Integration of Heat Pumps in Industrial Processes with Pinch Analysis

Prof. Dr. Beat Wellig
Lucerne University of Applied Sciences and Arts
CC Thermal Energy Systems & Process Engineering

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Outline

1. What is pinch analysis?
2. Integration of heat pumps with pinch analysis
3. Food industry case study
What is a «Pinch Analysis»?

- A different perspective on production plants and infrastructure
- A system orientated method for the determination of the optimal use of energy and plant design under the constraint of minimal cost (investment and operation)
- «Energy optimization based on a systematic approach instead of Trial-and-Error»
Principle of Pinch Analysis: Composite Curves (CCs)

- **Hot CC:** Cooling Requirements
- **Cold CC:** Heating Requirements

Select so that the total cost is minimum:

\[ \Delta T_{\text{min}} \uparrow : \text{Investment costs} \downarrow \]
\[ \Delta T_{\text{min}} \downarrow : \text{Investment costs} \uparrow \]

\[ \Delta T_{\text{min}} \downarrow : \text{Operating costs} \uparrow \]
\[ \Delta T_{\text{min}} \uparrow : \text{Operating costs} \downarrow \]
Special Characteristic of the Pinch Point

The pinch divides the entire system typically into two subsystems with

- **heat deficit** above the pinch and
- **heat surplus** below the pinch.

![Diagram showing pinch point with heat deficits and surpluses](image)
Heat deficit and surplus are shown in relation to temperature. Enables the optimization of the utility supply system ($H_{U_{opt}}$, $C_{U_{opt}}$).
The «3 Golden Rules» of Pinch Analysis

- No external cooling above the pinch
- No heat transfer over the pinch
- No external heating below the pinch
How does one integrate a heat pump?

A first option:

Heat pump operates below the pinch

«False» Integration:

The heat surplus is increased by the amount of compressor electrical power leading to a higher cooling requirement.

HU = Hot Utility
CU = Cold Utility
How does one integrate a heat pump?

A second option:

Heat pump operates above the pinch

«False» Integration:

The heat deficit is reduced by the amount of compressor electrical power. From an energetic perspective this type of integration is equivalent to electrical heating.

HU = Hot Utility
CU = Cold Utility
How does one integrate a heat pump?

A third option:

Heat pump operates over the pinch

«Correct» Integration:

The heat pump reduces both the cooling and the heating demands of the process and the associated operating costs.

HU = Hot Utility
CU = Cold Utility
How does one integrate a heat pump?

«Correct» Integration:

\[ \dot{Q}_{HU} - (\dot{Q}_0 + P_{el}) \]

\[ \dot{Q}_0 + P_{el} \]

\[ \dot{Q}_0 \]

\[ \dot{Q}_{CU} - \dot{Q}_0 \]

HU = Hot Utility
CU = Cold Utility
Food Industry Case Study

Energy optimization project in Swiss food company (2015):

- Production of sweet candies in the food industry
- Multi-product, semi-continuous processes
- Energy demand:
  - 5.1 GWh/y thermal
  - 3.6 GWh/y electrical
# Food Industry Case Study

6 relevant «Operating Cases» during the production year: OC1 – OC6

<table>
<thead>
<tr>
<th>Operating Hours [h]</th>
<th>Vapor 0.5 bar</th>
<th>Exhaust Air</th>
<th>Vapor 1 bar</th>
<th>CIP Water</th>
<th>Waste Water</th>
<th>Drying Air</th>
<th>Warm Water</th>
<th>Hot Water 3 bar</th>
<th>Recooling Water</th>
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</table>

- **cooling requirements, «hot streams»**
- **heating requirements, «cold streams»**

For example hot stream «Recooling Water»:
- Summer 700 kW
- Trans. period 200 kW
- Winter 120 kW
Food Industry Case Study
Integration of a Heat Pump: for example Transition Period, OC 4

**Composite Curves**

- HU demand: 140 kW
- HR potential: 196 kW

**Grand Composite Curve**

- Condenser HP: 130 kW
- Compressor: 30 kW
- Evap. HP: 100 kW

**HP for OC4** (not the proposed HP):
- Evap.: 27°C, 100 kW
- Cond.: 73°C, 130 kW
- COP ≈ 4.3
- Refrigerant R134a

Heat pump «operates over the pinch» (correct integration)
Food Industry Case Study
Integration of a Heat Pump: for example Transition Period, OC 4

- Integration of heat pump increases the HR potential from 196 kW to 426 kW
- Reduction of the HU demand approx. 2.1 GWh/y (-40%)
- Reduction of the CU demand approx. 0.7 GWh/y (-29%)

HU demand: 10 kW (negligible)
HR potential: 426 kW
Food Industry Case Study

Heat Exchanger Network (HEN): for example Transition Period, OC 4

(HEN Design from PinCH 3.0)
Food Industry Case Study

Proposed HP: Heating Capacity 155 kW, Refrigerant R134a, COP = 4.4, on/off-controlled, 18.5 m³ Thermal Energy Storage (TES) available

<table>
<thead>
<tr>
<th>OC</th>
<th>Condenser Load [kW]</th>
<th>HU Savings [MWh/y]</th>
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<td>85</td>
</tr>
<tr>
<td>OC6</td>
<td>155</td>
<td>147</td>
</tr>
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</table>

Economics of HR Measures and HP Integration:
- Cost Savings: 143’500 CHF/y
- Static Payback: 3.7 y
Conclusions

- «Correctly» integrated heat pumps operate over the pinch and reduce both the HU and CU demand
- A great number of case studies in Swiss industry show the potential of industrial heat pump application
- Over the last years, a dedicated engineering tool (PinCH 3.0) has been developed to support the application of the pinch method incl. HP integration
Acknowledgement

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Thank you for your attention!