Steam Purity Considerations
For New Turbines

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“Ideal” Steam

- Dry (steam “quality”)
- pH ~ 9.0 (neutralizing amines)
- Otherwise just gaseous H₂O
“Real World” Steam

“Potential” Bad Actors:

- Suspended solids
  - Metallic particles
- “Dissolved” solids
  - Na, Cl, SO₄, etc.
- Gases
  - CO₂, oxygen
- Vapourized silica
- “Organics”
Potential Impact of Poor Steam Purity

- Deposition on turbine blades
- Corrosion fatigue of blades, discs
- Particle erosion
- Wear of thrust bearing as stage pressure increases
- Sticking valve stems
- Plugging of seals
Potential Sources/Causes of Contamination

- Boiler carryover
- Attempering water
- Silica vaporization
- Vaporization of organic compounds
Boiler Carryover

- Boiler manufacturers steam purity guarantees typically based a maximum percent carryover for a given pressure, e.g. 0.05 – 0.1%

- Amount of impurities present (e.g. sodium) will depend on the quality of the boiler water
Attemperating Water

- Boiler feedwater
- Mill condensate
- Condensed steam ("sweetwater condenser")
Feedwater for Attemperation

- **Deaerator**
- **Economizer**
- **Boiler**
- **Primary Superheaters**
- **Secondary Superheaters**
- **Attemperation Water**
- **Desuperheat Water**
- **BFW**

<table>
<thead>
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<th>Feedwater Pathway</th>
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**To Steam Turbine**
Feedwater for Attemperation

- Convenient, “low cost” source, but …
- Subject to “normal” levels of FW impurities
  - Demineralizer leakage
  - Condensate polisher leakage
- Subject to FW quality excursions
  - Condensate contamination
  - Demineralizer / polisher regenerant
- Impurities in FW used for attemperating is the most common cause of industrial turbine fouling
Feedwater for Attemperation

If you must …

- Optimize demineralizer performance to reduce [Na] leakage
- Operate [cation] condensate polishers in the amine cycle
- Only feed volatile treatment chemicals before the take-off point
- Monitor FW quality closely
  - conductivity, Na
Mill Condensate for Attemperation

Deaerator

Desuperheat Water

BFW

Economizer

Saturated Steam

Boiler

Primary Superheaters

Secondary Superheaters

Attemperation Water

Condensate Receiver

To Steam Turbine
Mill Condensate for Attemperation

- Requires a high pressure pump
- Ideally a high purity, low risk condensate
  - Otherwise subject to potential condensate contaminants/risks
Sweetwater Condenser for Attemperation

- The ideal source
- Highest [initial] cost
- Expensive add on
- Common on most new higher pressure installations
Potential Sources/Causes of Contamination

- Boiler carryover
- Attemperating water
- Silica vaporization
- Organic compound breakdown products
Silica Vaporization

- Silica will partially vaporize at boiler pressures above about 400 psig
- Independent of boiler carryover
- Amount in steam dependent on temperature (pressure), silica concentration and pH
- Not a superheater issue, but definitely a turbine issue
- Generally not a problem if < 20 ppb in the steam
Boiler Water Silica Limits

RELATION BETWEEN DRUM PRESSURES, BOILERWATER SILICA AND pH VALUES
(Based on Maintaining Max. 0.02 ppm SiO₂ in Steam)
Vaporization of Organic Compounds

- All organics will experience some thermal decomposition (to lower molecular weight compounds) at increasing boiler temperatures/pressures
  - Natural organics from make-up water
  - Organic treatment chemicals
  - Process contaminants
  - Ion exchange resin
Vaporization of Organics Compounds

- Potential for adverse impact on steam turbines is subject to continuing debate
Typical Turbine Manufacturer
Steam Purity Limits

- Sodium: 5 - 20 ppb
- Silica: 10 - 20 ppb
- Chloride, sulfate: 3 – 15 ppb
- Cation Conductivity: 0.1 – 0.3 μS/cm
Typical Turbine Manufacturer Steam Purity Limits

<table>
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Why Measure Sodium?

- Sodium is the primary cation in the boiler water (or feedwater)
- Easily detected at ppb levels
- Reliable continuous analyzers available
- Can ratio to TDS using the boiler water Na/TDS ratio
- Indirectly detects all present anions
Typical Continuous Sodium analyzer
Cation Conductivity

So what is “Cation Conductivity” anyway?
Conductivity Definitions

- **Specific Conductivity (SC):**
  - An indirect measurement of all dissolved solids in the steam based on electrical conductance
  - Neutralizing amines are the major contributor to the conductivity of steam/condensate in a high purity system
  - Typically 3 – 5 µS/cm at pH 9.0
Conductivity Definitions

- Cation Conductivity (CC):
  - Sample is first “conditioned” by passing through an hydrogen form cation resin column
    - Converts all cations (\(\text{Na}^+, \text{NH}_4^+\) *) to hydrogen (\(\text{H}^+\)) ions
    - *All* anions (sulfate, chloride, phosphate, organics, \(\text{CO}_2\)) become acids
    - Typically baseline levels of 0.2 – 2.0 \(\mu\text{S/cm}\)
      - Essentially all due to organics

* Representing ammonia and amines
Conductivity Definitions

- **Cation Conductivity (CC):**
  - **Benefits:**
    - Eliminates background conductivity caused by amines, which can “mask” contamination
    - Significantly “amplifies” the impact of all anions on the resulting conductivity reading …the acids formed are 4 – 5 times more conductive than their neutral salts
Conductivity Definitions

- **Cation Conductivity (CC):**
  - **Limitations:**
    - Is still an indirect measure of multiple anions
      - known high risk anions (chloride, sulfate)
      - low [or unclear] risk anions (CO$_2$, organics)
    - Results in a “new” background conductivity
    - Does **not** detect caustic!

  NaOH + R-H $\rightarrow$ R-Na + H$_2$O
“Degassed” Cation Conductivity (CC):

- Sample is heated after the resin column to remove dissolved gases (CO$_2$) that contribute to [undegassed] cation conductivity.
- Sometime used following cation conductivity in order to eliminate the impact of and/or estimate the concentration of CO$_2$.
- More common in the utilities industry.
Cation Conductivity
Chloride and Sulfate

Concentration, ppb

Conductivity, umhos

- Red: Chloride
- Blue dashed: Sulfate
Cation Conductivity

Organic Acids

Concentration, ppb

Conductivity, umhos

Formic Acid

Acetic Acid
Cation Conductivity Measurement

Condensed Steam Sample

Cation (H⁺)
Resin
Column

Conductivity Meter

Conductivity
Probe
Cation Conductivity Measurement

Typically a “baseline” of 0.2 – 2.0 µS/cm
Cation Conductivity Measurement

Condensed Steam Sample

- Amines
- Trace organics
- Na₃PO₄

Cation (H⁺)
- Resin
- Column

Trace organic acids
- H₃PO₄

Conductivity Meter

> 0.2 – 2.0 µS/cm
Cation Conductivity Measurement

Condensed Steam Sample

Amines
Trace organics
NaOH

Cation (H⁺)
Resin Column

Trace organic acids
HOH (H₂O)

Conductivity Meter

0.2 – 2.0 µS/cm

Conductivity Probe
The Dilemma …

Typical “real world” steam cation conductivity levels in industrial systems

= 0.2 – 2.0 µS/cm

Turbine manufacturers specifications:

= 0.1 – 0.3 µS/cm

= Potential warranty conflict!!!
Industry Experience

- Strong evidence that the typical levels of background organics in “industrial” systems do not pose a risk to steam turbines.
- Cation conductivity is not the best method to monitor steam purity in industrial systems.
Industry Experience

- 20 plant study conducted in 2001 by GE Water & Process Technologies:
  - 31 turbines, 900 – 2850 psig steam
  - Wide range of pretreatment and chemical treatment
  - **Cation conductivities:**
    - Range: 0.19 – 1.9 µS/cm
    - Average: 0.72 µS/cm
    - Only one plant met the turbine manufacturers limit
Industry Experience

- Not a single turbine problem attributed to chemistry
Industry Experience

- 120 MW combined cycle cogen plant
  - Commissioned in 1989
  - 44 MW 1330 psig GE steam turbine
  - IP Steam exported/condensate returned from a host tire manufacturing plant
  - City water/demineralized make-up
  - Mixed bed condensate polishing
  - Coordinated treatment, neutralizing amines, DEHA
Industry Experience

- 120 MW combined cycle cogen plant
  - Cation conductivity consistently 2 – 5 µS/cm
  - Over 17 years of steady operation (to 2006), the steam turbine is still in excellent condition
The Bottom Line …

Organic acids:

- Are present at low levels in all industrial systems
- Are responsible for most of the “background” steam cation conductivity
- Are effectively neutralized in the turbine environment by normal amine treatment
- Despite contributing to cation conductivity, have not been shown to cause corrosion in boilers or steam turbines
Steam Purity Best Practices
(for modern steam turbines)

- Sweetwater condenser for attemperating water
  - Much lower risk compared to other sources
- Continuously monitor steam sodium
  - Turbine inlet as a minimum
  - Proper steam sampling (ASTM D-1066)
Steam Purity Best Practices
(for modern steam turbines)

- Cation conductivity can still be a useful tool, but ...
  - Recognize the limitations
  - Establish normal baseline for each system
  - Is not sufficient on its own
- Detailed excursion response procedures
Questions?