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

AWRI COMMERCIAL SERVICES
OUR KNOWLEDGE, YOUR RESOURCE

AWRI

Funded by:
GWRDC
GRAPE AND WINE RESEARCH AND DEVELOPMENT CORPORATION

Author: Dr Simon Nordestgaard, Senior Engineer, AWRI

This report is available for download from www.awri.com.au or www.gwrdc.com.au.

This document 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.

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.

Contents

1. Introduction

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

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

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

This report describes the work at Winery 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.

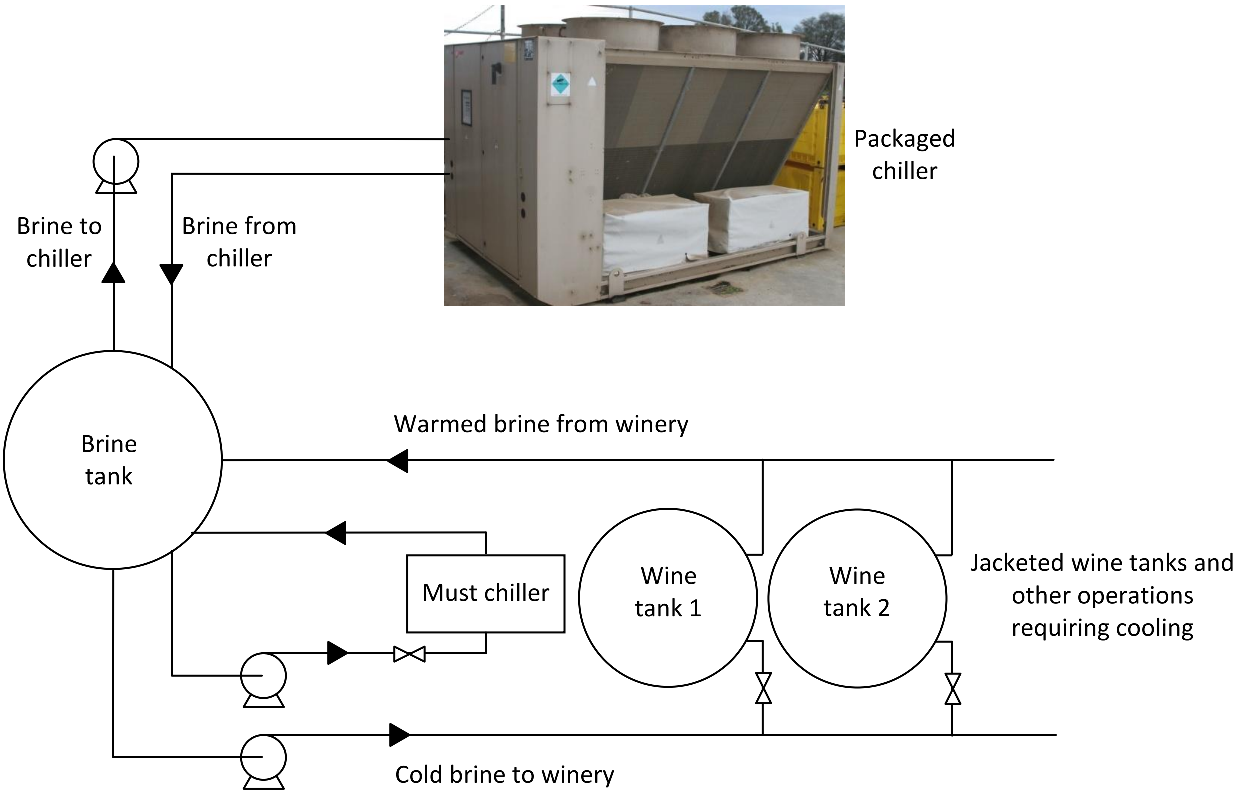

Figure 2.1: Winery A cooling system (illustrative only)

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.

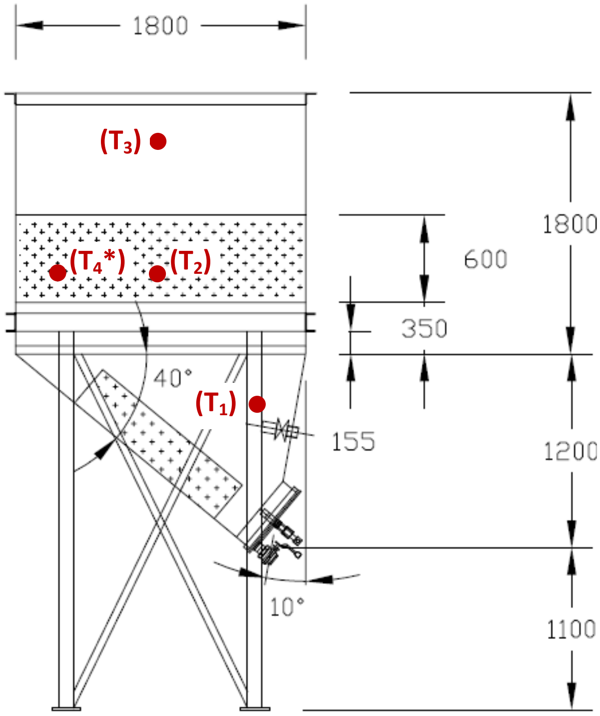

Figure 2.2: Schematic of 5-tonne open-topped fermenter with temperature sensor (T_1 to T_4) locations shown (Sensors T_1 to T_4 are centred across the tank looking into the page. T_4 is actually located 90° clockwise around the tank when viewed from the top of the tank)

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).

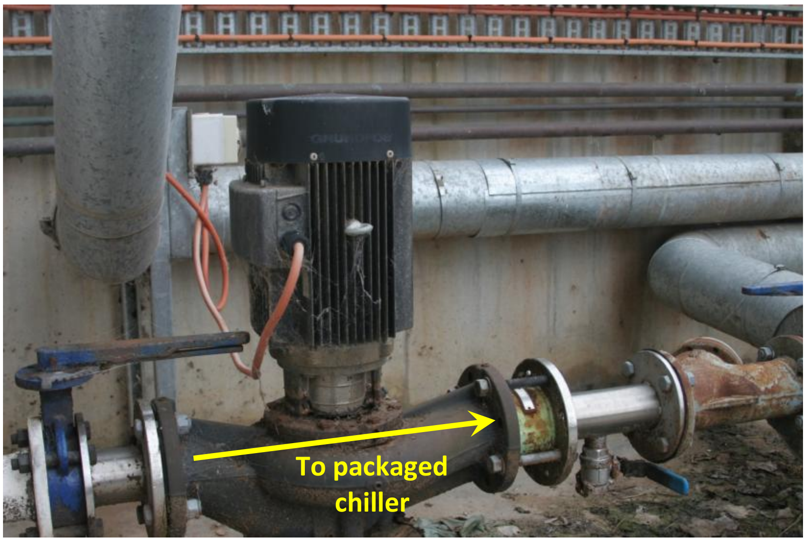

Figure 3.1: Pump that moves brine from the brine tank through the packaged chiller's evaporator

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.

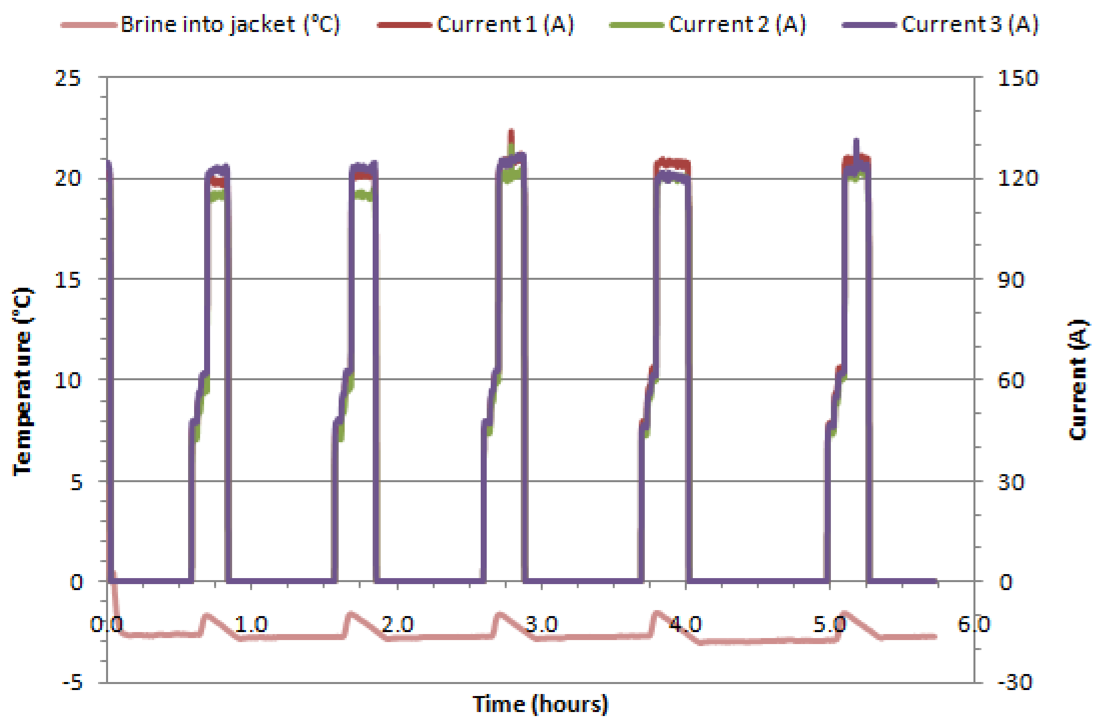

Figure 3.5: Packaged chiller current draw and brine temperature at inlet to tank jacket/plate during rainwater cooling experiment with nominally -5°C brine

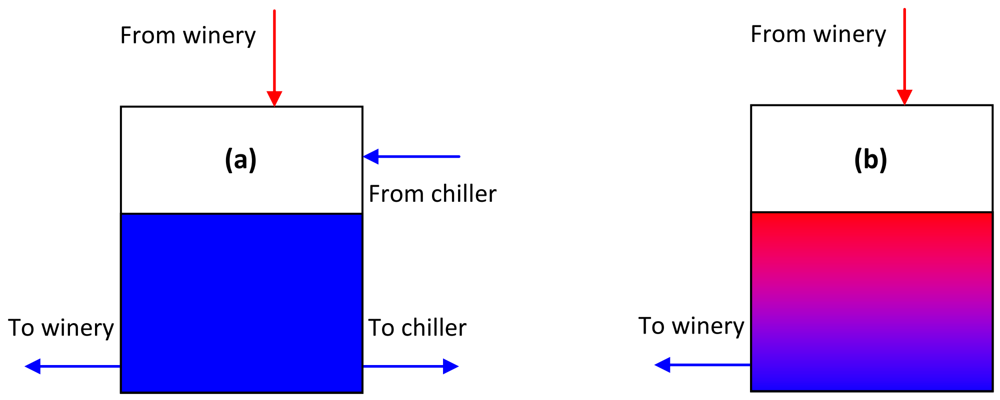

Figure 3.6: Brine tank stratification; (a) Immediately prior to the pump to the packaged chiller switching off, and (b) After the pump to the packaged chiller has been off for some time.

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.

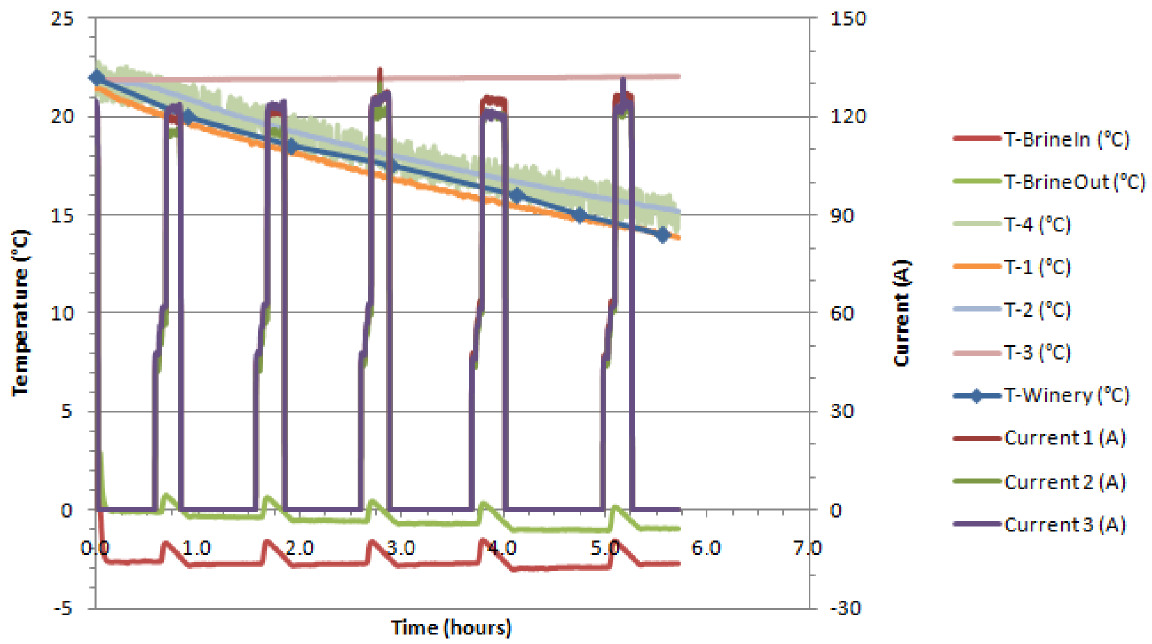

Figure 3.7: Rainwater cooling using nominally -5°C; water temperature at different tank locations, brine temperature into and out of the tank jackets, and current drawn by the packaged chiller

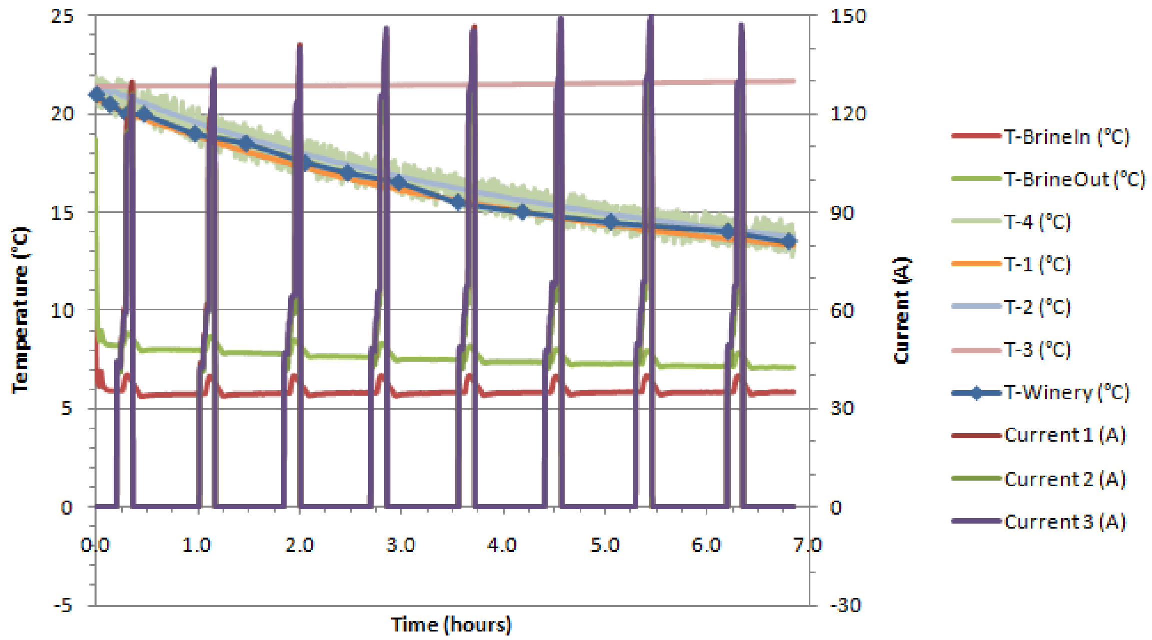

Figure 3.8: Rainwater cooling using nominally +4°C; water temperature at different tank locations, brine temperature into and out of the tank jackets, and current drawn by the packaged chiller

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.

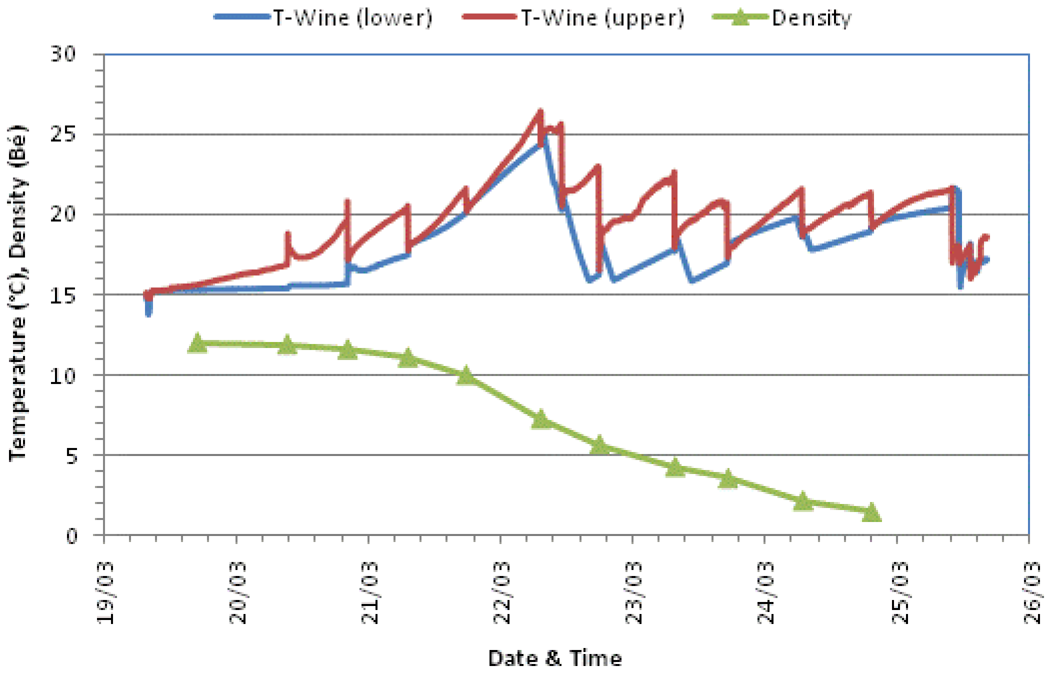

Figure 3.9: Fermentation controlled with +4°C brine (tank jacket/plate cooling only)

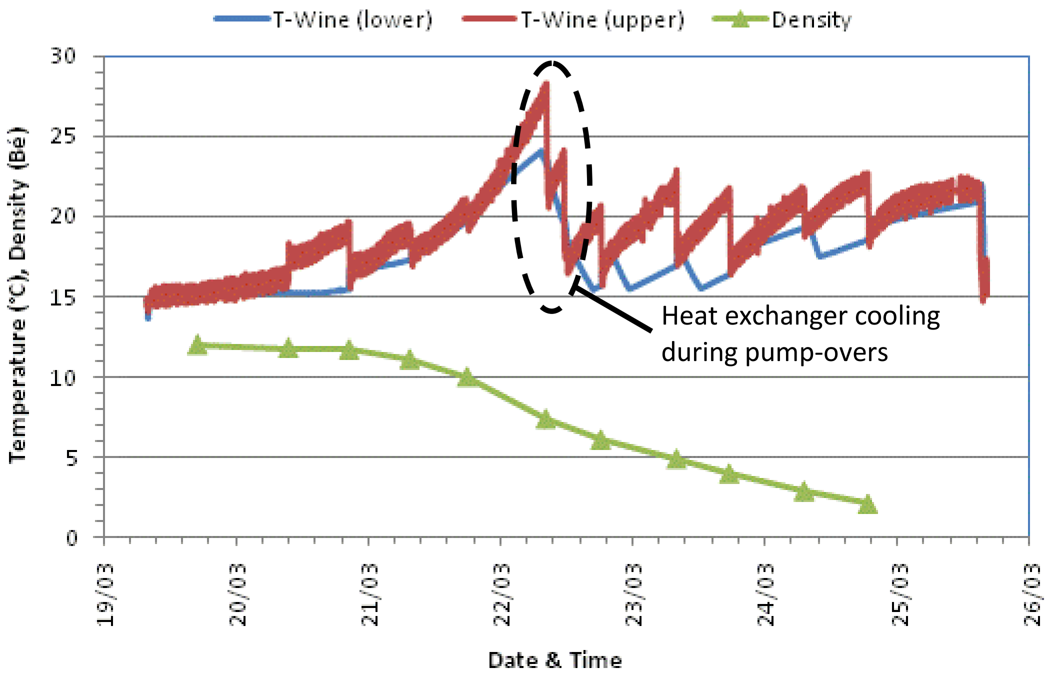

Figure 3.10: Fermentation controlled with +4°C brine (tank jacket/plate cooling as well as external heat exchanger cooling for two pump-overs on 22/03)

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.

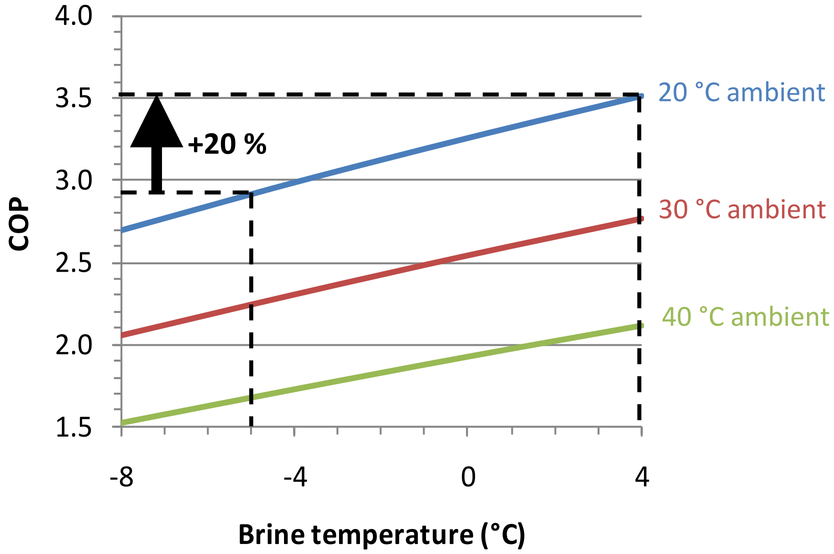

Figure 3.11: Coefficient of Performance (COP) of packaged chiller at maximum plant capacity (Improvement in plant efficiency from moving from -5°C to +4°C is highlighted)

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.