Efficient Industrial Process Electrification Through Integrated Heat Pumping

Dr Tim Walmsley
Ahuora – Centre for Smart Energy Systems
School of Engineering, University of Waikato
Overview

1. The Ahuora mission and team
2. Efficient process electrification methodology
3. Application to a milk evaporator case study – valuable collaboration/input from Tetra Pak, Fonterra, and Piller
4. Ways forward together for university and industry
Ahuora Mission

To help create sustainable, net-zero-carbon New Zealand industries that sit in harmony with taiao (the environment) and support tāngata (the people).
Efficient process electrification methodology

- Process design (inc. HEN)
- Heat pump selection & integration
- Pinch analysis
- Operating set-point optimisation
- Process simulation
Case study goals & considerations

• **Goal & scope:** develop fully electric milk evaporator system
  • Minimise electricity use within practical constraints
  • Results in process electrification and decarbonisation
  • Initial focus on thermal processing, RO considered later

• **Boundary conditions:** 14.5 wt% to 52 wt% milk solids, supplies 30t/h powder dryer, milk enters at 8°C, concentrate leaves at 79°C

• **Ideal solution characteristics:** Localised, efficient, proven, and practical*
Practical considerations

- **Product safety**: No direct heat exchange between synthetic refrigerants and milk flows
- **Product quality**: Achieve high heating rates (e.g., direct contact heating) or parallel heat exchange
- **Operability and control**: Use localised heat integration and heat pumps
- **Operating cost**: Set constraints and optimise operating set-points to minimise work
1. Initial process design

- Two-effect evaporator
- MVR on the first effect
- TVR finisher
- Basis: 30 t/h of powder
- About 30kW/t heat loss
2. Process simulation
3. Operating set-point optimisation

- Can we optimise the operating pressures of:
  - milk flash?
  - effect 1?
  - effect 2?
- What effect does 95°C milk heat treatment T have on energy use?

*Caution: need to ensure consistent boundary conditions*
4. Pinch analysis: stream data

- Identify key processing elements of the flowsheet: Effects 1 and 2, flash
- “Remove” existing heat exchangers and other integration (e.g., TVR ejectors)
- Identify “supply” and “target” temperatures with heat added (sink) or removed (source)
4. Pinch Analysis: targeting (example)

Objective: Identification of appropriate heat pumping

Above pinch: requires heating
Below pinch: requires cooling
4. Pinch analysis: iteration 1

**Key result:** Use an MVR heat pump on Effect 1

- **Effect 1:** evaporation load
- **Effect 1:** condensing load
4. Pinch analysis: iteration 2

**Key result:** MVR heat pump on Effect 2?

![Diagram showing temperature (T) vs. heat (H) and two processes: Effect 2: evaporation (Good) and condensing (Not good).]
4. Pinch analysis: iteration 3

**Key result 1:** Use an MVR on a vapour bleed from Effect 1 to replace DSI

**Key result 2:** Chiller heat pump and air-sourced heat pumps needed

**Key result:** MVR heat pump on Effect 2?

- Good
- Not good

- Effect 2: evaporation
- Effect 2: condensing

![Graph showing temperature (°C) versus heat (MW) for Effect 2, with segments indicating good and not good conditions.]
5. Heat pump integration & selection

Sub-critical heat pumps

- Screw: Kobelco SGH 165
- Piston: Viking Heat Booster R1336mzz(Z)
- Turbo: Ohsner IWDDS R2R3b

Transcritical CO₂ heat pumps

- Refrigerants: R134a/R245fa, R1336mzz(Z)
- Screw: Kobelco SGH 120
- Piston: Combitherm HWW R245fa
- Turbo: Engie thermec2
- Screw: Olsom ChillHeat P
- Piston: Frifothem Unifor 22
- Turbo: Combitherm HWW R1234ze(E)
- Screw: Ohsner IWWHS ER3b

CO₂-HP (5): COP = (T_ambient + 2*ΔT_Hi)/(T_ambient + ΔT_Hi) with T_ambient = 320 K

CO₂-HP (7): COP = (ΔT_Hi) / [(ΔT_Hi)^2 + (ΔT_Hi + 2*b)*ΔT_Hi + c] with T_ambient = 320 K
# Heat pump selection summary

<table>
<thead>
<tr>
<th></th>
<th>CO₂ HP (CIP Water)</th>
<th>CO₂ HP (COW Water)</th>
<th>CO₂ HP (Site hot water)</th>
<th>3-stage Vapofan MVR</th>
<th>Ammonia HP (Milk conc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condenser duty (kW)</td>
<td>608</td>
<td>2627</td>
<td>525</td>
<td>3274</td>
<td>497.6</td>
</tr>
<tr>
<td>Evaporator load (kW)</td>
<td>403</td>
<td>2062</td>
<td>414</td>
<td>2947</td>
<td>307</td>
</tr>
<tr>
<td>Work (kW)</td>
<td>205</td>
<td>566</td>
<td>111</td>
<td>327</td>
<td>191</td>
</tr>
<tr>
<td>COP</td>
<td>2.97</td>
<td>4.65</td>
<td>4.74</td>
<td>10.0</td>
<td>2.61</td>
</tr>
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</table>
VapoFan by Piller

• 2 + 1 stage VapoFan to get a temperature rise of 27K
• Mass flowrate – 3 trains of 1.5t/h
• Compact design
  • 1.5m by 2.5m for a standard 2-stage VapoFan
4. Pinch analysis: iteration 3 (re-visited)

**Key result:** MVR heat pump on Effect 2?

**Key result:** Optimise Flash and Effects 1 & 2 pressures

**Explore:** Number of Flash stages and their pressure
Milk flashing: Direct Contact Heaters

- Flash the heated milk, rapidly drop temperature, creates vapour
- Provides high heating rate to cold milk
- Investigate different DCH arrangements
# Process simulation of multiple DCHs

## Investigated cases

<table>
<thead>
<tr>
<th>Investigated cases</th>
<th>Direct steam injection required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 DCH</td>
<td>3195 kW</td>
</tr>
<tr>
<td>2 DCH in series</td>
<td>2648 kW</td>
</tr>
<tr>
<td>3 DCH in series</td>
<td>2170 kW</td>
</tr>
<tr>
<td>HX (lower heating rates)</td>
<td>1315 kW</td>
</tr>
</tbody>
</table>

**Key question:** How do these DSI values translate to total electricity required?
5. Final process design

"Break-even" target: 5262 kW\textsubscript{el}

Overall electricity usage: 3541 kW\textsubscript{el}

33% operating cost reduction

48.2 kt CO\textsubscript{2}-e/y compared to coal!
## Final process design options summary

<table>
<thead>
<tr>
<th>Options</th>
<th>Design features</th>
<th>Power requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MVR Effect 1 + MVR Effect 2 + Simple HP</td>
<td>4844 kW</td>
</tr>
<tr>
<td>2</td>
<td>1 DCH + Integrated concentrate heating</td>
<td>3929 kW</td>
</tr>
<tr>
<td>3</td>
<td>2 DCH + Integrated concentrate heating</td>
<td>3535 kW</td>
</tr>
<tr>
<td>4</td>
<td>3 DCH + Integrated concentrate heating</td>
<td>3530 kW</td>
</tr>
<tr>
<td>5</td>
<td>HX (no DCH) + Integrated concentrate heating</td>
<td>3498 kW</td>
</tr>
<tr>
<td>6</td>
<td>HX (no DCH) + Separate HP for concentrate heating</td>
<td>3477 kW</td>
</tr>
<tr>
<td>7</td>
<td>2DCH + Separate HP for concentrate heating</td>
<td>3541 kW</td>
</tr>
</tbody>
</table>
Investigating more operating states

Using process simulation, the robustness of the design and effect of different operating states can be understood, e.g.,

1. Evaporator tube-side temperature
2. Milk heat treatment temperature
3. High-concentrate solid, e.g., up to 62%
4. RO pre-concentrating of milk, up to 30%
Investigations via simulation

**Key result:** 1°C increase increases work by 10.6 kW

**Key result:** 1% increase in solids decreases work by 13.5 kW
Efficient process electrification

- Process design (inc. HEN)
- Heat pump selection & integration
- Operating set-point optimisation
- Pinch analysis
- End-user
- University
- Service provider
- Process simulation
Closing points

Towards a net-zero-carbon future, together:

1. **Need** to extend the operating temperature lifts of heat pumps, e.g. transcritical, to >100°C for great decarbonisation potential

2. **Need** to identify ways to retrofit and evolve current assets to integrate heat pumps

3. **Need** to collaborate across end-users, service providers, and universities

Want to collaborate? Connect on LinkedIn

Or email me directly:
tim.walmsley@waikato.ac.nz