Process engineering developments in wine production: Alternative technologies for tartrate stabilisation

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Abstract
Increasing global pressures are forcing the Australian wine industry to become more competitive. As a consequence, there is renewed industry focus on productivity and process efficiency in both the vineyard and the winery. The goal is to maximise profits by optimising product recovery whilst maintaining or improving on product design, quality, consistency, reputation and delivery for the customer. The introduction of alternative technologies to replace or augment traditional winemaking techniques is a feature of these efforts. Many of these technologies are widely employed in other industries, and thus, are not unique but are new for the wine industry. An example is tartrate stabilisation of wine. Cold stabilisation, with or without seeding, is widely used for this purpose. New technologies that have recently emerged as alternatives and are commercially exploited include electrodialysis and the Westfalia process. There is also interest in fluidisation and nanofiltration, but these technologies are not yet proven for commercial application. As a first step in deciding which technologies have merit as alternatives to cold stabilisation, the relative costs of each were considered for ‘retrofit’ (i.e. existing winery) and ‘greenfields’ (i.e. new) scenarios. Product loss was found to be an important factor affecting cost considerations when evaluating the economic performance of tartrate stabilisation options.

Introduction
The Australian wine industry is paying greater attention to opportunities to improve profitability by introducing alternative technologies to replace or augment traditional winemaking techniques. Cold stabilisation is an example of one step in the winemaking process where this is being considered. There are many potential options available (e.g. Zoceklein et al. 1995, Boulton et al. 1996). The challenge is how to choose between these options and ensure that the optimal technology is selected. Whilst the literature contains considerable technical information about various treatments and occasionally includes cost comparisons, there appears to be inadequate contemporary data that could be confidently used to uniformly, accurately and reliably evaluate and compare the relative economics of the different processes.

It was therefore decided to investigate the relative production costs of selected alternative technologies. This would allow identification of those technologies most likely to be cost competitive and perhaps superior to cold stabilisation. Furthermore, it would assist in deciding which technologies should be prioritised for laboratory and field testing, in order to evaluate technical and economic performance.

Conceptual designs and production cost estimates were prepared for commercial implementation of selected tartrate stabilisation options. These were designed to fit an existing winery at Berri Estates in the Australian Riverland. This winery is the largest in the Southern Hemisphere, and is owned and operated by Hardy Wine Company (HWC). Chilling without seeding, or cold stabilisation, is currently employed as the treatment method for prevention of tartrate instability. Each year approximately 106.5 million litres of wine are cold stabilised. Ion-exchange is not favoured as the company had previously experienced adverse effects on wine quality, and because wine products are exported to Europe, where there are difficulties with commercial acceptance of this process. The company wished to identify whether a more cost-effective process strategy was available as an alternative to cold stabilisation. Emerging technologies such as fluidised beds, electrodialysis and nanofiltration were considered, along with the introduction of seeding and application of the Westfalia process, among the proprietary systems that are available.

In addition, the effect of winery scale on production cost estimates, and the alternative solution of building a winery – the ‘greenfields’ scenario – were considered.

(Please note that the findings of this study have been condensed and annotated for brevity of presentation. Further details are available from the authors.)

Current cold stabilisation processes in the winery
Approximately 60% of wine cold stabilised at Berri Estates Winery is red, with the balance being white wines. These wines are stored at 8°C. The cold stabilisation process involves chilling in a heat exchanger to –4°C and holding in an insulated tank for at least seven days. Usually the chilling process will include energy recovery from a wine that has completed cold stabilisation treatment with refrigerant employed subsequently to reduce temperature to the target range.

Cleaning the tanks after cold stabilisation is a two-step process. During the making of red wines, the tank is agitated to re-suspend all of the loose settled crystals at the conclusion of the holding period. The wine is then centrifuged to separate out any tartrate crystals. These are manually collected and sold as by-product. Tanks are then cleaned, using concentrated caustic soda to remove crystal deposits on surfaces. These deposits are estimated to constitute approximately 50% of the tartrate removed from the wine. The caustic wash is re-circulated through the tank under pressure using a spray-ball, dissolving all of the remaining tartrate salts. Finally, the tanks are sanitised with citric acid solution containing potassium metabisulphite.

For white wines, bentonite fining is undertaken during cold stabilisation treatment. The stabilised wine is racked from bentonite and tartrate lees and clarified by diatomaceous earth (DE) filtration. Ooccluded wine in the bentonite or tartrate lees is recovered by rotary vacuum drum (RDV) filtration with a perlite pre-coat. Tanks are cleaned with a caustic wash and there is no tartrate recovery.

The current cold stabilisation process incurs losses and value downgrading of product. Wine is lost every time it is transferred through pipework and to and from a tank, in the discharge from the centrifuge, and at the RDV. A loss in quality occurs for white wine recovered from bentonite/tartrate lees by RDV.
Selection of technologies for evaluation

As it was not feasible to consider every available alternative, it was decided to limit the number included in the study. This decision was made in consultation with the wine producer. Berri Estates winemakers were provided with descriptions and a summary of the potential advantages and disadvantages of the various options for discussion and comment.

The treatments selected for evaluation were;
- Option 1 – Chilling by conventional cold stabilisation;
- Option 2 – Chilling with seeding;
- Option 3 – Chilling by Westfalia process – Figure 1(a);
- Option 4 – Chilling by fluidisation – Figure 1(b);
- Option 5 – Nanofiltration (combined with centrifugation) – Figure 1(c); and
- Option 6 – Electrodialysis – Figure 1(d).

Bentonite fining cannot be performed at the same time as tartrate stabilisation of white wine and, therefore, it must be undertaken as a separate processing step.

Some further descriptions and other relevant information about the alternative options are summarised below.

Seeding

This was perceived to be the treatment involving least incremental change at the winery. Addition of seed crystals ensures a supersaturated solution is created and provide nuclei for precipitation (Rhein and Neradt, 1979). Early studies suggested an optimal rate of crystal addition of 4 g/L at a particle size of 40 μm (Blouin et al., 1979; Rhein and Neradt, 1979). However, lower addition rates appear to be common industrial practice (based on authors’ observations). Seeding allows wine stability to be achieved within several hours. Seed crystals may be reused between five to eight times (Dharmadhikari 2002), after which grinding is required to restore performance. During reuse, the seed crystals may require rinsing or washing to remove fouling contaminants from their surfaces (Dharmadhikari 2002).

Westfalia process

This was presented as an example of an established treatment option that retained similar process and operational principles to cold stabilisation, which was most familiar to winemakers at the company. The Westfalia process uses recycled tartrate crystals to seed the wine. After seeding and a short contact period the tartrate crystals are separated using a cyclone and returned to the contact tank for reuse. The Westfalia process is considered one of the more successful proprietary chilling systems available on the market (Boulton et al. 1996), and the company already used Westfalia process technologies at the winery and had an excellent relationship with this equipment supplier.

Fluidisation

This was a process concept that appealed to the winemakers. In this process, the wine is pumped upwards through a fluidised bed of tartrate crystals, which provide surface area for crystallisation to occur. Successful bench testing has been conducted with fluidised bed crystallizers (Bolan 1996), but there appears to be no industrial-scale unit to date.

Nanofiltration

This process was of significant interest as it had been successfully implemented at the winery for other processing applications. It was thought that the existing equipment could be readily adapted for tartrate stabilisation. In 1978, Rhein, a German inventor, patented the use of reverse osmosis to reduce KHT concentration in wine. Companies like GE Osmonics and OLIVER OGAR ITALIA Spa claim to have developed membrane systems that partially concentrate the tartrate in wine and accelerate the tartrate crystallisation process. However, there are no reports of industrial use to date. Mannapperuma (2001) published results of a recent pilot-scale study using membranes to stabilise the tartrate in wine. In this study, nanofiltration was combined with microfiltration to concentrate the

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Process flow diagrams for (a) Westfalia process; (b) Fluidised bed; (c) Nanofiltration (with centrifugation); (d) Electrodialysis.
wine, inducing precipitation of bitartrate salt crystals. The crystals were removed from the nanofiltration retentate by microfiltration. Permeates from nanofiltration and microfiltration were combined to reconstitute the wine. However, wine losses for nanofiltration if combined with microfiltration were considered excessive. Instead it was decided to combine nanofiltration with centrifugation for crystal separation.

**Electrodialysis**

This process had recently been implemented by another wine producer in the same region, but anecdotal reports suggested that processing costs had been higher than anticipated. The technical feasibility of electrodialysis was demonstrated more than 30 years ago. In this method, electric fields and ion-selective membranes are used to separate tartrate salts from the wine without chilling or precipitation (Escudier et al. 1993). Advantages are claimed to include, *inter alia*, that wine quality is unaffected (Cameira dos Santos et al. 2000; Bach et al. 1999; Cottereau 1993; Wucherpfennig 1974); energy requirements are lower (e.g. 0.6 kWh/m³ of wine treated (Wucherpfennig 1974) and 0.2 to 0.5 kWh/m³ (Moutounet and Escudier 1991)); and equipment has a smaller footprint and can be automated to reduce labour requirements (Moutounet and Escudier 1991). According to Moutounet and Escudier (1991), the energy cost required for chilling the wine is threefold larger than the unit operating costs of an electrodialysis unit. The researchers also concluded that electrodialysis was economically competitive with chilling methods based on the estimated fixed costs such as investment and operating costs. There are commercial installations of electrodialysis units operating successfully in wineries in Europe, America and Australia. This study provided an excellent opportunity to examine the merits of this new processing technology.

**Results and discussion**

Estimates of economic performance for each option under ‘retrofit’ and ‘greenfields’ scenarios are summarised in Tables 1 and 2. Table 1 gives the capital and operating cost estimates. Accuracy of cost estimates can be considered at ±20 to 30%, which would be typical for this type of conceptual process costing exercise. Table 2 shows net present value — 10 years (NPV₁₀), unit operating cost (UOC) and unit production cost (UPC) — the economic performance indicators that were evaluated for ‘retrofit’ and ‘greenfields’. NPV analysis provides an indication of accumulated expenditure: capital investment and operating costs (as listed in Table 1), and revenue: tartrate recovery, over a period of time. The analysis was performed for a time period of 10 years. A discount factor of 8% was assumed.

The UOC is the operating cost per unit product. The UPC adds an amortised capital cost component to UOC, hence suggesting how much it costs to manufacture an individual unit. One litre of wine was used as the reference unit for UOC and UPC. Standard approaches were followed (refer Peters and Timmerhaus 1991) for calculation of these economic indicators.

For each cost or economic performance category listed in the Tables, the option which displays a superior cost or economic outcome has its cell shaded.

**Retrofit scenario** — Cold stabilisation has near-zero capital cost, as it is assumed all equipment for this option already exists at Berri Estates Winery. Options 2 and 3 – Seeding and Westfalia process — require additional capital investments of roughly $1.5 million (Australian) for installing additional centrifuges. Option 4 – Fluidisation — requires capital investment of about $2 million; nanofiltration involves a capital investment of approximately $5.5 million; whilst electrodialysis is the most expensive at over $10 million. It should be noted however that a nanofiltration plant can be used for other processes as well (e.g. clarification of juice) whereas electrodialysis and fluidised bed equipment are used solely for tartrate stabilisation. Cold stabilisation has the lowest annual operating cost at only $4.4 million. The Westfalia process has the next lowest annual operating cost and is approximately $0.8 million more than Option 1. Inspection of operating cost categories reveals that the main contributor to operating cost was wine loss. In this respect, Option 1 had the least wine loss of the options and this has ultimately converted into a lower overall operating cost despite higher costs in several other categories. These wine losses were principally associated with wastage in lees and residual product in hold-up volumes of process equipment and piping that were lost during flushing at the commencement and conclusion of a treatment cycle. Thus for alternative technologies in which bentonite fining

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**Table 1.** Summary of operating and capital costs for each process. The option which displays a superior cost or economic outcome has its cell shaded.

<table>
<thead>
<tr>
<th>Operating costs</th>
<th>Units</th>
<th>Option</th>
<th>Option</th>
<th>Option</th>
<th>Option</th>
<th>Option</th>
</tr>
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<tbody>
<tr>
<td>Energy</td>
<td>AUD/batch</td>
<td>420</td>
<td>423</td>
<td>419</td>
<td>413</td>
<td>282</td>
</tr>
<tr>
<td>Chemicals (including tartrate seed crystals)</td>
<td>AUD/batch</td>
<td>374</td>
<td>5457</td>
<td>903</td>
<td>1421</td>
<td>410</td>
</tr>
<tr>
<td>Labour</td>
<td>AUD/batch</td>
<td>719</td>
<td>911</td>
<td>1011</td>
<td>1083</td>
<td>1212</td>
</tr>
<tr>
<td>Consumables</td>
<td>AUD/batch</td>
<td>139</td>
<td>139</td>
<td>139</td>
<td>139</td>
<td>3160</td>
</tr>
<tr>
<td>Wine loss</td>
<td>AUD/batch</td>
<td>3295</td>
<td>6294</td>
<td>4611</td>
<td>6175</td>
<td>5931</td>
</tr>
<tr>
<td>Wine downgrades</td>
<td>AUD/batch</td>
<td>7838</td>
<td>7838</td>
<td>7838</td>
<td>7838</td>
<td>7838</td>
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<tr>
<td>Maintenance</td>
<td>AUD/batch</td>
<td>258</td>
<td>335</td>
<td>361</td>
<td>361</td>
<td>541</td>
</tr>
<tr>
<td>Total</td>
<td>Thousands AUD/batch</td>
<td>12.9</td>
<td>21.3</td>
<td>15.1</td>
<td>17.3</td>
<td>16.4</td>
</tr>
<tr>
<td>Cost savings</td>
<td>Millions AUD/yr</td>
<td>4.4</td>
<td>5.8</td>
<td>5.2</td>
<td>5.8</td>
<td>5.6</td>
</tr>
<tr>
<td>By-product recovery (i.e. tartate)</td>
<td>AUD/batch</td>
<td>59</td>
<td>470</td>
<td>470</td>
<td>470</td>
<td>235</td>
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<tr>
<td>Total capital costs</td>
<td>Millions of AUD</td>
<td>9.02</td>
<td>9.27</td>
<td>9.77</td>
<td>8.93</td>
<td>14.82</td>
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<tr>
<td>Greenfields</td>
<td>Millions of AUD</td>
<td>0</td>
<td>1.28</td>
<td>1.50</td>
<td>1.96</td>
<td>5.45</td>
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</table>
remains separate from the tartrate stabilisation process, the number of treatment steps and wine transfers involved increased, which increased wine loss. Seeding had the highest wine loss as the volume of wine occluded in crystal seeds was high and could not be recovered completely by centrifugation. Fluidisation had the next highest wine loss because of the large hold-up volume in the crystalliser, which contained occluded wine that could not be efficiently recovered by gas purging. Nanofiltration and electrodialysis had similar product losses. Cold stabilisation had the lowest product loss.

Also of note are the energy consumption values. There was no considerable saving in energy consumption between alternative chilling methods and conventional cold stabilisation. It was found that the majority of energy required for these methods involved initial chilling of the wine. Tanks at Berri Estates Winery are well insulated, and hence, subsequent energy losses during the holding period were predicted to be relatively minor. Nanofiltration was able to provide substantial energy reductions, up to 40%, over cold stabilisation. However, electrodialysis consumed only 25% less energy than cold stabilisation. Electrodialysis equipment suppliers often claim this technology has much lower energy demands – one-fifth of the energy required for cold stabilisation (Escudier 2002). This discrepancy could be attributable to either (i) their omission of energy requirements for pre-clarification by centrifugation as well as clarification after bentonite fining, which has to be performed separately; or (ii) over-estimation of the energy demands of cold stabilisation by not properly accounting for coefficient of performance associated with refrigeration plant.

Option 1 (cold stabilisation) produced the lowest NPV of all the options. UPC was much closer which makes a clear demarcation difficult given the accuracy of cost estimation.

Table 2. Economic performance indicators: NPV, unit operation cost (UOC) and unit production cost (UPC) for each option at winery capacities of 10 and 106.5 ML/year. The option which displays a superior cost or economic outcome has its cell shaded.

(a) Greenfield scenario

<table>
<thead>
<tr>
<th>Scale (ML/yr)</th>
<th>NPV10 millions of AUD</th>
<th>UOC, AUc/L</th>
<th>UPC, AUc/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-7.3</td>
<td>-54.1</td>
<td>5.1</td>
</tr>
<tr>
<td>2</td>
<td>-9.2</td>
<td>-73.3</td>
<td>7.5</td>
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<tr>
<td>3</td>
<td>-7.7</td>
<td>-56.7</td>
<td>5.3</td>
</tr>
<tr>
<td>4</td>
<td>-8.0</td>
<td>-61.4</td>
<td>6.0</td>
</tr>
<tr>
<td>5</td>
<td>-10.3</td>
<td>-69.0</td>
<td>5.6</td>
</tr>
<tr>
<td>6</td>
<td>-13.9</td>
<td>-87.8</td>
<td>6.5</td>
</tr>
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</table>

(b) Retrofit scenario

<table>
<thead>
<tr>
<th>Scale (ML/yr)</th>
<th>NPV10 millions of AUD</th>
<th>UOC, AUc/L</th>
<th>UPC, AUc/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-4.0</td>
<td>-37.9</td>
<td>4.5</td>
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<td>2</td>
<td>-6.7</td>
<td>-65.3</td>
<td>7.5</td>
</tr>
<tr>
<td>3</td>
<td>-5.2</td>
<td>-48.5</td>
<td>5.3</td>
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<tr>
<td>4</td>
<td>-5.8</td>
<td>-54.5</td>
<td>6.0</td>
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<td>-7.3</td>
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<tr>
<td>6</td>
<td>-9.9</td>
<td>-76.8</td>
<td>6.5</td>
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</table>
Fixed operating costs were adjusted in proportion to capital cost. Variable operating cost was reduced according to capacity. Economic performance indicators were then re-calculated. A winery capacity of 10 ML of wine per annum was assumed for the analysis, which was performed for both ‘retrofit’ and ‘greenfields’ scenarios. The results are included in Table 2.

This analysis indicates that cold stabilisation remains the best option for a smaller winery under either a ‘retrofit’ or ‘greenfields’ scenario, regardless of which economic indicator is used. Options 3 and 4 (Westfalia process and Fluidisation) also remain the next most affordable options. Electrodialysis continues to be the most expensive option.

Conclusions
Suitability and cost of various tartrate stabilisation technologies for commercial implementation at Berri Estates Winery have been considered for ‘retrofit’ and ‘greenfields’ scenarios. The economic factor that differentiates the available options is product loss. This study suggests that alternative methods may not provide significant technical and economical advantages over cold stabilisation. This is principally because the alternative methods require separate bentonite fining and additional processing and transfers. Thus, cold stabilisation seems to remain the optimal tartrate removal method. Furthermore, other chilling methods such as the Westfalia process and fluidisation, and nanofiltration, appear to be the next most competitive options. Electrodialysis was found to be the most expensive option. The influence of effluent treatment was not considered in this study but it is unlikely this factor would alter these findings. Furthermore the effects of each technology on product quality were not considered. Process-scale trials are recommended to evaluate the performance of selected technologies and collect operating and sensory data. This will permit more conclusive design and economic calculations to be performed.

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