reduced raw material use, lower energy costs and reduced wastage. The implementation of process sensors will allow winemaking resources, particularly winemakers, to be used more effectively and to focus on adding value to the product, rather than 'baby sitting' the process.

A cost-benefit analysis for the implementation of ferment sensors was carried out to identify the potential payback period for wineries considering investment in this type of technology. In order to make meaningful comparisons between wineries of differing size, the following categorisation (Table 5) was defined and the impact at each winery size category was determined.

Table 5: Winery size categorisation and approximate process scale parameters

Winery size	Crush (t)	Approx. no. tanks	Total no. ferments/vintage	Tank size (average kL)	Av. kL processed
Small	<500	10	30	7.5	225
Medium	500-2,500	25	75	15	1,125
Large	2,500-50,000	50	150	50	7,500
Huge	>50,000	100	300	250	75,000

For the purposes of financial modelling and calculating the payback period for investment, the following assumptions were made:

- The winery would invest in one sensor per fermentation tank.
- A 5 –year depreciation period would be applied to initial capital expenditure.
- Average ferment time (white and red) is 20 days.
- Sampling is once daily.
- Energy costs were indexed at 5%.
- Labour costs were indexed at 3%.
- Wine/must costs were indexed at 5%.
- The commercial rate for borrowed capital expenditure funds was 10% per annum (in order to calculate net present value (NPV)).
- Baume (reference) analysis costs were set as $10 per sample. These costs were completely removed with the introduction of the sensor technology.
- Incidence of problematic ferments per vintage was 3%. The impact of these (on must/wine quality downgrades) could be reduced by 50% with the introduction of the sensors.
- Sampling of tanks could be decreased by 50%.
- There is no measurable impact on throughout/tank capacity.

It is expected that the introduction of in-line Baume sensors will help to reduce reaction time to stuck and sluggish ferments, but it will not completely remove the incidence of them on their own.

Operating expenses included power requirements for the sensors and maintenance (cleaning) costs after each ferment. The input rates applied for electricity, labour and wine/must quality impact are summarised in Appendix 7. For the purposes of financial modelling, the cost of each sensor has been set at $2,000, with additional auxiliary installation costs of $250 per sensor. All three sensor technologies that have been formally rated through 2015 vintage trials are available commercially at around this price-point.

The overall impact of introducing these sensor technologies, measured as net present value (NPV), for each winery category size is provided in Appendix 8. A summary of this in given in Table 6.

Table 6: Summary of payback period for implementation of ferment sensors

Winery size	Crush (t)	Total initial investment ($)	Operating expenses ($ p.a.) initial year	Operational savings ($ p.a.) initial year	Payback period (years)
Small	<500	22,500	272	15,367	2.79
Medium	500-2,500	56,250	672	36,542	2.36
Large	2,500-50,000	112,500	1,338	118,084	1.66
Huge	>50,000	225,000	2,665	461,168	0.76

Financial modelling shows that the payback period for wineries becomes lower as the winery size increases, primarily due to the overall impact on reducing resultant wine/must quality downgrades by minimising the incidence of sluggish or stuck ferments. Initial capital expenditure outlay, including auxiliary equipment (piping connections, communications wiring etc.) for the very large wineries is significant however.

7. Outcome/Conclusion

Four viable, commercially available process sensors, for in-line measurement of Baume in ferments were identified. Of these, three were objectively assessed through 2015 vintage trials.

Based on performance at Petaluma, solely on white ferments, the micro-LDS sensor was deemed to be the most effective, although all three sensors exhibited process-related issues that may hinder the implementation of these technologies on a broader scale across the industry.

The attempted trial at De Bortoli highlighted that the red fermentation medium is much more challenging to deal with and requires additional process integration considerations. This may also necessitate the use of sensors that did not perform as well in the field trials (such as the Fermetrol probe or vibrating fork), or other sensor technologies that are currently still in development (such as biosensors).

The time and effort required to undertake proper installation and commissioning of these sensor technologies should not be underestimated, especially where there is a requirement for capturing, conversion, communication and storage of raw output data from the sensors and potential integration of this with existing process control systems.

Cost-benefit analysis carried out showed that the payback period for wineries implementing this type of technology broadly across fermentation tanks becomes lower as the winery size increases, although capital expenditure is higher. Implementation has the potential to reduce the incidence of sluggish or stuck ferments and minimise resultant wine/must quality downgrades. These sensors also have the potential to drastically reduce or eliminate analysis costs and resources associated with manual sampling of ferments, as well as improve fermentation throughput and increase ferment tank capacity.

8. Recommendations

Future recommendations include:

- Investigation of alternative methods of integrating sensors into fermentation vessels, such as retractable devices that can be inserted and removed from tanks to capture instantaneous readings.
- Investigation of the potential of biosensors to provide an alternative and meaningful measurement of Baume.
- Consideration for incorporating existing techniques, such as basic density or mass-flow measurement, into existing fermentation infrastructure, i.e. utilisation of existing ferment tank ports or other measurement devices (e.g. temperature probes) to provide parallel Baume outputs at a relatively low cost.
- Utilisation of sophisticated data management and analysis tools, such as ferment simulation models, to capture Baume (and other) data generated by in-line sensors and provide early-warning systems for fermentations that are likely to be problematic.

Appendix 1: Communication and Extension Activities

This technical report has been produced to summarise the key outcomes of the technology review and highlight results from the 2015 field trials that demonstrate effective evaluation of the selected technologies. A number of communication and extension mechanisms will be used to disseminate results and highlight key practical aspects for implementation and integration into the current winemaking process for wineries of different sizes, complexities and available resources.

Communication activities will include provision of key information from within this report to the AWRI roadshow program, publication of an article in a non peer-reviewed journal (Australian and New Zealand Grapegrower and Winemaker) and presentation through a key wine industry communication forum (e.g. ASVO Oenology Seminar). Communication activities will centre on the performance of the sensors, the benefits that the technologies can provide, the practical challenges involved in implementing the technologies and the payback periods that can be expected.

It may be appropriate to disseminate information and outcomes from this study to key industry stakeholders through fora focussed broadly on the introduction of new processing technologies, rather than limiting communications solely to fermentation sensor technology. Many learnings and outcomes from this study, particularly those related to introduction of new technology into the wine process environment and subsequent barriers to adoption, will be relevant to other unit operations and improvement opportunities.

Appendix 2: Intellectual Property

There is deemed to be no intellectual property raised from this study.

Appendix 3: References

Bendtsen, A.B. (2000). Exhaust gas monitoring of fermentation processes. *Innov. Pharm. Tech.*

Daoud, I. S. Searle, B. A. (1990). On-line monitoring of brewery fermentation by measurement of CO_2 evolution rate *J. Inst. Brew*. 96: 297-302.

Jones, G.P. (2002). A Monitoring and Control System for Wine Fermentation: Final Report to Grape and Wine Research & Development Corporation.

Katrlik, J. Svorc, J. Stredansky, M. Miertus, S. (1998). Composite alcohol biosensors based on solid binding matrix. *Biosensors & Bioelectronics*. Vol. 13. No. 2, 181-191.

Leca, B. Marty, J.L. (1997). Reusable ethanol sensor based on a NAD'-dependent dehydrogenase without coenzyme addition. *Anal. Chim. Acta*. 340 143-148.

Mazarevica, G. Diewok, J. Baena, J.R. Rosenberg, E. Lendl, B. (2004). On-Line Fermentation Monitoring by Mid-Infrared Spectroscopy. *App. Spec*. Volume 58, Number 7, 804-810.

Mello, L.D. Kubota, L.T. (2002). Review of the use of biosensors as analytical tools in the food and drink industries. *Food Chem*. 77: 237–256.

Ranasinghe, D.C. Falkner, N.J.G. Pan Chao. Wu Hao. (2013). Wireless Sensing Platform for Remote Monitoring and Control of Wine Fermentation. Institute of Electrical and Electronics Engineers (IEEE) Eighth International Conference on Intelligent Sensors, Sensor Networks and Information Processing. Published by IEEE.

Appendix 4: Staff

Staff involved in this study include:

AWRI

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Appendix 5: Sensor installation details for Petaluma field trials

Sensor	Vibrating fork	Fermetrol	Micro-LDS
Model	FTL50H/FTL51H	-	-
Installation	In-tank/Inline (min 2")	In-tank	Sample tap: from tank or inline
Orientation	In-tank: side of tank, types vertical. Inline: Vertical, down	Side of tank	-
Materials of construction	316 SS	SS, polymer	SS, Silicone, Epoxy, Glass
Pipe-work Connection type/size	Tri-Clamp 1.5", 2" SMS 2" or DRD Flange Varivent DN 50 Ingold DN25 Threaded connections	50mm Tri-Clover	Plastic barb or SS compression fitting on sensor > silicone hose > Sample tap on line or tank
Dimensions	Total approx. 150 L x 80mm W Approx. 80 mm protrusion into vessel	Probe is 205 mm L. Head 32 mm OD. The display unit is approximately 100 mm W x 100 mm H x 60 mm D	-
Positioning Requirements	5xDN (min750 mm) PRE 2xDN (min 250 mm) POST Temp min 250 mm POST	-	3.3 x 6.8 x 1.5 cm
Flow rate/pressure	Inline: max 5m/s @ 1mm^2/s and 1g/cm^3	-	Max: 20 psig (barbed fitting) Max: 300 psig (SS compression fitting)
Temp correction	Extra required, Pt100/1000	On-board	On-board
Power supply	Sensor powered from FML621 computer FML621: 90-250V AC OR 20-36V DC OR 20-28V AC	5V DC - either hard wired with the comms or from a separate plug in power pack	5V to 12V DC
Calibration process	None	Needs initial Be for each ferment.	Performed at factory
Operating range	Temperature –50 °C to 150 °C Pressure: up to 100 bar Viscosity up to 10,000 mm^2/s Densities ≥ 0.5 g/cm^3 or ≥ 0.7 g/cm^3	-	Fluid Temp Range: 5-70 C, Accuracy: +/- 0.03 C Standard Density Range: 0.6 to 1.3 g/cc, Accuracy: 0.0005 g/cc
PLC connection	Profibus PA (optional)	Modbus via RS-485 or Ethernet	Ethernet/Wi-fi
Sensor output type (4-20 mA, etc)	8x 4-20 mA (HART), Ethernet	Digital	2x 0-5V DC
Cleaning requirements	CIP OK up to 120°C	Must be removed for cleaning. Clean with water	Distilled water, reverse flow. Must Disconnect before CIP
Sensor maintenance	None	Storage in water when not in use	None
OHS considerations	None	None	None

Appendix 6: Sensor installation details for De Bortoli field trials

Sensor	Vibrating fork	Micro-LDS	VS-3000	Fermetrol
Model	FTL50H/FTL51H	-	BM	-
Installation	In-tank/Inline (min 2")	Sample tap: from tank or inline	In-tank/Inline (1.5"-10")	In-tank
Orientation	In-tank: side of tank, types vertical. Inline: Vertical, down, types in line with flow	-	In-tank: Side of tank, Inline: Vertical OR 45° upwards in Horizontal	Side of tank
Materials of construction	316 SS	SS, Silicone, Epoxy, Glass	SS, Glass	SS, polymer
Pipe-work Connection type/size	Tri-Clamp 1.5", 2" SMS 2"/ DRD Flange Varivent DN 50 Ingold DN25 Threaded connections	Plastic barb or SS compression fitting on sensor > silicone hose > Sample tap on line or tank	In-tank: 1.5" Tri-Clamp Inline: 68 mm Varivent	50 mm Tri-Clover
Positioning Requirements	5xDN (min750 mm) PRE 2xDN (min 250 mm) POST Temp min 250 mm POST	-	Ideally 12" upstream of asymmetrical reducer	-
Dimensions	Total approx. 150 L x 80 mm W Approx. 80mm protrusion	3.3 x 6.8 x 1.5 cm	83 mm x 83mm x 83 mm	Probe is 205 mm L. Head 32 mm OD. Display unit approx. 100 x 100 x 60 mm
Flow rate/pressure	Inline: max 5m/s @ $1mm^2/s$ and $1g/cm^3$	Max: 20 psig (barbed fitting). Max: 300 psig (SS compression fitting)	Max: 10 bar	-
Temp correction	Extra required, Pt100/1000	On-board	On-board	On-board
Power supply	Sensor powered from FML621 computer FML621: 90-250V AC OR 20-36V DC OR 20-28V AC	5V to 12V DC	Sensor Powered by VS-300 SMS. VS-300 powered by 100-240V AV OR 24V DC min 2.0A	5V DC - either hard wired with the comms or from a separate plug in power pack
Calibration process	None	Performed at factory	Calibration required with highest/lowest conc. of each analyte	Needs initial Be for each ferment.
Operating range	Temp. –50 °C to 150 °C Pressure: up to 100 bar Viscosity < 10,000 mm^2/s Densities ≥ 0.5 g/cm^3 or ≥ 0.7 g/cm^3	Fluid Temp Range: 5-70C, Accuracy: +/- 0.03C Standard Density Range: 0.6 to 1.3 g/cc, Accuracy: 0.0005 g/cc	Temp -2 to 85°C	-
PLC connection	Profibus PA (optional)	Ethernet/Wi-fi	Ethernet, Profibus DP	Modbus via RS-485 or Ethernet
Sensor output type (4-20mA, etc)	8 x 4-20 mA (HART), Ethernet	2x 0-5V DC	4x 4-20mA	Digital
Cleaning requirements	CIP OK up to 120°C	Distilled water, reverse flow. Must Disconnect before CIP	CIP OK up to 85°C	Must be removed for cleaning. Clean with water
Sensor maintenance	None	None	None	Storage in water when not in use
OHS considerations	None	None	None	None

Appendix 7: Input rates for financial modelling for implementation of ferment sensors

Labour rates	Package	$/hr	Base
Operations/production manager	$196,000	$ 118.93	$140,000
Maintenance/engineering manager	$151,500	$ 91.93	$110,000
Winemaker	$140,000	$ 84.95	$100,000
Cellar manager	$108,500	$ 65.84	$90,000
Cellar hand	$57,500	$ 34.89	$50,000

	Utilities	small	medium	large	huge
c/kWh	Electricity	18	12	10	8
c/MJ	Gas	5	3.5	3	2.5
c/L	Water	0.2	0.16	0.14	0.12

	Impact	small	medium	large	huge
$/L	Wine quality	1.5	1	0.5	0.25
$/kg	Must quality	1.0	0.7	0.4	0.2

Appendix 8: Financial modelling for implementation of ferment sensors

small winery	small	1	Discount rate	10.0%		
Expenditure	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Sensor	$ 20,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000
Auxiliary (mech, elec, comms)	$ 2,500					
Set-up/cal (labour)	$ -					
Consumables	$ -					
Other						
Total investment	$ 22,500	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000
Operating Expenses	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Power (kWh/day)	**0.1**	$ 11	$ 11	$ 12	$ 13	$ 13
Maintenance (clean per ferment - $)	**8.72**	$ 262	$ 270	$ 278	$ 286	$ 295
Total operating expenses		$ 272	$ 281	$ 290	$ 298	$ 308
Operating Savings	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Labour (sampling per ferment - $)	**87.23**	$ 2,617	$ 2,695	$ 2,776	$ 2,859	$ 2,945
Lab analysis (cost/sample - $)	**10.00**	$ 6,000	$ 6,180	$ 6,365	$ 6,556	$ 6,753
Quality risk (potential downgrade vol. (kL)	**3.375**	$ 5,063	$ 5,316	$ 5,581	$ 5,860	$ 6,154
Tank capacity			$ -	$ -	$ -	$ -
			0	**0**	**0**	**0**
Total operating savings		$ 13,679	$ 14,191	$ 14,723	$ 15,276	$ 15,852
Year	**0**	**1**	**2**	**3**	**4**	**5**
Pre tax cash flow (Revenue-Expenditure)	-$ 22,500	$ 9,407	$ 9,910	$ 10,433	$ 10,978	$ 11,544
Present value (PV)	-$ 22,500	$ 8,552	$ 8,190	$ 7,839	$ 7,498	$ 7,168
Net present value (NPV)	-$ 22,500	-$ 13,948	-$ 5,758	$ 2,081	$ 9,579	$ 16,747

medium winery	medium	2	Discount rate	10.0%		

Expenditure	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Sensor	$ 50,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000
Auxiliary (mech, elec, comms)	$ 6,250					
Set-up/cal (labour)	$ -					
Consumables	$ -					
Other						
Total investment	$ 56,250	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000

Operating Expenses	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Power (kWh/day)	**0.1**	$ 18	$ 19	$ 20	$ 21	$ 22
Maintenance (clean per ferment - $)	**8.72**	$ 654	$ 674	$ 694	$ 715	$ 736
Total operating expenses		$ 672	$ 693	$ 714	$ 736	$ 758

Operating Savings	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Labour (sampling per ferment - $)	**87.23**	$ 6,542	$ 6,738	$ 6,940	$ 7,149	$ 7,363
Lab analysis (cost/sample - $)	**10.00**	$ 15,000	$ 15,450	$ 15,914	$ 16,391	$ 16,883
Quality risk (potential downgrade vol. (kL)	**16.875**	$ 16,875	$ 17,719	$ 18,605	$ 19,535	$ 20,512
Tank capacity			$ -	$ -	$ -	$ -
			0	**0**	**0**	**0**
Total operating savings		$ 38,417	$ 39,907	$ 41,459	$ 43,074	$ 44,757

Year	0	1	2	3	4	5
Pre tax cash flow (Revenue-Expenditure)	-$ 56,250	$ 27,745	$ 29,214	$ 30,745	$ 32,339	$ 33,999
Present value (PV)	-$ 56,250	$ 25,223	$ 24,144	$ 23,099	$ 22,088	$ 21,111
Net present value (NPV)	-$ 56,250	-$ 31,027	-$ 6,883	$ 16,216	$ 38,303	$ 59,414

large winery	large	3	Discount rate	10.0%		
Expenditure	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Sensor	$ 100,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000
Auxiliary (mech, elec, comms)	$ 12,500					
Set-up/cal (labour)	$ -					
Consumables	$ -					
Other						
Total investment	$ 112,500	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000
Operating Expenses	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Power (kWh/day)	**0.1**	$ 30	$ 32	$ 33	$ 35	$ 36
Maintenance (clean per ferment - $)	**8.72**	$ 1,308	$ 1,348	$ 1,388	$ 1,430	$ 1,473
Total operating expenses		$ 1,338	$ 1,379	$ 1,421	$ 1,464	$ 1,509
Operating Savings	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Labour (sampling per ferment - $)	**87.23**	$ 13,084	$ 13,477	$ 13,881	$ 14,297	$ 14,726
Lab analysis (cost/sample - $)	**10.00**	$ 30,000	$ 30,900	$ 31,827	$ 32,782	$ 33,765
Quality risk (potential downgrade vol. (kL)	**112.5**	$ 56,250	$ 59,063	$ 62,016	$ 65,116	$ 68,372
Tank capacity			$ -	$ -	$ -	$ -
			0	**0**	**0**	**0**
Total operating savings		$ 99,334	$ 103,439	$ 107,723	$ 112,196	$ 116,864
Year	**0**	**1**	**2**	**3**	**4**	**5**
Pre tax cash flow (Revenue-Expenditure)	-$ 112,500	$ 77,996	$ 82,060	$ 86,302	$ 90,731	$ 95,355
Present value (PV)	-$ 112,500	$ 70,905	$ 67,818	$ 64,840	$ 61,971	$ 59,208
Net present value (NPV)	-$ 112,500	-$ 41,595	$ 26,223	$ 91,063	$ 153,034	$ 212,242

huge winery	huge	4	Discount rate	10.0%		

Expenditure	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Sensor	$ 200,000	$ 40,000	$ 40,000	$ 40,000	$ 40,000	$ 40,000
Auxiliary (mech, elec, comms)	$ 25,000					
Set-up/cal (labour)	$ -					
Consumables	$ -					
Other						
Total investment	$ 225,000	$ 40,000	$ 40,000	$ 40,000	$ 40,000	$ 40,000

Operating Expenses	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Power (kWh/day)	**0.1**	$ 48	$ 50	$ 53	$ 56	$ 58
Maintenance (clean per ferment - $)	**8.72**	$ 2,617	$ 2,695	$ 2,776	$ 2,859	$ 2,945
Total operating expenses		$ 2,665	$ 2,746	$ 2,829	$ 2,915	$ 3,004

Operating Savings	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Labour (sampling per ferment - $)	**87.23**	$ 26,168	$ 26,953	$ 27,762	$ 28,595	$ 29,452
Lab analysis (cost/sample - $)	**10.00**	$ 60,000	$ 61,800	$ 63,654	$ 65,564	$ 67,531
Quality risk (potential downgrade vol. (kL)	**1125**	$ 281,250	$ 295,313	$ 310,078	$ 325,582	$ 341,861
Tank capacity			$ -	$ -	$ -	$ -
			0	**0**	**0**	**0**
Total operating savings		$ 367,418	$ 384,066	$ 401,494	$ 419,740	$ 438,844

Year	0	1	2	3	4	5
Pre tax cash flow (Revenue-Expenditure)	-$ 225,000	$ 324,753	$ 341,320	$ 358,665	$ 376,825	$ 395,840
Present value (PV)	-$ 225,000	$ 295,230	$ 282,083	$ 269,470	$ 257,377	$ 245,786
Net present value (NPV)	-$ 225,000	$ 70,230	$ 352,313	$ 621,783	$ 879,160	$ 1,124,945

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