Rankine (steam) Cycle Cooling Options

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Rankine Cycle Cooling Considerations

- Steam turbine output and Rankine cycle efficiency is dependent on turbine exhaust conditions (Temperature & Pressure)

- Exhaust conditions are established by
  - Water temperature in once through cooling system
  - Wet bulb temperature for the wet cooling tower
  - Ambient dry bulb temperature for dry cooling system

- For concentrated solar thermal plant (CSP) exhaust cooling options are wet tower, dry cooling (air cooled condenser) or wet-dry hybrid system
Turbine Exhaust Cooling Options

Wet Cooling Tower
Turbine Exhaust Cooling Options

Air Cooled Condenser

Diagram showing a connection between a turbine and a condenser with labeled parts: steam and condensate.
Turbine Exhaust Cooling Options

Hybrid Cooling System

[Diagram showing a hybrid cooling system with components labeled: TURBINE, ACC, Surface condenser, Wet cooling tower, condensate.]
CSP Plant Cooling Options

- For CSP plant water is a scare resource
- For most CSP plant, once through cooling is not an option
- CSP plant output is dependent on ambient conditions - maximum output during high ambient temperatures
CSP vs. Fossil Plant Cooling

- Major difference between CSP and fossil fueled power plants
  - Fossil plant cooling options can be evaluated using annual mean dry bulb and wet bulb temperatures
  - Water use and plant output determined with average conditions are reasonable for economical analysis
  - For CSP plant it is necessary to evaluate hourly performance and determine plant output and water use for wet tower or loss of capacity for dry cooling
CSP vs. Combined Cycle Cooling

- For a 100 MW combined cycle plant with 60% capacity factor
  - Plant output at 32C and higher temperature is 17% of annual GWh output
  - Difference between dry cooling and wet cooling is <0.5% of the annual GWh output

- For a 100 MW CSP plant
  - Plant output at 32C and higher temperature is >34% of annual GWh output
  - Difference between dry cooling and wet cooling can be ~6% of the annual GWh output
Design Basis – CSP Plant

- 100 MWe Nominal Solar Trough Plant
- Location Barstow/Daggett, CA
- Solar Field Output Excelenergy/SAM
- Rankine Cycle Analysis GateCycle 6.0
- Turbine Exhaust Pressure
  - Design 85 mbar (2.5 in HgA)
  - Maximum 271 mbar (8 in HgA)
- Design Turbine Gross Efficiency 37.7%
# Dry, Wet and Hybrid Cooling Design Basis

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wet Cooling Tower</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient Dry Bulb Temperature</td>
<td>°C (°F)</td>
<td>40 (104)</td>
</tr>
<tr>
<td>Wet Bulb Temperature</td>
<td>°C (°F)</td>
<td>20 (68)</td>
</tr>
<tr>
<td><strong>Dry Cooling</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient Dry Bulb Temperature</td>
<td>°C (°F)</td>
<td>20 (68)</td>
</tr>
<tr>
<td><strong>Hybrid Cooling</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient Dry Bulb Temperature</td>
<td>°C (°F)</td>
<td>40 (104)</td>
</tr>
<tr>
<td>Wet Bulb Temperature</td>
<td>°C (°F)</td>
<td>20 (68)</td>
</tr>
<tr>
<td>Condenser Pressure @ Design Conditions</td>
<td>mbar (in HgA)</td>
<td>85 (2.5)</td>
</tr>
</tbody>
</table>
## Design Parameters for Wet Cooling Tower

**Condenser Pressure** 85 mbar @ 40 C Dry Bulb, 20 C Wet Bulb Temperature

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>MW Cooling Tower Duty</td>
<td>160</td>
</tr>
<tr>
<td>C Approach Temperature</td>
<td>5</td>
</tr>
<tr>
<td>C Inlet Wet Bulb Temperature</td>
<td>20</td>
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<tr>
<td>Exit Relative Humidity</td>
<td>0.98</td>
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<tr>
<td>Evaporation Loss Fraction</td>
<td>0.028</td>
</tr>
<tr>
<td>Number of Fans (Bays)</td>
<td>8</td>
</tr>
<tr>
<td>kW Total Fan Power</td>
<td>508</td>
</tr>
<tr>
<td>Cycles of Concentration</td>
<td>4</td>
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</table>
Design Parameters for Air Cooled Condenser

Condenser Pressure 85 mbar @ 20 C Ambient Temperature

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>C inlet air temperature</td>
</tr>
<tr>
<td>39</td>
<td>C outlet air temperature</td>
</tr>
<tr>
<td>43</td>
<td>C condensing steam temperature</td>
</tr>
<tr>
<td>165</td>
<td>MW condenser duty</td>
</tr>
<tr>
<td>10</td>
<td>C log mean temperature difference (LMTD)</td>
</tr>
<tr>
<td>162.5</td>
<td>kJ/h-m² C overall heat transfer coefficient, U</td>
</tr>
<tr>
<td>366,127</td>
<td>m² heat transfer area</td>
</tr>
</tbody>
</table>
Dry Bulb Temperature Distribution* – Barstow, CA

* Expected distribution when solar plant will be on line (3421 hrs on line)
Relative Humidity vs. Dry Bulb Temperature*–Barstow, CA

\[ y = 0.00010001x^2 - 0.02455648x + 1.61571832 \]

* Expected distribution when solar plant will be on line (3421 hrs on line)
Turbine Output – Air Cooled Condenser

- Net plant output, MWe
- Ambient temperature, F

Graph showing the relationship between net plant output and ambient temperature.
Wet vs. Dry Cooling – Lost MW

Ambient temperature, F

Wet tower - Dry tower, MWe

Nexant
Water Use kg/MWh vs. Ambient Temperature

\[ y = -0.0353858638x^2 + 20.3388269465x + 333.8363287753 \]
Plant Output – Wet to Dry

Fraction of wet cooling case plant output

Design Ambient Temperature 40C
Wet Bulb Temperature 20C

Wet 85 mbar
85 mbar
135 mbar
203 mbar
250 mbar
Dry 271 mbar

Fraction of wet cooling tower water consumption

0.94 0.95 0.96 0.97 0.98 0.99 1.00

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Conclusions

- Designing cooling system for CSP plant require detailed technical and economical analysis
- Water resources are scares at most solar site
- Dry cooling has high capital cost, high power consumption, and significant loss of capacity
Conclusions (contd.)

- Wet cooling has lower capital cost, no loss of output, but significant loss of water and waste disposal problems.

- Hybrid cooling can save significant water use, maintain high capacity, but with much higher capital costs and higher maintenance costs.
Thank You

Questions?

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