Dry and Hybrid Cooling Systems Analysis Activity at NETL

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Outline

1. Power plant cooling background

2. Cooling system choice on power plant efficiency

3. Impact of ambient conditions on evaporative losses

4. Cost results
Advanced Cooling Systems Analysis

- “Cost and Performance Impact of Dry and Hybrid Cooling on Fossil Energy Power Systems” (publication pending)

- Wet recirculating, dry, and wet/dry hybrid cooling systems for PC and NGCC plants (with and without CO₂ capture) assessed over a range of ambient conditions

- Limitation of current study: Equipment sizing (and therefore auxiliary load and cost) established for ISO design point. This would change if the design point were for a hot, arid location.
Wet Evaporative Cooling Systems

Source: NETL
In contrast to once-through cooling system which withdrawal on average 20,000 gal/MWhr and Consume ~0 gal/MWhr. Note the higher temperature water discharged from the plant will increase evaporation downstream but this is not reported within the plant boundary.
Dry Cooling Systems

Source: NETL
## Dry and Hybrid Cooling Study Case Matrix

<table>
<thead>
<tr>
<th>Case</th>
<th>Site Conditions¹,²</th>
<th>Unit Cycle</th>
<th>Steam Cycle</th>
<th>Combustion Turbine</th>
<th>Boiler Technology</th>
<th>Condenser Cooling Technology</th>
<th>CO₂ Separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 through 168</td>
<td>0 ft. Elevation 14.696 psia &amp; 5280 ft. Elevation 12.1 psia</td>
<td>PC</td>
<td>3500/1100/1100</td>
<td>N/A</td>
<td>SC PC</td>
<td>Wet Evaporative Tower</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PC</td>
<td>3500/1100/1100</td>
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<td>No</td>
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<td>SC PC</td>
<td>Air Cooled Condenser (ACC)</td>
<td>Yes</td>
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<td></td>
<td>Midwestern ISO 59 F dry bulb 60% R.H.</td>
<td>NGCC</td>
<td>2400/1050/1050</td>
<td>2 x State-of-the-art 2013 F-Class</td>
<td>HRSG</td>
<td>Wet Evaporative Tower</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>July Average High 85 F dry bulb 53, 69, &amp; 84% R.H.</td>
<td>NGCC</td>
<td>2400/1050/1050</td>
<td>2 x State-of-the-art 2013 F-Class</td>
<td>HRSG</td>
<td>Wet Evaporative Tower</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>January Average Low 20 F dry bulb 63, 70, &amp; 74% R.H.</td>
<td>NGCC</td>
<td>2400/1050/1050</td>
<td>2 x State-of-the-art 2013 F-Class</td>
<td>HRSG</td>
<td>Wet/Dry Parallel</td>
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Source: “Cost and Performance Impact of Dry and Hybrid Cooling on Fossil Energy Power Systems,” NETL, publication pending
Cooling System Choice on Power Plant Derate*
1. PC plant net power and efficiency are impacted more than NGCCs by dry cooling in the summer conditions. NGCCs are relatively insensitive.

2. NGCCs have the largest ambient condition-driven derate in absolute terms, regardless of the cooling technology type.

3. Large reduction in net power for PC plants with dry cooling and CO$_2$ capture:
   i. Higher capture solvent temperature (approaches dry bulb) requires higher circulation rates to maintain 90% capture, increasing parasitic load
   ii. Increased auxiliary load due to dry cooling fan power

*Derate: Degree of reduction in net power generation due to operational change or equipment addition*
PC plants with dry cooling experience the greatest generation derate in summer conditions:

- ~2% MWh reduction
- ~3% MWh reduction
- ~4% MWh reduction

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Cooling System Choice on Power Plant Derate

NGCC plants with dry cooling experience no significant generation derate in summer conditions.

Forthcoming dry cooling study to evaluate:

1. Deployment of dry cooling systems on existing coal units likely to be in the western U.S. (water rights)

2. If dry cooling deployed at large scale, what is the extent of the regional derate in generation?

3. Derate in generation will be greatest during summer months (high dry bulb temperature), when MWh’s needed the most (additional capacity needed?)
Impact of Conditions on Evaporative Losses
Impact of Conditions on Evaporative Losses

1. Regardless of plant type, evaporative losses always greatest at high temperature, low humidity

2. Evaporative losses eliminated from systems with strictly dry cooling systems, but this comes at a cost (extra equipment – air cooled heat exchangers + air cooled condenser)

3. Water use reduction in power systems is an objective, but large dry cooling parasitic load in hot conditions reduces MWh’s generated
**Impact of Conditions on Evaporative Losses**

PC evaporative losses greatest at high temperature

Source: “Cost and Performance Impact of Dry and Hybrid Cooling on Fossil Energy Power Systems,” NETL, publication pending

<table>
<thead>
<tr>
<th>Condition</th>
<th>Evaporative Losses (gal/MWh-net)</th>
</tr>
</thead>
</table>
| 85°F.d.b., 53% R.H.              | ![Graph Data](graph_data)
| 85°F.d.b., 69% R.H.              | ![Graph Data](graph_data)
| 85°F.d.b., 84% R.H.              | ![Graph Data](graph_data)
| 59°F.d.b., 60% R.H. (Design Condition) | ![Graph Data](graph_data)
| 20°F.d.b., 63% R.H.              | ![Graph Data](graph_data)
| 20°F.d.b., 70% R.H.              | ![Graph Data](graph_data)
| 20°F.d.b., 74% R.H.              | ![Graph Data](graph_data)

Can evaporate more water for cooling at lower relative humidity

- Increased Cansolv cooling load
- Reduction in net power

Higher evaporation in capture cases due to:

***Non-Capture***

***Capture***

Source: “Cost and Performance Impact of Dry and Hybrid Cooling on Fossil Energy Power Systems,” NETL, publication pending
Similar to PC, NGCC evaporative losses greatest at high temperature.

Source: “Cost and Performance Impact of Dry and Hybrid Cooling on Fossil Energy Power Systems,” NETL, publication pending
Perspectives on study cost results:

1. **Dry cooling equipment sized based on same set of ambient conditions (ISO) as wet evaporative for results comparison on a common basis; better assumption would’ve been to choose conditions where dry cooling is the likely design choice (water constrained areas)**

2. **Cost of electricity (COE) not static, it fluctuates based on generation (ambient conditions)**
   
i. **Summer/winter fluctuations for dry cooling > wet cooling, so dry cooling COE likely more variable than wet**
   
   ii. **Summer/winter net power fluctuations for NGCC > PC, so greater seasonal COE variation for NGCC than PC**

3. **In reality, cost of power plant dry cooling is probably site-specific, and feedback/perspectives on the matter are welcome!**
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