The Australian Wine Research Institute

GRAPE AND WINE RESEARCH AND DEVELOPMENT CORPORATION

Improving Winery Refrigeration Efficiency



FINAL REPORT to
GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

Project Number: **AWR 0902**

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Abstract

Refrigeration is a critical operation for quality Australian wine production. It is also the largest consumer of electricity in many Australian wineries. This project aimed to help wineries decrease electricity use and/or costs associated with refrigeration. A succinct reference guide was produced that provides an overview of winery refrigeration and opportunities for improvement. Case studies investigating selected opportunities/topics were also completed. The reference guide and detailed technical reports on the case studies are available for download from the websites of The Grape and Wine Research and Development Corporation and The Australian Wine Research Institute.

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Introduction

Refrigeration is a critical operation for quality wine production. Refrigeration is generally the largest consumer of electricity in Australian wineries, typically accounting for 50%-70% of total electricity use. This project aimed to assist the wine industry in better understanding refrigeration and improvement opportunities so that it may reduce electricity use and/or costs.

Method

At the outset of this project, a review of winery refrigeration technologies and improvement opportunities was completed. This consisted of a literature review, a web-based survey of wineries, winery visits and preliminary winery trials.

A draft reference guide on refrigeration was produced and circulated to an advisory committee comprising wine company personnel, a refrigeration contractor and the GWRDC program manager. This document was positively received but there was some feedback that it might be too long and that a briefer guide might be of more practical use to industry. A revised 16 page reference guide was then produced. This document was made available through the GWRDC and AWRI websites and the latest version is provided as Appendix 3 to this report.

Case studies were performed at two wineries (Winery A and Winery B) during 2011 in order to investigate some refrigeration-related improvement opportunities/topics in more detail. These were written up in three detailed technical reports, which are also available for download from the GWRDC and AWRI websites. These technical reports are provided as Appendices 4, 5 and 6 to this report. The topics covered by each report are summarised below.

1. Winery A – Case study report
    - Warmer brine temperatures
    - Cooling system operation and control systems
    - Cooling system maintenance
    - Plant shutdown/infrequent running
    - External heat exchangers

2. Winery B – Case study report 1
    - Warmer white fermentation temperatures
    - Tank stratification

3. Winery B – Case study report 2
    - Storage temperatures
    - Night-time cooling

Key findings from these case studies were incorporated into the latest version of the reference guide as this short document is likely to be much more widely read in the future than the detailed technical reports.

This project and the project outcomes have been widely communicated with the wine industry. Presentations have been given at conferences, winery operations workshops, and at AWRI roadshows and articles have been written for industry journals. The project has also been discussed directly during visits at more than 30 wineries. Details of selected communications are provided in Appendix 1. One of the most effective means of project communication has been through the provision of materials on the GWRDC and AWRI

websites and the high ranking these resources achieve in a Google search. For a Google search of “winery refrigeration” the relevant GWRDC and AWRI pages are currently ranked #1 and #2.

Conclusions

This project has successfully produced resources that can be used by wine companies to understand and improve winery refrigeration efficiency. These resources will remain on the GWRDC and AWRI websites. The reference guide (Appendix 3) should be referred to by wineries looking to understand and improve winery refrigeration as it provides a succinct coverage of the topic.

Future research directions

The Australian wine industry may benefit from further research, development and extension (R, D &E) on three cooling/refrigeration-related topics:

1. White juice clarification – flotation as an alternative to cold settling.
2. Cold stabilisation – alternative techniques and improved methods of assessment.
3. Tank and cooling jacket design.

Low residual juice solids are important for the fermentation of quality white wines. For this reason, white juice is typically clarified by chilling juice in order to settle solids. This is time-consuming and requires inefficient low brine temperatures and significant refrigeration during vintage - when refrigeration capacity is often limited. Furthermore, the cooling imparted is wasted as juice is warmed in preparation for fermentation. Flotation is an alternative method of clarification that does not require cooling and is more rapid than cold settling. This technique has been gaining significant uptake in some sections of the Australian wine industry, but there has apparently been fairly limited Australian R, D & E on the topic. A project to investigate the intricacies of this technique, its sensory impact and performance relative to cold settling would be useful for the Australian wine industry.

Consumers will reject wines containing precipitated tartrates. Cold stabilisation is therefore a critical winemaking process. Traditional cold stabilisation uses significant refrigeration and requires inefficient low brine temperatures. There are alternatives available including electrodialysis, packaged continuous tartrate stabilisation systems, and the crystallisation inhibitor, carboxymethylcellulose (CMC), which was relatively recently approved for use by Australian wineries. There are practical intricacies and caveats in the use of these additives/equipment. There are also ongoing issues in quickly and simply assessing whether a wine is sufficiently cold stable. The industry would benefit from further R, D & E on the topic of cold stabilisation – both on the alternative techniques available and on improving methods of assessing stability.

Winery tank and cooling jacket design and operation is another topic that would benefit from additional R, D & E. Tank jackets are an inefficient means of heat transfer but they are also a very simple, low risk and low labour option for cooling and their use is unlikely to decrease in the forseeable future. Optimising their design and use is therefore worthy of further investigation.

Appendix 1: Communication

Print publications

Roget, R., Nordestgaard, S. and Forsyth, K. (2011) Come in from the cold. The Australian and New Zealand Grapegrower and Winemaker (565): 61-64.

GWRDC (2011) New resource to cool refrigeration costs. In R & D @ Work, The Australian and New Zealand Grapegrower and Winemaker (575): 39.

Web publications (www.gwrdc.com.au and www.awri.com.au).

Nordestgaard, S., Forsyth, K., Roget, W. and O'Brien, V. (2012) Improving winery refrigeration efficiency – reference guide.

Nordestgaard, S. (2012) Winery A – Case study report.

Nordestgaard, S. (2012) Winery B – Case study report 1.

Nordestgaard, S. (2012) Winery B – Case study report 2.

Workshops

Winery operations workshop – refrigeration & wastewater. Hunter Valley. 8th December, 2011.

Winery operations workshop – refrigeration & wastewater. Ararat. 29th July, 2012.

Winery operations workshop – refrigeration & wastewater. Yarra Valley. 30th July, 2012.

Winemaking process improvement opportunities workshop (W05). 14th Australian Wine Industry Technical Conference. Adelaide, SA. 3rd July, 2010.

Winery operations improvement workshop – tartrate stabilisation. AWRI, Adelaide, SA. 13th October 2010.

Conference poster

Forsyth, K. and Roget, W. (2010) Maximising refrigeration efficiency (Poster). 14th Australian Wine Industry Technical Conference. Adelaide, SA. 3rd-8th July, 2010.

Conference presentation

Nordestgaard, S. (2011) Improving winery refrigeration efficiency and opportunities for cleaner production. Winery Engineers Association Conference. Nuriootpa, SA. 23rd June, 2011.

Other

Material from the project has been communicated at over 30 winery visits around Australia and as part of presentations at several AWRI Roadshows and at numerous other events.

Appendix 3: Reference guide



Improving Winery Refrigeration Efficiency

AWRI
COMMERCIAL SERVICES
OUR KNOWLEDGE, YOUR RESOURCE

AWRI

GWRDC
GRAPE AND WINE RESEARCH AND DEVELOPMENT CORPORATION

This booklet was prepared by Commercial Services, a business unit of The Australian Wine Research Institute (AWRI). It was funded by Australian grapegrowers and winemakers through their investment body the Grape and Wine Research and Development Corporation (GWRDC), with matching funds from the Australian Government. The AWRI is part of the Wine Innovation Cluster.

The information contained within the booklet is based upon sources and analyses which at the time of preparation are believed to be reliable. Subsequent to the publication date some sections may no longer be valid.

The information presented in this booklet is intended as a simple guide only and should not be relied upon or extrapolated beyond its intended purpose. Every winery is unique and it is important to involve an experienced engineer or contractor before making any major changes.

The information presented in this booklet must not be used in a misleading, deceptive, defamatory or inaccurate manner or in any other way which might be prejudicial to The AWRI, including and without limitation, in order to imply that The AWRI has endorsed a particular product or service.

Copies of this booklet are available for download from www.awri.com.au or www.gwrdc.com.au

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1 INTRODUCTION

Temperature control is a critical parameter in quality wine production. Cooling provided by refrigeration is a particularly important operation in Australian wineries, given the warm climates found in many regions.

Refrigeration is typically the largest consumer of electricity in Australian wineries, accounting for 50%–70% of total electricity usage. Electricity costs will inevitably rise with time, particularly with the introduction of schemes to manage greenhouse gas emissions. 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 wine industry improve refrigeration efficiency and decrease electricity usage and/or costs.

This reference guide provides a brief overview of winery refrigeration and potential improvement opportunities. Case studies investigating some of these opportunities in more detail have been performed and these are available for download from the AWRI and GWRDC websites. Excerpts from some of these studies are included in this guide.



2 WINERY COOLING USES

Key uses of refrigeration in Australian wineries are presented in Table 1, together with a brief description of their main purpose.

Table 1. Key uses of refrigeration in Australian wineries

Process	Purpose
Must cooling	Limits phenolic oxidation and premature fermentation
Juice clarification	Aids settling of juice solids
Fermentation	Controls fermentation rate
Cold stabilisation	Removes tartrate crystals to prevent precipitation after bottling
Wine storage	Limits the rate of oxidative browning and volatilisation of aroma compounds
Space cooling	Cools offices, wine or barrel storage areas

3 WINERY REFRIGERATION SYSTEMS

3.1 THE REFRIGERATION CYCLE

Refrigeration is the process of moving heat from a location where it is undesirable to another location. Winery refrigeration systems typically employ a vapour-compression cycle to achieve this, as illustrated in Figure 1. The heat is transferred from the juice, wine or brine to the evaporating refrigerant at the evaporator and the heat is rejected to air and/or water as the refrigerant condenses in the condenser.

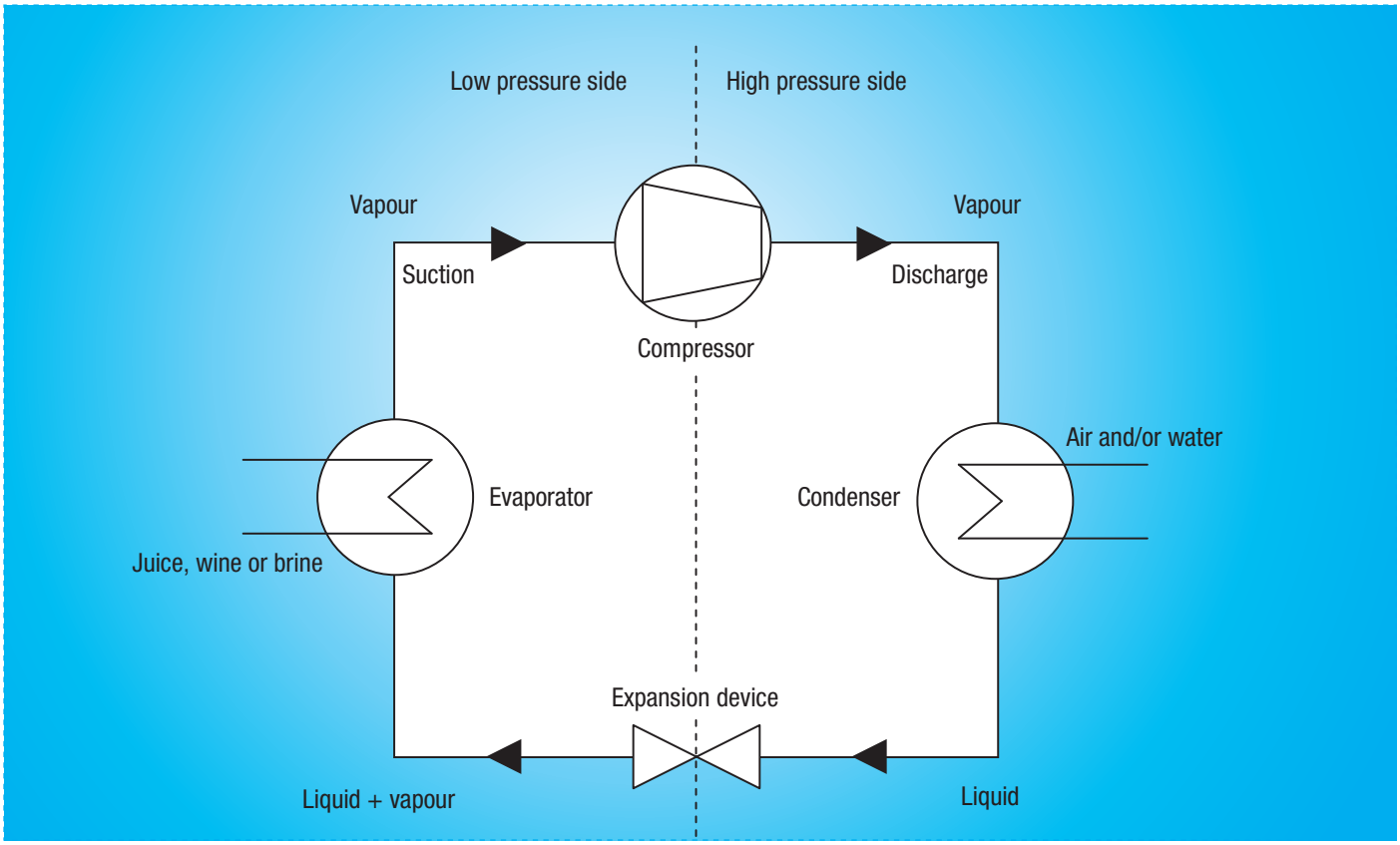


Figure 1. Simplified single-stage vapour-compression refrigeration cycle

3.2 BRINE RETICULATION SYSTEMS

In wineries, wine or juice may be heat exchanged directly with the evaporating refrigerant in which case the heat exchange operation is described as 'direct expansion'. Alternatively, a secondary coolant ('brine') may be heat exchanged with the evaporating refrigerant and then distributed around the winery to be used to cool juice or wine.

Brine systems are commonly used in Australian wineries. They are generally simpler and more flexible than systems that employ direct expansion. They also provide some stored cooling.

Brine is water with a freezing-point suppressant added. Proprietary freezing-point suppressant mixtures are commonly used. The active ingredients in the most common commercial product are ethanol and propylene glycol. The inclusion of propylene glycol means that sufficient freezing-point suppression can be provided without the brine containing so much ethanol (>24%) that the brine is classified as a class 3 flammable liquid. Corrosion inhibitors and colorants/tracer chemicals used to facilitate leak detection are also commonly included.

A simplified brine reticulation system is illustrated in Figure 2.

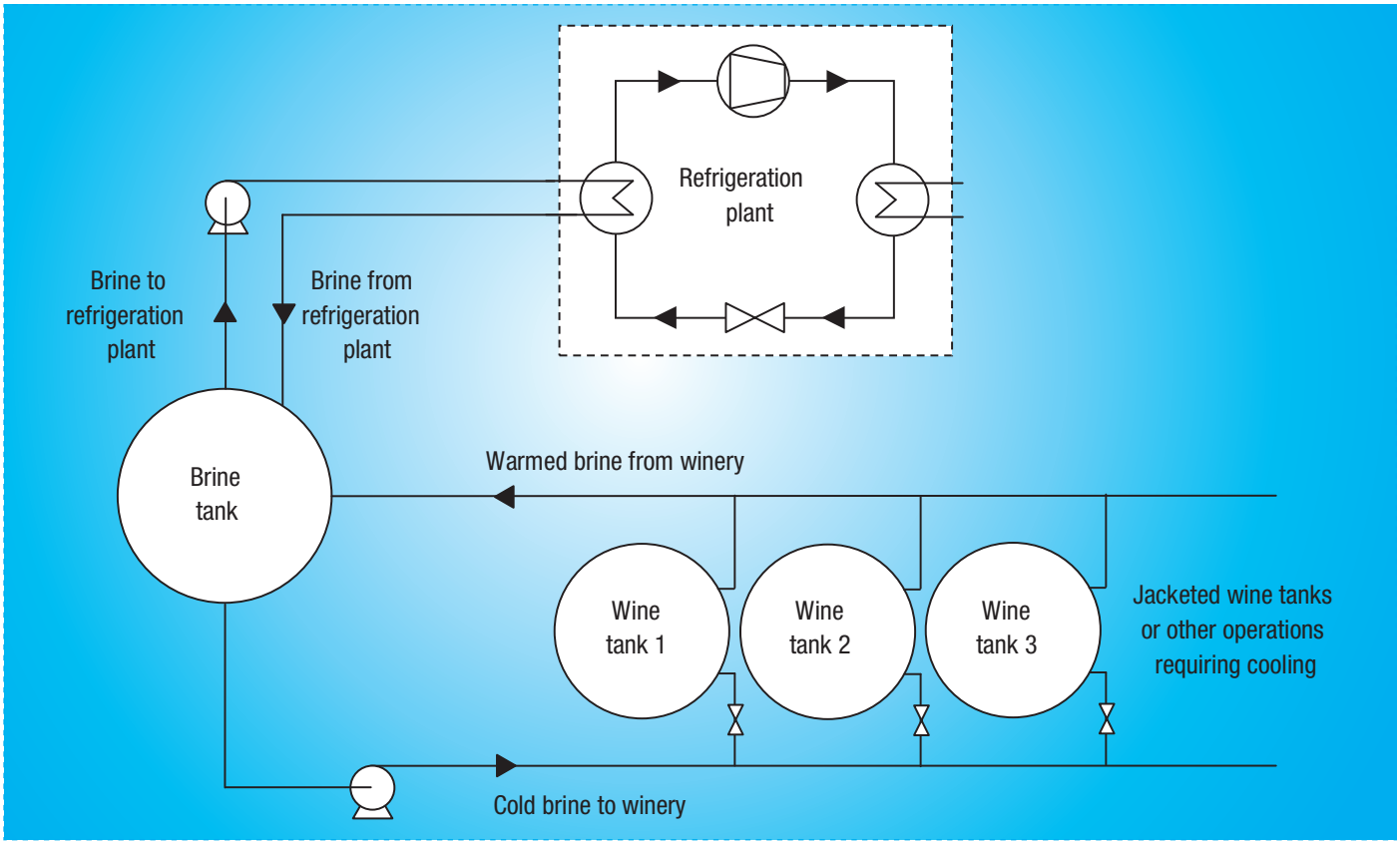


Figure 2. Simplified brine reticulation system

3.3 REFRIGERATION SYSTEMS USED IN DIFFERENT SIZED WINERIES

While refrigeration systems vary depending on the winery and supplier, some generalisations may be made.

Smaller wineries will tend to use packaged chillers in which all components of the refrigeration plant are integrated in one unit, while larger wineries typically have customised refrigeration plants. With a packaged chiller, a brine reticulation system is used, whereas some direct expansion cooling may be incorporated with customised refrigeration plants. Ammonia is typically employed as the refrigerant in larger refrigeration plants, but packaged chillers tend to use hydrofluorocarbon (HFC) refrigerants.

Packaged chillers typically have air-cooled condensers where refrigerant, contained in small diameter condenser tubes, is cooled by fans. Water-cooled condensers where refrigerant is heat exchanged with water may also be used. In that instance, water may subsequently be passed through a cooling tower before reuse. Evaporative condensers are generally used in large refrigeration plants. These are essentially a combination of a condenser and a cooling tower in one device; water passes over tubes containing the refrigerant and fans drive away the evaporating water. Evaporative condensers more readily condense refrigerant than air-cooled condensers, reducing the amount of compression that the compressor should need to perform

3.4 REFRIGERATION EFFICIENCY

The efficiency of a refrigeration plant is described by its coefficient of performance (COP). The COP is the ratio of the cooling power provided at the evaporator to the electrical power input to drive the compressor (electrical power input to drive auxiliaries like condenser fans and pumps is sometimes also included).

COP = Cooling Power (kW) / Electrical Power Input (kW)

In contrast with non-refrigeration measurements of efficiency, COP can be and generally is higher than 100% or 1. This is possible because the electrical power input is not directly converted to cooling, but rather it is being used to pump heat from one location to another.

COP is highly dependent on both equipment design and operating conditions. When assessing the capacity and COP of a refrigeration plant, it is critical that data is at conditions relevant to winery operation. In particular, COP varies considerably with compressor suction and discharge pressures and depending on whether the plant is being run at part load. A major market for packaged chillers is commercial building air-conditioning systems. The operating conditions in that environment are very different to those at a winery where lower brine temperatures (e.g. –7 °C as opposed to +5 °C) and therefore lower suction pressures are typically employed. Figure 3 presents the COP for one packaged chiller at a range of brine and ambient temperatures.

Refrigeration plant COP and capacity data reported by manufacturers will not include the heat gains and pumping electricity requirements associated with the brine system.

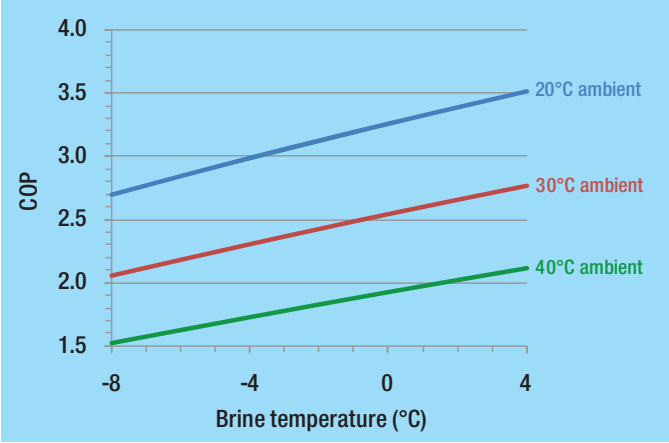


Figure 3. Influence of brine and ambient temperatures on COP for one packaged chiller operating at maximum capacity

ENERGY AND POWER

Energy and power are frequently confused with each other. Energy exists in a variety of forms, including heat (cold is negative heat) and electricity. The Joule (J) is the metric unit of energy. Power is the rate at which energy is generated or consumed. The metric unit of power is the Watt (W), which is equivalent to 1 Joule/second (J/s). 1 J and 1 W are small amounts and therefore units of kJ and kW are often used in practice. 1 kJ = 1000 J, 1 kW = 1000 W = 1000 J/s.

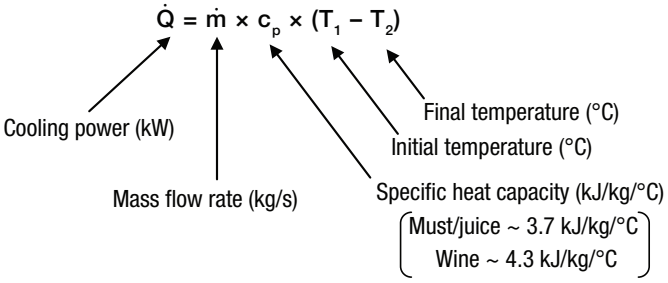
Electricity is billed in part on the basis of the quantity of kilowatt-hours (kWh) used. This is a measure of energy use not power. It is the rate of energy consumption (kW) multiplied by the time of that consumption (h). 1 kWh = 3,600 kJ.

3.5 COOLING REQUIREMENTS

The design of a winery cooling system should be performed on a case by case basis by an appropriately qualified supplier/ refrigeration engineer.

To assist in discussions with suppliers/engineers, wineries should start by developing a list of the operations requiring cooling (must chilling, juice chilling, fermentation, wine storage, cold stabilisation, etc.). This list should include information on these operations likely to influence cooling requirements (volumes, flow rates, product and ambient temperatures, cooling rates, fermentation rates, etc.) and the timing of these operations throughout the year – the overlap of different operations will be critical in understanding the total cooling requirements.

Peak cooling requirements typically occur during vintage. The key operations responsible for this demand are removing heat generated by the fermentation reaction, and chilling must and juice. The fermentation reaction releases approximately 10 kJ/L/°Baumé. Cooling requirements associated with must and juice chilling can be estimated using the following fundamental equation:



As an example, let us consider a winery that has peak refrigeration requirements occurring when the winery is simultaneously fermenting 50,000 L at a rate of 2 °Bé/day (0.000023 °Bé/s), must chilling 5,000 kg/h (1.4 kg/s) from 20 °C to 10 °C, and cooling 10,000 L (11,000 kg) of white juice at a rate of 2 °C/h (0.00056 °C/s) in order to settle juice solids.

The principal cooling requirements associated with each operation are:

Fermentation
50,000 L × 10 kJ/L/°Bé × 0.000023 °Bé/s = 11.5 kW.

Must chilling
1.4 kg/s × 3.7 kJ/kg/°C × 10 °C = 51.8 kW.

Juice chilling
11,000 kg × 3.7 kJ/kg/°C × 0.00056 °C/s = 22.8 kW

This gives a total of 86.1 kW. Once other heat loads such as warming of juice/wine from ambient conditions are factored in, the total heat load will be somewhat higher, perhaps 110 kW. Furthermore, there will also be heat gains associated with the brine reticulation system. The refrigerant plant may therefore need to have a cooling capacity of 130 kW to meet those process cooling requirements.

It is stressed that these methods provide order of magnitude estimates only and should not be relied upon for system design. However, methods of this nature might be useful in understanding/cross-checking recommendations from suppliers. Appropriate safety margins should always be employed in calculations and refrigeration plants should be designed/selected to operate efficiently throughout the year, not just at peak requirements.

3.6 ENVIRONMENTAL ISSUES

Refrigeration contributes to global warming principally through the use of electricity, which has predominantly been generated by coal-fired power stations. Some refrigerants are greenhouse gases themselves so fugitive emissions can also contribute to global warming.

Fugitive emissions of some refrigerants can also deplete the ozone layer and this was the driver in phasing out particular groups of refrigerants. Chlorofluorocarbons (CFCs) were phased out in 1995 and hydrochlorofluorocarbons (HCFCs) will be phased out by 2020 in accordance with the Montreal Protocol on Substances that Deplete the Ozone Layer (Department of Sustainability, Environment, Water, Population and Communities 2010).

The ozone depleting and global warming potentials of several refrigerants, representing each of the key refrigerant groups, are presented in Table 2.

Notably, ammonia, which is a common refrigerant in larger wineries, has both low ozone depleting and global warming potentials. HFCs like R134a that are typically used in newer packaged chillers, instead of R12 or R22, while having no ozone depleting potential, still have considerable global warming potentials. As of 1st July 2012, a levy is collected on some synthetic refrigerants at the point of manufacture/import at a rate equivalent to the carbon price. Given their high global warming potentials, this has resulted in large price increases on those refrigerants.

Table 2. Environmental impacts of refrigerants

ASHRAE[a] number	Name (Group)	ODP[b]	GWP_{100} [c]
R717	Ammonia	0	< 1
R12	Dichlorodifluoromethane (CFC)	1	10,900
R22	Chlorodifluoromethane (HCFC)	0.055	1,810
R134a	1,1,1,2-Tetrafluoroethane (HFC)	0	1,430
R290	Propane (HC)	0	20
R744	Carbon dioxide	0	1

[a]American Society of Heating, Refrigerating and Air-Conditioning Engineers.
[b]Ozone Depleting Potential: Index of a substance's ability to deplete stratospheric ozone.
[c]Global Warming Potential: Index of a substance's ability to contribute to global warming.
Environmental impacts from ASHRAE (2009).

4 IMPROVEMENT OPPORTUNITIES

Refrigeration-related improvement opportunities for wineries are outlined in this section. These opportunities are grouped broadly into two categories; low-cost and higher-cost improvement opportunities. Low cost opportunities are generally associated with changes in operating practices, while higher cost improvement opportunities often involve more significant refrigeration plant/winery modifications.

At the time of writing, there are grants available as part of the Australian Government's Clean Technology Food and Foundries Investment Program ($200 million total) for capital investment and associated activities that generate carbon and energy savings. Depending on company and project size, grants may be provided to fund up to 50% of project cost. Projects related to implementing many of the improvement opportunities outlined in this reference guide may be applicable. Please refer to the AusIndustry website (www.ausindustry.gov.au) for specific details on the program.

4.1 LOW COST IMPROVEMENT OPPORTUNITIES

4.1.1 Turning off the refrigeration plant when not in use

It can be advantageous to turn the refrigeration plant off, or to change the temperature settings so that it runs infrequently, when cooling is not going to be required for a significant period of time. Specific procedures for plant shut-down and start-up should be obtained from the refrigeration equipment supplier. The compressor oil heaters may need to be kept on or at least energised for a significant period prior to start-up in order to prevent excessive absorption of the refrigerant in the lubricating oil and possible damage to the compressor on start-up.

In turning refrigeration plants with a brine system off or running them infrequently, evaporation of freezing-point suppressants like ethanol also needs to be managed. Evaporation rate will be higher at higher temperatures. A pure ethanol solution would evaporate significantly around 13 ˚C. A brine solution may typically contain only 20% ethanol with the remainder principally being water, and some propylene glycol, which are likely to retard the evaporation of ethanol. While it is not entirely clear at what temperature there will be significant ethanol evaporation it would seem prudent to try and maintain ethanol based brines at a maximum of around 10 ˚C to limit evaporation.

PLANT SHUT-DOWN EXAMPLE

Cooling was not required at one small winery for approximately 4 months each year. The winery's packaged chiller had usually been left on during this period. One year, the chiller was switched off during this period, reducing annual winery electricity consumption by approximately 20%.

4.1.2 Temperature rationalisation

Temperature requirements should be discussed and objective protocols put in place for both winemaking and other site operations.

In winemaking operations, a balance often needs to be struck between the perceived risk of warmer temperatures and the cost of electricity to provide that cooling. This balance will vary for different styles and values of product. A method for wineries quickly to estimate potential savings from storing wine at warmer temperatures is provided in the box below so that wineries can make a judgement for their own products.

For general site operations low temperatures should not be used unless there is a sound reason for doing so. As an example, dry goods that do not need to be stored cold should not be stored in a refrigerated product warehouse. There is

WARMER WINE STORAGE

The approximate saving in refrigeration electricity costs from maintaining wine at a temperature of T_{High} (e.g. 10 °C) instead of T_{Low} (e.g. 5 °C) in a wine tank of diameter D (e.g. 3.3 m) and height L (e.g. 7.3 m) with aluminium clad 75 mm thick polystyrene insulation can be estimated using the equation:

$$\text{Saving (\$/kL/week)} = 0.006 \times \left(\frac{1}{L} + \frac{4}{D}\right) \times (T_{High} - T_{Low})$$

Assumptions: Unit electricity cost = $0.15/kWh, COP_{+brine} = 2 (A modified COP for estimation purposes that incorporates brine reticulation loop heat gains and pumping requirements), overall heat transfer coefficient = 0.47 W/m²/°C, and T_{High} is lower than the average ambient temperature.

both an energy requirement to cool these materials down and also likely increased heat gains to the warehouse from the outside environment associated with increased traffic to access the dry goods.

4.1.3 Night-time grape harvesting

Diurnal variations in grape temperature should be taken advantage of to minimise must cooling requirements. Grapes on the vine not exposed to sun closely follow the ambient temperature. If grapes are harvested at night when it is cool, there is reduced heat energy in the grapes, which otherwise may have needed to be removed by refrigeration at the winery.

4.1.4 Night-time cooling

Off-peak night-time electricity is often considerably cheaper than peak electricity. There is therefore advantage in shifting load from peak to off-peak tariffs by cooling wine at night rather than during the day. Wine stored in insulated tanks may be able to be maintained within an acceptable temperature range by night-time cooling alone.

If control systems are in place that allow the refrigeration plant compressor discharge (head) pressure to reduce (i.e. float) appropriately when the ambient temperature is lower, the refrigeration plant COP will also increase, yielding additional savings.

Night-time cooling is one of the most attractive in-winery refrigeration-related improvement opportunities as there is little risk to product quality. The wine is still being stored at essentially the same temperature, it is just that the electricity is being purchased on a less expensive tariff.

4.1.5 Brine temperature

When warmer brine temperatures are used, higher refrigeration plant compressor suction pressures can often be employed, resulting in considerable improvements in refrigeration plant COP.

Low brine temperatures (e.g. -5 to -10 °C) are often used year round in wineries. This is partly related to achieving reasonably fast product cooling rates using only tank jackets for heat exchange.

For operations where the process temperature is relatively high (e.g. fermentation, bulk wine storage) acceptable cooling rates can often still be achieved using much warmer brine, while still using only tank jackets for heat exchange. For operations that are performed at low temperatures (traditional cold stabilisation and to a lesser extent must chilling and juice cold settling) sub-zero brine temperatures are still required to ensure that there is sufficient temperature differential between the brine and juice/wine to provide a reasonable rate of cooling.

The required brine temperature is dictated by the lowest temperature operation on the brine reticulation loop. Scheduling is one tool that can be used to minimise the amount of time that that very low brine temperatures have to be used. For example, all cold stabilisation operations could be scheduled to occur in specific periods in the year instead of intermittently throughout the year. Another option is to find alternatives to those operations requiring low brine temperatures. Crystallisation inhibitors (e.g. carboxymethylcellulose, mannoproteins), electrodialysis, or packaged rapid contact systems (some refrigeration will still be required but this would usually be supplied by a dedicated refrigeration system) are alternative options available for cold stabilisation. Flotation systems can be used for juice clarification. Must chilling requirements may be reduced by night-time harvesting.

Even very small changes in refrigerant suction pressure can result in considerable improvements in COP. Therefore it is generally advisable to use as high brine temperatures as practicable for as much of the time as possible. It must be cautioned that COP improvements will only be realised if the control systems in place actually increase the suction pressure when warmer brine is used.

WARMER BRINE EXAMPLE

In a trial performed at one winery, red wine fermentations were adequately controlled using +4 °C brine circulated through the existing tank jackets. The cooling rate was reportedly slower than that achieved by the winery in previous vintages using sub-zero brine temperatures. Measurements reported on the winery's packaged chiller display screen confirmed that its control system did increase the suction pressure when the warmer brine was used.

4.1.6 Brine concentration

The freezing-point suppressant should be maintained at a concentration such that the brine would freeze at a temperature 5 ˚C below the lowest operating temperature (White et al.1989). Excessive concentrations should not be used as apart from being quite expensive, they will result in diminished heat transfer properties and increased pumping costs.

4.1.7 Brine pumping between the chiller and the brine tank

The pump moving brine through the chiller should not generally be running constantly as this is unnecessarily wasting electricity and may be preventing desirable stratification in the brine tank between cold brine at the bottom and the warm brine returning from the winery at the top.

Packaged chillers usually come with a built-in temperature probe at the brine inlet to the evaporator. Anecdotally, to avoid using a separate brine tank temperature measurement, the pump between the chiller and brine tank is sometime set to run permanently, such that this measurement is representative of the temperature in the brine tank. Operation of the chiller and this pump based on a temperature probe in the brine tank negates the need to run the pump continuously. It should be noted that with intermittent operation of this pump, the pump will have to be run for a period before the chiller compressor starts and for a period after it stops in addition to just when the compressor is running, to prevent the evaporator from freezing.

4.1.8 Brine reticulation around the winery

Brine should not be circulated to areas in the winery or through vessels where it is not needed as this can result in increased pumping requirements and ambient heat gains. Brine pumping contributes to overall refrigeration electricity usage. The control system should therefore ensure that brine reticulation pumps adapt appropriately to winery brine requirements and do not run unnecessarily at full speed when there is already appropriate brine pressure in the system.

4.1.9 Cooling with external heat exchangers

Tank jackets are widely used for winery cooling but they do not remove heat as efficiently as an external heat exchanger. Tank agitation does improve heat transfer to some extent. An advantage of tank jackets is that they are typically automated – generally someone just sets a temperature for the tank on a control system and that is it.

External heat exchangers can be very useful in some situations in providing more rapid cooling. Plate heat exchangers are considerably more effective at exchanging heat than tube-in-tube heat exchangers, however, they have small channels and therefore have higher pressure drops and are susceptible to blockages if solids are present.

EXTERNAL HEAT EXCHANGER EXAMPLE

In a winery trial, a small dimpled tube-in-tube heat exchanger was used to cool red ferments during pump-overs. The winery found this heat exchanger particularly useful for cooling 1-2 tonne ferments that had in previous years been cooled using cooling coils, which the winery had always found to be very ineffective.

4.1.10 Product heat exchange

Product heat exchange is a means of recovering useful energy. Pre-cooling wine for cold-stabilisation with wine finishing cold stabilisation using a plate heat exchanger is one example. If product heat exchange is not performed, the wine finishing cold stabilisation will gradually warm up possibly wasting the cooling that was originally imparted (whether or not it is truly wasted depends on whether or not the wine's lower temperature saves on refrigerated cooling later in that wine's lifetime). Product heat exchange does often involve increased planning. In the pre-cooling for cold stabilisation example, one wine must be ready to enter cold stabilisation at the same time as another wine has finished cold stabilisation.

4.1.11 Maintenance

Equipment should be properly maintained to ensure efficient operation. Condensers should be kept clean to maintain their effectiveness and bulky equipment like grape bins should not be left in a position where they can obstruct condenser air flow.

Depending on the style of refrigeration plant, and particularly where regular service arrangements are not in place, it may be worthwhile keeping a log of key operational parameters so that problems that will require a service call can be identified early (e.g. refrigerant leaks).

Before engaging a service technician it is worthwhile verifying that they have a good understanding of the operation of winery refrigeration systems (including equipment peripheral to the refrigeration plant itself, such as winery brine systems and control strategies) so that they can provide useful advice and

guidance while on site. They may not be able to provide this support if their principal interest is the maintenance of building air conditioning systems.

4.1.12 Electricity bills

Wineries should closely inspect their electricity bill and understand exactly how their electricity usage is charged. From this they can objectively work to minimise their bill. For example, if there is a large differential between peak and off-peak electricity prices it is worthwhile working to shift peak electricity use to off-peak periods.

Pricing available through different electricity providers should be investigated/negotiated. Paying less for the same amount of electricity is much easier than making changes in the winery to reduce electricity use.

4.1.13 Auditing

A site audit/review of winery cooling, refrigeration use and control strategies can help identify and prioritise site specific improvement opportunities. Temporary power meters can sometimes be a useful tool to understand electricity use.

4.1.14 Reference charts

Reference wall charts that provide staff with quick information on key settings (brine temperatures, wine storage temperatures, agitator settings, etc.) can be useful. They can assist in standardising operations at best practice. At many wineries different practices are used by different staff for the same product.

4.1.15 Training

Staff should be trained on the basic practical aspects of winery refrigeration and cooling. An understanding of the key operating and cost principles will allow staff to make informed production decisions that minimise refrigeration costs and ensure product quality during busy production periods where decisions need to be made on the run.

4.2 HIGHER COST IMPROVEMENT OPPORTUNITIES

4.2.1 Process control

There are many process control efficiency opportunities both for the refrigeration plant itself and how it interacts with the winery. While these will be system dependent, some generalisations can be made.

For the refrigeration plant, process control systems should be in place that allow the compressor suction pressure to increase appropriately when warmer brine temperatures are used so that increased COPs are realised. Similarly, process control systems should be in place that allow the compressor discharge (head) pressure to reduce appropriately (i.e float)

NIGHT-TIME COOLING CONTROL EXAMPLE

Changes were made to a tank farm control system at one winery to facilitate dual tank temperature set-points. Tank set-point temperature from 2 am – 6 am was set to be 0.5 °C below the normal set-point and to be 0.5 °C above the normal set-point for the remainder of the day (i.e. if the normal set-point was 5 °C, the set-point was 4.5 °C for 2 am – 6 am, and 5.5 °C at other times). This strategy showed a shift of refrigeration plant operation from short repeated cycles throughout the day to operation predominantly at night for a sustained period.

PHASE CHANGES AND ENERGY

Sensible heat is the amount of energy released or absorbed by a substance during a change of temperature, without a change in phase. For example, 4.2 kJ/kg is required to increase the temperature of water by 1 ℃. Therefore to raise the temperature of water by 10 ℃, 42 kJ/kg is required.

The latent heat is the amount of energy released or absorbed during a phase change. The energy is used to change the state of the material. The temperature remains constant and therefore the heat is somewhat hidden or ‘latent’. For example, approximately 2400 kJ/kg of energy is required to evaporate water.

This large magnitude of latent heat relative to sensible heat is indicative of the importance of phase changes in heat transfer. For example, in the refrigeration cycle the evaporating refrigerant is able to remove a much larger quantity of heat from the brine/wine/juice at the evaporator compared with if the refrigerant just increased in temperature without changing phase.

The condensation of water vapour on uninsulated steel tanks significantly heating the wine inside the tank is another example of the importance of phase changes in heat transfer.

at lower ambient temperatures, so that increased COPs are realised during winter and at night. Process control systems and drives should also be in place that ensure the refrigeration plant is operating as efficiently as possible at part load.

Improvements to control systems that manage the scheduling of winery cooling operations are also advantageous, such as those that facilitate night-time cooling. There are sophisticated largely off-the-shelf winery cooling control systems available that can do this. These systems often also automate other improvements, such as setting the brine temperature at the highest level possible based on the lowest temperature wine tank on the brine loop, and prioritising cooling operations when there is limited refrigeration capacity available.

4.2.2 Insulation

Insulation plays an important role in minimising refrigeration requirements. This includes insulation for the refrigeration plant and brine reticulation system as well as for wine tanks.

Condensation on wine tanks is something that should be avoided. This occurs when the tank surface temperature is less than the dew-point temperature.

The phase change of water vapour in the air to liquid drops on the tank surface causes considerable heating. It is notable that once insulation is thick enough to prevent condensation further increases in insulation thickness only result in minor savings in heat gain (White et al. 1991). 75 mm thick polystyrene insulation with aluminium skin cladding is commonly used for winery tank insulation.

When water vapour condenses on brine distribution pipes and when this water vapour then freezes heat is transferred to the brine from the phase change.

When formed, ice can insulate to some degree but it is nowhere near as effective as purpose specific insulators. Furthermore, as ice accumulates the surface area exposed to air increases gathering more heat from it. White et al. (1989) reports that this largely counteracts any small benefit from the insulating ice layer.

At some wineries, red fermentors are not insulated because fermentation may be performed at warmer than ambient temperatures, at least during the night. However, if a tank jacket is used to provide cooling, it may be worthwhile to insulate the tank jacket itself. Otherwise, with typically low brine temperatures, water vapour will condense on the outside of the jacket and then freeze, wasting some energy and also causing an occupational health and safety hazard when the ice falls off.

4.2.3 Refrigeration plant heat recovery

In a refrigeration plant, heat is rejected from the refrigerant at the condenser. This heat could potentially be recovered and used for other winery purposes. Some packaged chillers can come factory-fitted with an additional heat exchanger in series with the condenser that can be used to preheat water to approximately 50 °C. In some refrigeration plants heat may be recovered from compressor cooling/lubricating fluids. In evaluating the merit of heat recovery, the timing of heat recovery and the timing of the use of that recovered heat must be considered. Storage tanks may be employed to balance warm water produced against warm water use to some extent, but issues such as the growth of microorganisms in mildly warm water need to be carefully managed. It is also important to ensure that system alterations that facilitate heat recovery do not negatively impact upon refrigeration plant efficiency.

5 REFERENCES AND FURTHER READING

There are many sources of information on refrigeration that can be consulted for a detailed treatment of refrigeration theory, equipment and improvement opportunities, both specific to the wine industry and to refrigeration more generally.

White et al. (1989) have written an excellent, user-friendly, practical reference on winery refrigeration and the winemaking textbook by Boulton et al. (1996) also includes a useful chapter on heating and cooling. An energy best practice guide for Australian wineries produced for the Department of Industry, Tourism and Resources (2003) is available from the website of the Department of Resources, Energy and Tourism.

Other authors, often funded by governments focussed on minimising global warming, have produced a range of publications related to optimising industrial refrigeration that are available for download on the internet. For example, Bellstedt (2010) has produced a detailed technical reference guide on industrial refrigeration improvement opportunities, which is available for download from the website of the NSW Department of Environment and Heritage.

Many of the fundamental principles behind refrigeration apply irrespective of whether a winery refrigeration system or a domestic refrigerator or air conditioner is being considered. Therefore explanations on the operation of these familiar domestic devices available in books or on the internet (including videos on www.youtube.com) can be useful in developing an understanding of winery refrigeration.

ASHRAE (2009) ASHRAE Handbook – Fundamentals (SI).

Bellstedt (2010) Energy saver, Industrial refrigeration technology report, Industrial refrigeration and chilled glycol and water applications. www.environment.nsw.gov.au. Accessed June 2012.

Boulton, R.B., Singleton, V.L., Bisson, L.F. and Kunkee, R.E. (1996) Principles and practices of winemaking. Chapman and Hall, United State of America.

Department of Industry, Tourism and Resources (2003) A guide to energy innovation in Australian wineries, Energy efficiency best practice. www.ret.gov.au. Accessed August 2010.

Department of Sustainability, Environment, Water, Population and Communities (2010) Montreal Protocol on Substances that Deplete the Ozone Layer. www.environment.gov.au. Accessed October 2010.

White, R., Adamson, B. and Rankine, B. (1989) Refrigeration for winemakers. Winetitles, Australia.

White, R., Adamson, B. and Stott, J. (1991) Insulation. The Australian and New Zealand Wine Industry Journal 6(2):107–112.

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Appendix 4: Winery A – Case study report



Improving Winery Refrigeration Efficiency
Winery A
Case study report

- Warmer brine temperatures
- Cooling system operation and control systems
- Cooling system maintenance
- Plant shutdown/infrequent running
- External heat exchangers

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Abstract

Trials related to improving refrigeration efficiency were performed at a small winery (~500 tonne crush) during and around the 2011 vintage. These trials considered the use of warmer brine temperatures, the operational strategy used to control the cooling system, cooling system maintenance, plant shut-down/infrequent operation, and the use of an external heat exchanger.

Running this winery's cooling system with a brine temperature of +4°C year-round, instead of -5°C, would translate to an approximate 17% reduction in refrigeration related electricity usage (12% reduction in total winery electricity usage). In vintage trials, red wine ferments were adequately controlled using nominally +4°C brine circulated through the existing tank cooling jackets. However, the warmer brine temperature naturally meant a lower cooling rate. This was somewhat problematic for the trial winery whose specific fermentation paradigm involved rapidly cooling the ferment once it had reached a peak temperature. To facilitate this operational strategy, a brine cooled external heat exchanger was introduced to the red wine pump-over's to provide additional cooling surface area. At many wineries the reduced cooling rates obtained during fermentation may not be a major limitation to using warmer brine, however operations like must chilling, cold settling and cold stabilisation could be unless alternative strategies are employed. As a general rule of thumb, warmer brine temperature should be used for as much of the time as practicable. This can be partly facilitated by scheduling operations that require very low brine temperatures to occur over the same period. Technologies that negate the need for very cold brine temperatures (e.g. flotation for white juice clarification and alternative cold stabilisation techniques) may enable some wineries to operate with warmer brine temperatures year-round.

The cooling system at the trial winery was functioning sub-optimally as refrigerant had leaked from one of the packaged chiller's two refrigerant circuits rendering that circuit inoperable; reducing the cooling capacity of the packaged chiller and increasing the risk of total loss of winery cooling. This fault had gone undetected for a significant period of time, partly as a consequence of problems with service technicians. Wineries should establish a good working knowledge of their cooling systems, document correct operational procedures and keep a regular log of basic operational parameters. While improvements as a result of these practices may be difficult to quantify, they are likely to have much more significant economic impact than many other winery refrigeration-related changes.

The winery didn't require cooling for approximately four months each year and therefore shut down the packaged chiller altogether during this period. This strategy was very effective; reducing annual electricity consumption at the winery by approximately 24%. However, switching refrigeration systems off completely may mean that some of the brine freezing point suppressant could evaporate (depending on local weather conditions), partially negating the savings from reduced power consumption. For wineries that do not require cooling for a significant period of time a better strategy may involve changing the brine set-point and hysteresis settings on their cooling system so that the refrigeration plant only runs infrequently. A brine temperature set-point of around 10°C together with an appropriate hysteresis setting to limit starts/stops should achieve this.

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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 A. The use of warmer brine temperatures, cooling system operation and control, cooling system maintenance, plant shutdown/infrequent running and the use of external heat exchangers were investigated.

2. Materials and methods

2.1 Winery and cooling system

Winery A is a small winery with a crush of approximately 500 tonnes (90-95% red grapes). The majority of wine is matured in barrels.

The winery employs a packaged chiller (ERTAB 210; Trane, USA) to cool brine (total brine volume: ~10 kL) into a brine storage tank. One pump supplies cold brine to a must chiller, while another one is used to circulate brine around the winery to cool selected tanks/fermenters. There are a number of take-off points on this winery reticulation loop where temporary heat exchange devices (e.g. cooling coils, cooling plates, etc.) can be plumbed in. The system is illustrated in Figure 2.1.

The packaged chiller is charged with chlorodifluoromethane refrigerant (R-22) and the brine is a solution of ethanol, propylene glycol, corrosion inhibitors and dye (Alcool LF; Sucrogen Bioethanol, Australia) in water.

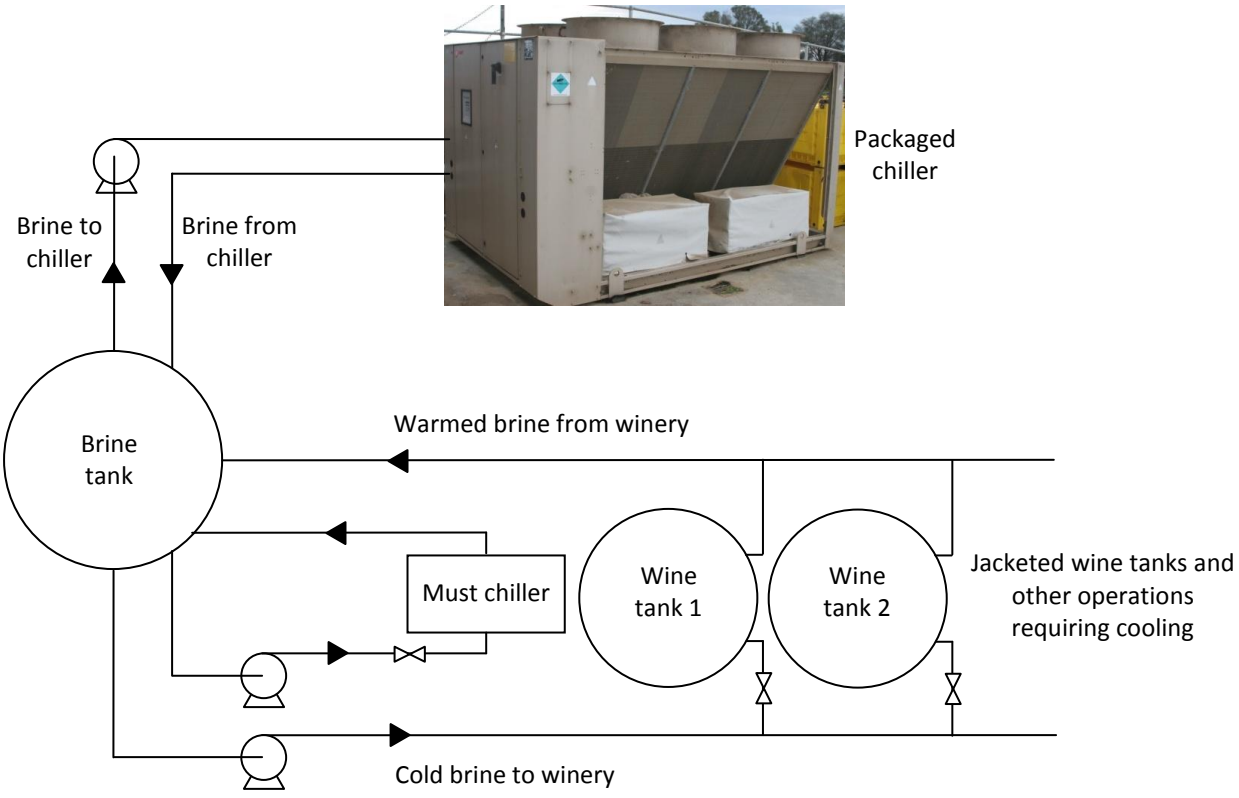


Figure 2.1: Winery A cooling system (illustrative only)

2.2 Cooling system operation and maintenance

Prior to the 2011 vintage, a number of observations had been made of the winery cooling system that indicated sub-optimal operation:

- The pump that moved brine from the brine tank through the packaged chiller operated all the time; even when the chiller was not running.
- Only one of the two compressors on the packaged chiller ever started.
- Some of the five condenser fans never ran.

To troubleshoot these issues, time was spent on site at the winery to better understand the operation of the winery cooling control systems. Manuals for the unit (and similar units) were obtained from the internet and the packaged chiller was serviced by a technician.

2.3 Effect of brine temperature on water cooling rate

A preliminary trial was performed in order to understand the cooling rate that could be obtained when using a much warmer than normal brine temperature. Brine temperatures of nominally -5°C or +4°C were employed to cool ~5.6 kL of rainwater in one of two 5-tonne open-topped fermenters. For each of the two trials the rainwater was cooled from approximately 21°C (initial standing water temperature) to approximately 15°C.

Rainwater temperature was monitored using 12-bit temperature sensors (S-TMB; Onset, USA) at four different locations in each tank (T_1 – T_4, see Figure 2.2). Brine temperatures into ($T_{Brine,in}$) and out of ($T_{Brine,out}$) the cooling jackets/plates (prior to branching to the two different jackets/plates on each tank) were measured using the same style of temperature sensors inserted in custom-built in-line thermowells.

Brine flow rate (again prior to branching) was measured using ¾" turbine flow meters (G2S07I09LMA; GPI, USA). The current draw of the packaged chiller was also measured using three 0-200 A split core current clamps (Magnelab, USA). All sensors were interfaced with a data logger (Hobo U30/NRC; Onset). For each flow meter, a pulse access module (GPI) and pulse input adapter (Onset) were required to achieve this, while for the current clamps a Flexsmart TRMS module (Onset) was needed. Data on tank temperature from the winery's own tank temperature probe (located in a thermowell immediately next to T_1) were recorded manually from the winery's temperature management system.

Data on refrigerant pressure were intermittently recorded manually from the packaged chiller display screen.

Photos showing key parts of the experimental arrangement are presented as Figures 2.2 to 2.6.

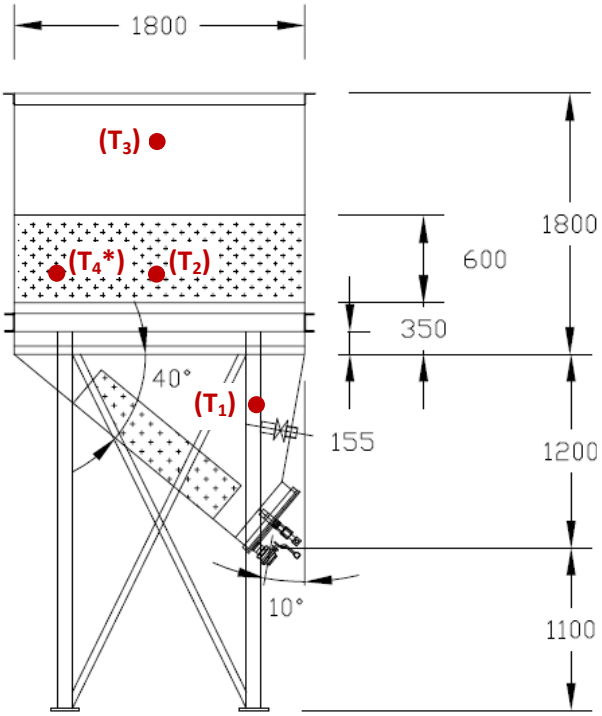


Figure 2.2: Schematic of 5-tonne open-topped fermenter with temperature sensor (T_1 to T_4) locations shown (Sensors T_1 to T_4 are centred across the tank looking into the page. T_4 is actually located 90° clockwise around the tank when viewed from the top of the tank)



Figure 2.3: 5-tonne open topped fermenter

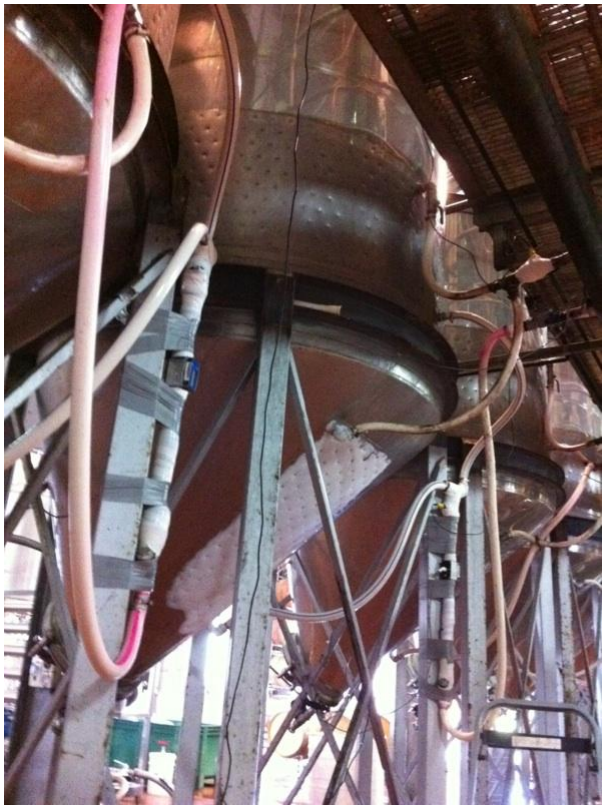


Figure 2.4: 5-tonne open-topped fermenters with brine connection lines and instrumentation shown

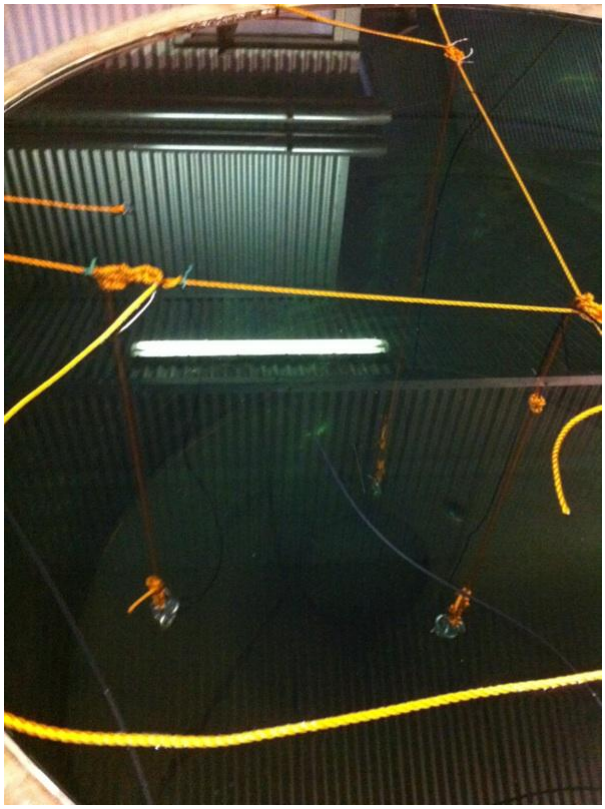


Figure 2.5: Rope and chain weights used to fix temperature sensor locations



Figure 2.6: Data logger connected to sensors

2.4 Fermentation cooling with warmer brine

The brine temperature (for the whole winery) was increased from -5°C to +4°C for a period during the 2011 vintage. In addition to general observation of the winery during this period, two side-by-side fermentations were specifically performed and monitored. Malbec grapes (4.6 tonnes) were loaded in each of two of the 5-tonne open-topped fermenters described previously (see Figure 2.2). During loading, the must feed hose was intermittently switched between the two tanks to ensure an even distribution of grape solids and free juice.

For one fermenter, cooling was provided solely by the existing tank cooling jacket/plate. For the second fermenter, additional cooling was provided by a brine cooled external heat exchanger (Figure 2.7, Modular 4T 51 76 2000 MI; Teralba industries, Australia) during pump-overs when desired.

Temperature sensors (S-TMB; Onset) were mounted at two depths in each fermenter (0.9 and 1.8 m below tank rim) on stainless steel mounts (purpose constructed) as shown for the empty tank (Figure 2.8) and for the tank filled with 4.6 tonnes of grapes (Figure 2.9). Data were recorded using the data logger described in section 2.3.



Figure 2.7: Dimpled tube-in-tube heat exchanger



Figure 2.8: Temperature sensing equipment mounted in an empty 5-tonne fermenter



Figure 2.9: Loaded 5-tonne fermenter with temperature sensing equipment mounted

3. Results and discussion

3.1 Cooling system operation

3.1.1 General control strategy

Prior to the 2011 vintage, it had been observed that the pump (Figure 3.1), which moved brine from the brine tank (Figure 3.2a) through the packaged chiller's evaporator, operated at all times instead of just when the chiller was running (and for a short period prior to and after it running). This was postulated to be undesirable for two key reasons:

- the pump was using unnecessary electricity; and
- the brine tank was vigorously agitated when the pump was running, preventing stratification and therefore some desirable separation between the cold brine at the bottom of the tank and the warmed brine returning from the winery at the top.

The packaged chiller had a factory-fitted control pad and display (Figure 3.3), however there was also an additional winery control panel for the cooling/brine reticulation system (Figure 3.4). At the time of this work, there was some uncertainty from winery staff about how exactly these systems interacted and how to operate them most efficiently. Generally, the system often appeared to be operated directly from the factory-fitted control pad on the packaged chiller. However, a number of controls on the winery control panel were more consistent with the system having been designed to run solely from this control panel (once the packaged chiller had been correctly configured using the factory-fitted control pad and display). To re-implement this process control hierarchy; "CONTROL" was set to "ON", "TRANE BRINE PUMP" was set to "AUTO" and the desired brine temperature set-point was input on the winery control panel's temperature controller (SR73; Shimaden, Japan). The existing winery control panel temperature controller hysteresis setting of ±0.3°C was retained.

With these settings, when the temperature in the brine tank (as measured by the brine tank temperature probe, see Figure 3.2b) reached 0.3°C above the set-point, the pump would start-up to pump the brine from the brine tank through the packaged chiller evaporator. Shortly after, a refrigerant compressor on the packaged chiller would start-up. The chiller would then operate according to the packaged chiller's own control systems until the temperature in the brine tank had been reduced to a temperature 0.3°C below the temperature set-point. On achieving this temperature the packaged chiller compressor(s)/fan(s) would shut-down. After a period of three minutes the brine pump would also shut-down. The packaged chiller display would read "Stopped by Ext Source".

On the packaged chiller control pad, fixed settings were input. These settings were such that the temperature measured at the exit from the packaged chiller's evaporator should never become low enough for the packaged chiller to independently shut-down (i.e. not based on brine tank temperature). The packaged chiller exit brine set-point was set to -7.5°C with a hysteresis of ±1.5°C. Therefore the brine leaving the packaged chiller's evaporator would need to get down to -9.0°C before the chiller would stop on its own accord. Given that the lowest brine temperature set-point to be used at the winery was -5°C, assuming a 3°C brine temperature drop through the evaporator

this condition should never occur. If it did become an issue, a lower packaged chiller exit brine set-point could be used, in conjunction with a larger packaged chiller hysteresis setting.

As already described, with the changes made, the pump between the brine tank only operated when the packaged chiller compressor was running (and for a short period prior to and after it running).

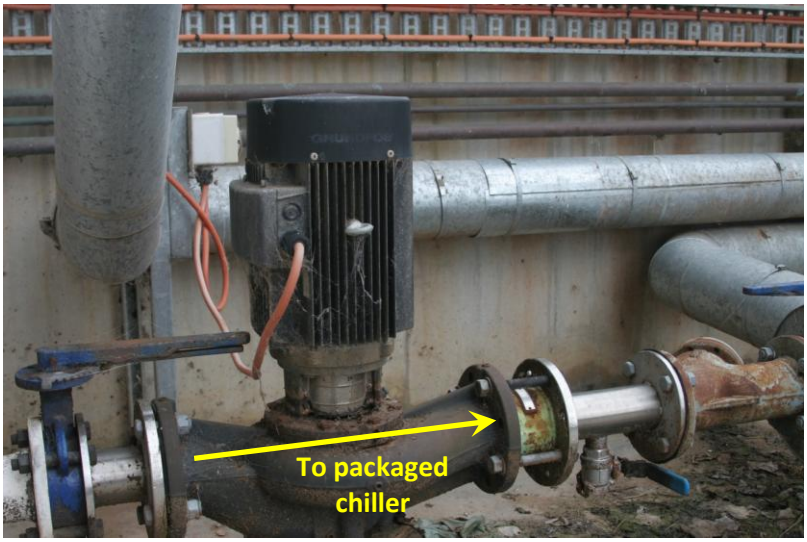


Figure 3.1: Pump that moves brine from the brine tank through the packaged chiller's evaporator



Figure 3.2: (a) Brine tank, (b) Close up on opposite side of brine tank showing brine pumps servicing the must chiller and the winery



Figure 3.3: Factory-fitted packaged chiller control pad and display



Figure 3.4: Winery control panel for cooling/brine reticulation system

3.1.2 Hysteresis settings and optimisation

As described in section 3.1.1, the existing controller hysteresis of ±0.3°C was retained. While this seems low, in reality, the effective hysteresis was significantly higher whenever there were limited cooling requirements in the winery. This was illustrated clearly in results from the rainwater cooling

experiment presented in Figure 3.5 (more detailed results are reported in section 3.4). The brine temperature at the inlet to the tank cooling jacket/plate increased when the packaged chiller started running (as indicated by the measured current to each of the packaged chiller's three phases). This was a consequence of a brine tank that had previously been stratified (warmer brine at the top of the tank and colder brine towards the bottom of the tank where the brine tank temperature probe was located – see Figure 3.2b) being agitated by the pump transferring brine through the packaged chiller and back into the brine tank (as outlined in 3.1.1, this now only occurred when a packaged chiller compressor was running and for a short period prior to and after this). Ultimately this stratification meant that an effective hysteresis setting of approximately +1.5°C/-0.3°C was obtained by the ±0.3°C hysteresis setting on the winery control panel. The stratification regime occurring in the brine tank is illustrated in Figure 3.6.

While it was not examined specifically as part of this work, it may beneficial to consider increasing the hysteresis setting even further than ±0.3°C. This will result in decreased start-ups and therefore less general wear on the packaged chiller's compressors. This is likely to be particularly beneficial when there are large brine requirements by the winery (e.g. during vintage) and therefore the brine tank is being more significantly agitated by this leaving and returning brine, limiting the brine tank stratification and thus reducing the effective hysteresis to a value closer to the actual hysteresis setting.

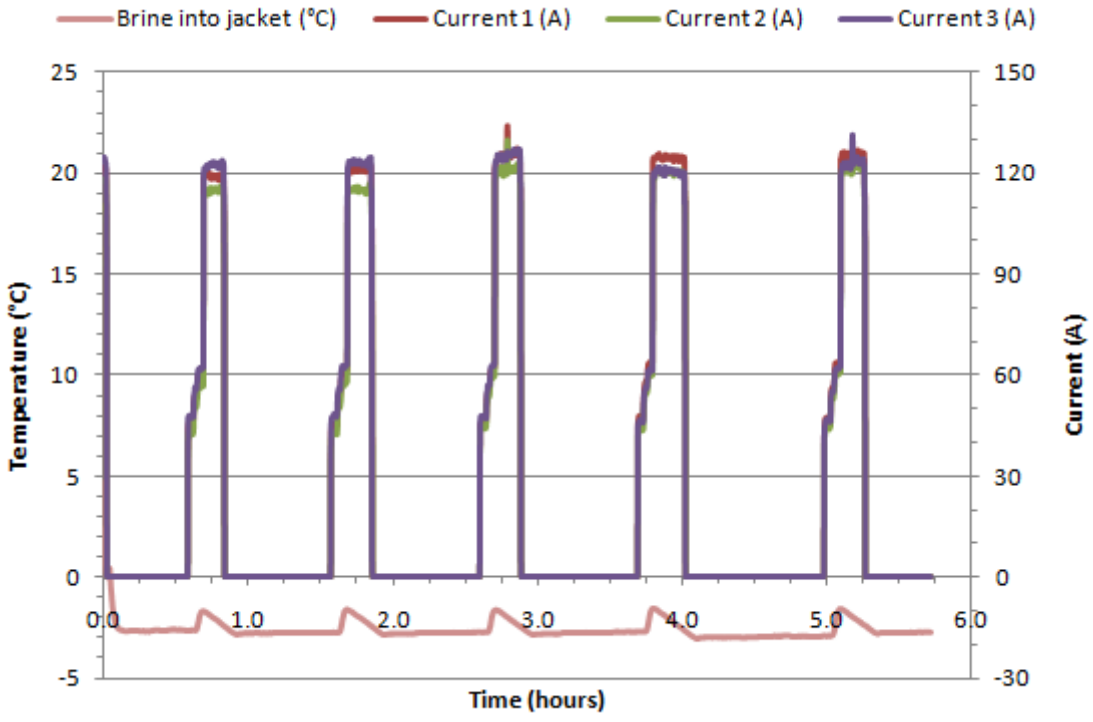


Figure 3.5: Packaged chiller current draw and brine temperature at inlet to tank jacket/plate during rainwater cooling experiment with nominally -5°C brine

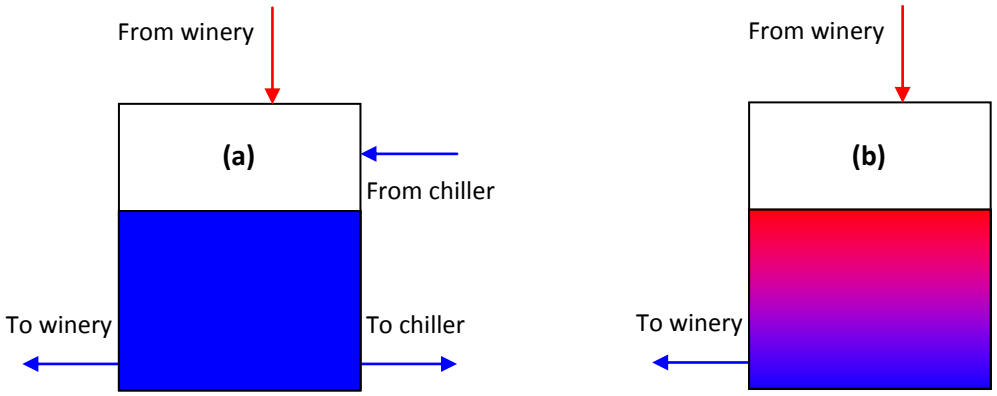


Figure 3.6: Brine tank stratification; (a) Immediately prior to the pump to the packaged chiller switching off, and (b) After the pump to the packaged chiller has been off for some time.

3.2 Shutdown or infrequent running when cooling is not required

Winery A mainly produces red wines and while there are significant cooling requirements during vintage, later in the year there are several months where there are no cooling requirements at all. To save electricity over this period, Winery A turned the power to the packaged chiller off for approximately four months at the end of 2009 (October 2009 – January 2010). Some other more minor measures to reduce electricity usage were also implemented at the winery but this was the biggest one.

Comparison of winery electricity bills from this period with those for the corresponding period in the previous year revealed significant reductions in electricity consumption. Electricity usage was apparently reduced from approximately 450 kWh/day to only 80 kWh/day. This corresponded with electricity savings of the order of $50 per day for Winery A over that 4 month period and a reduction in electricity usage of approximately 24% (370 kWh/day × 122 days / 188,000 kWh) per year.

This electricity saving strategy has evidently been a very successful one for this winery. There are some possible issues that do need to be considered and managed:

- The compressor oil heaters were turned off when the main power to the packaged chiller was switched off. Prior to using the packaged chiller again, the power would need to be switched on for at least 24 hours to allow the compressor oil heaters to warm up the lubricating oil or risk damaging the compressor on start-up (as a consequence of absorption of refrigerant in the lubricating oil).
- If the brine warms up too much, ethanol may begin to evaporate from solution, ultimately requiring a top-up to maintain an appropriately low brine freezing point when the system is put back into service.

To manage the issue of refrigerant absorption in the compressor lubricating oil, it would have been better to just switch the packaged chiller to “STOP” on the control pad, instead of switching the power to the unit off completely. With this strategy, the compressor oil heaters would have remained on allowing the packaged chiller to be restarted at anytime.

This does not solve the issue of ethanol evaporation. To manage both issues it may be better to not stop the packaged chiller at all, but instead just set a warmer brine set-point and wider hysteresis setting such that the packaged chiller operates infrequently. If a brine set-point of approximately 10°C were used one might expect relatively limited evaporation of ethanol. Furthermore, a run now and again will prevent the packaged chiller from sitting stagnant for too long a period of time.

Wineries should refer to the manufacturer and/or installer for specific operational procedures and ensure that their packaged chiller/refrigeration plant is operated in accordance with these; particularly regarding start-up and shut-down procedures.

3.3 Cooling system maintenance

Prior to the 2011 vintage it had been observed that only one of the two compressors on the packaged chiller ever ran. Furthermore some of the condenser fans did not switch on when it would have seemed appropriate for them to do so.

The packaged chiller had two circuits, each with their own compressor. The operational log of the two compressors could be shown on the packaged chiller display. The running statistics for the two compressors recorded approximately one year apart are reported in Table 3.1.

Table 3.1: Running statistics for packaged chiller compressors

Compressor	18/02/2010		28/01/2011	
	Starts	Time (hours)	Starts	Time (hours)
A	5,913	5,671	7,015	6,996
B	5,690	11,347	5,690	11,347

From these data it was evident that Compressor B had not run between 18/02/2010 and 28/01/2011, while Compressor A had started 1,102 times and run for 1,325 hours. In regards to compressor sequencing, the packaged chiller manual (Trane 2010) states "When there is a call for chilled water, the UCM-CLD will start the compressor which has the least number of starts. If the first compressor cannot satisfy the demand, the UCM-LCD will start the other compressor". Compressor B had a lower number of starts at 18/02/2010 and so it would be expected that this compressor would be the first one to start, but it had not done so over the entire period considered. Looking at the diagnostics on the packaged chiller display the following diagnostic had been recorded:

"A circuit shutdown has occurred!
Latched fault – Manual reset required
Low pressure cutout – Ckt 2
Circuit shutdown – Manual reset required."

Compressor B was associated with Circuit 2. A service technician was organised to attend the site to inspect the problem. The technician checked the system and found that there was no refrigerant in Circuit 2. The technician pressure tested the system with nitrogen and found the leak to be on a 1/4" copper line. The leak was repaired and Circuit 2 was recharged with refrigerant. Both compressors now operated in accordance with the sequencing described by the manufacturer.

The service technician also found that some of the condenser fans had tripped and reset them.

This maintenance resulted in a major improvement in the operation of the chiller. While this improvement may be difficult to quantify it is arguably more significant than most refrigeration-related changes that could be made to other winery processing techniques in order to save electricity, and with which there is often some risk that the reduced electricity usage has to be balanced against (e.g. warmer wine storage temperatures, etc.). The implications of the maintenance in this instance were:

- Packaged chiller had greatly improved capacity as both refrigerant circuits (and their compressors) could now run simultaneously.
- Risk of total cooling system failure was greatly reduced as the packaged chiller now had two fully operational refrigerant circuits. If there was a problem isolated to one circuit, such as the refrigerant leak that had now been repaired, the remaining circuit could still provide the winery with some cooling. With only one circuit operational (as was the case before the repairs) if there was a problem with this circuit during a peak period (e.g. vintage) there could have been significant issues for the winery, including the risk of wine damage; particularly if technicians or parts were unavailable.
- The wear on the compressors was managed better. The number of start-ups and total running times were now balanced between the compressors, such that their lifetime should be maximised.
- The ability of the packaged chiller to reject heat, and thus capacity was greatly improved by the capability for all fans to operate when required.

In dealing with service technicians there were a number of issues that complicated the process and that are worthy of discussion.

When a service technician initially attended the winery, the power to the packaged chiller was switched off (as part of the electricity saving measures discussed in section 3.2) and consequently the compressor oil heaters were off. The service technician could therefore not immediately run the compressors and diagnose the problem. While the manual for the packaged chiller stated the necessity of compressor lubricating oil being sufficiently warm (and this is a standard principle in refrigeration systems), there is nothing to this effect clearly written on the packaged chiller, nor was this message communicated to the winery by the service company prior to the technician's visit. In some respects, this is a design fault. There should be a large message on the chiller itself indicating the requirement for oil heaters to be on for a period prior to chiller start-up. It is unrealistic in an industrial environment to expect that the manual is always going to be available and/or referred to.

The service company was very much intent on locking the winery into a long-term maintenance contract, even prior to visiting the site. Long-term service contracts are no doubt a profitable arrangement for service companies. While hopefully some of the issues with the packaged chiller would have been detected by a service arrangement of this nature there can be considerable expense for the winery and often some loss of local knowledge and control on the operation of the system. A cheaper option for smaller wineries averse to entering into a service contract is to develop a good working knowledge of how their system operates and document this, and then keep a chronological log of key operational parameters. This should help wineries to recognise when there is a problem and a service technician needs to be engaged to look at the system. For example, in the case of the refrigerant leak already discussed, a simple regular log of the number of compressor starts and running times, combined with the knowledge that the compressor with the lowest number of starts should always start-up first, would have quickly indicated that there was a problem. A service technician could have been arranged and the problem would have been resolved in a much timelier manner.

Generally, it is the opinion of the author that wineries should choose a service technician/company that has some knowledge and experience with winery cooling systems and peripherals (brine pumps, control systems, etc.) as opposed to only knowledge about servicing the packaged chiller itself. This way the technician can provide some guidance, particularly if winery personnel dealing with the technician hang around with the technician while they are fixing problems and ask plenty of questions.

3.4 Effect of brine temperature on water cooling rate

The experimental results for cooling of rainwater using brine at nominally -5°C and +4°C are presented in Figures 3.7 and 3.8. The locations of the different temperature probes were as shown in Figure 2.2. The decrease in rate of cooling with the warmer brine temperature is described in Table 3.2.

Looking at the brine temperatures measured, it is immediately apparent that the temperature at the inlet to the tank jacket/plate was warmer than the nominal brine temperature corresponding with the brine tank set-point. When the packaged chiller was not running, the brine temperatures at the inlet to the jacket were approximately -3°C and +6°C for the nominal temperatures of -5°C and +4°C, respectively. This increase in temperature was apparently related to warming during movement of brine from the brine tank to the wine tank jacket. This rise of approximately 2°C between the brine tank and wine tank jacket was quite significant and given that the majority of the brine reticulation system was insulated, this was initially somewhat surprising. However, these experiments were performed prior to vintage at a time when the only cooling requirements in the winery were for this trial. The brine in the distribution line therefore had a relatively long residence time prior to entering the tank jacket. Notably, the distribution system temperature rise was significantly less (less than 1°C) during the fermentation trials discussed in section 3.5, which took place when there were many winery demands for cooling.

The difference between the brine inlet and outlet temperatures in Figures 3.7 and 3.8 provides some useful process insight. At constant brine flow rate and specific heat capacity, this difference is indicative of the amount of heat being removed from the rainwater in the tank (and from the air given that the outside of the tank jackets are not insulated). As each trial progressed, the gap between the inlet and outlet brine temperature decreased, consistent with a reduced temperature differential between the incoming brine and the reduced temperature rainwater. Notably, the gap decrease is more prominent with +4°C brine as the relative decrease in temperature differential with the rainwater is more significant than when using the colder -5°C brine.

Table 3.2 shows that the measured difference in cooling rate between the two different brine temperatures depended on temperature probe location. For Probe T_1, located at the bottom of the tank directly next to the winery's own probe (T_{Winery}), the cooling rate was 23% slower with the warmer brine, while based on probe T_2, located higher in the bulk of the tank, the cooling rate was only 11% slower. It is possible that with the colder brine there may have been a greater degree of cooling induced stratification related to the lower cooling plate. Notably, this cooling plate iced up on the outside (see Figure 2.4) prior to the main tank cooling jacket. The cooling rate for probe location T_4, located nearer to the tank jacket but at the same depth as probe T_2, was actually faster with the warmer brine. Probe T_3 was located only 0.35 m down from the tank brim, and correspondingly, was cooled very little by the tank cooling system and in fact warmed up through the day with the increasing ambient temperature.

Overall, it is fair to say that the cooling rate with the +4°C brine was slower than with the -5°C brine, however, the difference was apparently only rather minor (in the order of 10% - 30% for liquid in the temperature region of 15-21°C). Given this is at, or lower than, the temperatures typically employed

during fermentations, brine at +4°C should be suitable for cooling fermentations in this configuration.

It should be noted that the models of brine solenoid valves on the two 5-tonne open-topped fermenters used were slightly different, likely having some minor influence on the brine flow rate. The average flow rate to the tank jackets with the -5°C brine experiment was 45.7 L/min, while for the +4°C brine experiment was 48.7 L/min. In calculations comparing the decrease in cooling rate with the different brine temperatures, flow rate has been normalised as a conservative estimate so as not to overstate the benefits of using warmer brine. It should also be noted that the ambient temperatures on the two days on which experiments were performed were extremely similar. Data from www.bom.gov.au for the local weather station, showed minimum and maximum temperatures on the day of the -5°C brine experiment of 14.7°C and 32.5°C, respectively. For the day of the +4°C experiment the corresponding numbers were 14.3°C and 33.8°C. In each case experiments were started at the same time of day. Ambient temperatures are therefore unlikely to have significantly influenced the outcome.

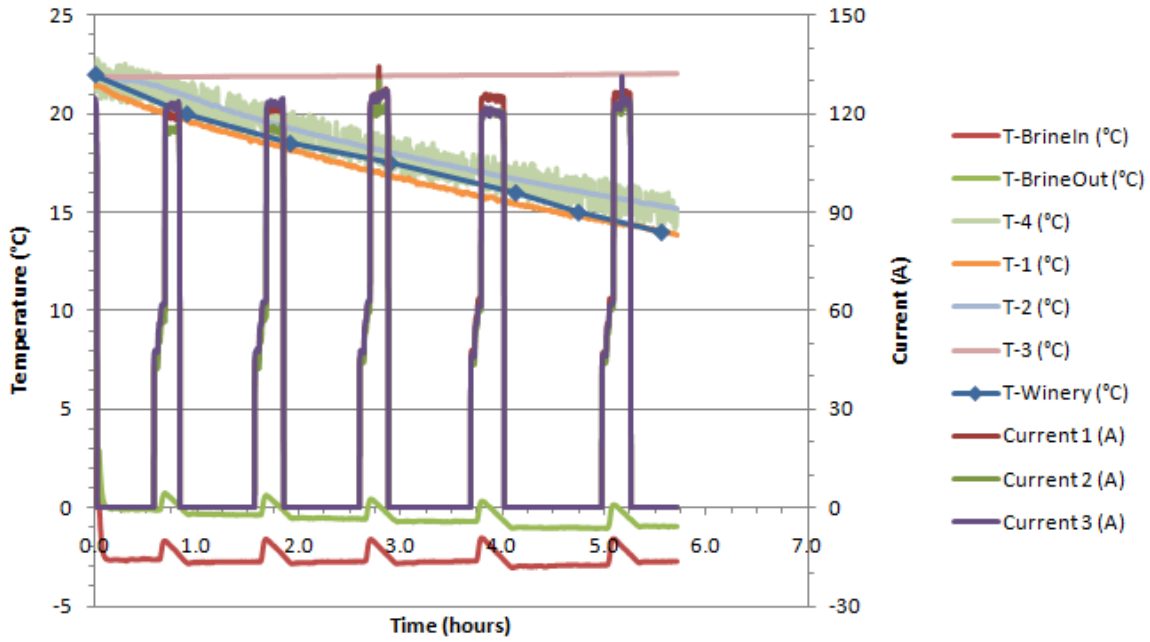


Figure 3.7: Rainwater cooling using nominally -5°C; water temperature at different tank locations, brine temperature into and out of the tank jackets, and current drawn by the packaged chiller

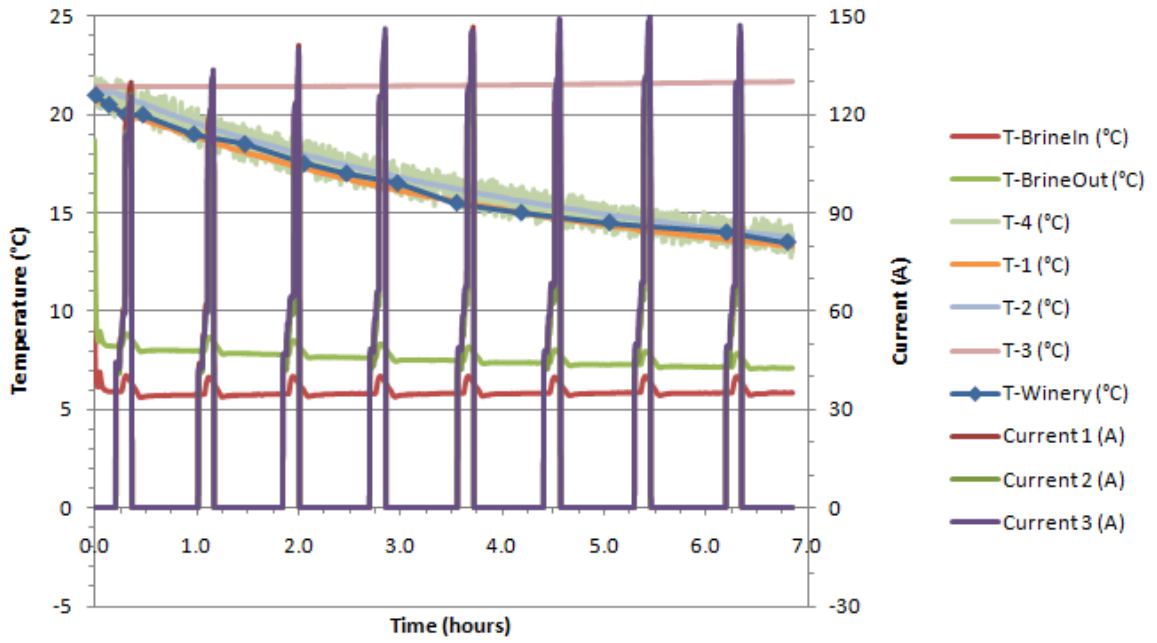


Figure 3.8: Rainwater cooling using nominally +4°C; water temperature at different tank locations, brine temperature into and out of the tank jackets, and current drawn by the packaged chiller

Table 3.2: Cooling rate with different brine temperatures

Probe[a]	-5 °C Brine			+4 °C Brine			Slower rate at +4°C[b] by
	Start T (°C)	End T (°C)	Rate (°C/hr)	Start T (°C)	End T (°C)	Rate (°C/hr)	
T_1	21.4	13.9	1.31	20.7	13.3	1.07	**23%**
T_{Winery}	22	14	1.4	21	13.5	1.1	**26%**
T_2	21.8	15.2	1.17	21.3	13.7	1.11	**11%**
T_3	21.9	22.1	-0.03	21.4	21.7	-0.04	**-8%**
T_4	21.8	15.2	1.16	21.9	13.0	1.29	**-5%**

[a]See Figure 2.2 for probe locations.

[b]Corrected for differences in brine flow rate.

The benefit of using warmer brine accrues from the realisation of higher refrigerant pressure at the suction side of the compressor such that the compressor can move a greater mass of refrigerant for the same amount of electricity input. The packaged chiller measures and displays the pressure at the evaporator/suction side of the compressor and this presented an opportunity to verify that under the in-built packaged chiller's control systems the suction pressure was increasing when the warmer brine temperature was used. Readings from the packaged chiller display are reported in Tables 3.3 and 3.4, for the experiments with -5°C and +4°C brine, respectively. The average evaporator pressure was evidently significantly higher when using the warmer +4°C brine. For refrigerant circuit 2, the average evaporator pressure was 382 kPa for +4°C brine, but only 245 kPa for -5°C brine.

Table 3.3: Packaged chiller operating conditions with -5°C brine (16/02/2011)

Time	Ckt 1 Evap P (kPa)	Ckt 1 Cond P (kPa)	Ckt 2 Evap P (kPa)	Ckt 2 Cond P (kPa)	Entering brine (°C)	Leaving brine (°C)	Notes
11:10	Off	Off	237.8	1308.7	-4	-5.9	Brine tank: -4.3°C
11:16	286	1223	244	1362	-4.5	-6.8	Brine tank: -4.6°C
11:20	279.2	1198.8	238.3	1352.2	-4.9	-7.2	Brine tank: -5.1°C
12:13	Off	Off	251.6	1420.3	-4	-5.7	Brine tank: -4.3°C
12:17	279.6	1272.5	245.1	1444.8	-4.5	-6.8	Brine tank: -4.7°C
12:21	279.6	1260.4	244.7	1430.6	-4.8	-7.1	Brine tank: -5.1°C
13:14	Off	Off	245.1	1444.4	-3.9	-5.7	Brine tank: -4.2°C
13:19	286.5	1320.7	242.6	1486	-4.5	-6.7	Brine tank: -4.7°C
13:22	286.5	1293.2	244.7	1461.6	-4.9	-7	Brine tank: -5.1°C
15:37	Off	Off	251.6	1499.6	-3.9	-5.6	Brine tank: -4.2°C
15:41	286.1	1327.6	251.6	1527.6	-4.4	-6.6	Brine tank: -4.7°C
15:46	286.1	1306.5	244.7	1499.6	-4.8	-7	Brine tank: -5.7°C
Average:	**284**		**245**				

Table 3.4: Packaged chiller operating conditions with +4°C brine (15/02/2011)

Time	Ckt 1 Evap P (kPa)	Ckt 1 Cond P (kPa)	Ckt 2 Evap P (kPa)	Ckt 2 Cond P (kPa)	Entering brine (°C)	Leaving brine (°C)	Notes
10:23	383	1279	428	1128	3.4	-0.3	Stopping
11:04	Off	Off	431	1079	4.8	4	
11:10	389	1210	348	1396	3.5	0	
13:37	Off	Off	444	1231	4.8	3.7	Brine tank: 4.8°C
13:40	Off	Off	355	1617	N/A	N/A	Brine tank: 4.3°C
13:43	410	1413	362	1644	3.8	0.8	Brine tank: 4.0°C
15:26	417	1430	362	1651	3.4	0.1	Brine tank: 4.1°C
15:29	327	1522	356	1632	N/A	N/A	Stopping
16:15	Off	Off	389	1295	4.6	3.2	Brine tank: 4.7°C
16:21	313	1505	349	1555	3.3	0	Brine tank: 4.0°C
Average:	**373**		**382**				

3.5 Fermentation cooling with warmer brine

The side-by-side ferments cooled using +4°C brine are summarised in Figures 3.9 and 3.10. Figure 3.9 shows the ferment cooled solely by the tank jacket/plate, while 3.10 shows the ferment cooled using the tank jacket/plate but also with the brine-cooled heat exchanger during two pump-overs on 22/03/2011 after the ferment had 'peaked'.

The general fermentation cooling strategy employed by Winery A was to not employ any cooling until the ferment was actively proceeding such that the temperature had or was about to 'peak' (typically at around 25°C). At this time the cooling system set-points would be adjusted to drop the ferment temperature as quickly as possible to around 16°C. The control system would then be used to manage the rest of the ferment at temperatures deemed appropriate.

The general fermentation solids-contacting strategy employed by Winery A involved 20 minute pump-overs in the mornings and afternoons, when ferments were actively proceeding (The flow rate measured during one pump-over using a graduated bucket was approximately 9,500 L/hr).

The principal outcome from these experiments was that the winery was able to control their ferments with the warmer brine temperature, even just employing the normal tank jacket/plate for cooling. However, the cooling rate was somewhat slower during cooling from the peak fermentation temperature of 25°C to 16°C. The cooling rate (as measured by the lower probe and by the winery probe) for the ferment just employing the normal tank jacket/plate was approximately 1.1°C/hr. As a rough comparison, limited plots obtained from the winery monitoring system for a brine temperature of -2°C suggested a rate of 1.6°C/hr and close to 2°C/hr for a brine temperature of -7°C, for similar reductions in ferment temperature.

Therefore the difference in rate of cooling with different brine temperatures was apparently much more significant than that observed in the rainwater cooling experiments reported in section 3.4. There are a number of factors that need to be considered in interpreting this result.

During the ferments performed in this study, the standard morning pump-over actually occurred at the very start of the pull-down period, and furthermore an additional 30 minute pump-over was performed in the late morning for both tanks to allow for an additional use of the external heat exchanger to cool one of the tanks.

The winery itself only had one temperature probe installed in these tanks and it was located in a thermowell towards the bottom. The author had been somewhat concerned about temperature stratification in the tank, particularly between the cap and the bulk liquid. As a consequence temperature had been measured at two different depths: closer to the bottom, such that the probe would be in the bulk liquid (but not so low that it would be buried in seeds) and higher up in the tank such that it would be within the cap. Figures 3.9 and 3.10 clearly show very different temperatures lower and higher in the tank. With each pump-over the cap temperature and the bulk liquid temperature equilibrate. The cap temperature and the liquid temperature then diverge until the next pump-over. This observation of warmer cap temperatures is consistent with reports from previous authors (Ough and Amerine 1961, Guymon and Crowell 1977). Guymon and Crowell (1977)

demonstrated that fermentation of sugar in the liquid adhering to the cap is faster than in the bulk liquid. Furthermore, they observed temperature gradients in the bulk liquid when fermentation was performed in contact with skins but not when fermentation was performed with free juice and postulated that the floating cap hinders the free circulation of liquid even during vigorous fermentation.

The larger than expected decrease in cooling rate with +4°C brine may be partially explained by the two pump-overs performed (particularly the first one at the very beginning of the pull-down period), which may have extracted extra heat from the cap back into the liquid. Furthermore, there may have been some liquid stratification in the comparison ferments at the lower brine temperatures during which no pump-overs had been performed as a consequence of the cap hindering the free circulation of liquid as postulated by Guymon and Crowell (1977).

While this analysis may partially explain the larger than expected reduction in cooling rate with +4°C brine, it remains that the cooling rate was still slower when using the +4°C brine than when using the -5°C brine. It is unclear whether the rapid drop in ferment temperature that was seen as desirable by the winery was really a necessity and whether it would make a meaningful difference if it occurred more slowly - even if it took twice as long. Overall there were no problems in controlling ferments and maintaining a given temperature. If the rapid drop in temperature is deemed genuinely critical to wine quality, more extensive pump-overs through an external heat exchanger could be employed. Alternatively, if there are concerns about additional solid-liquid contacting in doing that; the ferment liquor could be drained from the solids and then cooled by continuous circulation through an external heat exchanger and only then back-added to the solids, but this may be somewhat labour intensive.

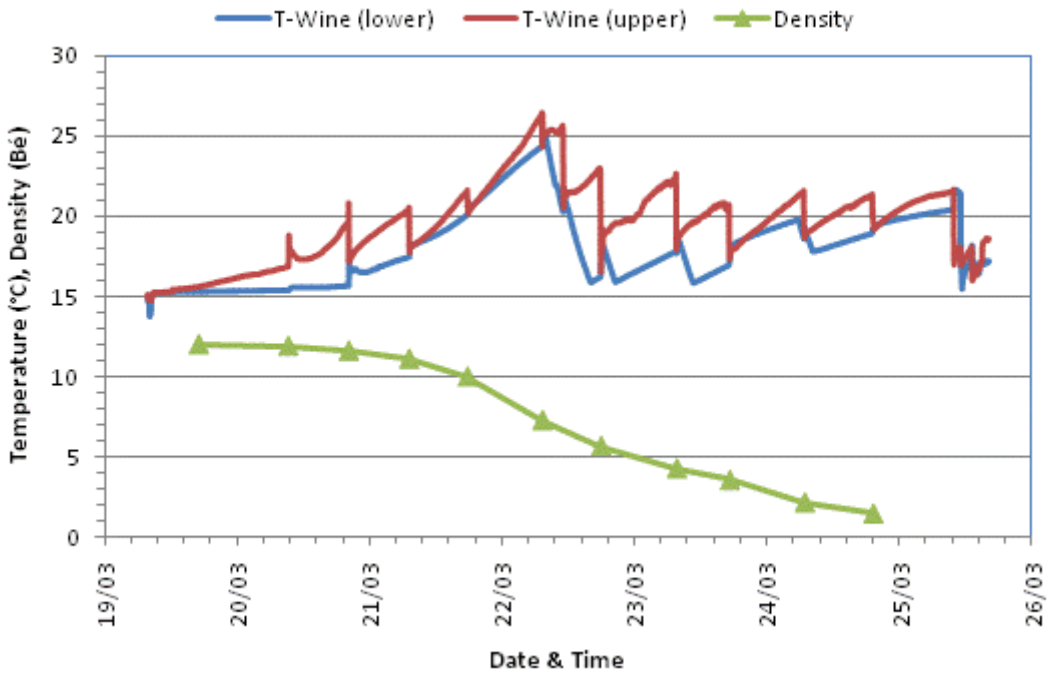


Figure 3.9: Fermentation controlled with +4°C brine (tank jacket/plate cooling only)

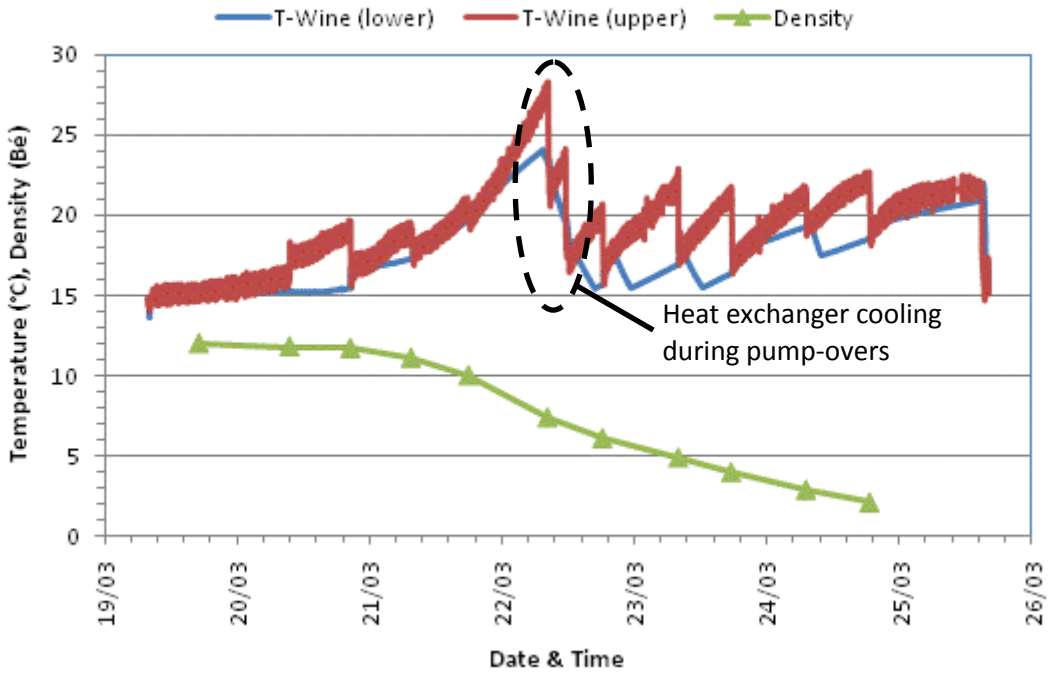


Figure 3.10: Fermentation controlled with +4°C brine (tank jacket/plate cooling as well as external heat exchanger cooling for two pump-overs on 22/03)

3.6 External heat exchanger

The external heat exchanger provided some cooling effect, the most visible being the effect on cap-temperature during the pump-overs on 22/03/2011 shown in Figure 3.10.

The use of the heat exchanger during the ferment was actually quite limited, with it only being employed for two pump-overs, so as not to deviate too much from the typical solids contacting strategy at the winery. If the heat exchanger was employed for a longer period it would have much more prominently influenced the cooling rate.

In addition to using the small portable heat exchanger for these ferments, the winery found it very useful for cooling other small ferments (in the order of 1-2 tonne ferment size). In previous years cooling coils had been used to control these ferments but these had always been very ineffective.

3.7 Management and scheduling with warmer brine temperatures

The manufacturer of the winery's packaged chiller has published data on the coefficient of performance for different brine and ambient temperatures (Figure 3.11). It demonstrates an increase in efficiency of approximately 20% for a change in brine temperature from -5°C to +4°C. These data are just for the packaged chiller. The efficiency of the brine distribution system also matters.

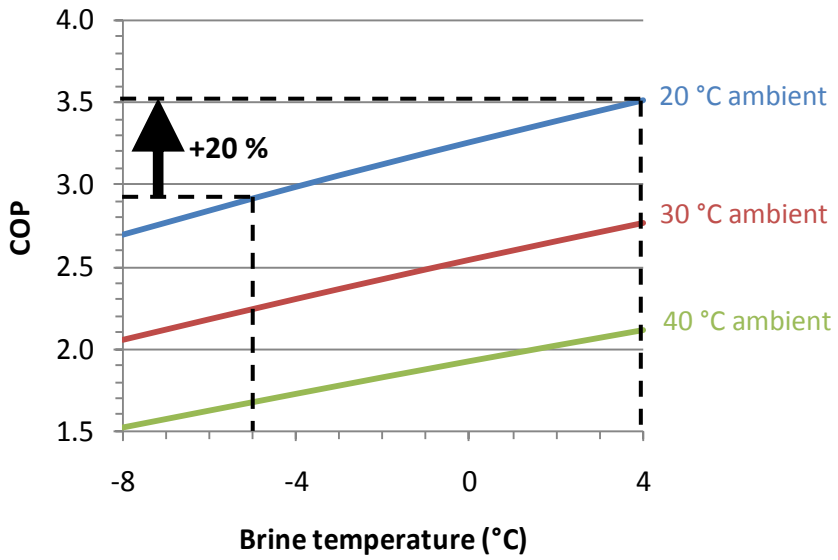


Figure 3.11: Coefficient of Performance (COP) of packaged chiller at maximum plant capacity (Improvement in plant efficiency from moving from -5°C to +4°C is highlighted)

With warmer brine, a greater volume of brine will be required to provide the same amount of cooling but there will be lower ambient gains for a given volume, and the brine will be less viscous and have better heat transfer properties. Overall with the use of the warmer brine, the 20% increase in packaged chiller efficiency would likely be diluted partially by the increased brine pumping costs. In this case, the net improvement in cooling efficiency realised may end up being only 17%. Assuming that refrigeration accounts for 70% of annual winery electricity use, the overall reduction in winery electricity requirements would be approximately 12%.

To actually realise these overall annual reductions in electricity requirements, a winery would have to never drop to using the more traditional colder brine temperatures (i.e. -5°C or lower), which may not be possible.

During the fermentation trials discussed in section 3.5, the winery received some white grapes that needed to be processed and the resulting juice cold settled. Some difficulties arose as the temperature differential between the warmer brine and the juice was not sufficient to cool the juice to temperatures below 10°C at a practical speed.

This highlighted one of the wine processing steps for which warm brine temperatures are problematic and which would need to be managed through either use of alternative processing

techniques or improved scheduling if warm brine temperatures were to be generally maintained. Key operations that generally require low brine temperatures are presented in Table 3.5. Notably these operations are associated more with white wine production than red wine production so there may be more scope for warmer brine temperatures in wineries focussed on red wine production. Batch flotation is one alternative technique for juice clarification that appears to be becoming relatively common in larger wineries that negates the need for cooling – often delaying the requirement for installation of additional refrigeration capacity.

Table 5: Winery operations incompatible with warmer brine temperatures and possible alternative processing techniques

Winery operation	Alternative
Must chilling	Night-time harvesting[a] , Dedicated must chiller refrigeration system
Juice settling	Flotation
Cold stabilisation	Packaged rapid contact systems, electrodialysis, crystallisation inhibitors (CMC, Mannoproteins, etc.)

[a]Such that grapes are already cool and don't require chilling. Pragmatic assessment of whether must chilling significantly improves quality and is thus generally necessary may also be worthwhile.

In general, without very significant capital investment, it may not be possible to completely eliminate the need for cold brine in some operations, particularly for cold stabilisation. In this case, it is best to try and use as high brine temperatures practicable for as much of the time as practicable. This can be achieved through scheduling operations that require low brine temperatures concurrently wherever possible, so that warmer brine can be maintained for the rest of the time.

If a winery can completely eliminate the need for cold brine temperatures and could use temperatures of the order of +4°C all year round, they would remove the need for a brine freezing-point suppressant and could just use water as the brine/coolant. Together with not having to purchase freezing-point suppressant, this has the added advantage of improved coolant heat transfer properties and ease of pumping. The problem with removing the freezing-point suppressant prematurely is if there is a situation that requires the brine/coolant temperature to be dropped: a large amount of fresh freezing-point suppressant would have to be added to facilitate this and when the operation was finished the system would have to be drained to add back the water. Furthermore, unless the drained brine was stored, a significant amount of money would be wasted.

Therefore, it would seem most sensible to instead just maintain a brine concentration such that the brine solution would freeze at 5°C below the lowest brine temperature that would ever be used (White et al. 1989), and then in the first instance see how well your winery can function with warmer brine. If the temperature needs to be turned down, the flexibility is retained. If, after several years, winery cooling requirements are effectively managed all year round with warmer brine, then the elimination of the freezing-point suppressant altogether may be justified.

4. Conclusions and recommendations

1. Red wine ferments were able to be controlled using +4°C brine at Winery A; however the cooling rate was reduced. If this brine temperature was able to be used all year round, the decrease in refrigeration related electricity consumption would have been in the order of 17% over using a brine temperature of -5°C. Assuming that refrigeration accounted for 70% of winery electricity usage, this corresponds with a reduction in winery electricity consumption of approximately 12%.

    a. *Brine temperatures should be as warm as practicable and should be used for as much of the time as practicable. Operations requiring very low brine temperatures, like cold stabilisation, should be scheduled to occur during the same period of the year, such that warm brine temperatures can be used for as much of the year as possible.*

    b. *Technologies that negate the need for very cold brines should be considered. Flotation as an alternative to cold juice settling and the use of crystallisation inhibitors as opposed to traditional cold stabilisation are examples of this.*

    c. *Quality benefits from must chilling should be evaluated objectively.*

    d. *Ideally, water with temperatures of the order of +4°C would be used as the coolant/brine all year round; however, this is not practicable without implementing alternative practices for must chilling, cold settling and cold stabilisation. Therefore, brine freezing-point suppressant concentration should be maintained such that the brine solution would freeze at 5°C below the lowest brine temperature needed. Only when it has been demonstrated that a winery can exist year round with warmer brine over several years, should a water coolant system with no freezing-point suppressant be adopted. .*

2. The cooling system at Winery A had typically not been run as intended by the system designer. This had led to the pump between the brine tank and packaged chiller running constantly, even when the packaged chiller was not running. This resulted in wasted electricity as well as preventing stratification in the brine tank that desirably kept the cold brine at the bottom somewhat separated from the warm brine returning from the winery at the top. Minor changes to settings were made to restore operation to the manner that had originally been intended.

    a. *Wineries should understand the general design of their system, document the correct operational procedure and verify that this continues to be followed as time passes. Documentation is important such that wineries are not reliant on the knowledge of specific staff members, who may leave in the future.*

3. Maintenance was performed on the packaged chiller at Winery A. Refrigerant had leaked from one of the two circuits on the packaged chiller. The cooling capacity had thus been reduced and furthermore, if there was a problem with the other refrigerant circuit, there could have been a complete loss of cooling to the winery. A complete loss of cooling could have been a major issue if it had occurred during vintage or at another inconvenient time, particularly if service technicians and/or parts were not available. This leak had gone undetected for a considerable period of time. Some of the condenser fans had also tripped limiting the ability of the chiller to reject heat and impacting chiller capacity. The refrigerant leak was repaired and the circuit recharged. The fans that had tripped were reset. The improvements in chiller capacity and reduction in risk from this maintenance are difficult to quantify, however, they are likely to be considerable and probably more worthwhile than many other refrigeration-related changes that might be made to winery processing techniques in order to save electricity, and with which there is often some associated quality risk against which the electricity saving has to be balanced against.

    a. *Wineries should understand how their cooling system works and keep a basic regular log of operational conditions, such that when there is a problem it is likely to show up as a deviation to the standard operating conditions. When there is a major deviation to operating conditions, a service technician should then be arranged to attend the site. The regularity of logging operating conditions will depend on the level of use of the system and the difficulty in data collection. Generally, it would seem that these data should be collected at least monthly and possibly more often if the system is in very heavy use.*

4. Winery A didn't require cooling for approximately four months in the year and as such had started to shut-down the plant altogether for this period. This was an effective strategy, reducing electricity requirements at the winery by approximately 24% in comparison with the previous year, in which it had not been shut-down. This did create some system start-up delay as the compressor oil heaters were also turned off and furthermore, there may have been some evaporation of ethanol, which might ultimately necessitate topping up the brine with more freezing-point suppressant.

    a. *If wineries are not going to require cooling for a significant period of time, they should consider changing the brine set-point and hysteresis settings on their cooling system for this period so the refrigeration plant only runs infrequently but such that significant ethanol does not evaporate from solution. A brine temperature set-point of around 10°C together with an appropriate hysteresis setting such that the refrigeration plant does not run too often should achieve this. This also has the advantage of not leaving the system idle for too long.*

5. The winery found a small portable heat exchanger to be a useful alternative to the cooling coils typically used in small (1-2 tonnes) ferments.

    a. *Wineries could consider the use of external heat exchangers as a means of achieving faster cooling rates as opposed to relying on tank jackets and cooling coils.*

5. 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 A for allowing us to perform this work and for their help and involvement. We would also like to thank Teralba Industries for subsidising the hire of the heat exchanger used.

6. References

Guymon, J.F. and Crowell, E.A. (1977) The nature and cause of cap-liquid temperature differences during wine fermentation. American Journal of Enology and Viticulture 28(2): 74-78.

Ough, C.S. and Amerine, M.A. (1961) Studies with controlled fermentation. VI. Effects of temperature and handling on rates, composition, and quality of wines. American Journal of Enology and Viticulture 12(3): 117-128.

Trane (2010) RTAA/RTAB air-cooled helical rotary liquid chillers; Installation – operation - maintenance. www.foodmachineryonline.com. Accessed 2010.

White, R., Adamson, B. and Rankine, B. (1989) Refrigeration for winemakers. Winetitles, Australia.

7. 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.
Compressor:	This device compresses refrigerant and is the main user of electricity in a refrigeration plant.
Compressor oil heater:	A heater that helps prevent absorption of refrigerant in the compressor lubricating oil; an occurrence that could potentially result in compressor damage on start-up.
Condenser:	The heat exchanger used to condense refrigerant after it has passed through the compressor. Air-cooling by fans that blow air across refrigerant tubes is commonly employed in packaged chillers.
Evaporator:	The heat exchanger in which the brine is cooled by the refrigerant (as the refrigerant evaporates).
Freezing-point suppressant:	An additive that lowers the temperature at which brine will freeze.
Hysteresis:	A setting in an on-off control system that prevents rapid switching as a parameter (e.g. temperature) drifts around the set-point. For example; with a temperature set-point of 10°C and a hysteresis setting of ±0.5°C; cooling will switch on when the measured temperature reaches 10.5°C and switch off when it reaches 9.5°C. Hysteresis is often referred to as dead-band.
Packaged chiller:	A standardised off-the-shelf refrigeration plant.
Refrigerant:	The working fluid in a refrigeration plant.
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.

Appendix 5: Winery B – Case study report 1



Improving Winery Refrigeration Efficiency
Winery B
Case study report 1

- Warmer white fermentation temperatures
- Tank stratification

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Author: Dr Simon Nordestgaard, Senior Engineer, AWRI

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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.

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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).

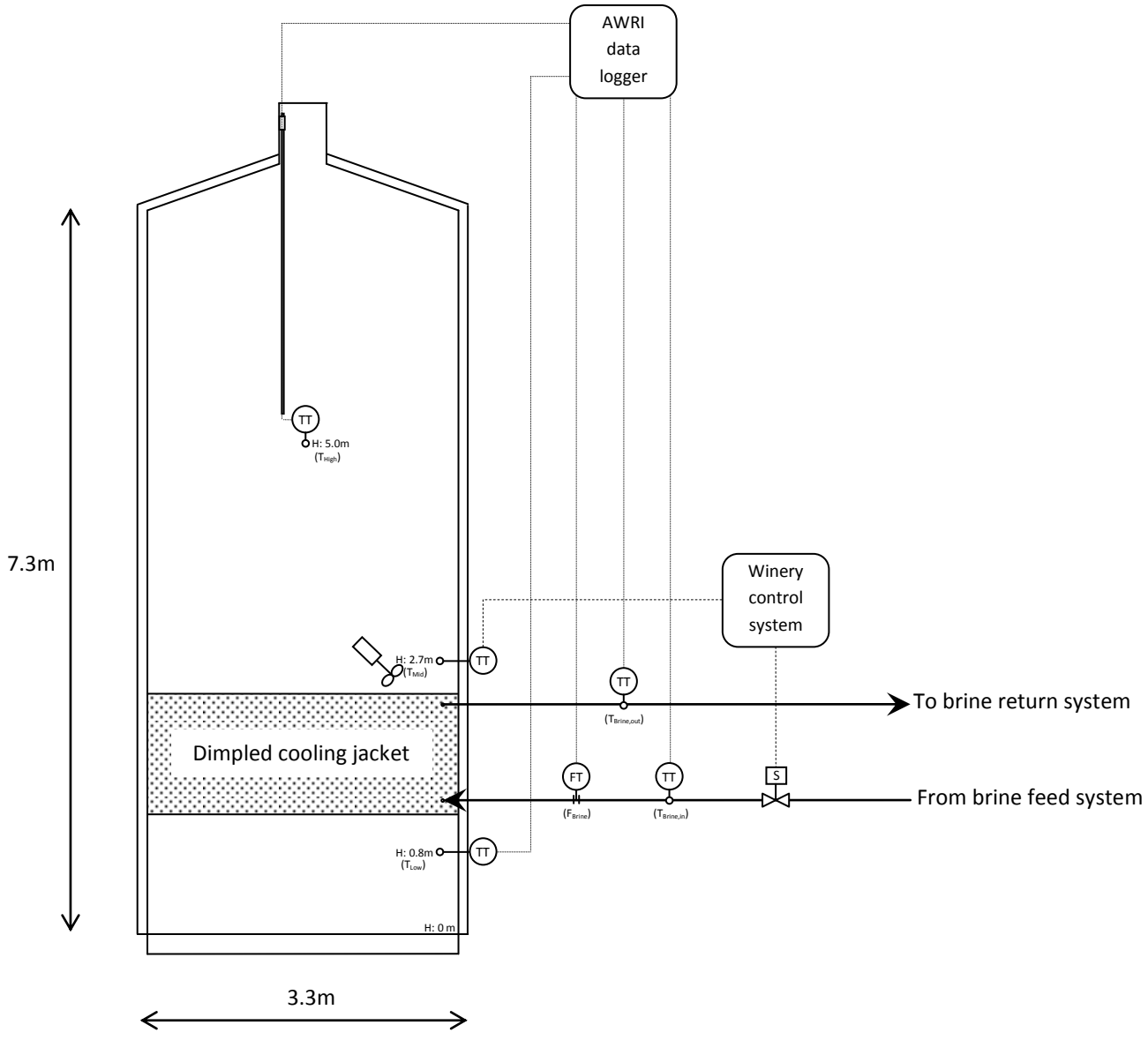


Figure 2.1: Approximate tank dimensions and control/data logging arrangement for one of the two 58 kL tanks (tank fittings, brine line ball valves and strainers not shown)

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

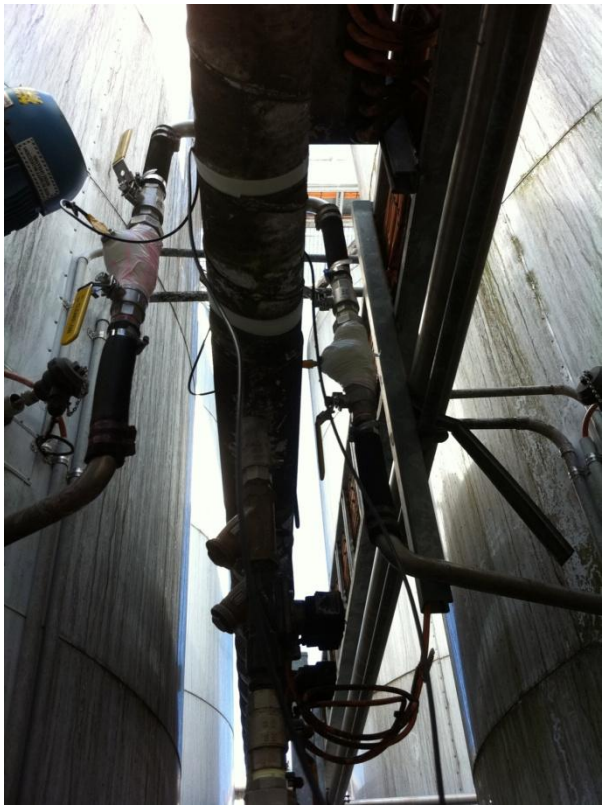


Figure 2.7: Temperature probes ($T_{Brine,out}$) installed in the brine outlet lines from the jackets of both tanks



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.

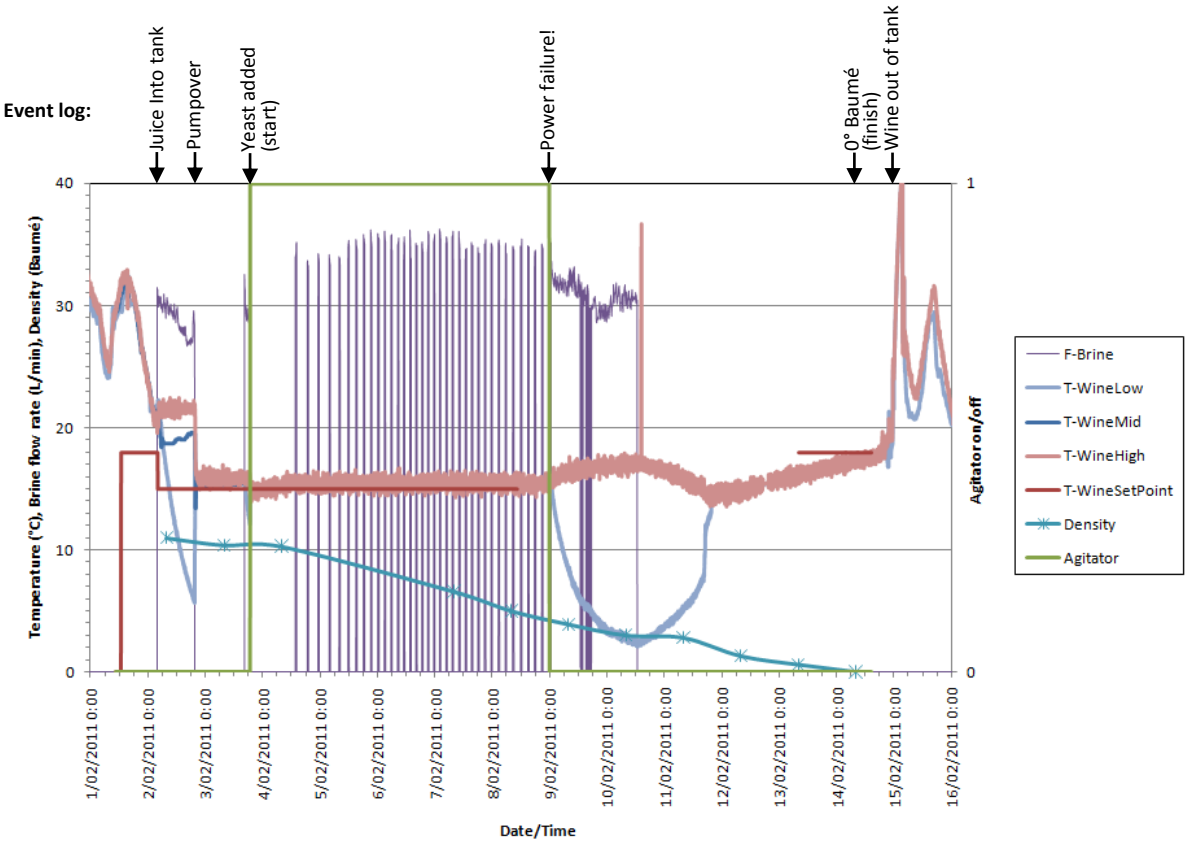


Figure 3.1: Trial 1 – Chardonnay – 15°C

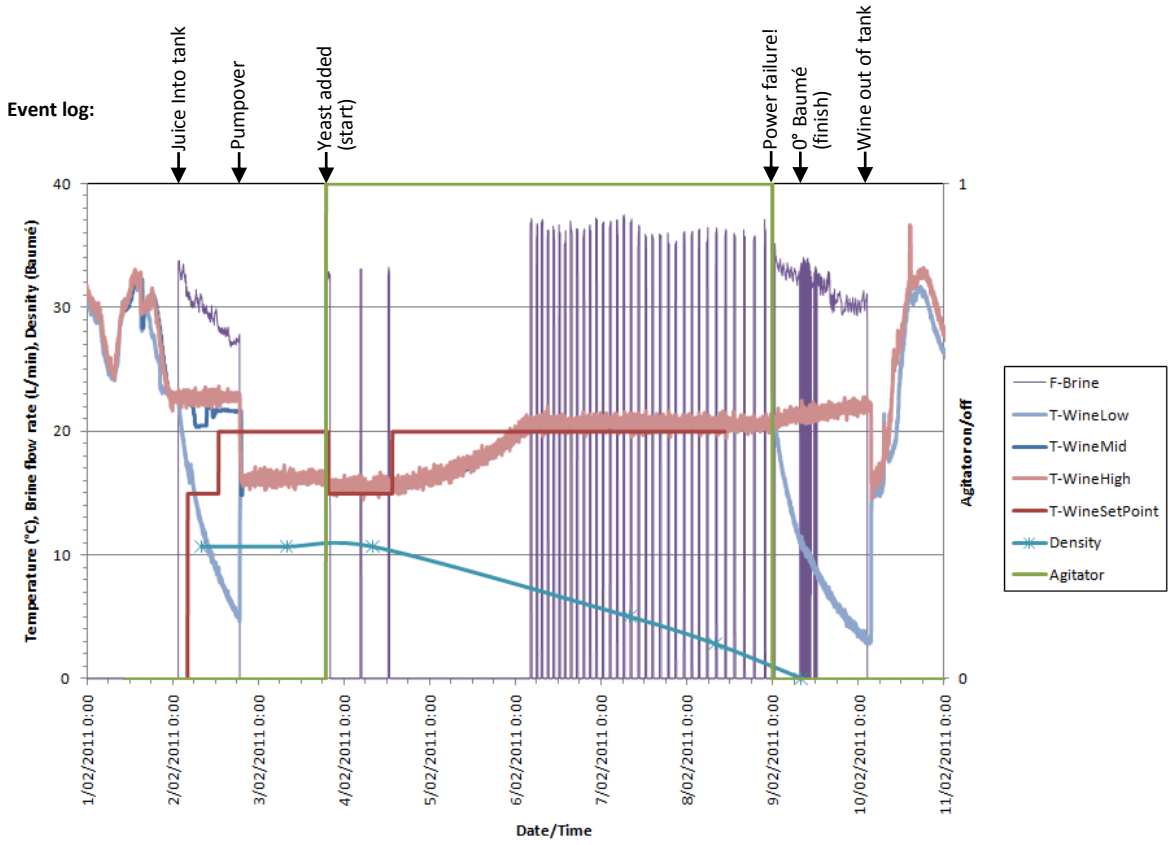


Figure 3.2: Trial 1 – Chardonnay – 19°C.

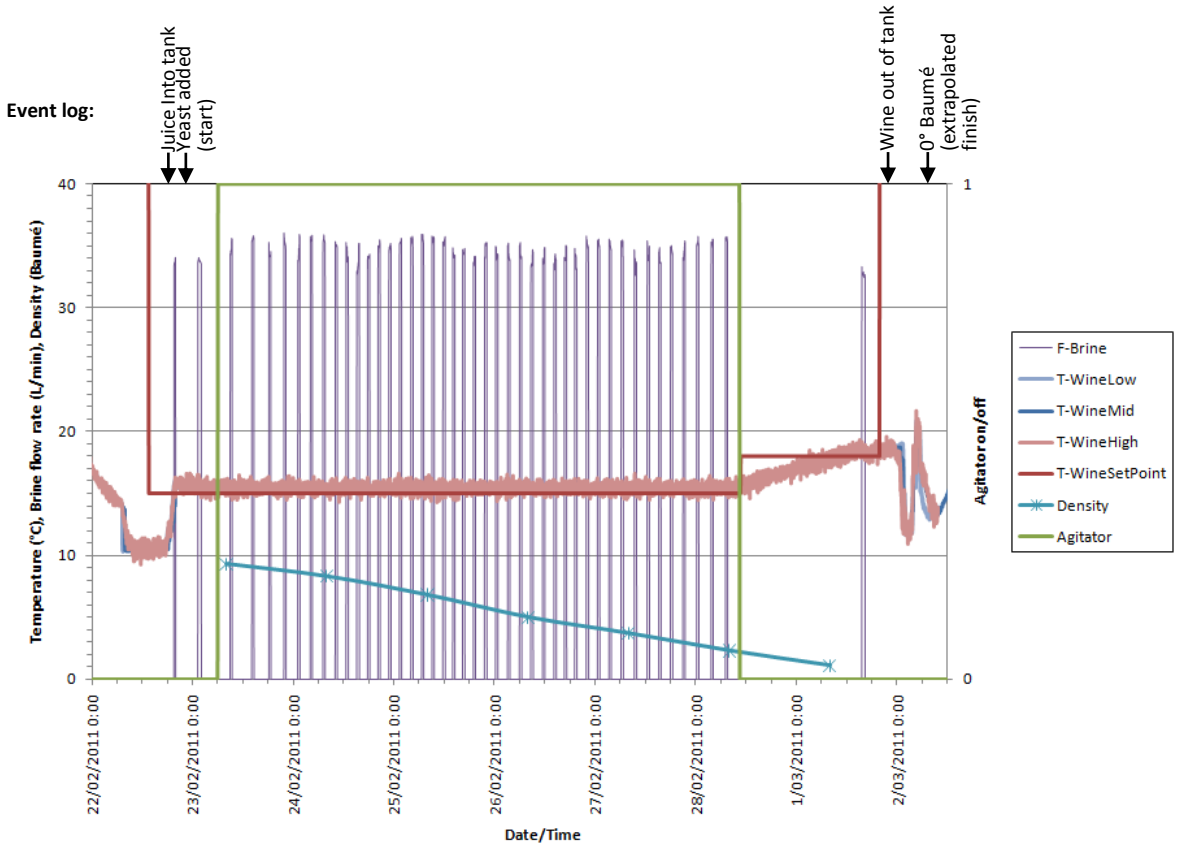


Figure 3.3: Trial 2 – Semillon – 16°C

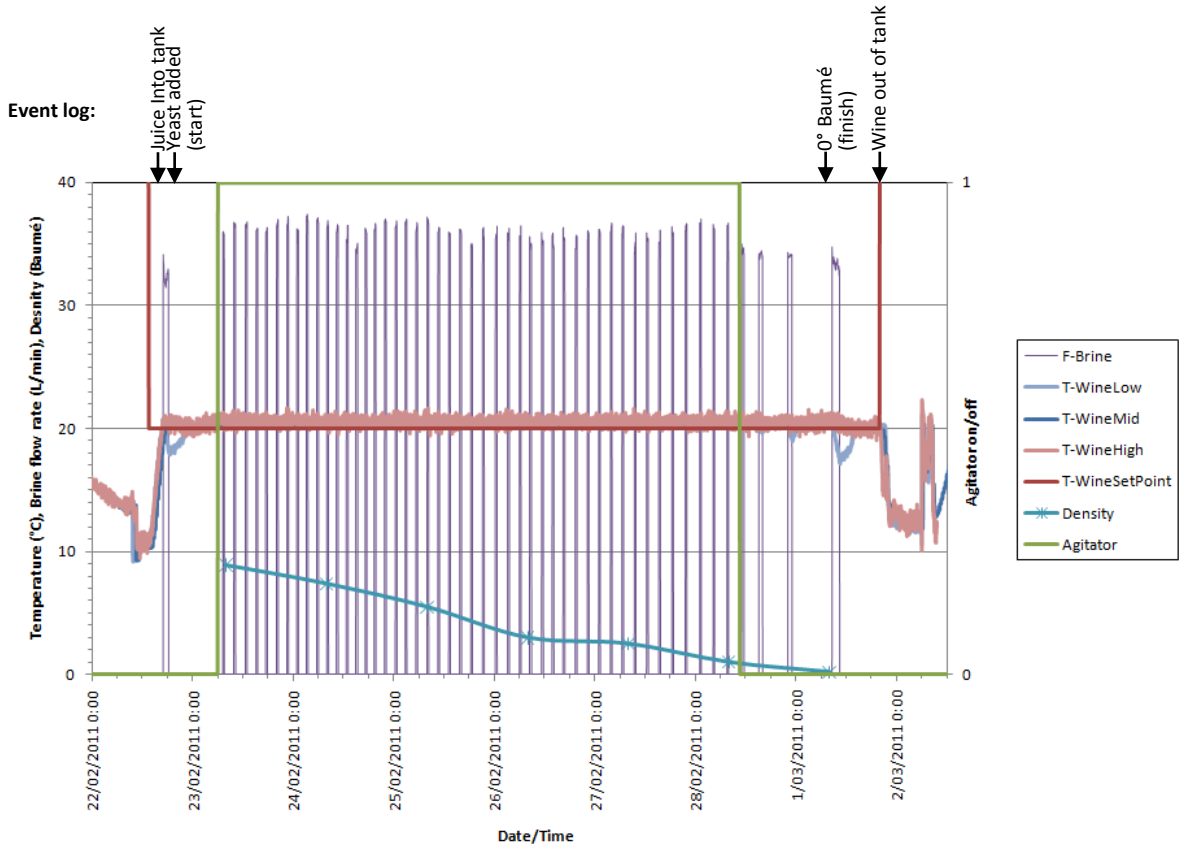


Figure 3.4: Trial 2 – Semillon – 20°C

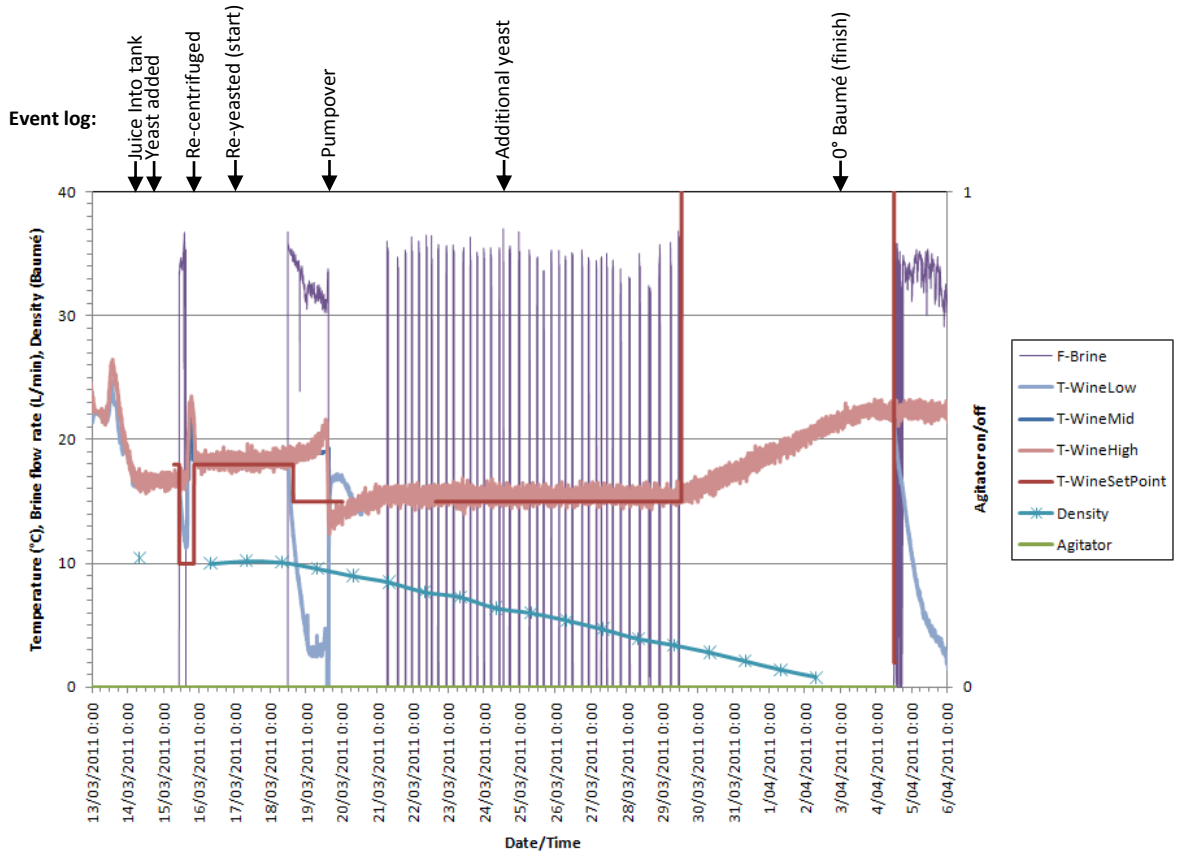


Figure 3.5: Trial 3 – Riesling – 16°C

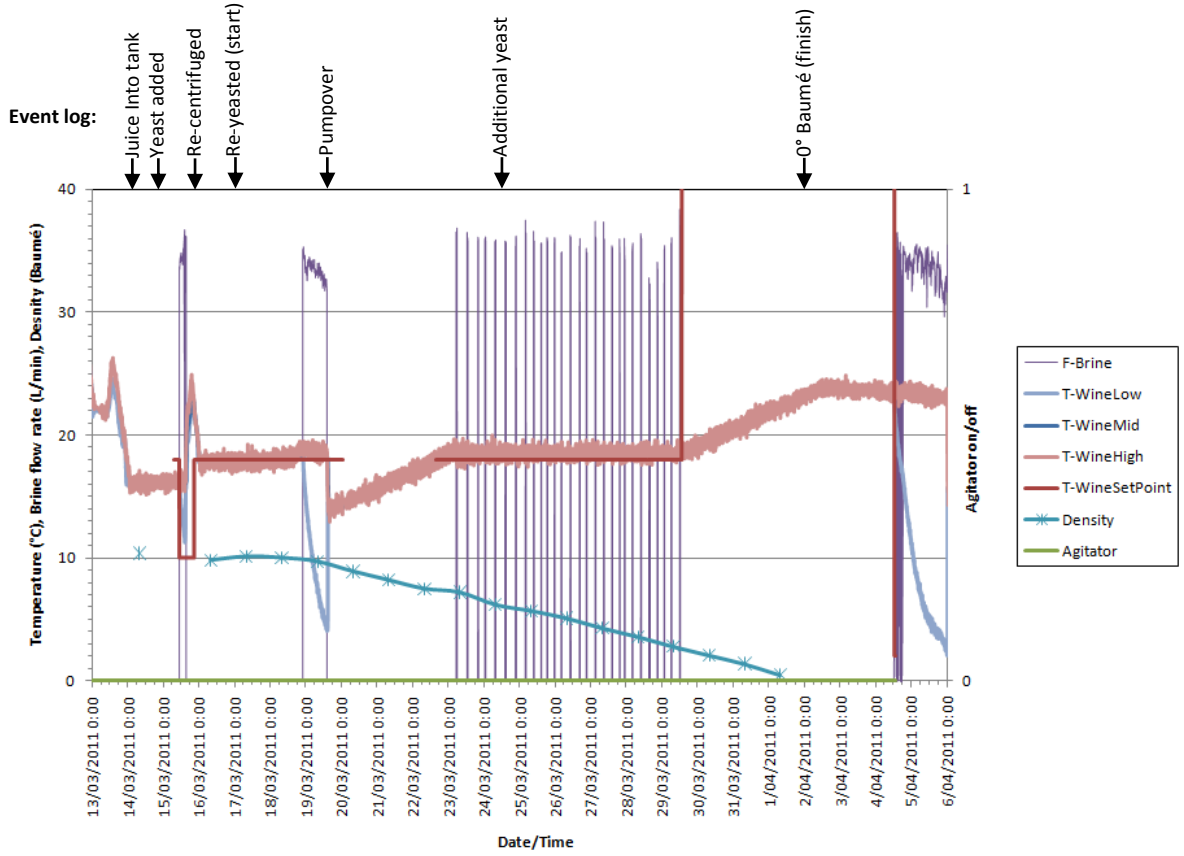


Figure 3.6: Trial 3 – Riesling – 18°C

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.

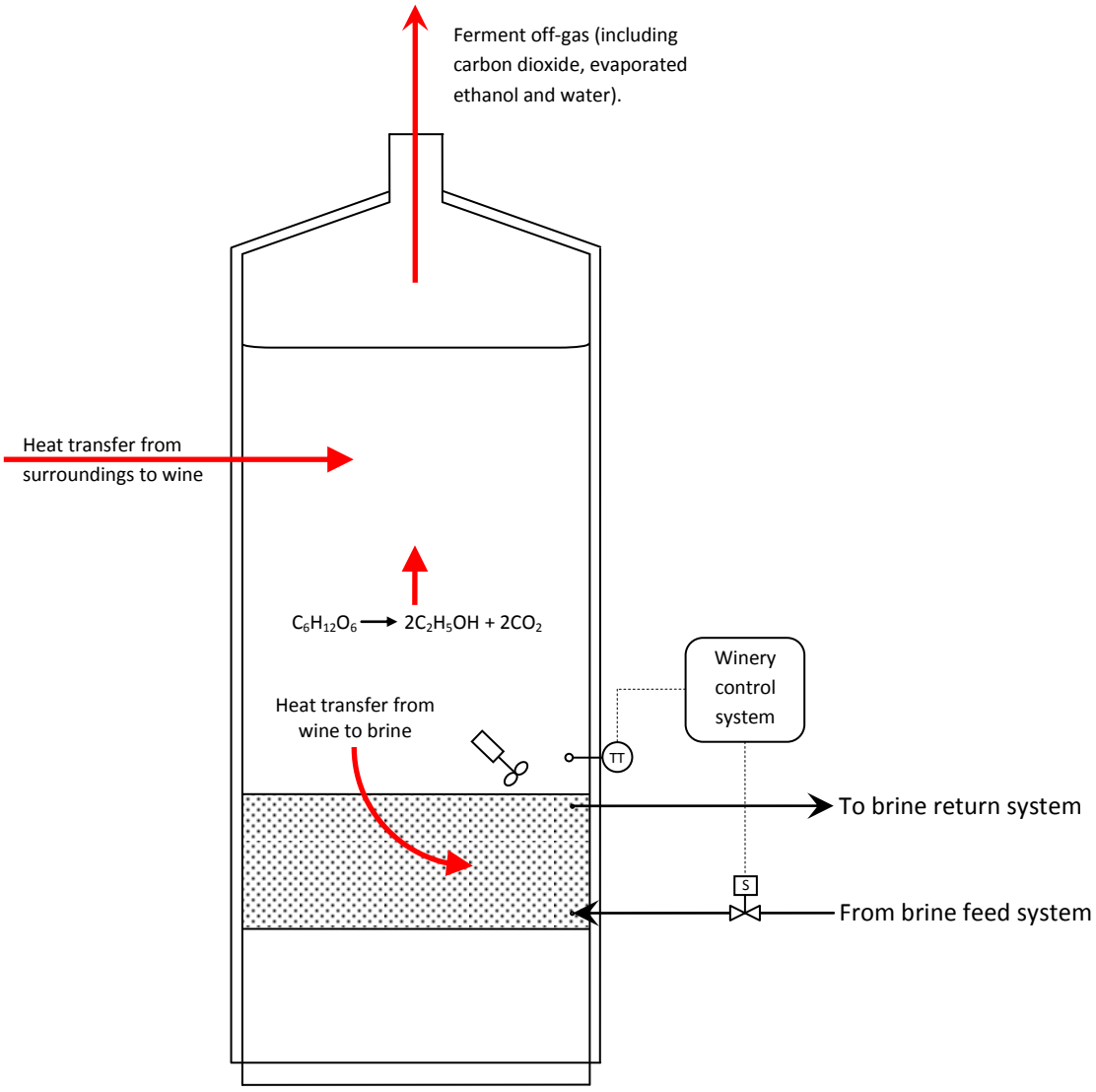


Figure 4.1: Heat generation and transfer during fermentation

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.

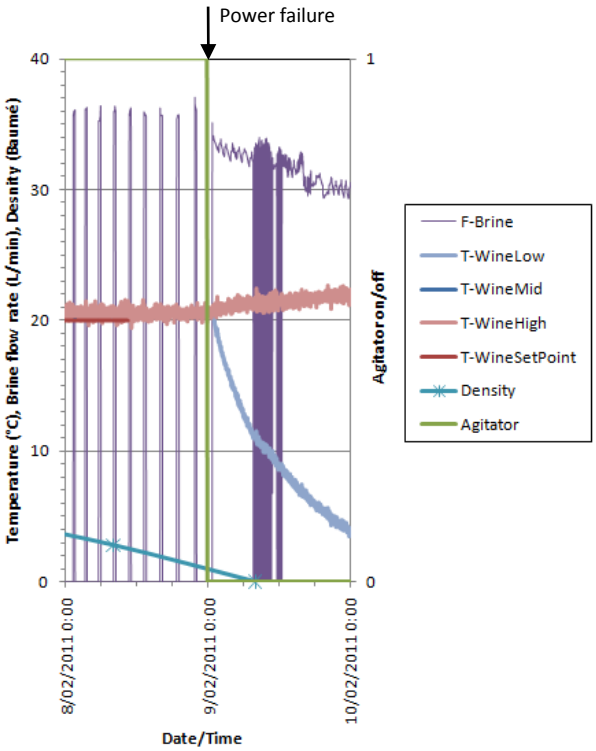


Figure 4.2: Stratification after power failure (agitator lockout) during Trial 1 – Chardonnay – 19°C

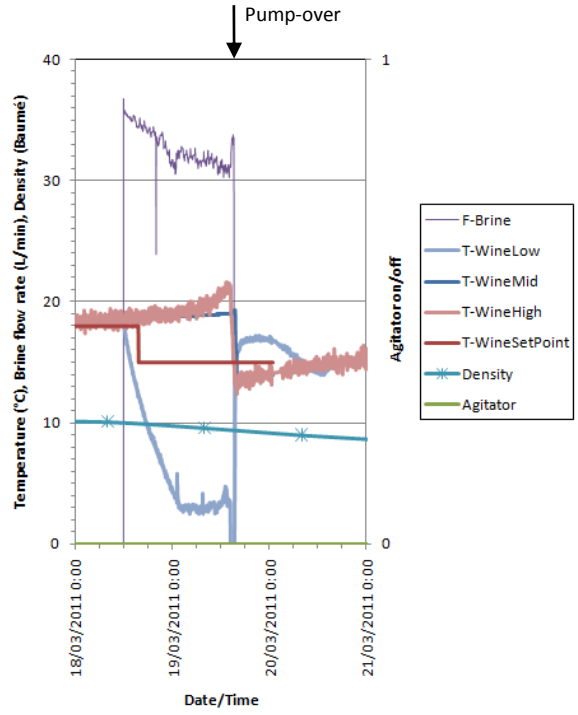


Figure 4.3: Stratification during Trial 3 – Riesling – 16°C

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.

7. References

ASHRAE (1982) Winemaking. In: ASHRAE 1982 Applications Handbook, Chapter 38.

Boulton, C. and Quain, D. (2006) Brewing yeast and fermentation. Blackwell Science, United Kingdom.

Boulton, R.B., Singleton, V.L., Bisson, L.F. and Kunkee, R.E. (1996) Principles and practices of winemaking. Chapman and Hall, United States of America.

Bureau of Meteorology (2011) Climate data online. www.bom.gov.au. Accessed May 2011.

Peynaud, E. (1984) Knowing and making wine. Translated by Spencer, A. John Wiley and Sons, United States of America.

Rankine, B.C. (2004) Making good wine. Pan Macmillan, Australia.

Ribéreau-Gayon, P., Dubourdieu, D., Donèche, B. and Lonvaud, A. (2006) Handbook of enology, volume 1, the microbiology of wine and vinifications, 2nd edition. Translated by Rychlewski, C. John Wiley and Sons, United Kingdom.

Williams, L.A. (1982) Heat release in alcoholic fermentation: A critical reappraisal. American Journal of Enology and Viticulture 33(3): 149-153.

Williams, L.A. and Boulton, R. (1983) Modeling and prediction of evaporative ethanol loss during wine fermentations. American Journal of Enology and Viticulture 34(4): 234-242.

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.

Appendix 6: Winery B – Case study report 2



Improving Winery Refrigeration Efficiency
Winery B
Case study report 2

- Storage temperatures
- Night-time cooling

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Author: Dr Simon Nordestgaard, Senior Engineer, The Australian Wine Research Institute

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Abstract

Trials were performed on the use of different wine storage temperatures and the use of night-time cooling in order to shift peak electricity use to cheaper off-peak electricity use.

Two storage temperature trials with a Chardonnay wine and a Semillon-Chardonnay wine found no significant sensory difference between wine that had been stored at an average temperature of 10°C as opposed to 5°C for a period of two-three months. The effect of storage temperature on quality may vary for other wines, and a simple equation to quickly estimate order of magnitude savings from storage (when using tanks with 75 mm thick polystyrene insulation) at warmer temperatures is provided so individual wineries can balance electricity savings against their own assessed risks of warmer storage temperatures to product quality:

$$\text{Maintenance saving (\$/kL/week)} = 0.006 \times \left(\frac{1}{\mathrm{L}} + \frac{4}{\mathrm{D}}\right) \times \left(\mathrm{T_{High}}\text{-}\mathrm{T_{Low}}\right)$$

Where T_{Low} and T_{High} are the alternate storage temperatures under consideration (e.g. 5°C and 10°C), and L and D are the tank height and diameter, respectively in m.

Night-time cooling trials were performed for a tank-farm consisting of twenty-four 10 kL tanks serviced by a custom ammonia refrigeration plant and brine reticulation system. Modifications were made to control systems to allow different day and night tank temperature set-points. This strategy worked effectively with refrigeration plant power monitoring demonstrating the shift of refrigeration plant operation from short repeated cycles throughout the day to operation predominantly at night for a sustained period.

The shifting of peak to off-peak electricity use by this or similar means is an opportunity for wineries to save on electricity costs. Often energy saving opportunities in wineries have to be balanced against a risk to quality (e.g. storing wine at warmer temperatures), which can be difficult to quantify. In comparison, night-time cooling has minimal quality risks when correctly implemented, as wine is still being stored at essentially the same temperatures – just using cheaper electricity for refrigeration. Additionally, refrigeration plants should operate more efficiently in lower ambient temperatures (if compressor discharge pressure is allowed to float appropriately), and operation for a sustained period instead of short repeated cycles would be expected to reduce wear on equipment. Options for different wineries will depend on their existing control system. As a conservative means of estimating potential savings it is recommended that the differential between the unit price of peak and off-peak electricity combined with the quantity of electricity that is likely to be shifted from the peak to the off-peak tariff be used. Where new control systems are being installed, a control system that accommodates the increased use of off-peak as opposed to peak electricity should be selected as a matter of course.

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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 related to bulk wine storage. Storage temperatures and the use of night-time cooling were investigated.

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 Storage temperature trial

Two storage temperature trials were performed outside in two 58 kL (nominal) stainless steel tanks insulated with 75 mm thick Isolite Class SL expanded polystyrene. The first trial involved storing Chardonnay wine for approximately two months with a tank temperature set-point of 5°C or 15°C. The second trial involved storing Semillon-Chardonnay wine for a period of approximately four months with a tank temperature set-point of 5°C or 15°C. The hysteresis ('deadband') setting was 0.5°C (i.e. if the set-point was 5°C, the tank brine jacket valve would open when the wine temperature had warmed to 5.5°C and then would close when the wine temperature had been reduced to 5°C). The tank agitator status was set to Auto, such that the agitator was on whenever brine was flowing through the tank cooling jacket and was off when the brine was not flowing.

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) logging at one minute intervals. 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}) were logged at five minute intervals together with the set-point temperature and the tank agitator status using the winery Citect SCADA system. However, the availability of this data was inconsistent as a consequence of intermittent system issues. The experimental arrangement was identical to that used in 2011 vintage fermentation trials performed at Winery B. Additional photos illustrating the experimental arrangement are included in that case study report.

The cooling imparted on the wine by the brine flowing through the tank jacket over the course of the storage trial 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 storage time, assuming the brine properties presented in Table 2.1. Average daily ambient temperature data during the trial were calculated by taking the average of the minimum and maximum temperatures from the closest (~10 km away) weather station (Bureau of Meteorology 2012).

Wine chemical analyses were performed by the winery's laboratory during the trial using standard techniques. Duo-trio difference sensory testing was performed once during each storage trial at the winery. In both cases, the 5°C wine was used as the reference.

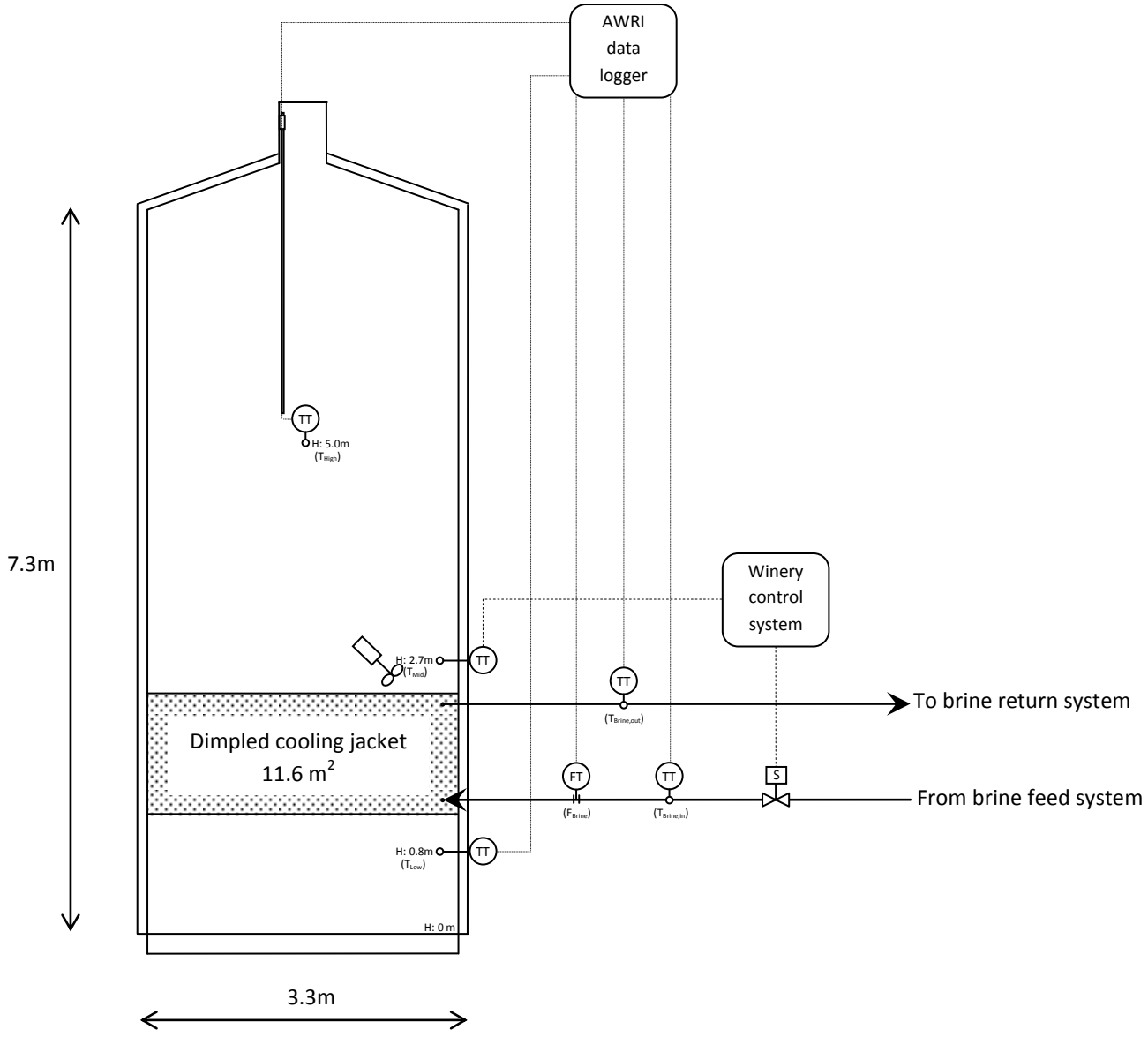


Figure 2.1: Approximate tank dimensions and control/data logging arrangement for one of the two 58 kL tanks (tank fittings, brine line ball valves and strainers not shown)

Table 2.1: Properties of brine and wine

Property	Brine[a]	Wine[b]
Density (kg/m^3):	985	978
Specific heat capacity (kJ/kg/°C):	3.6	4.3

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

[b]Wine properties from Rankine (2004), assuming a wine temperature of 10°C.

2.3 Night-time cooling trial

The night-time cooling trial was performed in a tank farm comprising twenty-four 10 kL wine tanks serviced by a custom ammonia refrigeration plant and a brine reticulation system. The wine tanks had dimpled cooling jackets and were insulated in a similar manner to the 58 kL tanks discussed previously but were located in a shed. The general tank-farm/brine distribution arrangement is shown in Figure 2.2. Key components of the refrigeration plant and the wine tank design are shown in Figures 2.3 and 2.4, respectively.

The tank farm temperature control system consisted of a Programmable Logic Controller (PLC) interfaced with a PanelView screen. This was also partially interfaced with a Citect SCADA system. Prior to the trial, the control system only allowed for a single temperature set-point for each tank. Modifications were made to the system to facilitate this trial and allow the setting of dual set-points: a 'day' set-point and a 'night' set-point. The ability to set the time when the 'day' and 'night' started was also added. The Citect SCADA system was programmed to log the actual temperature, set-point temperature and agitator status for each of the 24 tanks in the farm at 20 minute intervals.

Electricity use by the refrigeration plant (including the brine tank to refrigeration plant pump) was monitored using a power logger (PowerMonic PM30Plus-E; Gridsense, Australia, Figure 2.5) at 30 second intervals. 0-100 A current clamps were used on each phase. The pump distributing brine to the tank farm was on a separate electrical circuit and was monitored using three 0-20 A current clamps (Magnelab, USA, Figure 2.6). Voltage and power factor were not measured for this pump so average values obtained from the main power logger were employed to calculate power use. These current clamps were interfaced with a data logger (Hobo U30/NRC; Onset) using a Flexsmart TRMS module (Onset) and data were logged at 30 second intervals. Ambient temperature during the trial was monitored using a temperature sensor interfaced with the same data logger.

The trial procedure was to alternate between periods using single tank set-point temperatures and periods using different day and night set-point temperatures (i.e. dual set-points). Night was set as being between 2:00 am and 6:00 am, with day being the remaining hours. The tank farm was in regular production use and for this trial it was not possible to dictate when wine entered or exited. Between 11 and 13 of the 24 tanks contained wine being subject to temperature control at different times during the trial. The protocol when switching from the single-set point mode to the dual set-point mode was to make the night set-point 0.5°C lower than the single set-point (which the winemaker had set) and the day set-point 0.5°C higher than the single set-point for each wine tank. For example, if a set-point of 5°C was used when in the normal single set-point mode, a night set-point of 4.5°C and a day set-point of 5.5°C would be used. In all cases, the hysteresis setting was 0.5°C.

The refrigeration plant itself had a separate control system. The refrigeration plant brine set-point was -8°C with a hysteresis setting of 2°C (i.e. the refrigeration plant would start running when the brine tank temperature had warmed to -6°C and stop running when the brine tank had been cooled to -8°C).

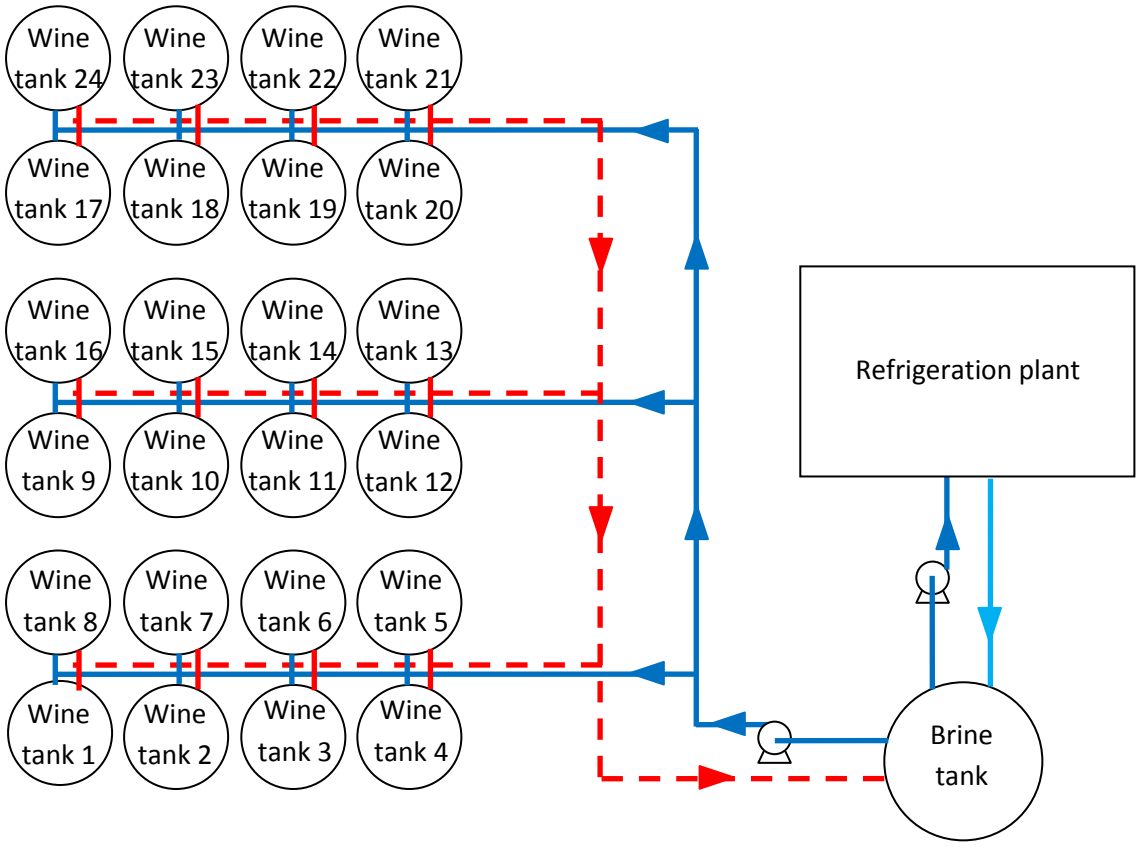


Figure 2.2: Simplified tank farm arrangement showing brine distribution to cooling jackets on 10 kL wine tanks

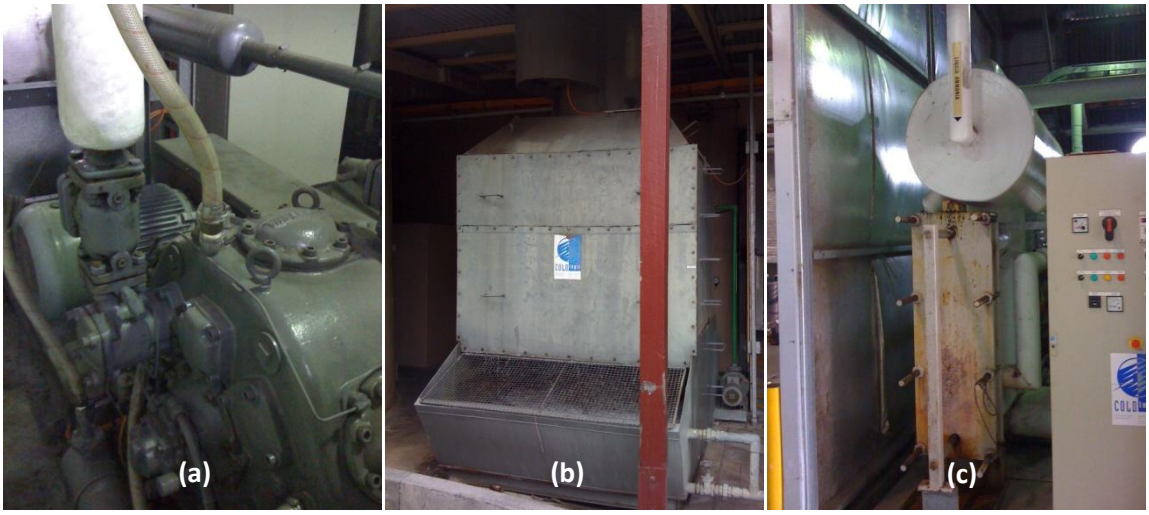


Figure 2.3: Key refrigeration plant components: (a) Compressor, (b) Condenser, and (c) Evaporator

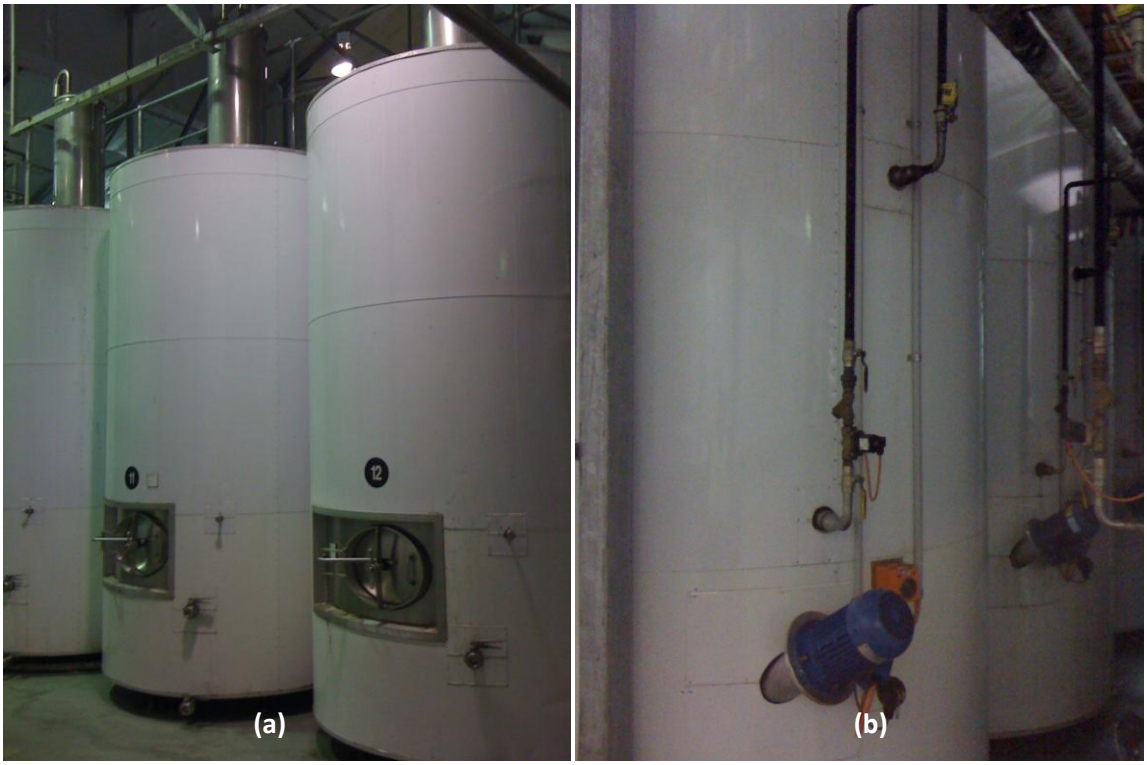


Figure 2.4: 10 kL wine tanks: (a) front, and (b) rear



Figure 2.5: Power logger connected to refrigeration plant power supply



Figure 2.6: Current clamps connected to brine distribution pump power supply

3. Results and discussion

3.1 Storage temperatures

The brine flow rate through each tank jacket, wine set-point and actual temperature, and daily average ambient temperature are shown in Figures 3.1 and 3.2 for the Chardonnay trial and Figures 3.3 and 3.4 for the Semillon-Chardonnay trial. Please note that the gaps in wine set-point and actual temperature data were related to winery data logging system issues. The winery control systems themselves were still working correctly during these times. Chemical and sensory data are reported in Tables 3.1 and 3.2.

In each trial, the wine had been previously stored in a larger common tank before being divided between the two 58 kL tanks. In the Chardonnay trial, the wine was at approximately 10°C when it was pumped into the two 58 kL tanks. The set-point in one of the tanks was 5°C, therefore brine flowed initially for a period to pull the wine temperature down to set-point. Cooling was then intermittently required to maintain the wine temperature at 5°C. For the tank with a set-point of 15°C, no cooling was required throughout the Chardonnay trial as the relatively low ambient temperature (averaging approximately 10°C) meant that the wine never warmed to the set-point temperature. Similar general patterns were seen for the Semillon-Chardonnay trial. However, as the ambient temperatures were higher, the 15°C set-point wine eventually warmed and did require cooling. In Figure 3.3, it is also clear that the period between brine jacket operations decreased as the ambient temperature increased.

As an indication of costs associated with cooling, the cost of pulling down the temperature of the Chardonnay from 9.7°C to 5°C was $0.37/kL (assuming an electricity cost of $0.15/kWh and a COP_{+brine} of 2). The average maintenance cost over the rest of that trial was $0.07/kL/week. In the Semillon-Chardonnay trial, the maintenance costs were significantly higher for the same wine temperature as a consequence of warmer ambient temperatures, e.g. they averaged $0.22/kL/week for maintenance at 5°C over the period between 3/11/2011 and 20/12/2011. The influence of the wine-average ambient temperature differential on cost is presented in Figure 3.5 based on data for five different maintenance periods during the trials. The overall heat transfer coefficient over these periods, calculated from the brine exchange energy, ranged from 0.65 to 0.85 $W/m^2/°C$, with an average of 0.76 $W/m^2/°C$. This was higher than the 0.47 W/m2/°C expected from theory (see Appendix A for calculation). This may indicate a problem with the insulation on these specific tanks or might be related to the applicability of data from the weather station located 10 km away and to the averaging of the minimum and maximum temperatures to derive the average ambient temperature.

No significant difference between the two temperature treatments was observed during sensory analysis in either trial (Tables 3.1 and 3.2). However, it should be noted that the average wine temperature over the storage period was actually 5°C vs 10°C in both instances as opposed to 5°C vs 15°C, since the wine was initially at less than 15°C. These results are only for two wines and the effect of storing wine at different temperatures on quality is not going to be decided by this trial alone, particularly given the different existing industry opinions on this matter. However, it is possible to make some quick order of magnitude estimates of the potential savings possible from

storing wine at warmer temperatures, such that individual winemakers can make decisions on whether the savings outweigh the risks for their specific product. Using the theoretical overall heat transfer coefficient of 0.47 W/m^2/°C, and the previously stated assumptions of COP and electricity cost, the electricity saving from storing wine in (75 mm polystyrene insulated) tanks at a temperature of T_{High} instead of T_{Low} can be estimated using (see Appendix B for derivation):

$$\text{Maintenance saving (\$/kL/week)} = 0.006 \times \left(\frac{1}{L} + \frac{4}{D}\right) \times \left(T_{High} - T_{Low}\right) \qquad \text{Eq. 1}$$

If we look at a winery that typically stores wine in tanks that are 10 m tall and 7 m in diameter, the saving from using a storage temperature of 10°C instead of 5°C would be $0.02/kL/week. If that winery held stocks of 30,000 kL subject to this regime throughout the year, the annual saving would be approximately $31,000 (if this calculation was performed using the experimentally determined overall heat transfer coefficient of 0.76 W/m^2/°C the saving would be $51,000). Whether this saving justified the risk of storing at the warmer temperature is something that would be a decision for that winery. Any saving is beneficial and if there is no risk it is an easy decision, but this example considered a fairly large volume of wine, and a large change in storage temperature (10°C - 5°C = 5°C) and the savings were not huge. This was based on a well insulated tank. The results will be different for an uninsulated tank, where heat gains may result in savings several times this, and heat transfer associated with condensation on the outside of tanks may become important.

In addition to the maintenance temperature saving, the cost of pulling down the temperature of a large volume of wine can be considerable as was observed in this trial. Employing the same assumptions on electricity price and system performance described previously, the cost of the electricity used to pull wine down from $T_{Initial}$ to T_{Final} (°C) can be estimated using (see Appendix C for derivation):

$$\text{Pull-down cost (\$/kL)} = 0.09 \times (T_{Initial} - T_{Final}) \qquad \text{Eq. 2}$$

This is somewhat different to the maintenance saving in that this might not be completely wasted. If the wine is subsequently going to be stored at a warmer temperature, the extra 'cold' can offset some of the refrigeration requirement to maintain the wine at that warmer temperature. The 'cold' may also be recovered by product-product heat exchange. The lifetime temperature profile of the wine really needs to be considered to understand cost. If wine had been stored at 5°C and then it was warmed up prior to bottling to 15°C, without any heat recovery, then from Eq. 2, $0.90/kL has been spent (excluding the cost of energy used to provide warming).

In the current trial, when a set-point of 15°C was used, the wine was often at a much lower temperature since the wine was at a lower temperature when it was pumped into the tank. In this case, the use of the set-point temperature alone to describe the wine temperature would be misleading. It is speculated that wine might often be stored cooler than winery staff think is being stored at because of situations such as this.

Dimpled cooling jackets with a surface area of 11.6 m^2 were installed on the tanks used in these trials. These were calculated to have an overall heat transfer coefficient of approximately 400

$W/m^2/°C$ during cooling. In this trial, the tank agitators were set to auto such that they ran whenever the brine was flowing. In arrangements without this vigorous mixing it is expected that the cooling jacket heat transfer coefficient would be significantly lower. In this winery and many others it is atypical to agitate during storage. Agitation was a necessity in these tanks to prevent brine-induced stratification as a consequence of the placement of the only cooling jacket at the bottom of the tank (see Winery B case study report 1 for further details). The use of agitation during brine flow is something that should be considered by wineries given the likely much higher heat transfer coefficients. The overall savings in energy may be relatively small (slightly reduced heat gains/brine pumping from reduced brine recirculation) but the faster cooling speed can have benefits including completing a pull-down in tank temperature in periods of cheaper electricity (i.e. night-time cooling).

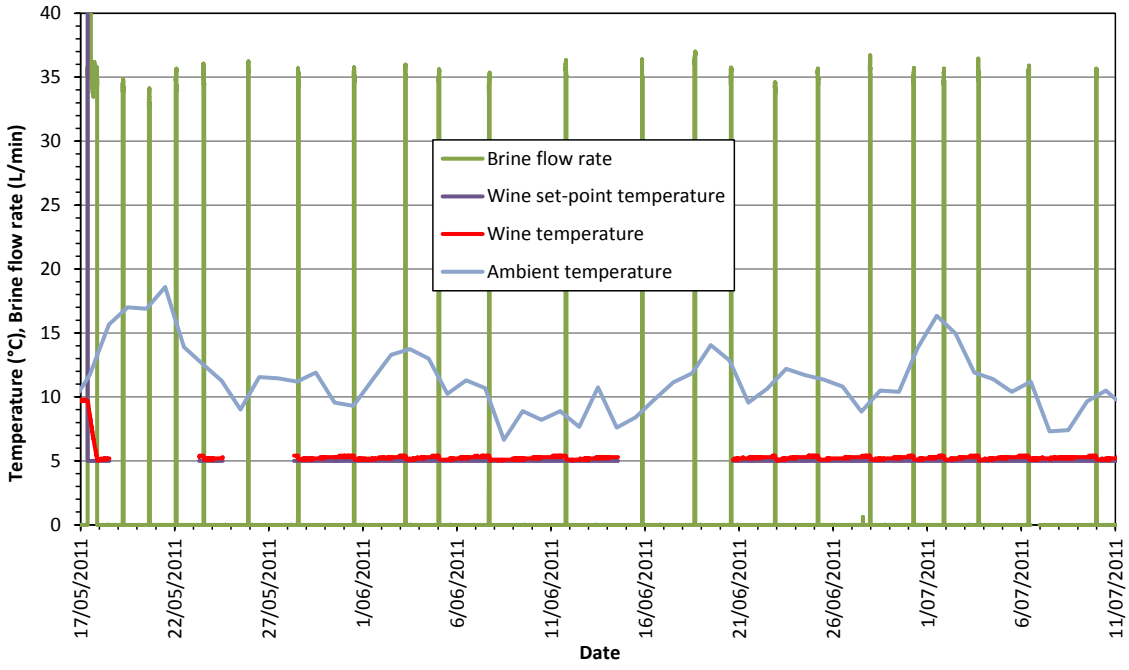


Figure 3.1: Chardonnay, 5°C set-point

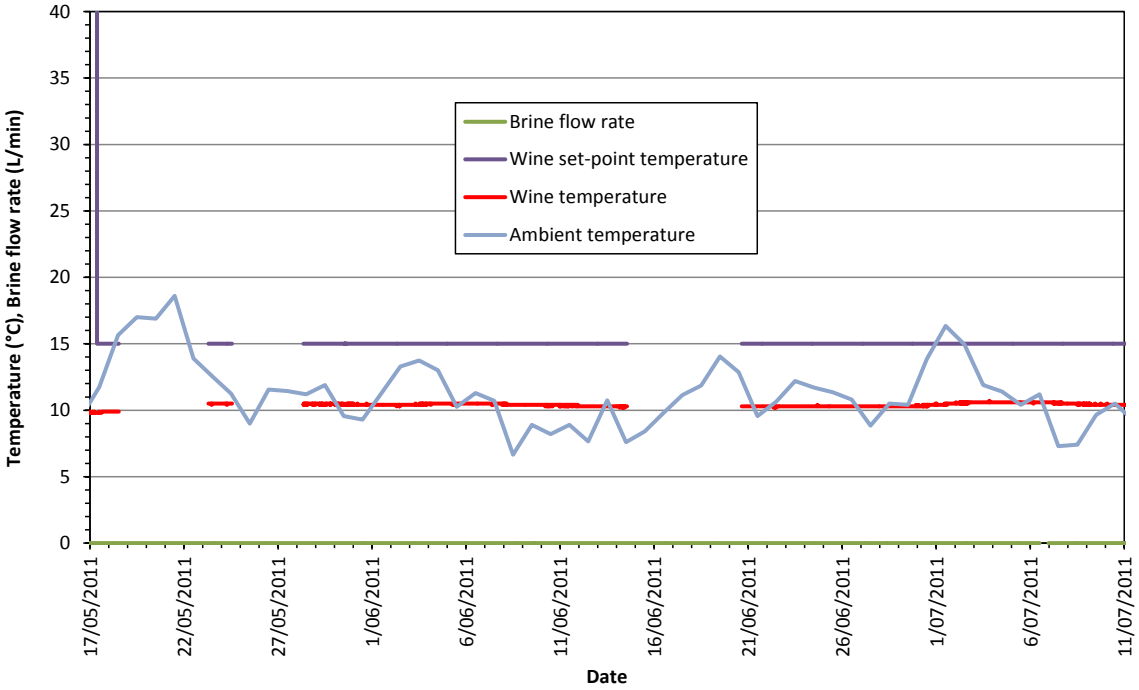


Figure 3.2: Chardonnay, 15°C set-point

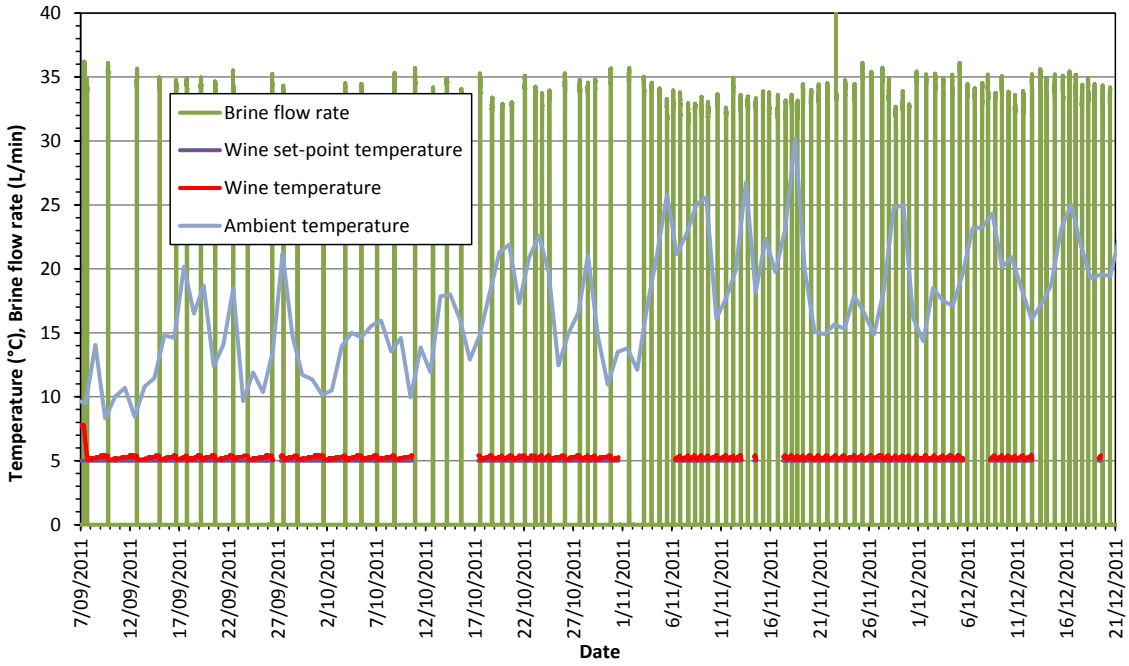


Figure 3.3: Semillon-Chardonnay, 5°C set-point

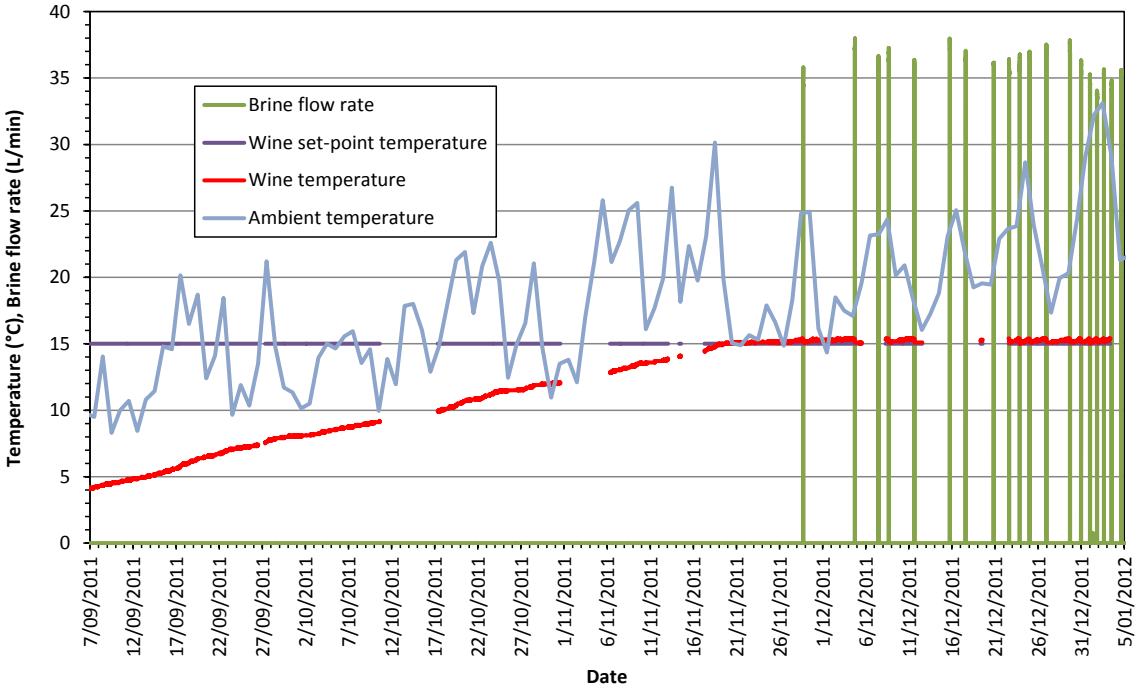


Figure 3.4: Semillon-Chardonnay, 15°C set-point

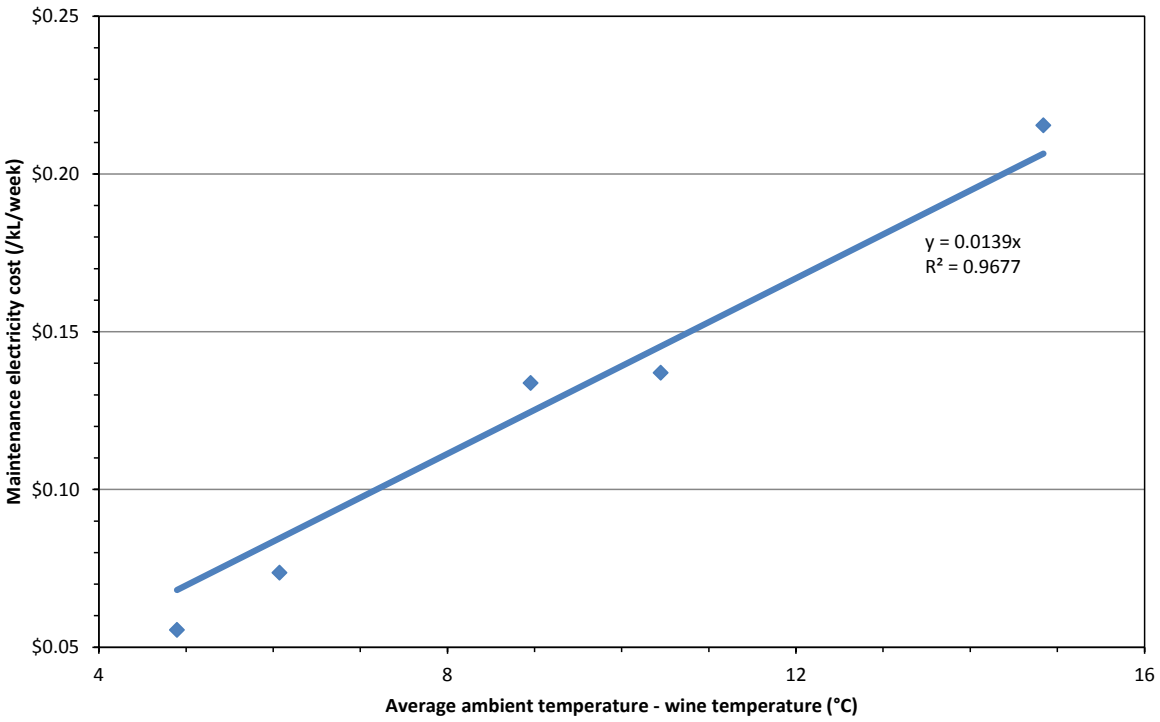


Figure 3.5: Relationship between temperature differential and electricity requirements during trials

Table 3.1: Chemical and sensory analysis for Chardonnay wine

Storage period (days)	Set-point Temp. (°C)	Average Temp. (°C)	Alcohol (%v/v)	TA (g/L)	pH	Ascorbic acid (mg/L)	Free SO_2 (mg/L)	Total SO_2 (mg/L)	DO (mg/L)	CO_2 (g/L)	OD_{280} (au/cm)	OD_{320} (au/cm)	OD_{420} (au/cm)	Duo-trio sensory
43	5	5.2	13.1	6.1	3.24	58	35	126	0.04	1.74	n.d.	2.547	0.086	n.m.
	15	10.4	13.1	6.1	3.23	57	35	128	0.03	1.73	n.d.	2.543	0.089	
65	5	5.3	13.1	n.m.	3.27	71	38	112	0.055	1.81	7.95	2.712	0.093	no significant. difference
	15	10.4	13.1	n.m.	3.27	74	38	121	0.03	1.82	8.41	2.75	0.094	p = 0.55[a]

[a]31 sensory panellists in duplicate, standard glasses used.

Table 3.2: Chemical and sensory analysis for Semillon-Chardonnay wine

Storage period (days)	Set-point Temp. (°C)	Average Temp. (°C)	Alcohol (%v/v)	TA (g/L)	pH	Ascorbic acid (mg/L)	Free SO_2 (mg/L)	Total SO_2 (mg/L)	DO (mg/L)	CO_2 (g/L)	OD_{280} (au/cm)	OD_{320} (au/cm)	OD_{420} (au/cm)	Duo-trio sensory
1	5	5.1	11.05	6.4	3.26	70	28	121	0.046	2.3	7.64	2.7	0.069	n.m.
	15	4.3	11.08	6.4	3.25	71	25	112	0.032	2.31	7.56	2.7	0.073	
28	5	5.2	11	6.6	3.29	59	23	110	0.095	2.34	7.56	2.76	0.065	n.m.
	15	6.5	11	6.6	3.29	65	24	109	0.093	2.29	7.57	2.71	0.065	
56	5	5.2	11	6.2	3.19	68	28	108	0.025	2.31	7.66	2.71	0.076	n.m.
	15	8.2	11	6.2	3.18	66	28	109	0.015	2.33	7.72	2.73	0.08	
91	5	5.2	11.1	6.4	3.29	67	32	114	0.001	2.27	7.58	2.64	0.041	No significant difference
	15	10.5	11.1	6.4	3.29	77	35	116	0.005	2.27	7.92	2.7	0.07	p = 0.81[a]
119	5	5.2	10.9	6.4	3.29	67	30	119	0.018	2.25	7.58	2.76	0.064	n.m.
	15	11.3	10.8	6.4	3.28	69	35	116	0.012	2.31	8.14	2.84	0.075	

[a]30 sensory panellists, black glasses used.

3.2 Night-time cooling

The power usage by the refrigeration plant and the brine reticulation pump together with ambient temperature are shown in Figure 3.6 for periods where a single set-point or dual set-points were in use. Plots showing the tank set-point temperature and actual temperature for parts of these periods for tanks employing single set-point temperatures of 2, 5 and 12°C are shown in Figures 3.7, 3.8 and 3.9, respectively.

Figure 3.6 displays a clear difference in the operation of the refrigeration plant between the dual and single tank set-point modes. With the dual set-point mode, the refrigeration plant ran for a sustained period starting at 2:00 am, and remaied off for much of the day-time, while with the single set-point mode, the refrigeration plant ran regularly for short periods through both the day and night. In the dual set-point mode, this particular refrigeration system should run more efficiently as the compressor discharge pressure should float down with lower ambient temperatures as the condenser will be able to more easily cool refrigerant (whether this will be realised on other systems will be dependent on whether compressor discharge pressure is allowed to float with temperature – often it is not). Running the refrigeration plant for a sustained period and reducing the on/off switching would also be likely to reduce the wear on the compressor. The largest readily quantifiable benefit of the increased night-time operation would be shifting peak electricity use to cheaper off-peak electricity use.

In Figures 3.7-3.9, in the dual set-point mode with lower storage temperatures (2°C or 5°C), on warm days cooling was sometimes required during the day, while with warmer storage temperature (12°C) cooling was never required during the day even on the warmest day. With larger but similarly insulated tanks, cooling would likely often not be required during the day even for lower storage temperatures.

During the current trial, winery staff were made aware of the trial, and two dot-point instructions were placed next to the control screen on the settings to use. However, on one occasion, the same temperature set-point was used for both the day and night set-points for one tank. This suggests that in widespread winery adoption of control strategies taking advantage of off-peak cooling a simplified user input strategy may be required, particularly in large wineries with many personnel who have access. The user input arrangement could involve only a single set-point being entered, with appropriate working set-points and hysteresis settings then being implemented in the background at different times as appropriate.

Pulling-down wine temperature significantly for cold stabilisation in-tank is something that must be accommodated in any night-time cooling control strategy as this involves a significant load. The simple dual set-point strategy adopted can accommodate this to an extent. For example, if it were 1:00 pm and a winemaker wanted to pull-down the tank temperature from 10°C to -4°C, then they could set the night set-point to -4°C and the day set-point as 10°C, so the cooling only starts at night. However, to accommodate cooling of this nature, the definition of night-time used in this trial (2:00 am - 6:00 am) might need to be expanded to include the entire period of cheap off-peak electricity (9:00 pm - 7:00 am at this winery) otherwise it might take several night-times to get the wine down to the cold stabilisation temperature.

In order to assess possible savings if this night-time cooling strategy was adopted across the entire winery, the current winery electricity use profile (excluding the packaging facility, which was on a separate meter) was inspected for June 2010 – May 2011. Maximum monthly usage occurred in January to March. Given that winery refrigeration capacity may be stretched during this vintage period, it was conservatively assumed that no shifting of peak electricity to off-peak electricity in this period would be possible. In the April-December period, approximately 55% of electricity was currently consumed during off-peak periods. It was assumed that 60% of total winery electricity was related to refrigeration and that, like overall electricity use, 55% of refrigeration-related electricity use was consumed off-peak. It was estimated that the winery might realistically be able to increase the off-peak refrigeration fraction to 80% using a strategy similar to that outlined in this report. This would involve shifting approximately 580,000 kWh annually from peak to off-peak or a saving of $38,000 annually based on their peak/off-peak electricity price differential of $0.065/kWh. This is a conservative value as it does not include savings related to any refrigeration efficiency improvements. A cost was sought from the current winery refrigeration control supplier to implement this control scheme across the winery. Given that this winery is quite complex and has numerous refrigeration-related control systems of varying ages, they would only provide a budget price of $580/tank (excluding any required PLC upgrades) in the first instance. Given approximately 300 tanks at the winery under temperature control, this equated to a cost of $174,000 and to a payback period of 4.6 years. A more detailed quotation could be prepared by the supplier if the winery desired, but it would take some time to prepare. It is hoped that it could ultimately be done for much more cheaply than this. The programming for this 24-tank trial cost only $2,160 ($90/tank), however this did not completely integrate with the Citect SCADA control system. At this winery, it may only prove economic to perform control changes on specific tank farms/refrigeration systems. At other wineries without the unusually complex mixtures of different outdated systems found at the trial winery, the changes would likely be performed much more economically.

An alternative option to programming a custom solution is to purchase a largely off-the-shelf system such as VinWizard. This software has various modules available to utilise off-peak power and can be retro-fitted over the top of existing PLC hardware if required. A system of this style may prove a more cost-effective option in some wineries, particularly given that it may facilitate other energy saving and capacity increasing improvements such as automatically setting the brine temperature at the highest temperature possible based on the lowest temperature wine tank on the brine loop. A winery that is installing a new control system should ensure that it includes functionality to take advantage of cheaper off-peak electricity as a matter of course.

While the cost of control system modification will vary according to the state of existing systems, with correct implementation the risks to wine quality are minimal, since wine is still being stored at essentially the same temperature. This makes it an attractive improvement option.

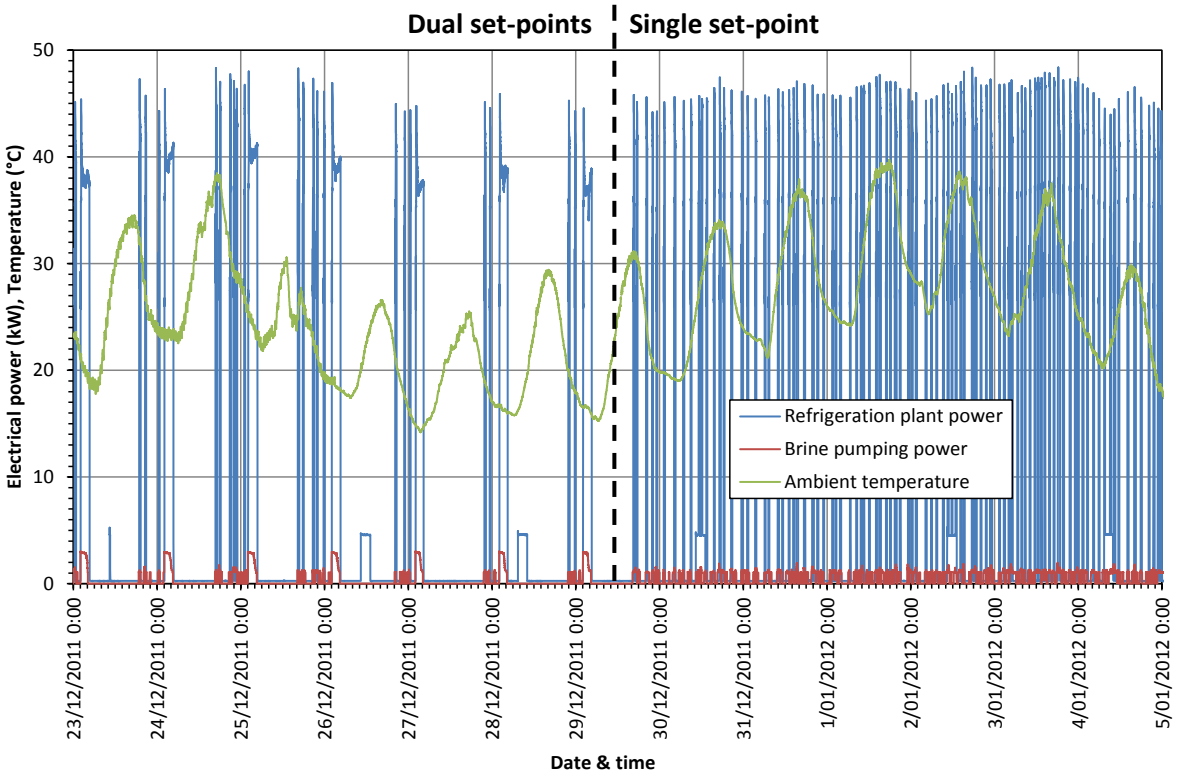


Figure 3.6: Difference in refrigeration plant operation when employing dual or single set-point temperatures

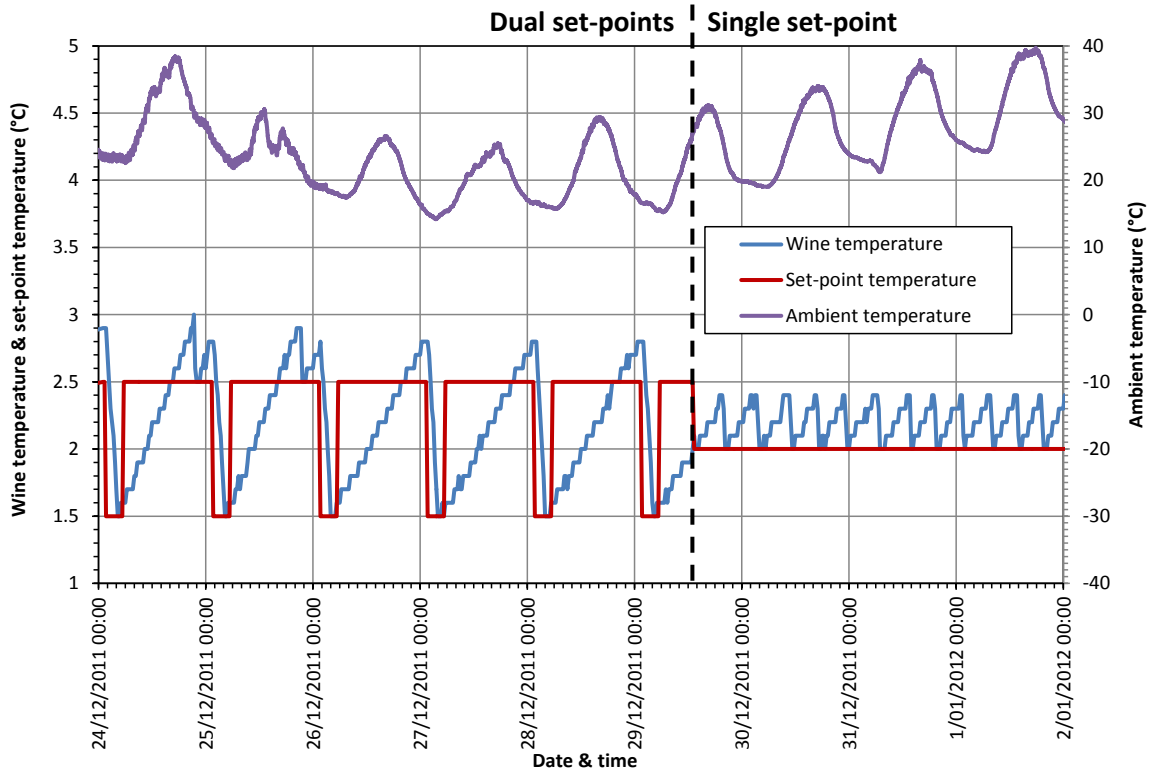


Figure 3.7: 2°C single set-point, agitator auto (i.e. on when brine is running)

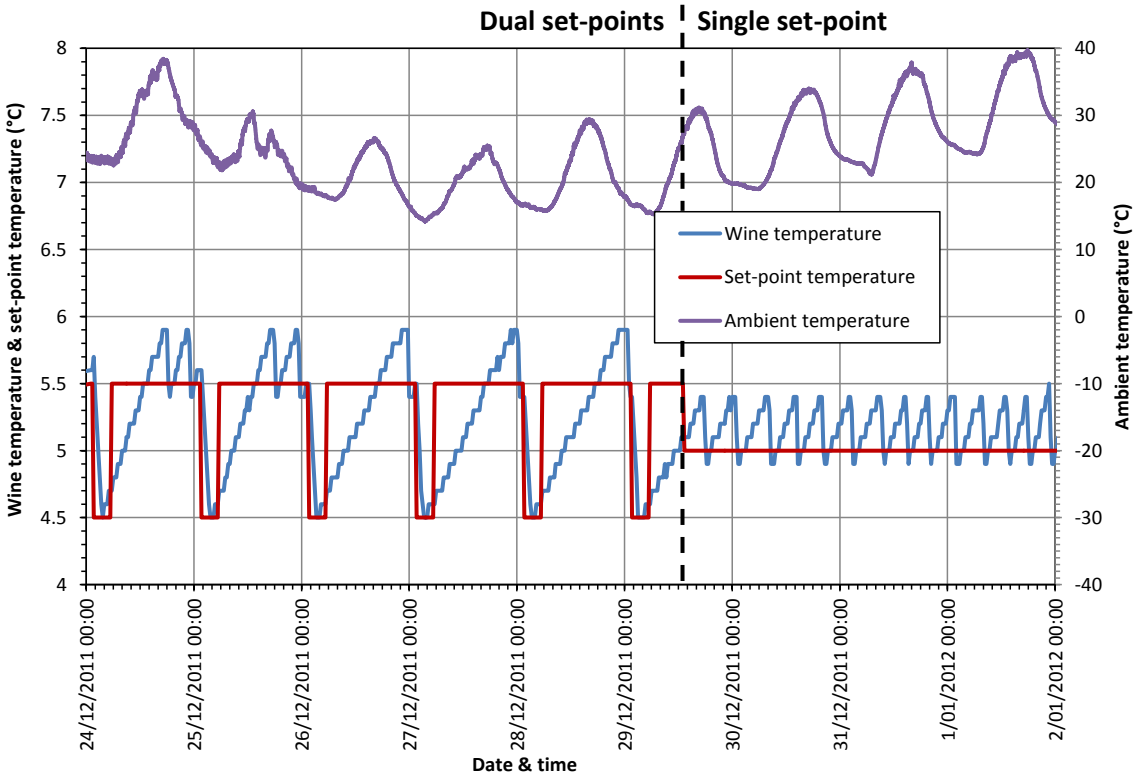


Figure 3.8: 5°C single set-point, agitator off

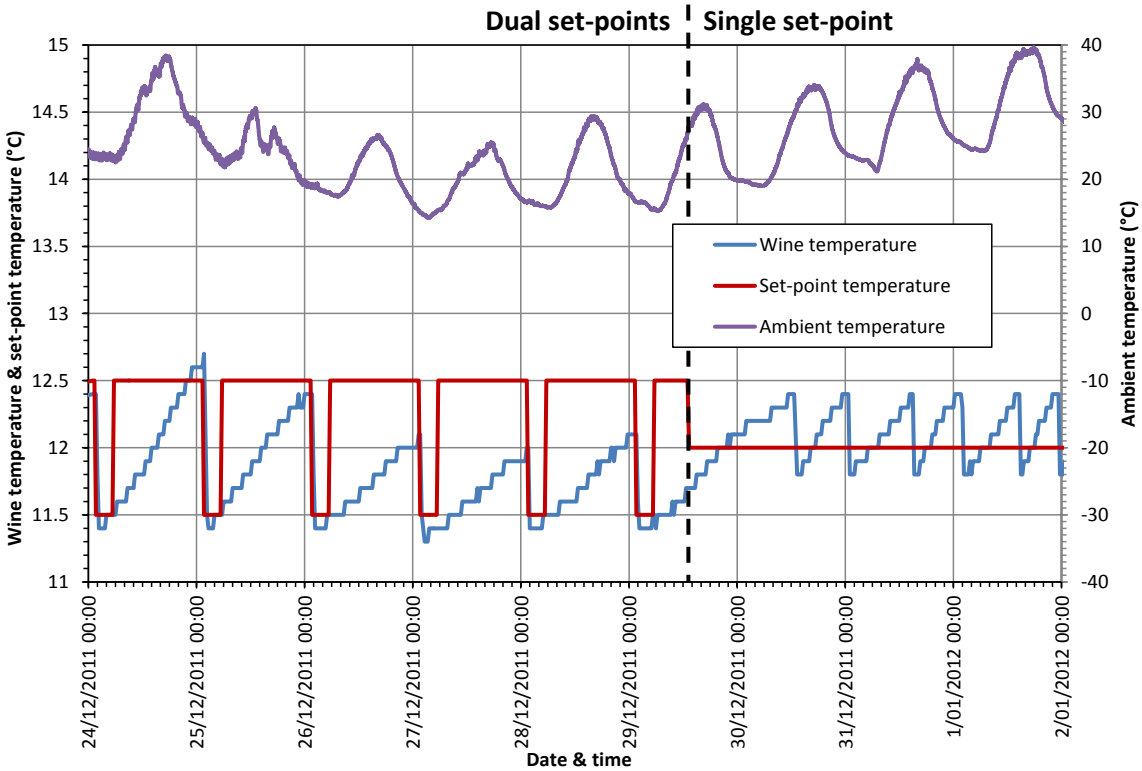


Figure 3.9: 12°C single set-point, agitator off

4. Conclusions and recommendations

1. No significant sensory difference was found for either a Chardonnay or a Semillon-Chardonnay wine stored at 10°C as opposed to 5°C for two-three months. The effect of storage temperature on quality will vary for different wines.

    a. *The following simple equation should be used by wineries to quickly estimate order of magnitude electricity savings from storage (when using tanks with 75 mm thick polystyrene insulation) at warmer temperatures. The winery should then balance potential electricity savings against their own assessed risk to product quality:*

    $$\textit{Maintenance saving (\$/kL/week)} = 0.006 \times \left(\frac{1}{L} + \frac{4}{D}\right) \times \left(T_{High} - T_{Low}\right)$$

    Where T_{Low} and T_{High} are the alternate storage temperatures under consideration (e.g. 5°C and 10°C), and L and D are the tank height and diameter, respectively in m.

2. Night-time cooling trials using different day and night tank temperature set-points demonstrated the shift of refrigeration plant operation from short repeated cycles throughout the day to operation predominantly at night for a sustained period. The shifting of peak to cheaper off-peak electricity use is a good opportunity for wineries to save on electricity costs with minimal risk to wine quality.

    a. *Wineries should look to shift their electricity use to off-peak tariffs. Options for different wineries will depend on their existing control system. As a conservative means of estimating potential savings, it is recommended that the differential between the unit price of peak and off-peak electricity combined with the quantity of electricity that is likely to be shifted from the peak to the off-peak tariff be used. Where new control systems are being installed, a control system that accommodates the increased use of off-peak as opposed to peak electricity should be selected as a matter of course.*

    b. *Wineries should consider alterations to refrigeration plant control systems that allow the refrigeration plant discharge pressure to float appropriately with differing ambient temperatures so that improved efficiencies in refrigeration plant performance during night-time cooling can also be realised.*

5. Acknowledgements

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6. References

Azom (2012) The A to Z of materials. www.azom.com. Accessed May 2012.

Bureau of Meteorology (2012) Climate data online. www.bom.gov.au. Accessed May 2012.

CSR (2012) Industrial insulation design guide. www.bradfordinsulation.com.au. Accessed May 2012.

Matweb (2012) Matweb material property data. www.matweb.com. Accessed May 2012.

Rankine, B.C. (2004) Making good wine. Macmillan, Australia.

RMAX (2012) Isolite thermal conductivity design values. www.rmax.xom.au. Accessed May 2012.

7. 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.
Compressor:	This device compresses refrigerant and is the main user of electricity in a refrigeration plant.
Condenser:	The heat exchanger used to condense refrigerant after it has passed through the compressor.
Evaporator:	The heat exchanger in which the brine is cooled by the refrigerant (as the refrigerant evaporates).
Freezing-point suppressant:	An additive that lowers the temperature at which brine will freeze.
Hysteresis:	A setting in an on-off control system that prevents rapid switching as a parameter (e.g. temperature) drifts around the set-point. For example; with a temperature set-point of 5°C and a hysteresis setting of 0.5°C; cooling will switch on when the measured temperature reaches 5.5°C and switch off when it reaches 5°C. Hysteresis is often referred to as dead-band.
PLC:	A Programmable Logic Controller (PLC) is a highly reliable special-purpose computer used in industrial monitoring and control applications.
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.

Appendix A: Theoretical overall heat transfer coefficient

Wine temperature (T_i) = 5°C
Air temperature (T_e) = 15°C

Assume that tank wall is at wine temperature.

Tank wall and insulation construction (thickness, Δx, and thermal conductivity, k):

Stainless steel: Δx_1 =0.0016 m, k_1 = 16.3 W/m/°C (Azom 2012)
Isolite Class SL: Δx_2 =0.075 m, k_2 = 0.0386 W/m/°C (RMAX 2012)
Aluminium sheathing: Δx_3 =0.00055 m, k_3 = 171 W/m/°C (Matweb 2012)

Surface heat transfer coefficient (f): 5.7 W/m^2/°C (CSR 2012)

This approximation of surface heat transfer coefficient combines both convection and radiation at the external surface of the cladding.

The overall heat transfer coefficient (U) is thus:

$$\frac{1}{\frac{\Delta x_1}{k_1}+\frac{\Delta x_2}{k_2}+\frac{\Delta x_3}{k_3}+\frac{1}{f}} = 0.47 \text{ W/m}^2\text{/°C}$$

Appendix B: Derivation of maintenance saving

Theoretical overall heat transfer coefficient (U) = 0.47 W/m^2/°C (see Appendix A)
Tank surface area = $\pi D^2/4 + \pi DL$ m^2
Tank volume = $L\pi D^2/4$ m^3
(where tank is approximated as a cylinder for simplicity, and D and L are tank diameter and height, respectively in m).
Average ambient temperature (T_e)

Unit electricity cost = \$0.15/kWh = \$4.17 × 10^{-8} /J
COP_{+brine} = 2 (A modified COP for estimation purposes that incorporates brine reticulation loop heat gains and pumping requirements)

The difference in heat gain per kL (m^3) from using a wine storage temperature of T_{High} instead of T_{Low} (°C) is:

$$\frac{0.47 \times \left(\frac{\pi D^2}{4} + \pi DL\right) \times \left((T_e - T_{Low}) - (T_e - T_{High})\right)}{\left(\frac{L\pi D^2}{4}\right)} = \frac{0.47 \times \left(\frac{\pi D^2}{4} + \pi DL\right) \times (T_{High} - T_{Low})}{\left(\frac{L\pi D^2}{4}\right)}$$

$$= 0.47 \times \left(\frac{1}{L} + \frac{4}{D}\right) \times (T_{High} - T_{Low}) \quad J/s$$

The saving in electricity cost per kL per week (604,800 seconds), is:

$$0.47 \times \left(\frac{1}{L} + \frac{4}{D}\right) \times (T_{High} - T_{Low}) \times \frac{\$4.17 \times 10^{-8} \times 604{,}800}{2}$$

$$= \$0.006 \times \left(\frac{1}{L} + \frac{4}{D}\right) \times (T_{High} - T_{Low})$$

Note: If for whatever reason, $T_{High} > T_e$, this equation will exaggerate the potential savings as refrigeration will not be required when wine is at temperatures above the average ambient temperature.

Appendix C: Derivation of pull-down cost

Wine specific heat capacity = 978 kg/m^3 (Rankine 2004)
Wine density = 4,300 J/kg/°C (Rankine 2004)

Unit electricity cost = \$0.15/kWh = \$4.17 × 10^{-8} /J
COP_{+brine} = 2 (A modified COP for estimation purposes that incorporates brine reticulation loop heat gains and pumping requirements)

The heat removal required to pull-down the wine temperature from $T_{Initial}$ to T_{Final} (°C) per kL (m^3) is:

$$978 \times 4{,}300 \times (T_{Initial} - T_{Final}) \quad J$$

The electricity cost to achieve this heat removal is:

$$\frac{978 \times 4{,}300 \times (T_{Initial} - T_{Final}) \times \$4.17 \times 10^{-8}}{2} = \$0.09 \times (T_{Initial} - T_{Final})$$