Introduction

Water Use in CCGT Power Plants

Reducing Water Consumption

Power Plant Example
  • 3-1x1 CCGT units with dry-cooling
  • Blowdown recycle system and wastewater treatment

Summary

Questions
Introduction

• By 2038, combined-cycle gas turbine (CCGT) power plants are expected to make up over 50% of the US power production market.

• CCGT power plants tend to utilize large amounts of water for cooling and steam generation.

• Water regulations have become increasingly stringent in recent years, both restricting water discharge and limiting intake volume.

• CCGT power plant developer are looking into:
  • Secondary treated wastewater use as makeup water
  • Wastewater volume reduction or treatment
  • Dry-cooling system and wastewater treatment
Main Water Users in CCGT Plants

• High purity treatment system
  • Rejects from membrane-based treatment, or
  • Regeneration waste from traditional ion exchange

• Steam cycle blowdown and quenching
  • Blowdown to maintain steam purity in cycle
  • Quench water to cool blowdown to 140°F

• Evaporative cooler
  • Condition (cool) CTG inlet air for added efficiency

• Cooling tower = **BIGGEST USER**
  • Heat rejection from steam cycle
  • Makes up ≥ 94% of the total plant makeup
Wastewater Reduction

Makeup Water: Potable Water, Surface Water, or Well Water

• An outline of seven different possible configurations for CCGT power plants will be presented
  • Case 1 – Cooling Tower with no additional treatment
  • Case 2 – Cooling tower with membrane-based WWT system
  • Case 3 – Cooling tower with ZLD system
  • Case 4 – Air Cooled Condenser (ACC) with no WWT or recycle
  • Case 5 – ACC with blowdown recycle system
  • Case 6 – ACC, recycle system, and membrane-based WWT system
  • Case 7 – ACC, recycle system, and ZLD system
Case 1 – Cooling Tower with no Treatment

500 MW CCGT Plant, Tower COC = 4, Evap Cooler COC = 4

1,727 GPM

~75% Evaporation

423 GPM (~25%)
Case 2 – Cooling Tower with Membrane-based WWT System

500 MW CCGT Plant, Tower COC = 4, Evap Cooler COC = 4

1,530 GPM

~88% Evaporation

177 GPM

~12%
### Case 2 – Cooling Tower with Membrane-based WWT System

<table>
<thead>
<tr>
<th>System recovery (%)</th>
<th>Number of serial element positions</th>
<th>Number of stages (6-element vessels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 - 60</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>70 - 80</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>85 - 90</td>
<td>18</td>
<td>3</td>
</tr>
</tbody>
</table>

Two-stage systems are generally capable of operating at an overall recovery rate of 55-75%. For such systems the average individual recovery rate per element will vary from 7-12%. To operate a two-stage system at an overall recovery much higher than 75% will cause an individual element to exceed the maximum recovery limits. When this happens, a third stage will have to be employed which places more elements in series, shifting the average element recovery rate to lower values.
Case 3 – Cooling Tower with ZLD System

1,306 GPM

~100% Evaporation

~0 GPM

500 MW CCGT Plant, Tower COC = 4, Evap Cooler COC = 4
**Case 3 – Cooling Tower with ZLD System**

**Brine Concentrator:**
- A type of evaporator – also known as a falling film evaporator.
- Often used in tandem with other equipment to achieve a ZLD system.
- Concentrates streams of approximately 5% TDS to approximately 20% TDS or 50,000 ppm to 200,000 ppm.
  - If the streams must be concentrated further, crystallizers must be used.

**Crystallizer:**
- Treats water with TDS of upwards of 20%
- Produce solids
- High cost and few installations on a CC plant

Case 4 – Air Cooled Condenser (ACC), no WWT or recycle

105 GPM

500 MW CCGT Plant, Tower COC = 4, Evap Cooler COC = 4

~33% Evaporation

~64%

67 GPM
Blowdown Recycle System

• Steam cycle blowdown is typically quenched to 140°F. To recycle this stream, a heat exchanger or chiller need to be installed in the recycle path.

• Blowdown needs to be cooled below the max temperature limit for the demineralized water treatment (DWT) system; the membranes in particular.

• Operation of DWT system may be limited to night shift during hot summer months.
Case 5 – ACC with blowdown recycle system

500 MW CCGT Plant, Tower COC = 4, Evap Cooler COC = 4

~67% Evaporation

~33%
Case 6 – ACC, recycle system, and membrane-based WWT System

45 GPM

~87% Evaporation

500 MW CCGT Plant, Tower COC = 4, Evap Cooler COC = 4
Case 7 – ACC, recycle system, and ZLD System

500 MW CCGT Plant, Tower COC = 4, Evap Cooler COC = 4

~100% Evaporation

~0 GPM
## Comparative Water Consumption and Plant Discharge

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Description</th>
<th>Source Water Flow (gpm)</th>
<th>Plant Discharge Flow (gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooling tower, no WWT system</td>
<td>1,727</td>
<td>423</td>
</tr>
<tr>
<td>2</td>
<td>Cooling tower with WWT system</td>
<td>1,530</td>
<td>177</td>
</tr>
<tr>
<td>3</td>
<td>Cooling tower with ZLD system</td>
<td>1,306</td>
<td>≈ 0</td>
</tr>
<tr>
<td>4</td>
<td>ACC, no recycle or WWT system</td>
<td>104.6</td>
<td>67.2</td>
</tr>
<tr>
<td>5</td>
<td>ACC with recycle system</td>
<td>56.6</td>
<td>19.3</td>
</tr>
<tr>
<td>6</td>
<td>ACC, recycle system, and WWT system</td>
<td>45.2</td>
<td>6.1</td>
</tr>
<tr>
<td>7</td>
<td>ACC, recycle system, and ZLD system</td>
<td>40.5</td>
<td>≈ 0</td>
</tr>
</tbody>
</table>

![Bar chart showing water flow rates across different cases.](chart.png)
Air Cooled Condenser

- Essentially no water consumption
- Uses 1-2% of total annual production for 500 MW plant
- Higher performance loss at higher ambient temperatures
- Larger heat transfer area

Cooling Tower

- Higher efficiency
- Smaller heat transfer area
- High water consumption by evaporation
- Additional air permitting
# BUDGETARY COST FOR WASTEWATER REDUCTION

<table>
<thead>
<tr>
<th>ITEM</th>
<th>EQUIPMENT COST</th>
<th>TOTAL INSTALLED COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Stage High Pressure Membrane System ($125 gpm)</td>
<td>$1.9M - $4.7M</td>
<td>$5M - $10M</td>
</tr>
<tr>
<td>Wastewater Chiller for 125 gpm cooling from 140F to 90F (185 ton)</td>
<td>$1M - $1.3M</td>
<td>$2M - $3M</td>
</tr>
<tr>
<td>Wastewater Tank (500K gal)</td>
<td>$0.8M - $1.0M</td>
<td>$1M - $1.5M</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$3.7M - $7M</strong></td>
<td><strong>$8M – $14.5M</strong></td>
</tr>
</tbody>
</table>
Example – 3-1x1 CCGT units with ACC, blowdown recycle, and WWT System

Gross Output ≈ 1,400 MW
Potable Source Water
Evap Cooler COC = 4
DWT Recovery = 72%
WWT Recovery = 58-82%

During normal operation, wastewater goes to municipality.

Discharge flow allowed varies throughout the year. This is the reason for the range on WWT recovery.

If high recovery operation utilized, wastewater is trucked off-site for disposal.
SUMMARY

- Almost 50% of freshwater used per day is for power plants

- Intake and discharge flow restrictions

- There are many ways to reduce water consumption
  - Water reuse within plant, recycling good quality water
  - Membrane technologies can further reduce wastewater volume
  - Zero liquid discharge is possible, but high cost and hard to operate

- New plants should at least evaluate option for ACC option
  - Weigh the pros against the cons
  - Less water consumption with ACC, but higher costs and larger footprint
Questions?

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