Cooling Towers – Water Quality and Quantity Considerations

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Presentation Topics

- Modifications in chemical treatment in circulating cooling towers
  - 2 PSCo power stations
  - To address permit discharge
  - To address safety concerns

- Hybrid Cooling System
  - To reduce water use
Part 1: Cherokee Station
sulfate reduction

Cherokee Station

- Discharge is to the South Platte River
  - Permit issued by the WQCD
  - Segment has a water supply use
  - Sulfate effluent limit set at 535 mg/L
- Limit cannot be met with existing treatment
  - Consideration of treatment options
  - Consideration of operational changes
- Reduced sulfuric acid addition in the cooling tower by operating at a higher pH with scale inhibitor
  - Cost savings in sulfuric acid
  - Effort to reduce sulfate in the discharge effluent
Purpose of sulfuric acid: avoid calcium carbonate scaling in condenser (can be major impact on unit performance)

- Problem: adds sulfate to discharge water
- Raising pH from 7.2-7.6 range to 7.8-8.2 greatly increases risk of calcium carbonate formation.
- Scale inhibitor effective at elevated pH was required.
Cherokee Station

Results (after 4 years):

- Water Quality – the average concentration of sulfate in the effluent has decreased by about 15%, but not enough to fall below the 30-day average effluent limit (sulfuric acid contribution dropped from 82% to 67% of total in discharge)
- Cost Savings – overall, increased scale inhibitor cost with reduced sulfuric acid cost resulted in about 10% chemical cost savings
- Performance – no evidence of scale formation in condenser tubes

Part 2: Comanche Station
alternative pH control with carbon dioxide
Driving force:
alternative to costly and unreliable sulfuric acid line replacement

March 2014
- Temporary tank installed in March 2014
  - Initial pH Range – 6.5 to 7.0
    - Used 4500 to 5000 pounds of CO₂ the first day to achieve initial pH range
    - At $0.12/pound = $600/day
    - Concluded that CO₂ can control pH, but at this rate not affordable
March 2014

- After 1st day changed pH range – 6.8 to 7.8
  - Cut CO$_2$ feed back to 2500 to 3000 pounds/day
  - At $0.12$/pound = $360/day
  - Ran with average pH of 7 to 7.2 for 4 days

June 2014

- pH range – 7.0 to 7.8
  - Manually set CO$_2$ feed rate at 8 to 10 psi
  - CO$_2$ feed back to 1000 to 1200 pounds/day
  - At $0.12$/pound = $144/day
  - Ran with average pH of 6.8 to 7.8 For 43 days
  - Felt that we optimized the required CO$_2$ usage to maintain desired pH range
Dollars & Cents

- CO₂ Test - $15,000 (tank rental, CO₂, feed system fabrication & installation)

- Long Term
  - Annual sulfuric acid cost for one unit (acid, pump/pipe repairs, safety shower/eye wash cost, spill remediation, backup supply of totes) - $58,000
  - 2014 Capital Project to install sulfuric acid tank and feed system at Unit 1 CWT - $150,000

Dollars & Cents

- CO₂ cost for one unit (CO₂ @ 1200 lbs/day, tank rental, install automated system)
  - CO₂ - $.10/lb if installed on Unit 1 & 2
  - Total - $68,000/year
  - Approximately $10,000 more/year than acid but worth it due to safety, environmental, improved control & system chemistry
  - Also, installing on both unit 1 & 2 for less than new acid system on 1 unit
  - Contract with on bulk gas would also reduce pricing on ALL Comanche bulk gases (hydrogen, CO₂, nitrogen)
Current status after ~ 1 year:

- pH is controlled at 7.5-8.0 (usually run 7.7-7.8)

- Problem issues - plugged diffusers, telemetry failure (both remedied)

- Economics overall:
  - Initial installation of CO₂ feed system (2 units) was about $30K less than installing sulfuric acid feed replacement on Unit 1, where replacement was needed
  - Annual cost is close to break-even, about $10K more for CO₂ but improved safety, environmental and operational issues, along with improved overall contract concessions, make it cost-effective
  - Ongoing monitoring and evaluation
  - No scale inhibitor needed due to upfront clarifier
Part 3: Comanche Station
Unit 3 Hybrid-Cooled System

Evaporative (Wet) Cooling Tower

Surface Condenser  Wet Cooling Tower
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Dry (Air) Cooling

Air Cooled Condenser

Air Cooled Condenser: Under Construction
Main Turbine Exhaust Duct: 35' diameter
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Typical Large Air-Cooled Condenser

- 45 fans, drawing ~8 MW combined
- 9 ‘streets’ or bays, 20,358 tubes total
- tubes:
  - single-row
  - 35.3 feet (10.8 m) length
  - 8.2 by 0.75 inch (21 by 2 cm) cross-section
  - carbon steel with aluminum exterior fins
  - 0.059 inch (1.5 mm) wall thickness
  - 1,158,902 ft² internal (107,000 m²)
  - 16,514,080 ft² external (1,500,000 m²)

Air Cooled Condenser Applications

- Initially applied in water-deficient regions of the world:
  - South Africa
  - Australia
  - Western United States
  - China

- Recent installations in areas with plenty of water, due to environmental regulations limiting water use.
State of California:

“No once-through cooling with seawater”
(2010)

- recirculating evaporative cooling
towers technically still allowed, but --
Update to rule 316(b) of the Clean Water Act

Previous mitigation requirement applied to units with intake > 50 MGD (~75 MW steam turbine with once-through cooling)

Mitigation actions now required for facilities with intake design greater than 2 MGD (~150 MW steam turbine with recirculating evaporative cooling towers)

ACCs in Eastern US

- ~ 21 (at least 4 additional by 2017)
- Since 1991; most since 2000
- Cases forcing alternative to water
ACC Cooling Inefficiency vs. WCC in Hot Weather

Dry bulb vs. Wet bulb Temperature
Lower vacuum with ACC in hot weather, compared with water-cooled condensers, decreases steam turbine efficiency, requiring more fuel consumption for the same generating output.

- More fuel burned = more CO₂ emissions.

In the hottest ambient conditions, condenser vacuum typically is inadequate for unit to achieve full generating capacity – 10 to 15% reduction in electricity output from the steam turbine.

This shortage of electric power must be made up from other, less efficient power plants.
Study Results, California Energy Commission (combined cycle plants)

- On a year-round basis, dry cooled plants would produce 854 lbs of CO₂ per MW-hour, and wet cooled plants produce 840 lbs per MW-hour, or a 1.6% increase in CO₂ emissions with dry cooling.
- On “hottest days,” dry cooled plants produce 5.3% more CO₂ than wet cooled plants, and lose 4.1% of generating capacity.
- Impact for coal-fired plants is approximately twice as great (entire impact is steam turbine).

Long Term Planning

- Dry cooled plants are good for water savings, but not ideal for limiting CO₂ emissions.
- The amount of CO₂ increase may not seem large (about 3 - 4% for coal-fired plants), but environmental pressure in the future may cause these plants to shut down earlier than intended.
Improvement of Dry Cooling Efficiency

- Use water intermittently during hottest weather.
  - Parallel wet-dry condenser
  - Spray systems
  - Indirect dry cooling (Heller) with water spray option
- These require some water: potential sources - recycled waste water, ocean water, freshwater source with restricted availability, ???

Typical Steam Cycle Chemistry Program for Supercritical Units

- pH 8.5 – 9.0 with ammonia addition
- Oxygenated treatment
- Condensate polishing in hydrogen form

--- Assumes water cooling
Units with Air-Cooled Condensers:

- Must address corrosion product release from large internal carbon steel surface area (over a million square feet for a larger unit)

- Must be concerned with through-wall corrosion of tubes and consequent air inleakage.

Operation at pH 8.5 – 9.0
Potential Consequences of Iron Transport from ACC

Potential Consequences of Corrosion in the ACC
**Management of Iron Corrosion & Transport**

- Condensate particulate filter
- Elevation of steam cycle pH to 9.6 – 10.0

**Rapid loading of condensate filters**
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Early Condensate Environment (steam cycle pH 9 vs 10)

Bulk pH = 9

Vacuum

NH₃

NH₃

NH₄⁺

Condensate: pH ~8

Vacuum

NH₃

NH₃

NH₃

NH₃

NH₄⁺

NH₄⁺

NH₄⁺

Condensate: pH ~9

Bulk pH = 10

ACC impact depends on unit type & design:

- combined cycle
  - more tolerant of particles and air ingress
  - high pH operation typically simple

- once-through supercritical
  - low tolerance for particles
  - impact of leaks on polisher
  - impact of high pH operation on polisher
Pre-Operational ACC Inspection
Weld flux debris

Diagram showing the distribution of elements such as Ca, Mg, Na, Al, K, Ti, and Mn.
Post-Operational ACC Inspection: Lower (main exhaust) Duct
DHACI Rating: Main Exhaust Duct
B (on a scale of A to C)

Post-Operational ACC Inspection: Upper Duct
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Ideal Upper Duct Access

Non-Ideal Upper Duct Access
Typical Upper Duct Access

Metal loss at cross-pieces
Metal loss at cross-bars

Metal loss at tube entries
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Christine Johnston and Andrew Howell
DHACI Rating: Upper Duct #2
3 (on a scale of 1 to 5)
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Leaks in Lower Condensate Header

From Craig Ripley 2011 ACCUG meeting
Coating process options

Note: only high-pressure cladding and molten aluminum dipping are believed to have been used for Al coating of ACC tubes at this point.

- High pressure cladding
  - costly process although costs have lowered
  - strong steel-to-aluminum bond
Coating process options

- Dipping tubes in molten aluminum
  - lower cost
  - lower thickness
  - uniformity and durability of coating uncertain

Coating processes

- Influence of manufacturing process on internal tube Al contamination is uncertain
  - dipped tubes risk internal Al if not enclosed adequately (parallel with known problem for Zn-coated tubes)
  - brazing temperature is too low for Al volatilization
Concerns regarding Al coating

- Possible ingress of Al to tube interior during manufacture
  - deposition on HP section of steam turbine and loss of turbine performance
  - limited options for removal of Al deposits from HP turbine other than turbine outage (7 to 10-year cycle)
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Improper Galvanic Tube Coating
Upper Duct Isolation