Improving Winery Refrigeration Efficiency
Winery B
Case study report 1

- Warmer white fermentation temperatures
- Tank stratification

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Abstract

Three side-by-side fermentation trials were performed during the 2011 vintage to investigate the influence of white juice/wine fermentation temperature on cooling requirements. The trials identified a reduction in overall cooling requirements of between 0 and 8% for ferments controlled at elevated temperatures (e.g. 20°C as opposed to of 16°C). Reductions of this order were consistent with a review of the mechanisms of heat generation and transfer during fermentation. Increased evaporation of ethanol and water was likely a key source of the small reduction in overall cooling requirements at warmer fermentation temperatures.

For a winery fermenting 30,000 kL per annum it was estimated that the potential electricity savings associated with reduced cooling requirements at warmer fermentation temperatures were approximately $4,000 per annum. Given that annual electricity consumption for a winery of this size costs in the order of $1,000,000 and there remains some unquantified risk of sensory damage; the use of warmer fermentations of the order of 4°C is not likely to be justifiable on the basis of electricity savings alone. Faster fermentations, resulting from warmer fermentation temperatures may assist wineries limited by fermentation tank capacity, but faster fermentations do require a higher rate of cooling and available refrigeration capacity could potentially become an issue during some peak periods.

The 58 kL tanks used in these trials were fitted with only one cooling jacket; positioned towards the bottom of the tanks. The location of this jacket sometimes resulted in significant cooling-induced stratification when the brine was flowing through the jacket but the agitator was not on. Stratification did not generally occur when fermentation was actively proceeding as the generation of carbon dioxide induced mixing that was sufficient to ensure temperature homogeneity.

Poor tank cooling, agitation and temperature measurement configurations have the potential to negatively influence wine quality and consistency, increase energy use, and can result in misleading characterisation of tank temperature on winery monitoring systems, which could in turn result in sub-optimal decision making. Wineries should be aware of this and possibly consider auditing the temperatures at different points in tanks at their site to verify that temperatures reported on winery monitoring systems are accurate.

Contents

1. Introduction

Refrigeration can account for 50%-70% of winery electricity consumption. Improving the efficiency of winery refrigeration is therefore of considerable interest. The Grape and Wine Research and Development Corporation (GWRDC) funded a project by Commercial Services at The Australian Wine Research Institute (AWRI) to help the Australian wine industry improve refrigeration efficiency and decrease electricity usage and/or costs.

As part of this project, a reference guide was produced and is available for download from the GWRDC (www.gwrdc.com.au) and AWRI (www.awri.com.au) websites. This short guide provides background on the operation of winery refrigeration systems and lists improvement opportunities.

Case studies were performed at two wineries (Winery A and Winery B) during 2011 in order to investigate some improvement opportunities/topics in more detail. These case studies have been written up in three technical reports (this document and two others) and are available for download from the aforementioned websites.

This report describes the work at Winery B during the 2011 vintage. The use of warmer white fermentation temperatures and tank stratification were investigated. The impetus to study warmer white wine fermentation temperatures at Winery B was mainly from preliminary trials performed during the 2010 vintage at the winery that had indicated that there may be reductions in overall cooling requirements for white fermentations (without significant sensory impact) if they were to be performed at warmer temperatures than sometimes practiced (e.g. 18°C instead of 14°C). For practical reasons, these preliminary trials had been performed sequentially using different batches of Chardonnay grapes. The 2011 vintage trials were therefore to be performed under more controlled conditions side-by-side.

2. Materials and methods

2.1 Winery and cooling system

Winery B is a large winery (>20,000 tonnes) with five refrigeration plants (all employing ammonia as refrigerant), which provide direct expansion cooling of some tanks/devices as well as cold brine for reticulation around the winery to cool other tanks.

2.2 Trial design, tank specifications and monitoring equipment

Three side-by-side fermentation trials were performed during the 2011 vintage. In each trial one of the tanks was fermented at a warmer temperature than the other. Fermentations were performed in two 58 kL (nominal) insulated stainless steel tanks cooled using brine. The experimental arrangement employed for each tank and the approximate tank dimensions are illustrated in Figure 2.1.

For each tank, brine flow rate (F_{Brine}) was measured using a ¾" turbine flow meter (G2S07I09LMA; GPI, USA) and brine temperatures into ($T_{Brine,in}$) and out of ($T_{Brine,out}$) the cooling jacket were measured using 12-bit temperature sensors (S-TMB; Onset, USA) inserted in custom-built in-line thermowells. Juice/wine temperature was measured using a sensor inserted in a new thermowell installed next to the tank door (T_{Low}) and also by a sensor directly in the juice/wine much higher in the tank (T_{High}). These sensors were interfaced with a data logger capable of communicating via the GSM cellular network (Hobo U30/GSM; Onset). A pulse access module (GPI) and pulse input adapter (Onset) were required to interface each flow meter with the data logger.

In addition to this AWRI data logger, temperatures recorded by the winery's own temperature probe (T_{Mid}) was logged via the winery SCADA system, together with the set-point temperature and agitator status. However, the availability of these data was inconsistent; apparently as a consequence of data losses during power failures.

Photos showing the different components of the experimental arrangement are presented in Figures 2.2 to 2.8.

2.3 Data analysis

For the purposes of this trial, fermentation time was taken to be the time between yeast addition and the juice/wine reaching a density of approximately 0° Baumé (or extrapolated to the time when that density would have been reached).

The tank temperature at any point in time was estimated by assuming the wine below the top of the cooling jacket was at the temperature reported by the lower probe, T_{Low}, and half of the remaining wine was at the temperature of the middle probe, T_{Mid}, and half was at the temperature of the upper probe, T_{High}. The time-weighted average tank temperature over the fermentation time was used to nominally describe the fermentation.

The cooling imparted on the wine by the brine flowing through the tank jacket over the course of each ferment was calculated from the logged brine flow rate (F_{Brine}) and brine temperature rise ($T_{Brine,out}$ – $T_{Brine,\ in}$) during each minute of the fermentation time, in conjunction with the brine properties presented in Table 2.1. The theoretical cooling required if there had been no temperature rise in the wine was then calculated by adding the product of the temperature rise over the fermentation time and the specific heat capacity of the juice/wine, which was taken to be 4.3 kJ/(L.°C) (Rankine 2004).

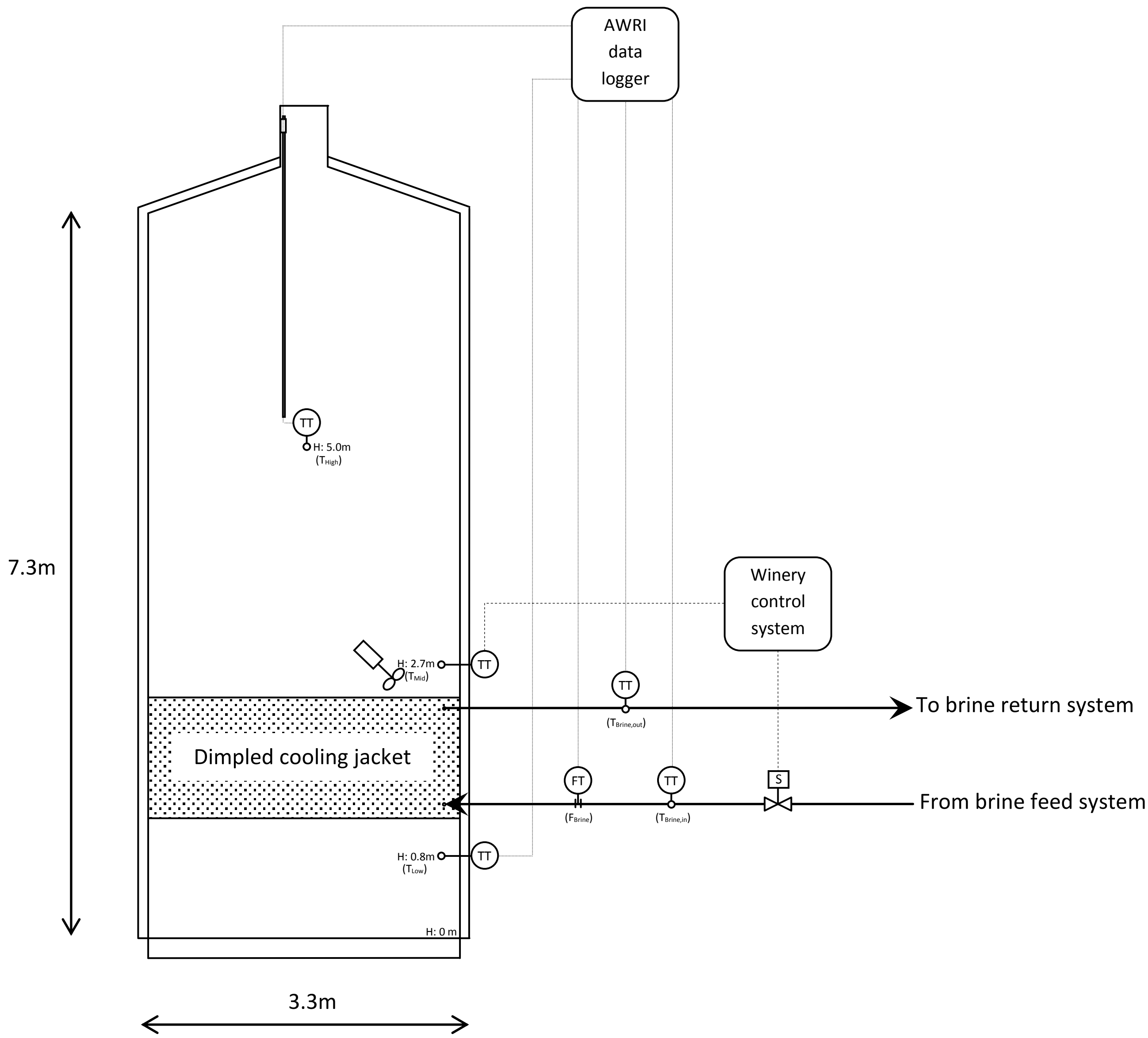

Figure 2.1: Approximate tank dimensions and control/data logging arrangement for one of the two 58 kL tanks (tank fittings, brine line ball valves and strainers not shown)

Table 2.1: Brine properties

Parameter	Value[a]
Density:	985 kg/m^3
Specific heat capacity:	3.6 kJ/(kg.°C)

[a]From Alcool LF data spreadsheet obtained by email from Wendy Do at Sucrogen Bioethanol in November 2010. Assumed a brine freezing point of -15 °C, which corresponds with an Alcool LF concentration of 34% v/v.

Figure 2.2: 58 kL tanks employed in experiments

Figure 2.3: Higher temperature probe (T_{High}, viewed from door of empty tank)

Figure 2.4: Tank agitator and thermowell containing the winery temperature probe (T_{Mid}), which transmits to the brine solenoid valve control system

Figure 2.5: Ground level external view of one of the tanks. The lower temperature probe (T_{Low}) is inserted in the new thermowell installed next to the tank door

Figure 2.6: Flow meters (F_{Brine}) and temperature probes ($T_{Brine,in}$) installed in the brine inlet line to the jacket of both tanks

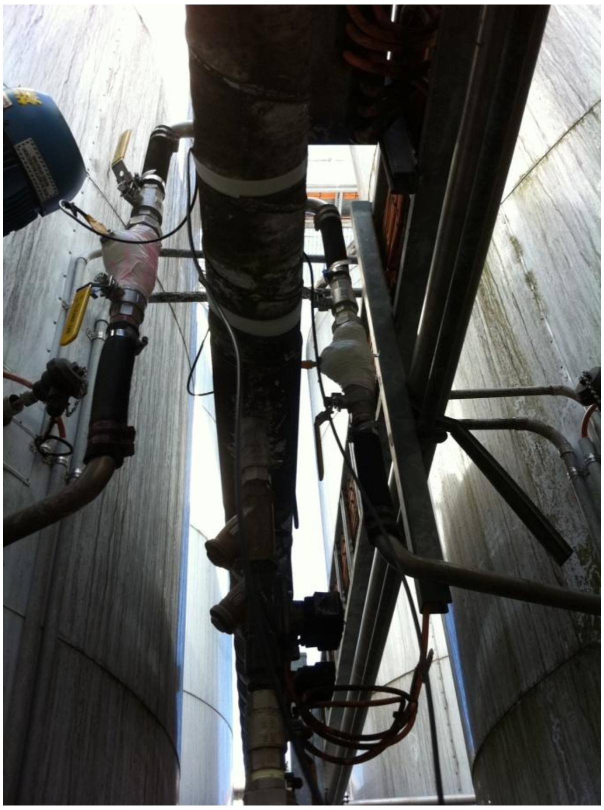

Figure 2.7: Temperature probes ($T_{Brine,out}$) installed in the brine outlet lines from the jackets of both tanks

Figure 2.8: GSM equipped data logger connected to the temperature sensors and flow meter pulse adapters

3. Results

Experimental results are summarised in Table 3.1. Detailed parameter traces over each of the three side by side-by-side trials are presented in Figures 3.1 to 3.6. Key operational events are marked on these plots. Additions of diammonium phosphate, polyvinylpolypyrrolidone, copper sulfate and sulfur dioxide were also made as directed by winemakers with the same doses being added to both tanks in the fermentation trial.

Table 3.1: Summary of side-by-side fermentation trials

	Low temperature	**High temperature**
Trial 1		
Chardonnay (Riverland)		
Average temperature (°C)	15	19
Volume (L)	45,400	45,400
Length (days)	10	5.3
Initial density (°Baumé)	10.7	11.0
Agitator	On/off[a]	On/off[a]
Cooling (kJ/L)	78	66
Juice/wine temperature rise (°C)	3	6
Cooling corrected for temperature rise (kJ/L)	91	91
Trial 2		
Semillon (Riverina)		
Average temperature (°C)	16	20
Volume (L)	51,200	51,100
Length (days)	7.4	6.7
Initial density (°Baumé)	9.3	8.9
Agitator	On	On
Cooling (kJ/L)	65	71
Juice/wine temperature rise (°C)	3	0
Cooling corrected for temperature rise (kJ/L)	77	71
Trial 3		
Riesling (Langhorne Creek)		
Average temperature (°C)	16	18
Volume (L)	50,600	48,800
Length (days)	17[b]	16[b]
Initial density (°Baumé)	10.4	10.4
Agitator	Off	Off
Cooling (kJ/L)	64	52
Juice/wine temperature rise (°C)	4	6
Cooling corrected for temperature rise (kJ/L)	81	78

[a]Power failure during fermentation. The agitator did not restart when power was restored (standard practice to avoid gushing).
[b]Additional yeast was added mid-way through the fermentation.

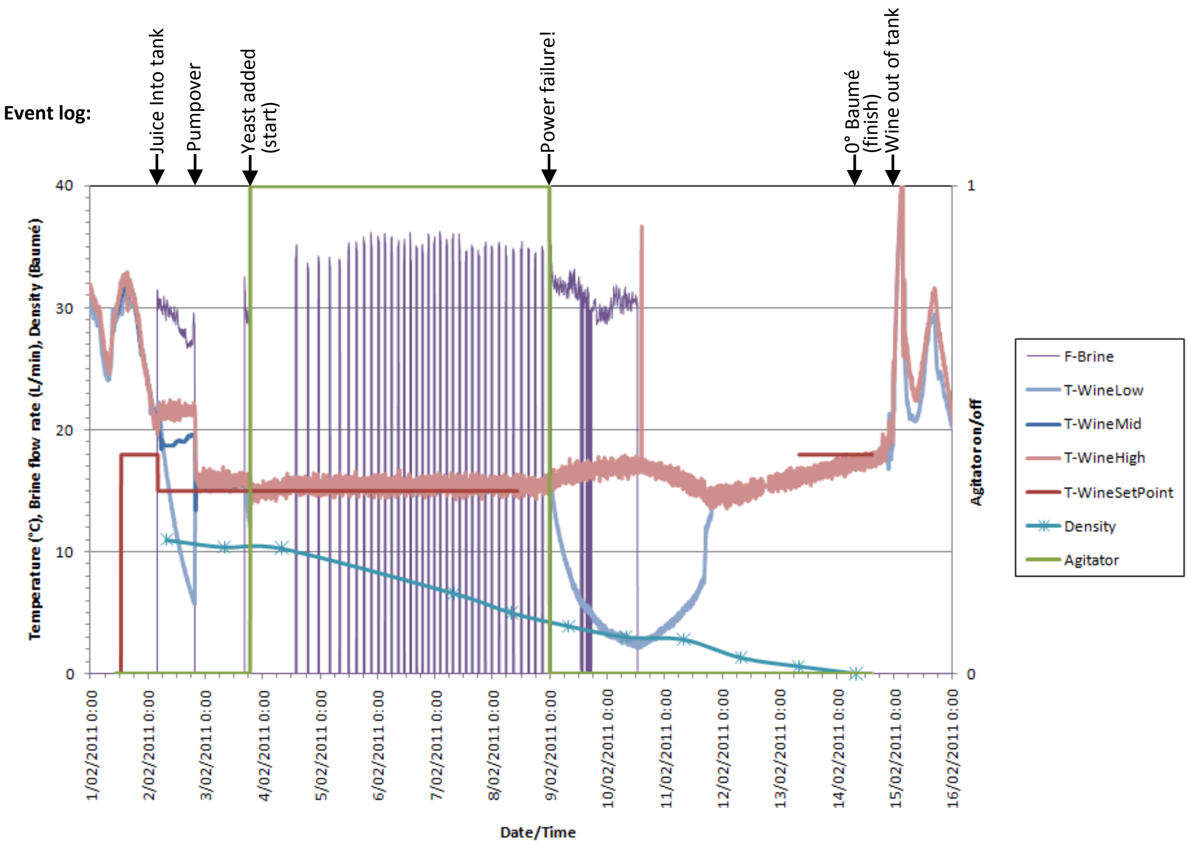

Figure 3.1: Trial 1 – Chardonnay – 15°C

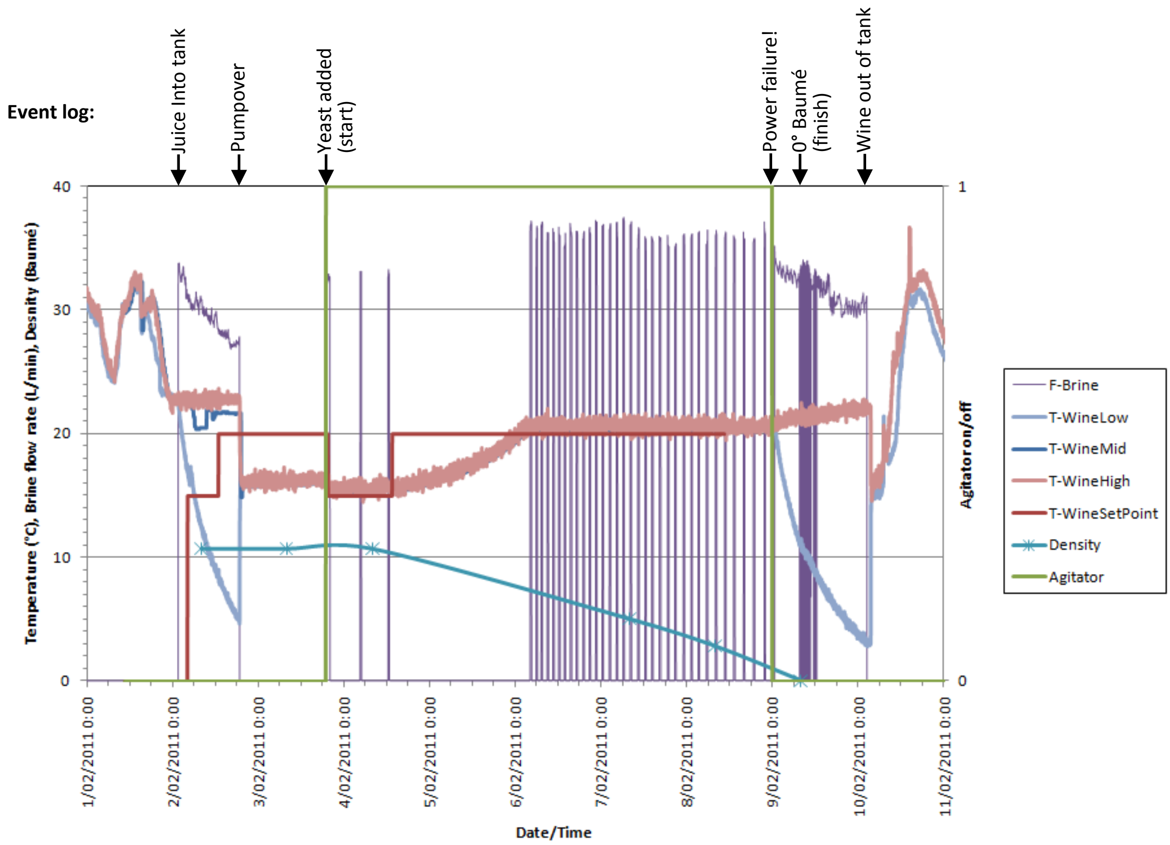

Figure 3.2: Trial 1 – Chardonnay – 19°C.

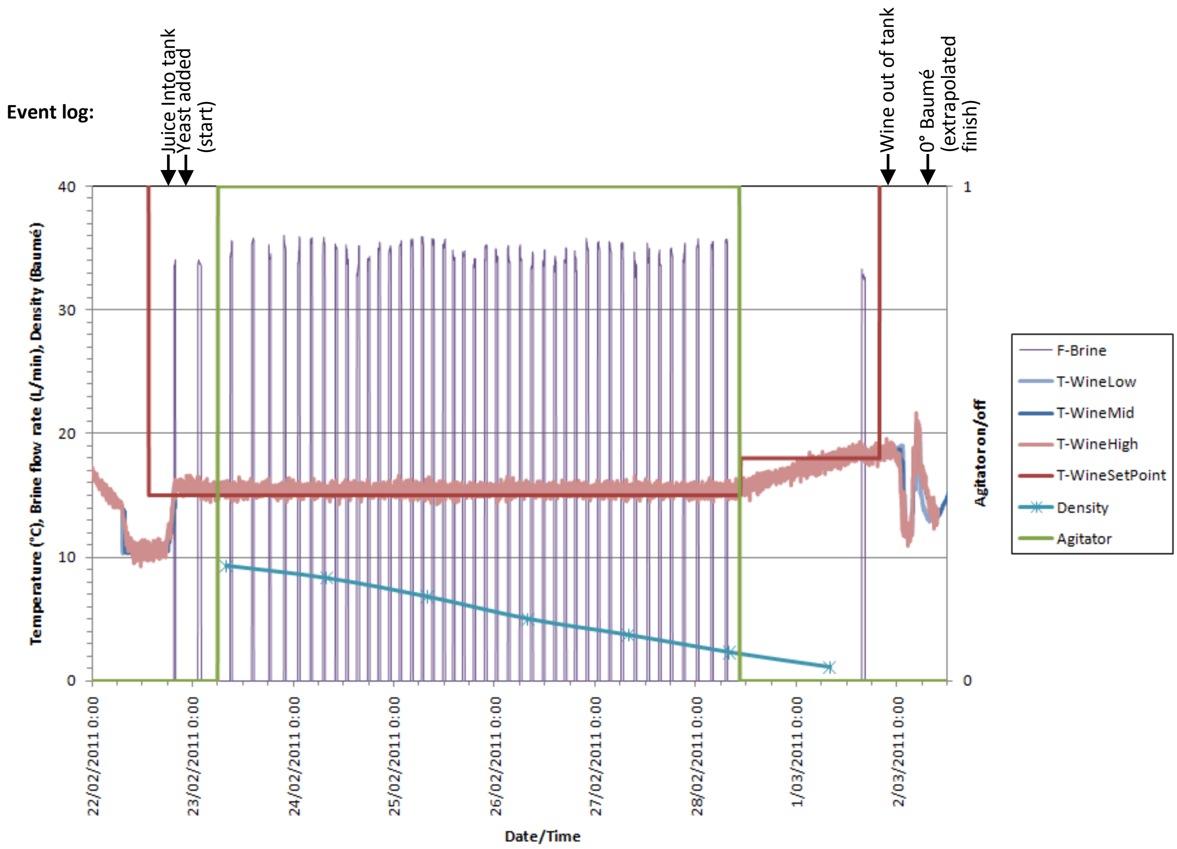

Figure 3.3: Trial 2 – Semillon – 16°C

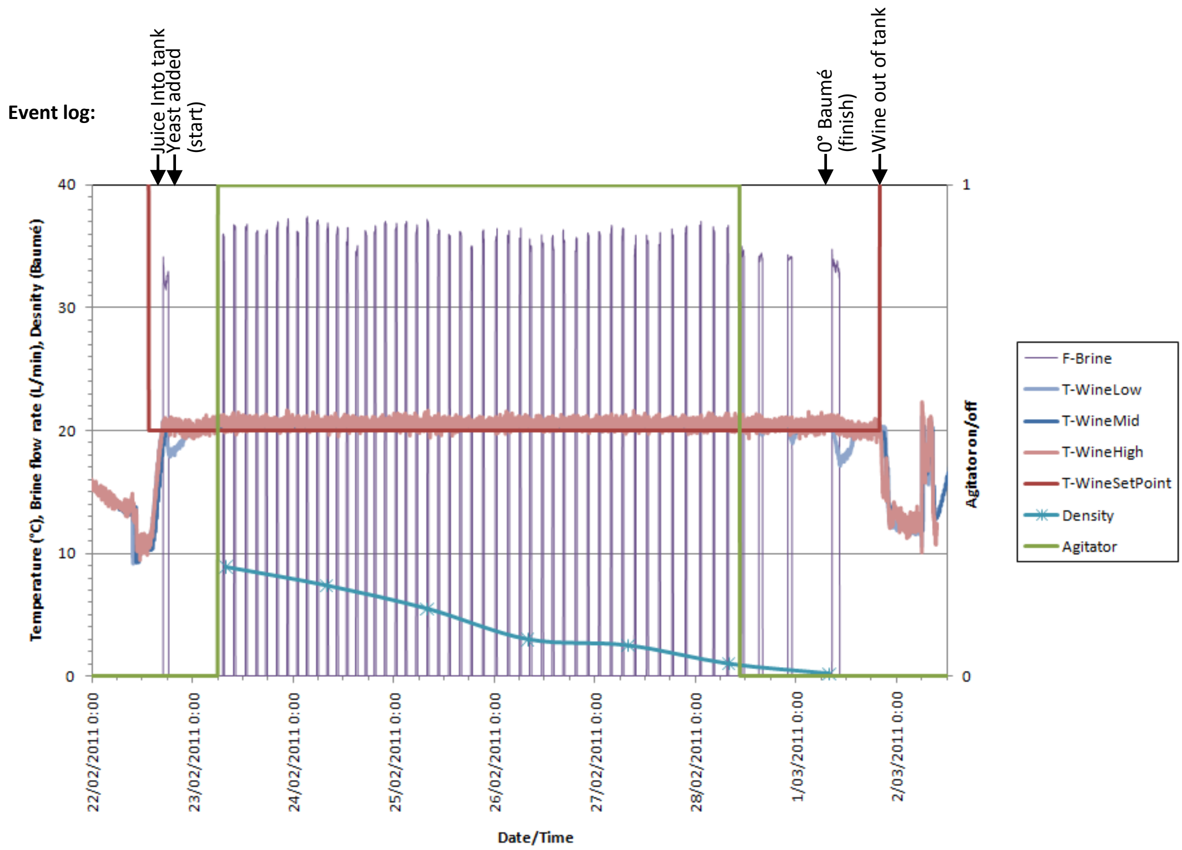

Figure 3.4: Trial 2 – Semillon – 20°C

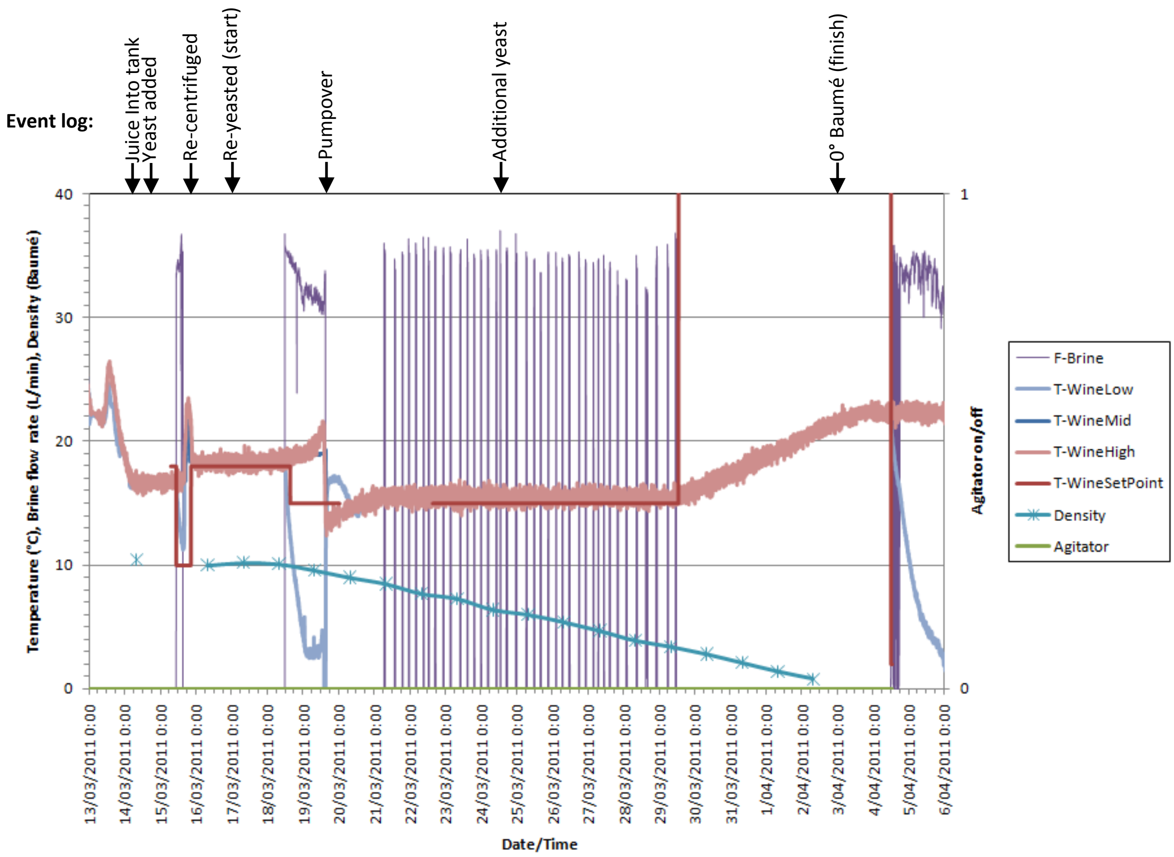

Figure 3.5: Trial 3 – Riesling – 16°C

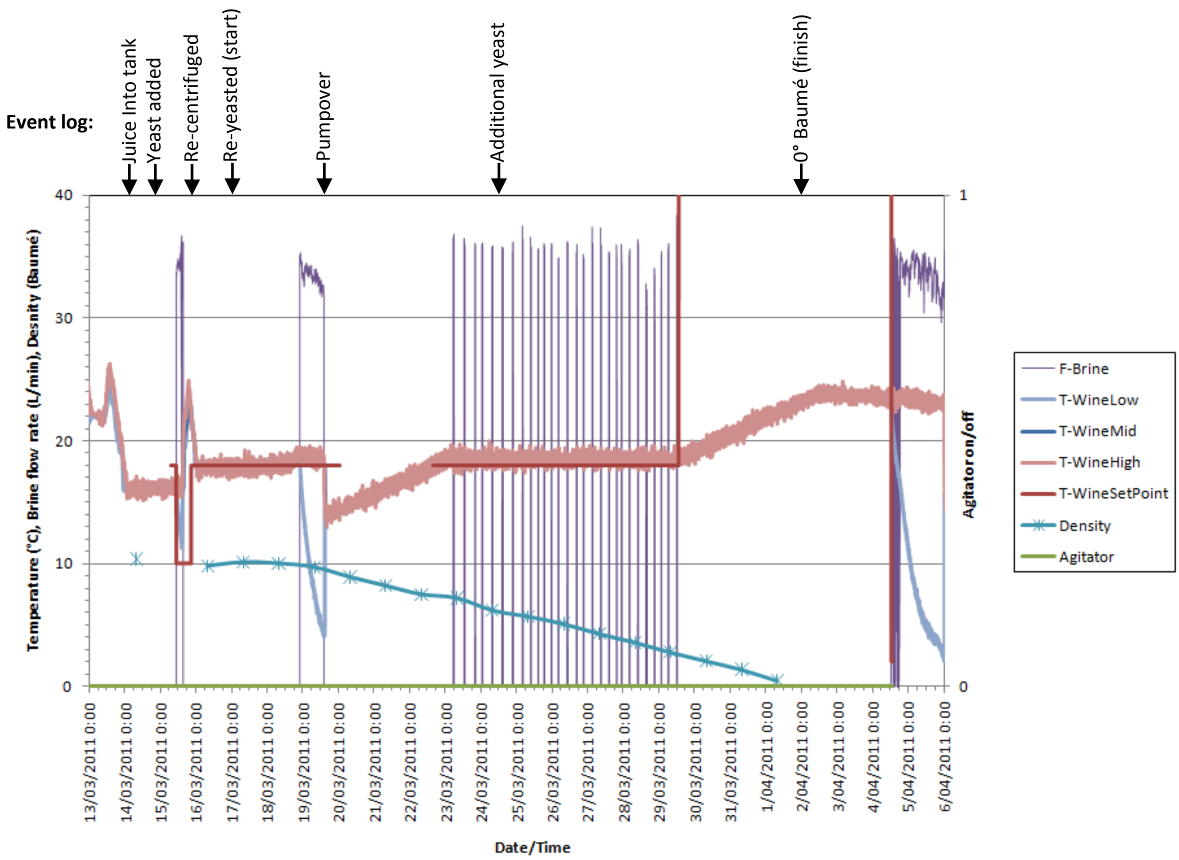

Figure 3.6: Trial 3 – Riesling – 18°C

4. Discussion

4.1 Sensory analysis

Sensory comparisons between side-by-side ferments were to be performed in order to balance any possible energy savings from using higher fermentation temperatures against any negative sensory influences. Unfortunately, there were issues that prevented meaningful sensory comparisons being undertaken in all three trials. The Semillon grapes used in Trial 2 were badly diseased and the wines showed negative sensory characters irrespective of treatment temperature. For both treatment temperatures of Trial 3 (Riesling), the fermentations were becoming stuck, which negatively affected the sensory characters of the wines.

4.2 Cooling requirements

The results from the three side-by-side trials (Table 3.1) showed overall cooling requirements (corrected for juice/wine temperature rise) for different fermentation temperatures were very similar. For Trial 1 (Chardonnay) the results were the same for both fermentation temperatures, while for Trial 2 (Semillon) and Trial 3 (Riesling) cooling requirements were slightly lower for the fermentation performed at the warmer temperature.

To better understand the factors that can influence cooling requirements it is worth considering the different mechanisms by which heat is generated and transferred during fermentations and how each of these may be influenced by the use of different fermentation temperatures. The key mechanisms are illustrated in Figure 4.1 and in summary are:

- Generation of heat from the fermentation reaction as sugar is converted to ethanol.
- Transfer of heat to the fermenting juice/wine from the air through the tank walls.
- Removal of heat in the carbon dioxide leaving the fermenter and by the evaporation of water and ethanol.
- Transfer of heat from the wine to the brine by means of the cooling jacket (this is the cooling measured as part of this study).

While it is widely acknowledged that the rate of energy release as a result of the fermentation reaction increases with temperature (e.g. Peynaud 1985), there is no evidence in the literature, to the author’s knowledge, to suggest that the total energy released from this reaction decreases with increasing temperature. The total energy released from the fermentation reaction is reported to be in the order of 100 kJ/mol sugar (ASHRAE 1982, Williams 1982, Boulton et al. 1996, Rankine 2004, Ribéreau-Gayon et al. 2006). As an order of magnitude estimate per volume of juice, if we assume a concentration of 1 mol/L of sugar (i.e. 180 g/L glucose and fructose), the energy released by the reaction over the course of the fermentation will be approximately 100 kJ/L. Notably in the fermentations performed, the cooling required (corrected for temperature rise) was highest for the Chardonnay (Trial 1), which had the highest initial sugar content and lowest for the Semillon (Trial 2), which had the lowest initial sugar content.

The heat transfer to or from the wine through the tank walls could possibly be influenced by the fermentation temperature. Simplistically, the driving force in this heat transfer process is the temperature difference between the juice/wine and the air on the other side of the tank wall. Therefore, if the juice/wine is warmer, the warming driving force will be reduced. Preliminary results from storage trials performed in one of the same tanks set at 5°C demonstrated ambient heat gains of approximately 0.6 kJ/L/day. This occurred between 17 and 31 May, during which time the ambient temperature averaged 13°C (average of maximum and minimum daily temperatures as recorded at a weather station approximately 10 km from the winery, Bureau of Meteorology 2011), corresponding with an ambient-wine temperature differential of 8°C. Average ambient temperature calculated in the same manner for Trials 1, 2 and 3 were 22°C, 24°C and 17°C, respectively. The corresponding average juice/wine temperature pairs for each trial were 15/19°C, 16/20°C and 16/18°C. Therefore, the maximum ambient-wine temperature differential encountered during fermentation trials was also 8°C and occurred during Trial 2. If direct proportionality is assumed, the difference in ambient gains between the 16°C and 20°C treatments is only 0.3 kJ/L/day or approximately 2 kJ/L in total over the length of the Trial 2 fermentations.

Energy is carried away by the 35-50 volumes of carbon dioxide released from the fermenter during fermentation (Rankine 2004) and also by the evaporation of ethanol and water, an effect which increases with temperature (Williams and Boulton 1983). Overall, this results in cooling of the juice/wine in the order of 6 kJ/L at a fermentation temperature of 15°C and 10 kJ/L at a fermentation temperature of 20°C, assuming a sugar concentration of 1 mol/L (Boulton et al. 1996).

Energy accumulates in the juice/wine itself as its temperature rises and this can be a rather significant consideration in calculations of this nature if temperature is not held constant over the length of the fermentation by cooling systems. The specific heat capacity of wine is approximately 4.3 kJ/(L.°C) so if the temperature rises from 18°C to 24°C over the course of a ferment as a result of changes to the set-point, 26 kJ/L is accumulated by the wine. For this reason, all calculations of cooling requirements from experimental data were corrected for temperature rises to ensure that correct comparisons were made between treatments that had different temperature rises. It is also important to consider that ultimately wine will typically be stored at temperatures below even the lowest fermentation temperature considered.

From the analysis presented, there may be expected to be some reduction in cooling requirement related to increased evaporation of ethanol and water at warmer fermentation temperatures, perhaps in the order or 4 kJ/L between fermentations at 15 and 20°C as well as some reduced ambient heat gains in the order of 2 kJ/L. This approximately 6 kJ/L reduction in cooling requirements is relatively minor in relation to the approximately 100 kJ/L released from the fermentation reaction itself. This small predicted reduction in cooling requirements with warmer fermentation temperatures is consistent with the observed experimental results.

To contextualise the savings possible from using warmer fermentation temperatures (e.g. 20°C instead of 15°C), it is worth considering the cost of a 6 kJ/L difference in fermentation cooling across the entire winery. If we assume that 30,000 kL are fermented at the winery each vintage, COP_{+brine} is 2 (a modified COP for estimation purposes that incorporates brine reticulation loop heat gains and pumping requirements), and that the cost of electricity is $0.15/kWh, the savings from fermenting at warmer temperatures amount to only $3,750 across the entire site each vintage. When the possibility of quality downgrades is taken into consideration, the use of warmer fermentation temperatures does not appear to be worth pursuing on the basis of electricity savings, particularly given that faster fermentations require a higher rate of cooling and available refrigeration capacity could become an issue during some peak periods.

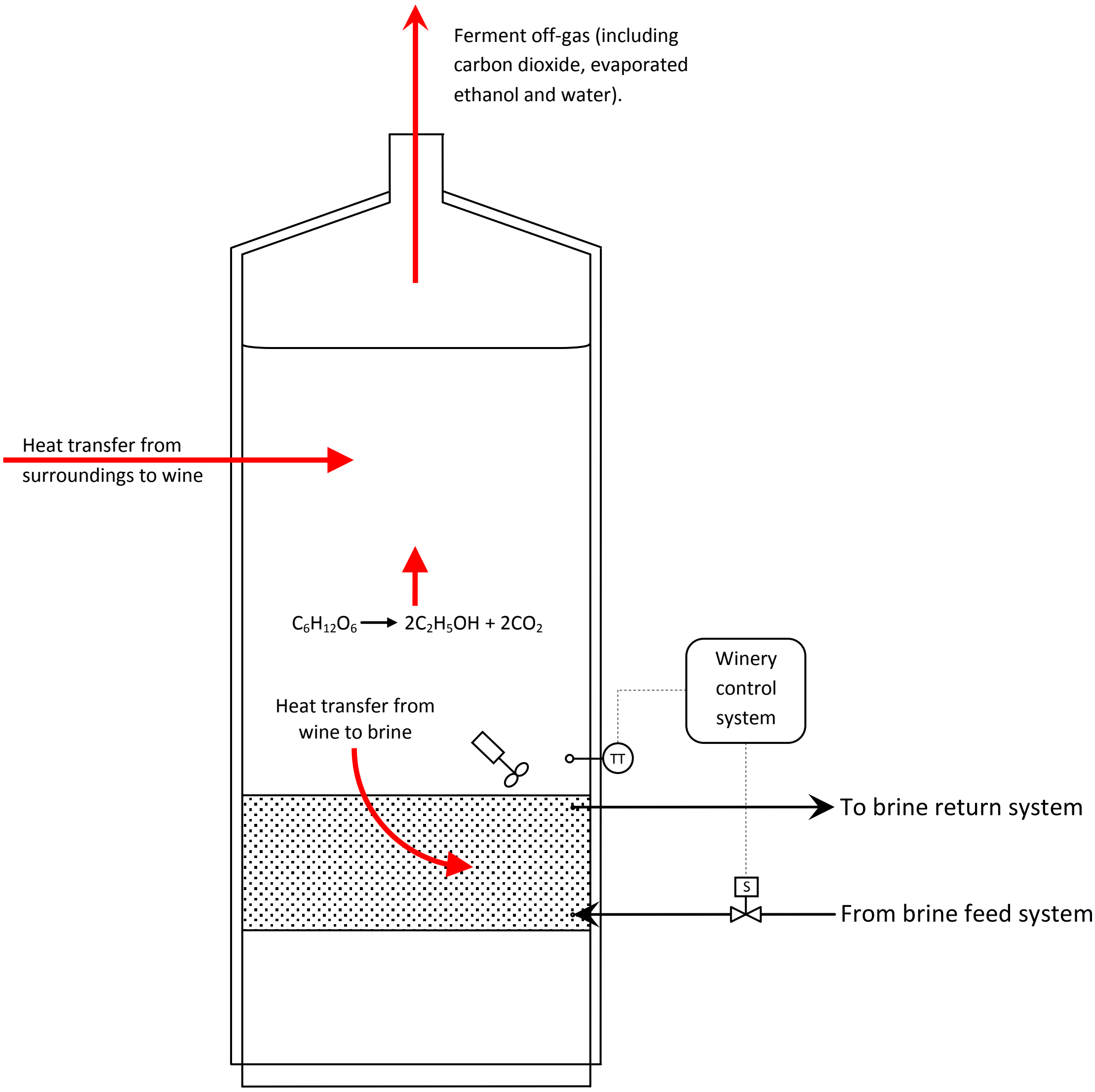

Figure 4.1: Heat generation and transfer during fermentation

4.3 Tank design and stratification

During the trials, the presence of temperature sensors at three different levels in the tanks allowed for a better understanding of what was occurring in each tank than would normally be possible with only one temperature probe.

It is apparent in Figures 3.1 to 3.6 that whenever the agitator was running the temperature in the tank was essentially uniform. This was not necessarily the case when the agitator was not running, with stratification sometimes being induced by the cooling jacket.

When fermentation was actively occurring, but the agitator was not running, as was the case for Trial 3 (Figures 3.5 and 3.6) the temperature typically remained fairly uniform throughout the tank. The currents imparted by the rising carbon dioxide gas, evidently provided sufficient agitation to achieve this. One exception was at the end of the 15°C Trial 1 fermentation (Figure 3.1). When the power failed and the agitator was locked out, the density of the juice/wine was still at approximately 4.5° Baumé and the batch was still fermenting yet the tank still stratified.

Excerpts from Figures 3.2 and 3.5 presented in Figures 4.2 and 4.3, respectively illustrate examples of brine-induced stratification observed when fermentation was not actively proceeding and the agitator was off.

As shown in Figure 4.2, there was a brief power failure at approximately midnight on 09/02/2011, which locked out the agitator. From this point onwards the brine flow stayed on almost indefinitely as the winery probe never reached the set-point temperature. The temperature lower in the tank diverged considerably from that higher in the tank, reaching as low as 3°C despite the tank temperature set-point being 20°C.

Figure 4.3 shows the early stages of one of the ferments in Trial 3. At a point in time, it was evident from daily wine sampling that the juice temperature was very low at the bottom of the tank and a pump-over was therefore performed to rectify this issue. This instance could have been avoided altogether by setting the cooling set-point a couple of degrees above the actual juice temperature initially, so that cooling was only activated when the fermentation was actually proceeding (as evidenced by the temperature rise). This is a practice already employed by winemakers familiar with the issues involved. There were problems with the fermentations performed in Trial 3 becoming partly stuck and it is possible that this may have been somewhat related to the influence of these very low temperatures at the bottom of the tank on the yeast.

Interestingly in Figure 4.3, following the pump-over, the temperature at the bottom of the tank actually remained greater than that higher up in the tank for approximately 15 hours. This is unusual as warmer wine generally has a lower density and as such in this situation will quickly rise towards the top, mixing and homogenising the tank in the process. In studies with beer it has been demonstrated that as beer cools it reaches a maximum density at approximately 3°C and below that temperature the beer actually decreases in density possibly resulting in temperature inversion (Boulton and Quain 2006). It is possible that a similar phenomenon may have occurred in this instance.

Excessive cooling at the bottom of the tank can influence the speed and quality of the fermentation. Potentially it may also waste electricity. The energy will typically be recovered when the tank is next mixed, but the temperature may now be lower than what was actually required.

Temperature stratification can be extremely misleading given that there is typically only one temperature probe in each tank and the winemaker may have to make decisions based on the measurement reported on the monitoring system.

From informal discussions, it appears that a number of people at the winery were aware that these tanks can suffer from cooling-induced stratification. It has been suggested that the problem is related to the location of the temperature probe, and that it could be resolved by relocating the temperature probe to a position lower in the tank. With the relocation of the temperature probe to the bottom of the tank, it would appear that the extreme stratification would not occur, but it also may not be possible to cool the upper part of the tank sufficiently as the cooled juice/wine will typically be the densest and tend to stay at the bottom of the tank. The fundamental design flaw in these tanks is really the existence of only one jacket and this being located at the bottom of the tank. However, it is quite plausible that these tanks were only ever designed with the intention of the jacket only being used when the agitator was on or when agitation was provided by fermentation.

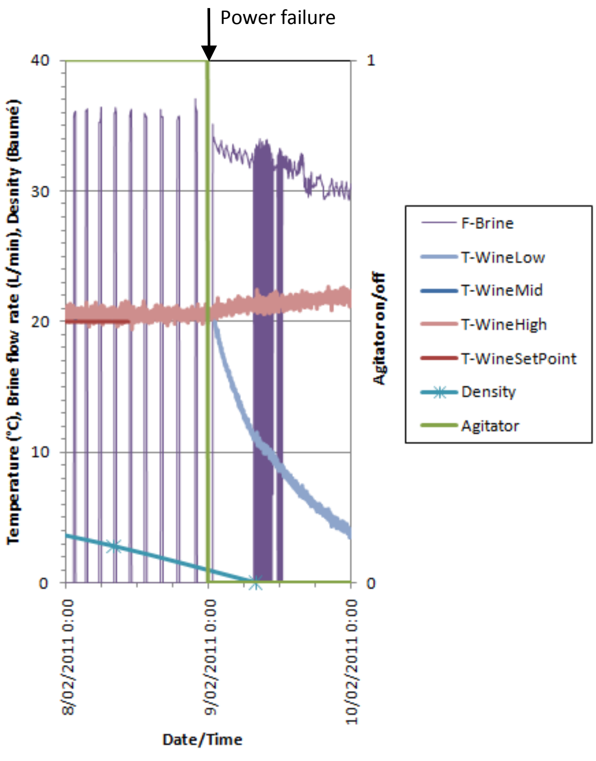

Figure 4.2: Stratification after power failure (agitator lockout) during Trial 1 – Chardonnay – 19°C

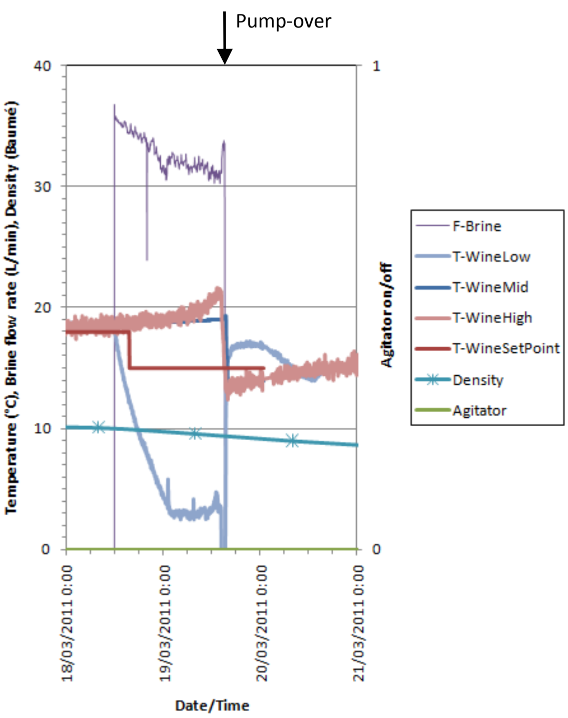

Figure 4.3: Stratification during Trial 3 – Riesling – 16°C

5. Conclusions and recommendations

1. Cooling requirements were reduced by between 0 and 8% for fermentations performed at warmer fermentation temperatures (e.g. 20°C instead of 16°C) during the 2011 vintage. Examination of heat generation and transfer mechanisms supported this result of a small reduction in overall energy use with warmer fermentation temperatures. Across a site fermenting 30,000 kL per annum, it is estimated that the electricity savings from using warmer fermentation temperatures would amount to approximately $4,000 per annum.

    a. *Given the modest savings and the potential risks of sensory damage, generally it would not seem to be worthwhile pursuing the use of marginally warmer than usual white fermentation temperatures. The exception to this could be in wineries with very limited tanks appropriate for fermentation, in which case the faster speed of fermentation at warmer temperatures may be useful to manage throughput (at the same time it must also be considered that faster fermentations do require a higher rate of cooling and available refrigeration capacity could potentially become an issue during some peak periods).*

2. There were significant problems with brine-induced stratification when the agitator was not running and fermentation was not actively proceeding. Temperatures at the bottom of the tanks sometimes reached as low as 3°C when, at the same time, the temperature nearer to the top of the tank was as high as 20°C. This was related primarily to the design of the tanks, with them having only one cooling jacket and this being located towards the bottom of the tank. There is potential for stratification of this nature to influence wine quality and consistency and possibly waste energy through excessive cooling. Results output by single-point temperature probes in tanks presented on winery monitoring systems can also become extremely misleading in these circumstances.

    a. *Wineries should be aware of the potential for brine-induced stratification and consider auditing the temperatures at different points in tanks at their site to verify that tank temperatures reported on winery monitoring systems are accurate.*

6. Acknowledgements

This project was funded by Australian grapegrowers and winemakers, through their investment body, the Grape and Wine Research and Development Corporation, with matching funds from the Australian government. We would also like to express our thanks to all the staff at Winery B for allowing us to perform this work and for their help and involvement.

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8. Glossary

Brine:	The fluid that is cooled by a refrigeration plant and then circulated around the winery to cool vessels and other operations. Brine consists of water with freezing-point suppressants together with corrosion inhibitors and colorants.
COP:	The coefficient of performance (COP) describes the efficiency of a refrigeration plant. It is the ratio of the cooling power to the electrical power input, principally that to drive the compressor. The overall efficiency of the winery cooling system will also be influenced by brine reticulation system heat gains and pumping electricity requirements.
Freezing-point suppressant:	An additive that lowers the temperature at which brine will freeze.
Refrigerant:	The working fluid in a refrigeration plant.
SCADA:	Supervisory Control And Data Acquisition (SCADA) generally refers to a centralised system for controlling and monitoring an industrial site.
Set-point:	The desired setting.
Specific heat capacity:	The amount of energy required to raise the temperature of a unit mass of a substance by a given amount.
Stratification:	Layering; related to less dense warmer liquid layering on top of more dense colder liquid in this instance.
Thermowell:	A thin closed-ended tube that extends into a vessel (or into other equipment) into which a probe can be inserted to measure temperature without direct contact with the vessel contents.

For further background, the reader is directed to the 'Improving Winery Refrigeration Efficiency' reference guide produced as part of this project. This can be downloaded from the AWRI (www.awri.com.au) and GWRDC (www.gwrdc.com.au) websites.