Techno-economic Analysis of enhanced Dry Cooling for CSP


Massimo Moser
German Aerospace Center (DLR)
Institute of Technical Thermodynamics
Department of System Analysis and Technology Assessment
Motivation

- Which factors are important for the site selection of a steam power plant?
  - Proximity to load centers
  - Accessibility and presence of transmission corridors
  - Availability of low-cost fuel
  - Presence of water for cooling purposes

- Low-cost fuel is often available in water scarce regions. Examples:
  - Coal plants located near to coal mines in South Africa
  - CSP! (even if currently evaporation cooling is mostly used)

→ In these cases dry cooling is the only viable option!
Dry Cooling - State of the Art and Improvements

- The heat exchange is governed by the dry bulb temperature ($T_{DB}$)

- Strong impact of $T_{DB}$ on cooling efficiency

- No water consumption/withdrawal

- Direct or indirect layout (Heller)

- Different approaches for the improvement of dry cooling:
  - Hybrid-wet cooling
  - Deluge cooling
  - ACC optimized design
  - Optimized dispatch

Tawney 2003
Methodology

• Simplified model → sensitivity analysis of LEC on key parameters:
  • ACC cooling design (Initial temperature difference)
  • Solar multiple
  • Solar field specific investment cost

• REMix model → Optimal plant dispatch of a dry cooled CSP plant:
  • Standard dispatch (100 % till complete TES discharge)
  • Optimized dispatch I (constant price)
  • Optimized dispatch II (time-variable price, demand proportional)
Technical Model

\[ T_{\text{cond}} = T_{\text{BD}} + \text{ITD} \]

ITD = Initial Temperature Difference

TTD = Terminal Temperature Difference

\[ Q_{\text{cond}} = A \cdot U \cdot LMTD = A \cdot U \cdot \frac{\text{ITD} - \text{TTD}}{\log\left(\frac{\text{ITD}}{\text{TTD}}\right)} \]

- Assumption: constant ITD, TTD
Design Point Specifications and Investment Cost

- Assumption: design point specifications have been set for the 20% percentile of the annual temperature
  - Inability to maintain design output during the hottest hours of the year

- A trade-off exists between CAPEX, power block efficiency and annual yield!
Sensitivity of LEC on key Parameters

- In the case of elevate investment cost, a highly efficient cooling has to be preferred.
- The same applies to conventional power plants with high fuel costs!

Assumptions: SM1.3 w/o TES / SM2 7.5 h TES / SM3 12 h TES
REMix – Analyzed cases

- 100 MW_{el_net} CSP “Andasol-like”, solar-only operation, dry cooling
- SM 1.4; 7.5 h TES (not optimized; high dispatch flexibility)
- 3 sites in Jordan

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Kerak</th>
<th>Irbid</th>
<th>Aqaba</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>°</td>
<td>31.18</td>
<td>32.55</td>
<td>29.52</td>
</tr>
<tr>
<td>Longitude</td>
<td>°</td>
<td>35.70</td>
<td>35.85</td>
<td>35.00</td>
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<tr>
<td>DNI</td>
<td>kWh/m²/y</td>
<td>2,545</td>
<td>2,537</td>
<td>2,371</td>
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<tr>
<td>T_{DB_AVG}</td>
<td>°C</td>
<td>17.0</td>
<td>17.6</td>
<td>24.9</td>
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<tr>
<td>T_{DB_80_%}</td>
<td>°C</td>
<td>25.1</td>
<td>24.7</td>
<td>32.5</td>
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</tbody>
</table>

- Hourly simulation with the optimizing tool REMix
- 3 operation strategies:
  - Standard dispatch → used as reference
  - Optimized dispatch I (constant price)
  - Optimized dispatch II (time-variable price, demand proportional)
## REMix - Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Kerak</th>
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<th>Aqaba</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operation Strategy</strong></td>
<td></td>
<td>Standard Operation</td>
<td>Optimized Dispatch + Fixed Price</td>
<td>Optimized Dispatch + Variable Price</td>
</tr>
<tr>
<td><strong>Q(_SF)</strong></td>
<td>[GWh(_{th})]</td>
<td>1180.4</td>
<td>1180.4</td>
<td>1180.4</td>
</tr>
<tr>
<td><strong>n start-up - PB</strong></td>
<td>[-]</td>
<td>348</td>
<td>303</td>
<td>303</td>
</tr>
<tr>
<td><strong>P(_{EL,GROSS})</strong></td>
<td>[GWh/(\gamma)]</td>
<td>419.0</td>
<td>427.8</td>
<td>421.4</td>
</tr>
<tr>
<td><strong>P(_{EL,NET})</strong></td>
<td>[GWh/(\gamma)]</td>
<td>383.5</td>
<td>391.6</td>
<td>385.9</td>
</tr>
<tr>
<td><strong>Plant Parasitics</strong></td>
<td>[GWh/(\gamma)]</td>
<td>35.4</td>
<td>36.2</td>
<td>37.6</td>
</tr>
<tr>
<td><strong>(\eta_{GROSS - PB})</strong></td>
<td>[%]</td>
<td>36.5%</td>
<td>36.8%</td>
<td>36.3%</td>
</tr>
<tr>
<td><strong>(\eta_{NET - PB})</strong></td>
<td>[%]</td>
<td>33.5%</td>
<td>33.8%</td>
<td>33.1%</td>
</tr>
<tr>
<td><strong>(\Delta LEC)</strong></td>
<td>[%]</td>
<td>0.0%</td>
<td>-2.0%</td>
<td>3.6%</td>
</tr>
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</table>

*Minimization of PB start-up procedures*
REMix – Results Analysis

• In the case of constant feed-in price:
  • Minimization of the number of start-ups
  • Max. production in the early morning hours (lower $T_{DB}$)

• In the case of time-variable price, the impact of the temperature seems to play a secondary role in the optimization strategy
Conclusions

• Air cooled condensers will be the preferred option for large-scale introduction of CSP in water-scarce and DNI-rich regions

• The optimal ACC design results from a technical-economic trade-off between turbine efficiency and investment cost; In CSP plants, highly efficient ACC are required for high SM/TES and high specific CAPEX

• Ca. 2 % LEC reduction can be reached in dry cooled CSP plant by partial plant commitment shifting towards night hours

• In the case of demand-driven plant commitment, slightly higher feed-in tariffs should be introduced. However, in this case CSP would be able to displace the most expensive plants during peak periods.
Thank you for your attention!

Contact

Massimo Moser
DLR German Aerospace Center
Institute of Technical Thermodynamics

✉️ massimo.moser@dlr.de
📞 +49 711 6862 779