OPTIMIZING THE BALANCE OF PLANT FOR A CYCLING COMBINED CYCLE OTSG FACILITY

By

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Overview: Typical Steam/Condensate Loop Components

- ST Condenser Hotwell
- Condensate Extraction/Forwarding Pumps
- Condensate Polisher
- Boiler Feedwater Pumps
- Boiler
- Steam Turbine (ST)
- Steam Condenser
- ST Bypass to Condenser
Steam Turbine & Condenser Operation

Vacuum and gland-seal steam overview
Condenser Vacuum

- ST Condenser operates under vacuum to increase shaft horsepower from the ST

- Vacuum helps maintain water chemistry
  - $O_2$ and $CO_2$ removal per Henry’s Law

- Low pressure & high temperature drive off $O_2$ and $CO_2$ that are dissolved in the water
Gland Seals & Steam-Jet Air Ejectors

- Gland Seals maintain vacuum on ST rotor shaft at casing penetration

- Steam produced in HRSG (or Auxiliary Boiler) is used

- Steam-Jet Air Ejectors continuously remove air (i.e. $O_2$) that leaks into condenser
  - Used in combination with Liquid-Ring Vacuum pump
Deaeration

- In most OTSG CCPP’s, deaeration is done inside ST Condenser
- ST Condenser operation alone drives O₂ levels down (~20 ppb)
- Alternatively, Vacuum Deaerators or Pressurized Deaerators are also commonly used
KEY POINT

• To keep condensate loop closed, the following are necessary:
  1. Continuous source of steam for gland seals until full load is achieved
  2. Maintain vacuum on ST Condenser to sustain acceptable water chemistry

• CCPP’s operate best when operated continuously, however…
Cyclic Power Plant Operation Off-Peak Choices

1. Break closed condensate loop vacuum and shut everything down

2. Maintain only ST gland-seal steam (from an aux boiler) which will keep closed condensate loop under vacuum and the ST condenser in operation

3. Slow roll ST using an auxiliary steam source
Breaking Condensate Loop Vacuum
Breaking Condensate Loop Vacuum

• If there is no auxiliary steam source for gland seals, then condenser vacuum must be broken during off-peak shutdowns

• Air ingress causes dissolved oxygen (DO) levels to rise out of specification, and stay that way on re-start
  – This is a significant corrosion risk to system components in a daily cycling plant

• Air ingress causes flash rusting (hematite blooming) on all exposed carbon steel surfaces (TDS/TSS)
  – Condenser Hotwell, Deaerator, Flash Tank
  – High TDS/TSS throughout loop
Dissolved Oxygen (DO) Operational Considerations
Dissolved Oxygen – Expert’s Opinion

• “One of the most frequently encountered corrosion problems (in boilers) results from exposure of metals to dissolved oxygen.” – The NALCO Guide to Boiler Failure Analysis.

• EPRI and other sources recommend DO levels be kept below 10-ppb (e.g. 5-7 ppb) for systems containing mixed metallurgy. The Heat Exchanger Institute (HEI) uses 7-ppb as the design standard for Steam Surface Condensers.
Figure 8: Micrographs taken from the prepared section marked “B-B” in Figure 1 before etching, illustrating cross-sectional view of the main crack (red arrow) and numerous smaller cracks (yellow arrows) observed along the inner surface (Not etched). The inset illustrates the brazed weld and the fins (etched).
Figure 11: Locally enlarged micrographs taken from the main crack and one of the smaller cracks shown in Figure 8 after etching, illustrating bright grains adjacent to the oxide layers along the cracks. (Original magnification: 500x. Etched with 10% ammonium persulfate electrolytic etchant)
Iron Oxide (Rust) Formation

Operational considerations of high TDS/TSS from Hematite Blooming and associated iron transport
Fig. 23 & 24 Photomacrographs illustrate the watermarks on the I.D. surface in the bend sections. The arrows highlight the suspected direction of flow (0.6X, Section into halves)
Ten years of operation
Consequences of Breaking Condensate Loop Vacuum

- Increased polisher loading & cost of polisher operation due to high TDS from iron transport
- Increased make-up water costs due to venting on start-up & dumping bad water
- Slower plant start-up due to re-established of water quality when closed condensate loop is brought back into service (and subsequently the steam turbine)

Why break vacuum then?
Cost Considerations of Maintaining Vacuum Off-Peak
Breaking Condensate Loop Vacuum - Advantages

• There is no energy cost penalty for shutting down the plant internals at night while off the grid.

• The plant may be able to operate with reduced (or no) staff overnight, resulting in additional cost savings.

• This will be a cheaper plant to build from a capital cost standpoint.
Operating Cost Considerations for Maintaining Vacuum

- Must run the Auxiliary Boiler overnight to provide steam to the ST gland seals and the Condenser steam-jet air evacuators
  - Natural Gas (heat energy)
- Must run the Condensate Forwarding Pumps, LP feedwater pump (Auxiliary Boiler), and Condenser Cooling-Water pumps or Air Cooled Condenser fans
  - ~400-500 hp
- Must also consider operator/personnel costs
Capital Cost of Auxiliary Steam Sources

- A package boiler capable of producing 20 kpph of steam at 225 psig & 420°F is approximately $200K CAD
  - Gland seal steam: 400-800 lb/hr for 30 MW STG
  - ST slow roll: ~20 kpph for 30MW STG

- Some CCPPs are part of larger process plants where auxiliary steam sources may be readily available
  - Can be brought into power plant with cost-effective 2”-3” diameter carbon steel piping
Keeping Condensate Loop Closed - Advantages

- Will allow the **fastest possible CCPP start-up** (1 hour or less is achievable)
- **Decreased equipment life-cycle maintenance costs** (e.g. less corrosion, cyclic-fatigue cracks, pressure part replacements, plant downtime, etc.)
- **Reduced polisher operating costs** (reduced iron transport & longer polisher-train run times)
- **Lowest possible make-up water costs** (minimal venting losses during start-up)
Financials (revenue for Fast-Start)

- Electricity prices (Ontario) = $0.07/kW-hr off-peak and $0.12/kW-hr peak

- 1-Hr/dy of extra peak steam cycle operation in a typical 2x1 CCPP by slow rolling ST (125MW, 30MW for the STG) = [30,000 kW-hr x $0.12] x 365 = $1,314M/yr.

- Factor in lower polisher and make-up water operating costs as well as substantially reduced high-DO-related maintenance costs

- Estimated additional earnings per year to close loop = \$1.4M/yr
Financials (cost for ST slow-roll)

- Aux Boiler NG fuel = \(~\$0.25/m^3\) OR \($0.00733/ft^3\)
- NG Cost/yr = 25 mmBTU/hr \times $0.00733/ft^3 \times 8hr / 1020 BTU/ft^3
- NG Cost/yr = \([\$1437/dy \times 365-dy/yr]\) = \($524,505/yr\)
- Pump Electricity cost = \([400+60+100]hp \times 1.341\text{kW/hp}\)
- Pump Electricity cost = 751 kW \times 8\text{-hr} \times 0.07/\text{kW-hr} \times 365
- Pump Electricity cost (off peak) = \($153,504/yr\)
- Operator cost = $100/hr \times 8\text{-hr} \times 365\text{days} = \($292,000/yr\)

- Estimated cost/yr to close loop = \(~\$0.97M/yr\).
- Compared to estimated additional earnings per year to close loop = \(~\$1.4 -1.5M/yr\)
Financials (cost for gland seal steam only)

- Aux Boiler NG fuel = \(~$0.25/m^3\) OR \($0.00733/ft^3\)
- NG Cost/yr = 5 mmBTU/hr \times \$0.00733/ft^3 \times 8hr / 1020 BTU/ft^3
- NG Cost/yr = \([\$287.5/dy \times 365-dy/yr]\) = \$104,920/yr

- Pump Electricity cost = \([100+60+100]\)hp \times 1.341kW/hp
- Pump Electricity cost = 751 kW \times 8-hr \times 0.07/kW-hr \times 365
- Pump Electricity cost (off peak) = \$71,266/yr

- Operator cost = \$100/hr \times 8hr \times 365\text{days} = \$292,000/yr

- Estimated cost/yr to close loop = \(~$0.47M/yr\).
- Compared to estimated additional earnings per year to close loop = \(~$0.7M/yr\) (assume 30 min faster start)
Ways to Reduce Parasitic Load Cost

• NG fuel prices are less than electricity costs
  – Use steam-jet air ejectors for maintaining vacuum instead of electric (liquid ring) vacuum pumps (preferred by plant designers)

• Use lower horsepower Cooling-Water bypass pump (e.q. 40 hp vs 500 hp) to maintain night-time circulation and cooling loop chemistry

• Incorporate a VFD on the Cooling-Water pump motor

• Use a small impulse ST to drive some of the parallel pumps (less common in CCPPs)
CCPP Configurations

Optimized for OTSG
<table>
<thead>
<tr>
<th>Plant</th>
<th>Auxiliary Boiler</th>
<th>HP ST/Condenser By-Pass</th>
<th>LP ST/Condenser By-Pass</th>
<th>HP Start-Up Vent</th>
<th>LP Start-Up Vent</th>
<th>HP Desuperheater</th>
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Summary
Optimal Steam Loop BoP

• Maintain Condensate Loop Vacuum
  – Include an Auxiliary Boiler in the plant design

• ST- Condenser should be spec’d for part load operation
  – Increased condensate sub-cooling, increased $O_2$ absorption
  – Greater air ingress forces larger pumps

• Dedicated ST Condenser By-passes
  – Steam/condensate loop remains operational upon ST trip
  – OTSG start-up directly into steam distribution system
Optimal Steam Loop BoP

- LP Desuperheaters
  - Required for fast-start of LP steam system

- Atmospheric Start-Up Vents
  - Required if no dedicated ST Condenser by-pass

- Auxiliary Boiler with HP-to-LP Letdown station
  - ST rotor can be kept hot and spinning during overnight shutdown
  - LP steam distribution system can be pressurized for quicker start-up
Questions?