Improving Winery Refrigeration Efficiency

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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) has funded a project by Commercial Services at The Australian Wine Research Institute (AWRI) that aims to help the wine industry improve refrigeration efficiency and decrease electricity usage and/or costs.

This booklet is part of the first stage of the project. It provides a brief overview of winery refrigeration together with some improvement opportunities identified from a literature review, a web-based survey of Australian winery refrigeration practices, and preliminary experiments performed during the 2010 vintage.

2 WINERY COOLING REQUIREMENTS

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 one location, to another location where it is less objectionable. Winery (and other industrial) 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 discharged from the refrigerant at the condenser. The compressor increases the pressure (and consequently the temperature) of the refrigerant driving the cycle.

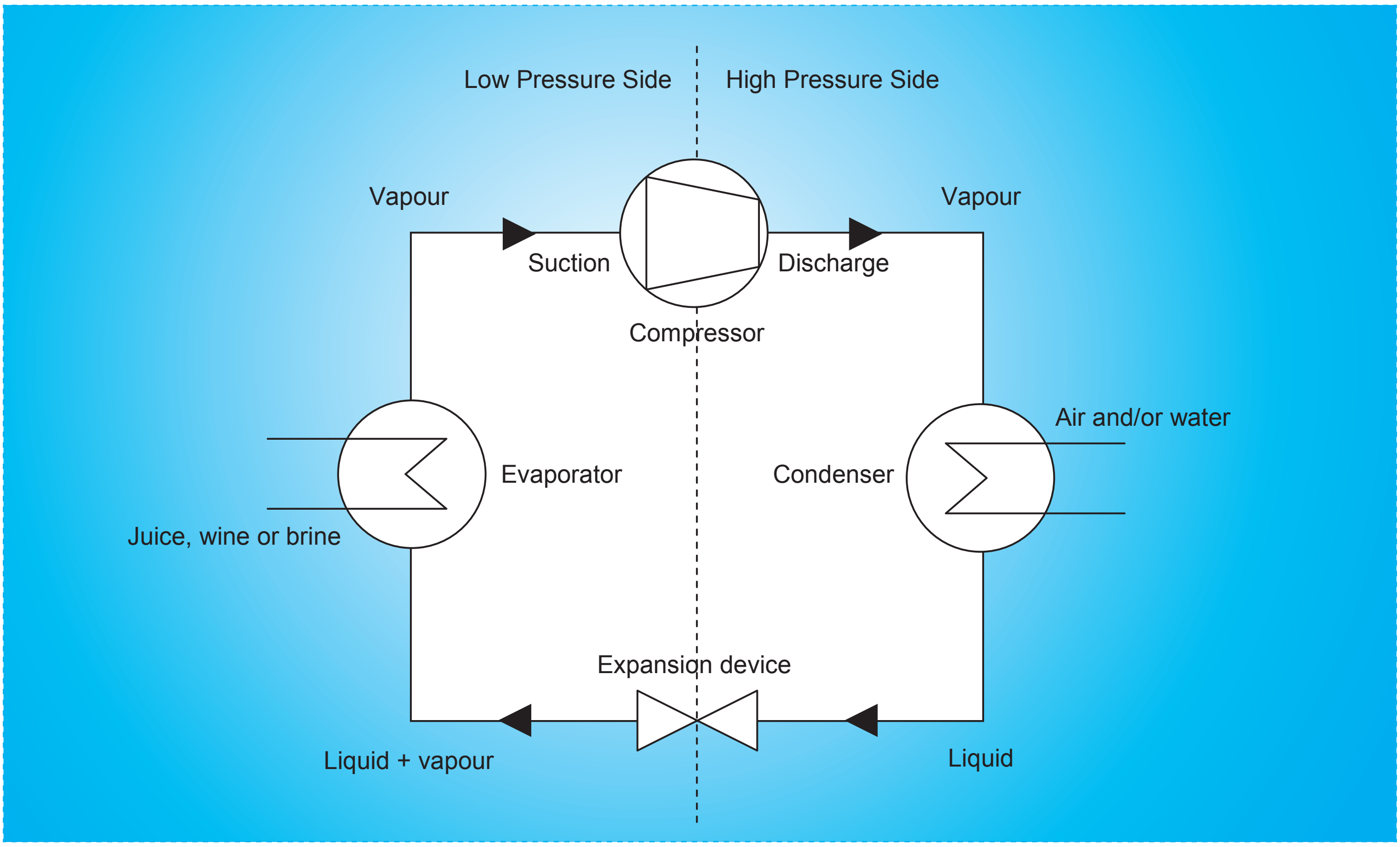

Figure 1. Simplified single-stage vapour-compression refrigeration cycle

3.2 BRINE RETICULATION SYSTEMS

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

Brine systems are commonly used in Australian wineries. They have higher power usage for a given cooling effect when compared with direct expansion operation; however, they have some advantages.

Stored brine can be used to balance against peak demand and brine is relatively cheap, safe and non-volatile and therefore can be more easily reticulated around a winery than a primary refrigerant.

Water with a freezing-point suppressant is commonly used as the brine. The freezing–point suppressant may be a water-soluble liquid or salt.

Ethanol, propylene glycol or mixtures of the two chemicals are common freezing-point suppressants. Corrosion inhibitors and colorants to facilitate leak detection are also commonly incorporated in commercially available freezing-point suppressant mixtures.

A simplified brine reticulation system is illustrated in Figure 2.

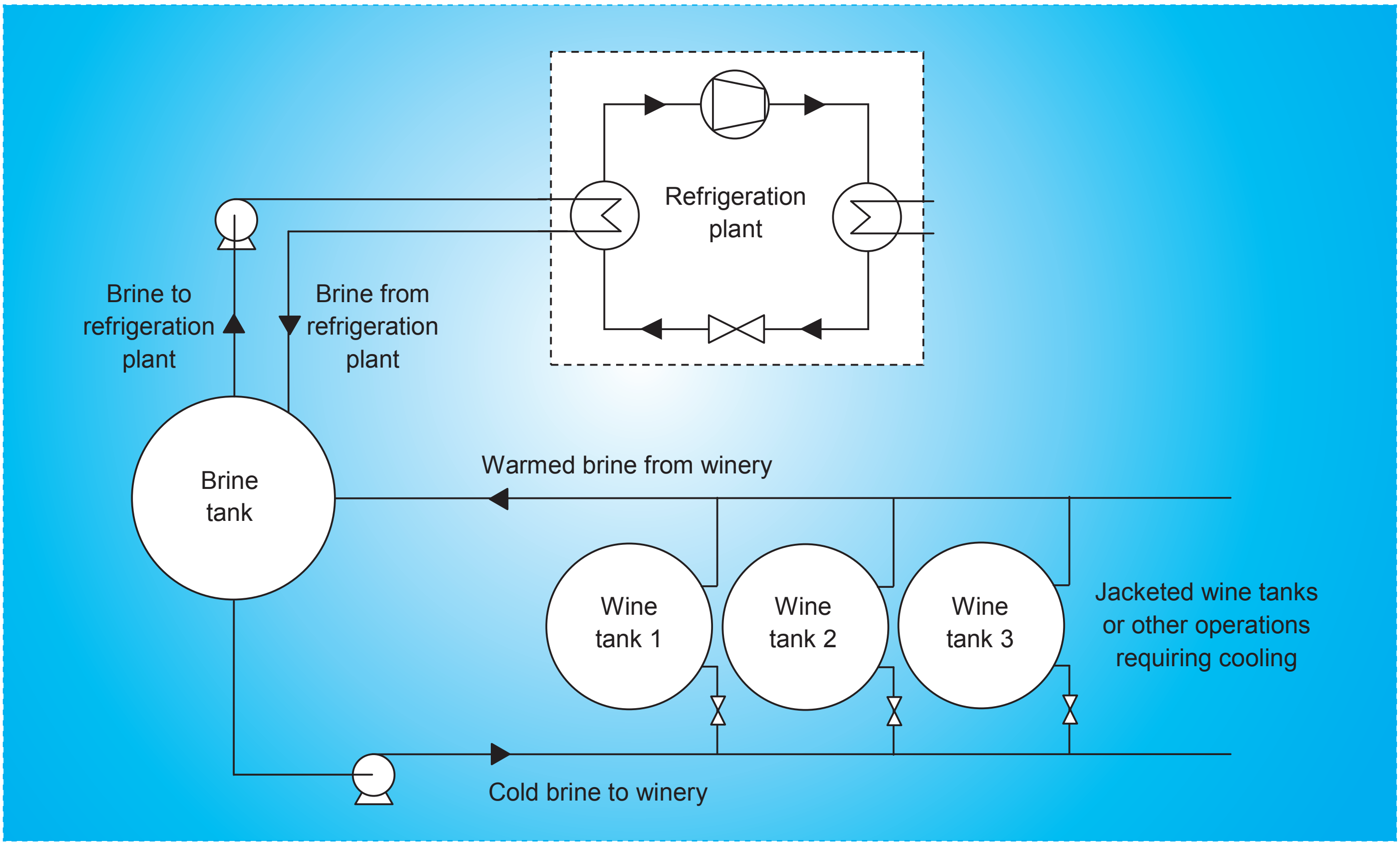

Figure 2. Simplified brine reticulation system

3.3 REFRIGERATION SYSTEMS USED IN DIFFERENT SIZED WINERIES

While refrigeration systems vary depending on the specific winery and the supplier, it is possible to make some generalisations on systems used in wineries of different sizes.

Smaller wineries will tend to use standardised packaged water/brine chillers, while larger wineries will tend to use more customised systems. Packaged chillers used in smaller wineries can have low capital costs but higher running costs.

Packaged chillers principally use hydrofluorocarbons (HFCs) as refrigerants, while larger customised refrigeration systems commonly use ammonia as their refrigerant. Compressors appropriate for ammonia are generally more expensive than those that can be used with HFCs; however, the heat transfer properties of ammonia are somewhat superior.

Packaged chillers commonly employ integrated air-cooled condensers. Fans are used to drive air across the refrigerant tubes condensing the refrigerant. Intermediate-sized systems sometimes employ water-cooled condensers. With these devices water is used to condense the refrigerant, and the water is then passed through a cooling tower before recirculation.

Discussions with refrigeration contractors have suggested that air-cooled condensers may still often be used in preference to water-cooled condensers in intermediate sized systems because of regulatory and maintenance requirements associated with cooling towers. Large winery refrigeration systems employ evaporative condensers. This is essentially a combination of a condenser and a cooling tower in one device. Water passes over tubes containing the refrigerant and a fan drives away the evaporating water. While evaporative condenser capital costs are higher, they can achieve much lower condensing temperatures and require much less fan power than air-cooled condensers. Smaller wineries tend to exclusively cool brine and circulate this around the winery for process cooling. Larger wineries with customised refrigeration systems often also employ some direct expansion cooling.

In choosing a refrigeration system for a winery, you should obtain recommendations and pricing from two or more refrigeration suppliers and each supplier should be asked to explain and justify the balance of capital and operating costs associated with their recommended designs.

3.4 REFRIGERATION EFFICIENCY

The efficiency of a refrigeration system is typically described by the coefficient of performance (COP). This is the ratio of the cooling effect provided at the evaporator to the power input, principally that to drive the compressor.

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

Unlike other common equipment efficiency measures, COP can be, and generally is, higher than one. This is possible because the electrical power input is not directly converted to cooling, but instead it is used to pump heat from one area to another. That is, the heat is transferred from the wine/juice/brine at the evaporator and then this heat is transferred from the refrigerant to the air and/or water at the condenser.

While the principal power input to be included in the calculation of COP is that to drive the compressor, power to drive other auxiliaries like condenser fans and pumps can also be included.

When interpreting COPs provided by manufacturers it is important to consider that COP varies with evaporator and condenser pressure/temperature and therefore operation must be assessed at the actual winery conditions.

The main market for many of the packaged chillers is actually in air-conditioning and therefore the evaporator temperature at which COP and chiller capacity are reported at may not correspond with the low brine temperatures (-10 to -5 °C) commonly employed at wineries.

The considerable influence of brine temperature on COP for one packaged chiller is illustrated in Figure 3 at different ambient temperatures.

Refrigeration plant COPs reported by manufacturers will also be further diluted by heat gains and pumping electricity requirements associated with the brine reticulation system.

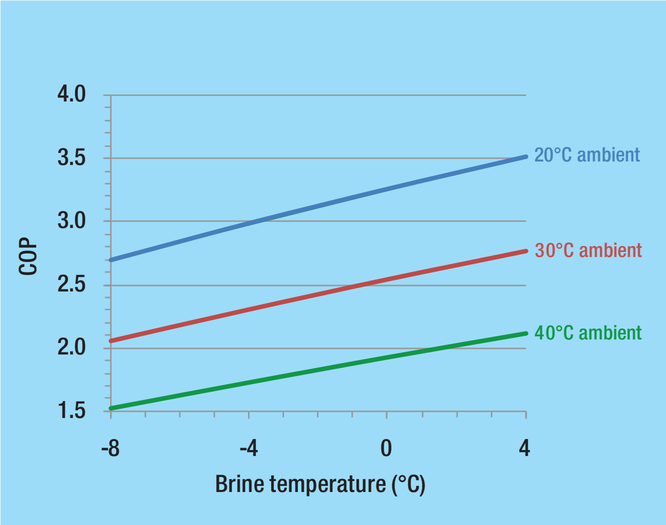

Figure 3. Influence of brine and ambient temperatures on COP for one nominal 210 kW cooling capacity packaged chiller (excludes brine reticulation system related heat gains and pumping electricity requirements)

ENERGY AND POWER

Energy and power are frequently confused. Heat and electricity are forms of energy. The Joule (J) is The International System of Units (SI) unit of energy. The kilojoule (kJ) is equivalent to 1000 J. Power is the rate at which energy is generated or consumed. The units of power are therefore the Joule/second (J/s), which is equivalent to the SI unit the Watt (W). kJ/s or kW are equivalent to 1000 J/s or W.

Electricity usage, for most wineries, is charged by the kilowatt.hour (kW.hr). This is a measure of energy not power. It is the rate of energy consumption (power) multiplied by the time of energy consumption.
1 kW.hr is equivalent to 3600 kJ. In some larger wineries, electricity usage may be charged on a basis which also includes a penalty for the power factor (the ratio of the real power flowing to the load to the apparent power in the circuit) associated with the site.

3.5 ENVIRONMENTAL ISSUES

Refrigeration principally contributes to global warming through the use of large amounts of electricity that in Australia has been mainly generated in 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 the phasing out of several key groups of refrigerants. In accordance with the Montreal Protocol on Substances that Deplete the Ozone Layer; chlorofluorocarbons (CFCs), which have a particularly high ozone depleting potential, were phased out by 1995 and hydrochlorofluorocarbons (HCFCs) will be phased out by 2020 (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 large wineries and at other large industrial sites, has both low ozone depleting and global warming potentials.

Also of interest is that HFCs like R134a that are typically used in newer packaged chillers, instead of R12 or R22, while having no ozone depleting potential, still have a significant global warming potential.

Table 2. Environmental impacts of refrigerants

ASHRAE[a] number	Name (Group)	ODP[b]	GWP[c]
R717	Ammonia	0	< 1
R12	Dichlorodifluoromethane (CFC)	0.82	8100
R22	Chlorodifluoromethane (HCFC)	0.055	1500
R134a	1,1,1,2-Tetrafluoroethane (HFC)	0	1300
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 destroy atmospheric ozone.
[c]Global Warming Potential: Index of a substance's ability to be a greenhouse gas.
Adapted from: International Institute of Refrigeration (2000)

4 IMPROVEMENT OPPORTUNITIES

In this section a number of refrigeration-related improvement opportunities for wineries are outlined. These opportunities are divided into two sections. The first section describes opportunities that generally involve relatively low costs and that are principally associated with changes in operating practices. The second section outlines further improvement opportunities that involve more significant plant modifications and/or costs. Most wineries will already have implemented at least some of the strategies discussed.

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 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.

4.1.2 Temperature rationalisation

Temperature requirements should be discussed and objective protocols put in place for the entire winery or company. It is apparent from winery visits that different winemakers at the same winery will sometimes employ different practices for the same product. On the one hand, if some winemakers are using unnecessarily low temperatures, electricity is being wasted. On the other hand, if those low temperatures were warranted, the winemakers employing higher temperatures are risking product quality. These considerations apply to all operations where cooling is applied including must chilling, fermentation, and wine storage. In preliminary experiments performed during the 2010 vintage, Chardonnay juice for sparkling wine base was fermented at 14, 16 or 18 ˚C. Fermentation was considerably faster at 18 ˚C compared with that at 16 and 14 ˚C, with no noted quality deficiencies, potentially allowing for increased throughput at the winery if fermentations were performed at the higher temperature. Peynaud (1984) reports that yeast transform sugar 10% more quickly for each degree (˚C) increase in temperature. Excessively low temperatures should not be used unless there is a reason for doing so. This applies for both winemaking and other site operations. For example, dry goods that do not need to be stored cold should not be stored in a refrigerated product warehouse. There is 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 those 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 and winter scheduling

Refrigeration plants operate more efficiently at lower ambient temperatures. Lower condensing temperatures correspond with lower compressor discharge pressures meaning the compressor can move a higher mass flow rate of refrigerant with the same amount of work.

Diurnal and seasonal variations in ambient temperature should be taken advantage of to maximise refrigeration plant efficiency.

Diurnal variations can be taken advantage of by cooling brine and wine to lower temperatures at night 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. In addition to refrigeration plants being more efficient at night when the ambient temperature is lower, off-peak electricity is also usually cheaper. Seasonal variations can be taken advantage of by performing cold stabilisation during winter.

4.1.5 Brine temperature

Unnecessarily low brine temperatures should not be used.

The refrigeration cycle operates more efficiently with higher refrigerant temperature and pressure at the suction side of the compressor. The compressor can move a higher mass flow rate of refrigerant with the same amount of work. When higher brine temperatures are used, higher refrigerant suction pressures can generally be employed (when setting a higher brine temperature it should be verified that the refrigerant suction pressure is actually being altered by the control system otherwise these efficiency gains will not be realised). With higher brine temperatures there will also be lower ambient heat gains in the brine reticulation systems and the brine will be less viscous. Higher brine temperatures may result in a decreased cooling rate, however, depending on the winemaking requirements this may not be an issue.

PRELIMINARY TRIAL

In a preliminary trial during the 2010 vintage, the apparent COP of the refrigeration system and brine reticulation system (as assessed by the measured change in wine temperature and refrigeration plant electricity usage) increased by approximately 6% and 11% at brine temperatures of -3 ˚C and -1 ˚C, respectively, relative to the COP at a brine temperature of -5 ˚C. This corresponds with theory.

The brine temperature should be adjusted to appropriate levels for different periods of the year to correspond with the cooling requirements of operations being performed. Careful scheduling of cold stabilisation, which typically requires the lowest brine temperatures, to occur in certain specific periods instead of intermittently throughout the year, can help to minimise the period of time when low brine temperatures are required.

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 transporting the brine through the chiller should generally not be constantly running as this is unnecessarily wasting electricity. The refrigeration plant is only required to chill the brine when the temperature of the brine stored in the tank has risen. It is therefore appropriate that the refrigeration plant and the brine pump between the brine tank and refrigeration plant are triggered based on brine tank measurements.

Packaged chillers often 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 sometimes set to permanently run, such that this measurement is representative of the temperature in the brine tank. The constant operation of this pump appears to be a wasteful operation. Operation of the chiller and the pump based on a temperature probe directly in the brine tank negates the need to run a pump continuously and the associated electricity costs. It is worthwhile investigating how this pump is controlled at your winery. It should be noted that with intermittent brine pump operation 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

Jacketed tanks are widely used for winery cooling but they generally cool poorly due to the stationary fluid at the inside surface of the tank. Tank agitation improves the heat transfer to some extent. With increasing tank size, cooling jackets typically become less efficient because of the decreased cooling surface area to wine volume ratio. This may necessitate the use of overly cold brine to achieve sufficient rates of cooling, which in turn can decrease refrigeration plant efficiency. With excessively cold brine and poor tank agitation there can also be issues of ice formation on the inside of the tank jacket, further reducing the effectiveness of wine cooling. The use of an external heat exchanger will generally provide more efficient heat transfer than a tank jacket, particularly for larger volumes. Heat exchanger configurations differ in their efficiency. For example plate heat exchangers are considerably more effective at exchanging heat than tube in tube and shell and tube heat exchangers, however, they have small channels and therefore are susceptible to blockages and high pressure drops if large solids are present.

4.1.10 Product heat exchange

Product heat exchange is a means of energy recovery. Pre-cooling wine for cold-stabilisation with wine finishing cold stabilisation using an external heat exchanger, possibly a plate heat exchanger, is one example. This means that the cold stabilised wine does not simply gradually warm back up to the storage temperature, in the process losing the energy that was imparted to cool it down in the first place. This does require some planning to ensure that one wine is ready to enter cold stabilisation at the same time as another wine is finishing cold stabilisation.

4.1.11 General maintenance

Equipment should be properly maintained to ensure efficient operation. For example, leaking solenoids on tank jackets can result in empty tanks being cooled unnecessarily and water vapour condensing and freezing on the interior of the jackets, wasting energy.

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 airflow.

Brine strainers should be kept clear as blockages can lead to increased brine pumping energy use.

When engaging a service technician it is worthwhile ensuring they actually have a good understanding of the operation of winery refrigeration systems (including equipment peripheral to the refrigeration plant itself, such as brine pumps, brine tanks, temperature sensors and control strategies) so that they may provide useful advice and guidance while on site. They may not be able to provide this support if their principal interest is in the maintenance of air conditioning systems.

4.1.12 Electricity bills

Wineries should closely inspect their electricity bill and understand exactly how their electricity usage is charged. They can then objectively work to minimise their bill through procedural changes, such as increased usage of off-peak as opposed to peak power. Pricing arrangements with different suppliers should also be investigated to minimise electricity costs.

4.1.13 Auditing

Auditing of winery refrigeration and electricity usage can help to identify and prioritise site specific opportunities. Temporary power meters can be a useful tool to audit electricity usage and later to verify whether any modifications have been effective. Older systems that have been progressively modified should be closely inspected to verify that alterations that have been made have not compromised the original design and/or efficiency.

4.1.14 Reference charts

Wall charts that provide operators with quick reference on key settings can be of practical use. For example, charts that tell the operator the brine temperature set point to be used during different periods and process temperature and agitator settings, for operations like cold stabilisation and fermentation.

4.1.15 Training

Operations staff should be trained on the practical aspects of refrigeration and winemaking temperature requirements. An understanding of the key operating and cost principles will allow them to make informed production decisions that minimise refrigeration costs and ensure product quality during busy production periods.

4.2 HIGHER COST IMPROVEMENT OPPORTUNITIES

4.2.1 Process control systems and variable speed drives

Motors that are being constantly run at full speed are often wasting electricity. Improved control systems and sometimes variable speed drives, can save electricity. This principle applies to the pumps circulating brine between the brine tank and refrigeration plant and between the brine tank and the winery as well as to condenser fans and pumps. The performance and control systems associated with the refrigeration plant compressor(s) at part load will also influence electricity usage.

Central control systems with succinct presentation of data are another possible improvement that can help staff quickly and accurately monitor many tanks and operations. Well designed control systems can also help implement greater usage of off-peak as opposed to peak power.

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 however 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.

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 °C. Therefore to raise the temperature of water by 10 °C, 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.

4.2.3 Refrigeration plant heat recovery

Heat in the refrigerant after compression may be recovered and used, for example, to heat water that can then be used for cleaning. Some packaged chillers can be factory-fitted with heat recovery devices that can heat water to approximately 50˚C. While in theory any quantity of heat that can be recovered offers the potential to improve process efficiency, in practice the quantity and quality of heat and the timing of heat recovery must be appropriate to offset the capital investment. For example, the hottest water will be collected when the refrigeration plant is heavily utilised, but will this correspond with demand for warm water at the winery?

4.2.4 Separate brine tanks

Warm brine from the winery is often mixed with cold brine from the refrigeration plant into a single brine storage tank. The cold brine from the refrigeration plant therefore has to be colder to achieve a given brine tank temperature for distribution to the winery.

It may be advantageous in some instances to employ two brine tanks (or to have one tank with an internal dividing section). One tank can be used to store the cool brine from the refrigeration plant and the other tank can be used for the warm brine returning from the winery. In this manner the refrigeration plant can generally be operated with a higher refrigerant temperature and pressure at the suction side of the compressor, increasing efficiency. The two tanks need to have an overflow connection to balance against occasions of high winery cooling demand.

5 REFERENCES AND FURTHER READING

There are many useful sources of information on refrigeration that can be consulted for a detailed treatment of refrigeration theory and equipment. White et al. (1989) provides an excellent user-friendly practical reference on winery refrigeration and the winemaking textbook by Boulton et al. (1996) is another useful wine-specific reference.

Additional information on improving winery energy efficiency is also available in an energy best practice guide produced by the Department of Industry, Tourism and Resources (2003). This is still available for download from the website of the Department of Resources, Energy and Tourism. Sustainability Victoria (2009) also produced a non-industry specific refrigeration energy efficiency best practice guide, which is available for download from their website.

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