Influence of the pinch-point-temperature difference on the *Preheat-parallel* CHP configuration

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Problem statement – geothermal power plant

Electricity from deep-geothermal energy

- Renewable & sustainable
- Constant power output, independent of the weather conditions
  ➞ baseload
  ⇐ PV/wind

Problem statement – feasibility?

Geothermal conditions NW Europe (Belgium)

- Thermal gradient: 30°C/km
- Low brine temperature: T=130°C
- High drilling costs
  >50% of total costs

- Pure electrical power plant not economically feasible

- Improve plant economics via CHP
- Potential of Preheat-parallel CHP layout
Preheat-parallel CHP configuration

- Combination of series and parallel CHP layouts
- Preheating-effect

Diagram:

- District heating Heat exchanger 1
- ORC
- District heating Heat exchanger 2

Flow:
- Cold source
- Water return 50°C
- Hot source 130°C 194kg/s
- Water supply 75°C

Heat and Electricity:
- HEAT
- ELECTRICITY
Goals

- Preheat-parallel CHP plant performance
- Effect of pinch-point-temperature difference
- Preheat-parallel versus series and parallel CHPs
- Maximization of net electrical power output
  \[ \dot{W}_{net} = \dot{W}_t \eta_g - \dot{W}_p / \eta_m - \dot{W}_{wells}, \quad \dot{W}_{wells} = 600 kW \]
- Comparison based on exergetic plant efficiency
  \[ \eta_{ex} = \frac{\dot{W}_{net} + \dot{E}x_{DH}}{\dot{E}x_{b,prod}} \]
- Model implementation: Python + CasADi/IpOpt + REFPROP
Preheat-parallel: Performance

75/50 DH system, \( \dot{Q}_{DH} = 6 \text{MWth} \)

\( \dot{W}_{net} = \dot{W}_t \eta_g - \frac{\dot{W}_p}{\eta_m} - \dot{W}_{wells} = 5.14 \text{MW}_e \)

\( \eta_{ex} = \frac{\dot{W}_{net} + \dot{E}_{x_{DH}}}{\dot{E}_{x_{b, prod}}} = 38.31\% \)

\( \Leftrightarrow \text{Pure power plant:} \ \dot{W}_{net} = 5.58 \text{MW}_e \ \& \ \eta_{ex} = 35.73\% \)

Diagram:

- Cold source
- Heat exchanger 1
- District heating
- Heat source 130°C
- 194kg/s
- Water return 50°C
- Water supply 75°C
- ORC
- Heat exchanger 2
- District heating
- HEAT

\( \dot{W}_t = 3.09 \text{MWth} \)

\( \dot{W}_p = 2.91 \text{MWth} \)

24/09/2017
Preheat-parallel: Influence of $\Delta T_{\text{pinch}}$ on performance

75/50 DH system, $\dot{Q}_{DH} = 6\text{MWth}$

$\dot{W}_{\text{net}} \downarrow$ with $\Delta T_{\text{pinch}}$

preheating-effect $\downarrow$ with $\Delta T_{\text{pinch}}$
Preheat-parallel: Influence of $\Delta T_{\text{pinch}}$ on operating conditions

75/50 DH system, $\dot{Q}_{DH} = 6\text{MWth}$

For $\Delta T_{\text{pinch}} \uparrow$
- $T_{b,\text{ORCout}} \uparrow$
- $T_{\text{mid}} \downarrow$  \(\Rightarrow\) keep $m_{b,\text{ORC}}$ high
- $T_{\text{evap}} \downarrow$
- $T_{b,\text{inj}} \uparrow$
Preheat-parallel: Influence of $\Delta T_{\text{pinch}}$ on operating conditions

75/50 DH system, $\dot{Q}_{DH} = 6$ MWth

For $\Delta T_{\text{pinch}} \uparrow$
- $T_{b,\text{ORCout}} \uparrow$
- $T_{\text{mid}} \downarrow$ $\Rightarrow$ keep $m_{b,\text{ORC}}$ high
- $T_{\text{evap}} \downarrow$
- $T_{b,\text{inj}} \uparrow$

For $\Delta T_{\text{pinch}} \uparrow$
- $m_{b,\text{ORC}} \downarrow$ to satisfy heat demand
- $m_{\text{wf}} \downarrow$ due to lower heat addition to ORC

24/09/2017
Preheat-parallel: Influence of the heat demand

75/50 DH system

For $\dot{Q}_{DH} \uparrow$, the preheating-effect $\uparrow$ but $\dot{W}_{net} \downarrow$
Preheat-parallel: Influence of the return temperature

75/50 and 75/35 DH system, $\dot{Q}_{DH} = 6\text{MWth}$

For $T_{\text{return}} \downarrow$, $\dot{W}_{net} \uparrow$ and preheating-effect $\uparrow$
Preheat-parallel versus series

- **Preheat-parallel CHP**
  - Higher $\dot{W}_{\text{net}}$ and $\eta_{\text{ex}}$ than series CHP
  - Less sensitive to $\dot{W}_{\text{net}} \downarrow$ with $\Delta T_{\text{pinch}}$
  - Highest gains for low $\dot{Q}_{\text{DH}}$ and low $T_{\text{return}}$

**Graphs**

- **75/50 DH system**
- **75/35 DH system**
Preheat-parallel versus parallel

- **Preheat-parallel CHP**
  - Higher $\dot{W}_{net}$ and $\eta_{ex}$ than parallel CHP
  - More/equally sensitive to $\dot{W}_{net}$ ↓ with $\Delta T_{\text{pinch}}$
  - Highest gains for high $\dot{Q}_{DH}$ and low $T_{\text{return}}$

75/35 DH system

**75/50 DH system**

- $\dot{Q}_{OH} = 3\text{MW}$
- $\dot{Q}_{OH} = 6\text{MW}$
- $\dot{Q}_{OH} = 9\text{MW}$
Preheat-parallel versus series and parallel CHPs

- The preheat-parallel CHP has:
  - Higher $\dot{W}_{net}$ and $\eta_{ex}$ for investigated conditions
    - Brine: 130°C & 194kg/s & DH system: 75/50 and 75/35
  - Higher gains for low $T_{return}$
  - Highest sensitivity towards variations in $\Delta T_{pinch}$

  Series > Preheat-parallel > Parallel

- Versus series
  - Highest gain for low $\dot{Q}_{DH}$

- Versus parallel
  - Highest gain for high $\dot{Q}_{DH}$
Conclusions – *Preheat-parallel* CHP

**Performance**
- 75/50 DH system & $\dot{Q}_{DH} = 6\text{MWth} \rightarrow \dot{W}_{net} = 5.14\text{MWe} & \eta_{ex} = 38.31\%$
- pure power plant $\eta_{ex} = 35.73\% \rightarrow$ better utilization of low-T geoth. source!

**Effect of $\Delta T_{\text{pinch}}$ on**
- Performance: $\dot{W}_{net}$ ↓ and $\eta_{ex}$ ↓ with $\Delta T_{\text{pinch}}$
- Optimal operating conditions

**Preheat-parallel favorable when**
- Large $T_{\text{supply}} - T_{\text{return}}$, Low $T_{\text{return}}$
- Higher $\dot{Q}_{DH}$

**Preheat-parallel better than series and parallel CHP** (for considered conditions)
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Thanks for your attention!