HRSG Forum HF2021
Virtual Conference
19th August 2021
Kirk Buecher

Online Instrumentation Overview

for the Healthy Operation of HRSG Plants

METTLER TOLEDO

Agenda

1 **Intro**

2 **Overview of the "Minimum Key Level of Instrumentation" concept**

3 **Review of those Key Instruments**

4 **- Conductivity, Cation Conductivity, pH, DO, Sodium, Phosphate and ORP**

5 **Review of Optional others**

6 **- Degassed Cation Conductivity, Silica and TOC**

7 **Where measured and some comments on why**

8 **- Makeup, Condensate, Feedwater, Drum/Evaporator and Steam**

9 **Q&A if time allows**

Overview – Minimum Key Level of Instrumentation

Why is this needed:

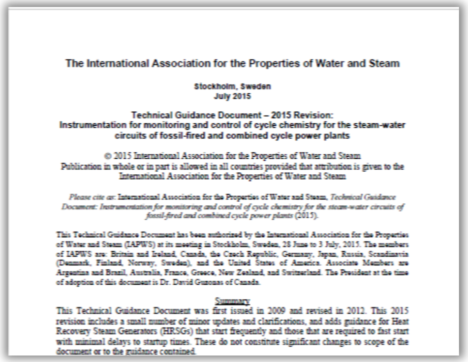
- Far too many plants are under instrumented and/or the analytics poorly managed/ maintained **to avoid preventable (repeat) failures**
- To impress on the importance that **safe, reliable, happy, Power and Cogen plants require ongoing, continuous, online monitoring** of water/steam chemistry to minimize corrosion and suppress formation of deposits

Who developed it:

- IAPWS Power Cycle Chemistry Working Group with representatives from 21 different countries
- Members in this group have ties to EPRI, VGB, ASME, ASTM, academics, local and regional power standard setting organizations, major power companies and significant suppliers of Boilers, Turbines, Water Treatment, plant analytics and control systems

What is it:

- A Technical Guidance Document that specifies the minimum analytical equipment to achieve ongoing plant control success, with optional instrumentation that may be needed based on unique plant conditions



The International Association for the Properties of Water and Steam

Stockholm, Sweden
July 2015

Technical Guidance Document – 2015 Revision:
Instrumentation for monitoring and control of cycle chemistry for the steam-water circuits of fossil-fired and combined cycle power plants

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This Technical Guidance Document has been authorized by the International Association for the Properties of Water and Steam (IAPWS) at its meeting in Stockholm, Sweden, 28 June to 3 July, 2015. The members of IAPWS are: Britain and Ireland, Canada, the Czech Republic, Germany, Japan, Russia, Scandinavia (Denmark, Finland, Norway, Sweden), and the United States of America. Associate Members are Argentina and Brazil, Australia, France, Greece, New Zealand, and Switzerland. The President at the time of adoption of this document is Dr. David Guzonas of Canada.

Summary

This Technical Guidance Document was first issued in 2009 and revised in 2012. This 2015 revision includes a small number of minor updates and clarifications, and adds guidance for Heat Recovery Steam Generators (HRSGs) that start frequently and those that are required to fast start with minimal delays to startup times. These do not constitute significant changes to scope of the document or to the guidance contained.

Overview – Minimum Key Level of Instrumentation

These recommendations were developed based on the following concepts:

- **Identification: Every plant** should have at least a minimum level of instrumentation (MLI) which can **uniquely identify (pin point) the key parameters and drivers to each and every failure/damage mechanism which can occur in that plant.**
- **Redundancy:** The MLI does not only analyze the chemistry locally, **but needs to provide sensitivity analysis for the cycle (holistic view)** in the event of a defective or out of service instrument. Thus an instrument within the minimum key level is backed up by other instrumentation or verification technology, so that in the event of a serious contamination event, the operator **does not need to take time to validate the reading** of an individual instrument.

- **Trust:** The MLI should provide complete assurance to an operator without that operator or his team having to go into the plant to “check” an instrument or to take a grab sample. This relates to the point above.
- **Alarm & Respond** The MLI should all be audibly alarmed in the control room or on the distributed control system.

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Conductivity

AKA Specific Conductivity or Direct Conductivity

- Simple, fast, generally non-specific, determination of the ionic load of the sample stream being tested
- Rough assessment of the purity (or lack of) of the water
- For boiler feedwater, steam and condensate, the dominate ions are what **you** added to the system; Ammonium, other Amines and their decomposition products and hydroxide.
  - In the absence of other contaminants, conductivity can be directly correlated to the additive concentration
- For boiler/evaporator water, the possible mix of impurities is too variable for correlation, but provides rapid feedback on the trends and chemical conditions
- Note: Sample temperature change causes variability in:
  - the conductivity measurement itself
  - changes in Ionic mobilities of the contaminates/additives
  - and when weak bases are present, changes in their dissociation
  - So to ensure accuracy, keep sample temp close to 25c and/or use the latest technology for temp compensation

Temp Algorithm	Application Areas
Standard	**Appropriate for ultrapure to highly saline water. Suitable for use throughout desalination and pure water treatment systems.**
None	Uncompensated measurement to meet final pharmaceutical water monitoring requirements
Linear % per C setting	**Special chemical processes usually involving strong acids or bases, can be referenced to 20 or 25 C**
Ammonia	**Developed for power industry cycle chemistry samples dominated by Ammonia and/or amines like ETA (ethanolamine). Accounts for the effects of temperature on the dissociation of pure water in the presence of these bases.**
Cation	**Developed for the power industry for use with samples that have passed through a cation exchanger and contain trace acids which affect temperature coefficient.**
Light 84	Similar to Standard with slight modifications/corrections at higher temps based on technical studies in pure water published by T.S.Light
Standard 75 C	Same as standard but referenced to 75C for specialized microelectronics UPW applications (75°C is 2.4818 Mohm-cm)
Alcohol (0.5 & 0.75 settings)	Required when pure water contains 50% or 75% isopropyl alcohol
Glycol (0.5 & 1)	Required when pure water contain 50% or 100% ethylene glycol

Cation Conductivity

AKA Conductivity after cation exchange (CACE) or Acid Conductivity

- Sample must first pass through a column of strongly acidic cation resin, which removes ammonium, sodium and other cations present
- Measurement is used to highlight the presence of potentially corrosive ionic contaminants, providing rapid indication of :
  - Cooling water ingress, especially at seawater cooled plants
  - Contamination of the makeup water
- Most often used for monitoring of condensate, feedwater and condensed steam
- Or in a plant operating with AVT or Caustic Dosing
- **Notes:**
  - Sample temperature again must be managed for accuracy and to avoid damage to the resin
  - The resin itself becomes part of the measurement so higher quality resin, well maintained and replaced **prior** to exhaustion are keys to success

pH

Critical but surprisingly difficult

- pH of water greatly affects it's reactivity towards many compounds
- pH of boiler/steam water must be maintained in the alkaline range to minimize corrosion
  - For all steel systems generally target 9.0 to 9.8
  - Mixed metallurgy a little more complicated, but 8.8 to 9.1
  - Ammonia, organic amines and phosphate are added to maintain target alkaline pH ranges
- However, "right tool" for the job is required to overcome issues with the glass membrane, reference electrode, liquid electrolyte, temperature compensation and the variability of dissociation of alkaline solutions and the low ionic strength/conductivity of the water.

Notes :

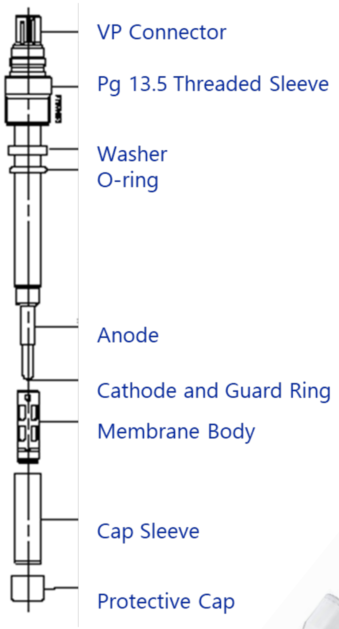
- Quality Matters
- Mind the bowls
- Regular recalibration needed
- Where possible backup and verify with pH derived from conductivity

Measuring electrode
Reference electrode
Temp. compensator
Solution ground

Dissolved Oxygen

High and Low levels are bad

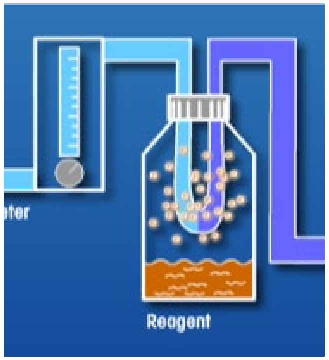
- High levels of DO when combined with ionic contaminates like chlorides, can increase the risk of under-deposit corrosion which can lead to large scale tube failures and in HRSG high pressure evaporators
- Low levels of DO, especially when a reducing agent is used, can lead to increased iron transport and FAC
- So reliable, accurate DO measurement is essential to maintain the protective oxide layers throughout the feedwater system
- Notes:
  - Historically, membrane polarographic, sensors have been used, but require regular and skilled maintenance
  - Newer LDO/ODO technology offers faster reaction time, greater accuracy and much easier, less frequent maintenance
  - Oxygen scavengers and organic breakdown products can influence results
  - Look carefully at sample fittings and housings for ingress

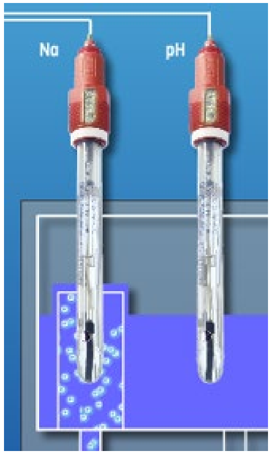


Sodium

More sensitive than conductivity

- On-line sodium ion selective based electrode provides a very sensitive indication of contaminants in condensate and carryover of boiler additives/contaminates into the steam
- Possible interference with the measurement is controlled by dosing ammonia or DIPA (Diisopropylamine) to raise the pH of the sample stream before measurement
- Notes :
  - Some sodium electrodes will see a reduction in sensitivity/accuracy if they are only exposed to very high purity, low sodium water, requiring more frequent maintenance
  - Analyzers with Auto calibration and sensor conditioning, require **far** less labor to maintain than those with manual calibration and sensor etching

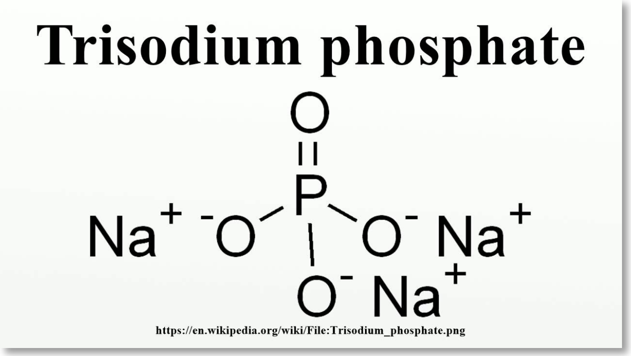




Phosphate

Sometime you just need a direct measurement

- When dosing Phosphate, direct on-line measurement is necessary to provide unambiguous control for those boilers/HRSG evaporators that are subject to hide-out and return
  - Units operating above 1,500psi and/or subject to frequent load changes are at elevated risk
  - As well as those plants using anything other than Trisodium Phosphate at the 3-1 molar ratio
- Although it is possible, to infer likely phosphate levels by careful monitoring pH and the relationship between conductivity and cation conductivity, or to do period grab sampling, these are insufficient to provide good control
- Notes :
  - Historically, some phosphate analyzer's struggled with reliability, high levels of reagent consumption and maintenance requirements**, improved technology is available now**



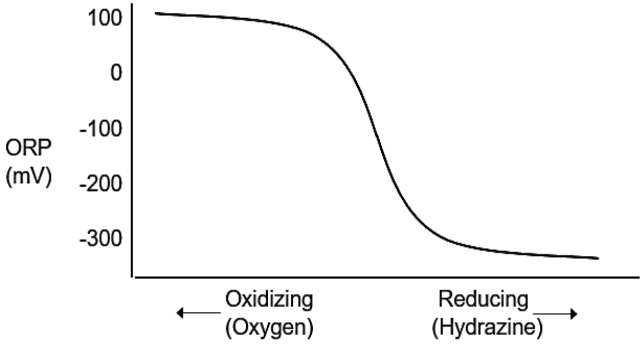
Trisodium phosphate

https://en.wikipedia.org/wiki/File:Trisodium_phosphate.png

Oxidation/Reduction Potential (ORP)

Only a Key Instrument for plants with Copper Alloys

- Redox conditions in feedwater can provide valuable insight to operators of plants with copper alloys present
  - These plants need to operate with reducing feedwater chemistry
- Measured potential becomes more positive as the balance of the species present in the water become more oxidizing
- ORP alerts the operator to those times when oxidizing conditions exist that would trigger increased rates of copper alloy corrosion and release of ions/oxide particles
- ORP can help monitor and control the oxygen scavenger dosing



Notes:

- ORP sensors are available as stand alone or in combination with pH electrodes (helps with holistic view)
- Calibration is important but often done incorrectly
- Correct location of the sensor relative the scavenger dosing pump is required

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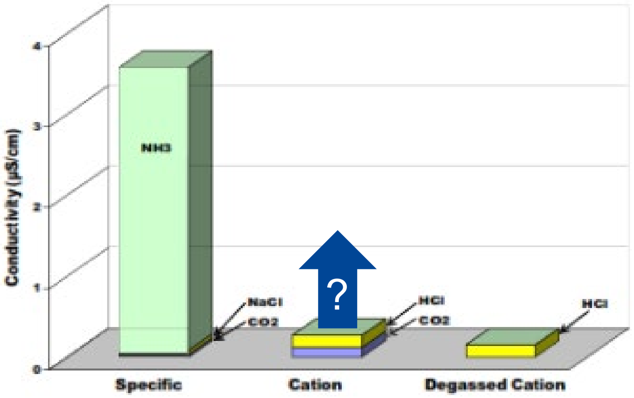
Optional: Degassed Cation Conductivity

AKA Degassed Conductivity after cation exchange (DCACE)

- Cation Conductivity is also responsive to the presence of weak acids, but this is subject to suppression if the concentration of the strong acid anions is enough to cause association of the weak acids
- Common example of this is the response to carbonate/ bicarbonate from CO2 in the steam water circuit
- To accurately measure the more corrosive contamination of interest, the CO2 must be removed generally by boiling or equilibration with a gas stream
- Most critical for fast start and frequently cycled units, which historically had to wait to restart until Cation Conductivity reached target limit, while carrying the unknown conductivity increase due to CO2
- Resulting in faster starts while maintaining confidence in steam quality
- **Notes:**
  - Sample temperature again must be managed for accuracy and to avoid damage to the resin
  - When a reboiler is used for CO2 removal, temperature becomes more important for the final sensor



Optional – Silica

Avoiding deposition on turbine blades

- Operation targets are set for silica in drum boilers providing steam to turbines in order to ensure that the risk of deposition within the turbine is adequately controlled
- However, since the essential target to meet is in steam quality, it is important to directly measure it there
- Silica deposits negatively impact performance and increase vibration shut down risks
- Although broadly used, Silica analyzers are considered optional because some plants that have low level silica in their source water and excellent water treatment, can manage with periodic grab sampling

Notes:

- Historically, some silica analyzer's struggled with reliability, high levels of reagent consumption and maintenance requirements, **improved technology is available now with multi-stream monitoring and the ability to monitor phosphate simultaneously**. This improves the ROI for measuring silica throughout the plant

Optional – Total Organic Carbon

Critical tool for Cogeneration Plants

- The presence of organic materials in make-up water can have a detrimental influence on makeup water treatment plant operation.
  - Organics also reduce resin life of condensate polishers
- Some organic materials reaching the steam-water circuit may cause the formation of deposits that impact on heat transfer.
- More seriously, organics reaching the boiler, degrade, producing organic acids lowering boiler pH and may generate other potentially corrosive products
- This is a High risk problem for Cogeneration Plants with condensate return bringing back organic based contamination from the production process

Notes:

- Real time, on-line measurement of organics (TOC) can provide rapid diversion of organic contaminated water protecting the boiler/polisher until the problem is solved

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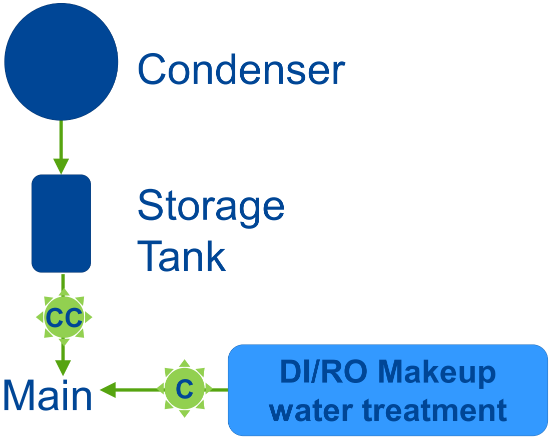
Make-up Water

Catch problems early

- **Conductivity**
  - For demineralized water, the Minimum Key Level Instrumentation (MLI) requirement is measurement of **conductivity** upstream of the point of mixing with dosed condensate.
- **Cation Conductivity**
  - For condensate from a storage tank open to atmosphere (vented), the MLI requirement is measurement of **conductivity after cation exchange (CACE)** upstream of the point of delivery of the water into the main circuit
- Optional Silica - if the history of the plant has shown variability in levels and/or dependent on source/raw water with high levels of silica
- Optional TOC - if the history of the plant has shown variability in levels and/or dependent on source/raw water with high levels of organics


Condenser

Storage Tank

CC

Main

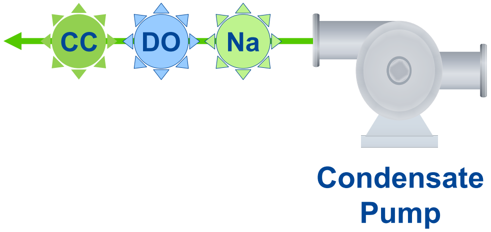
C

DI/RO Makeup water treatment

Condensate

At condensate extraction Pump Discharge

- **Importance of these measurements** :
  - First warning of condenser leak, regeneration chemicals from the makeup plant, contaminated condensate from the storage system
  - Air in-leakage
- **Cation Conductivity** – rapid alert to ingress of corrosive anions
- **Sodium** – a must for sea water cooled plants without Condensate polishing
  - Sodium much higher sensitivity than conductivity, so better tool for detection, monitoring of condenser leaks
- **Dissolved Oxygen** – Detect air ingress into the high pressure part of the cycle
- Optional Conductivity and pH, but really helpful for confirmation information, part of holistic view
- Optional Degas – can clearly separate whether or not an increase in cation conductivity is from CO2 or not



Feedwater with Condensate Polisher

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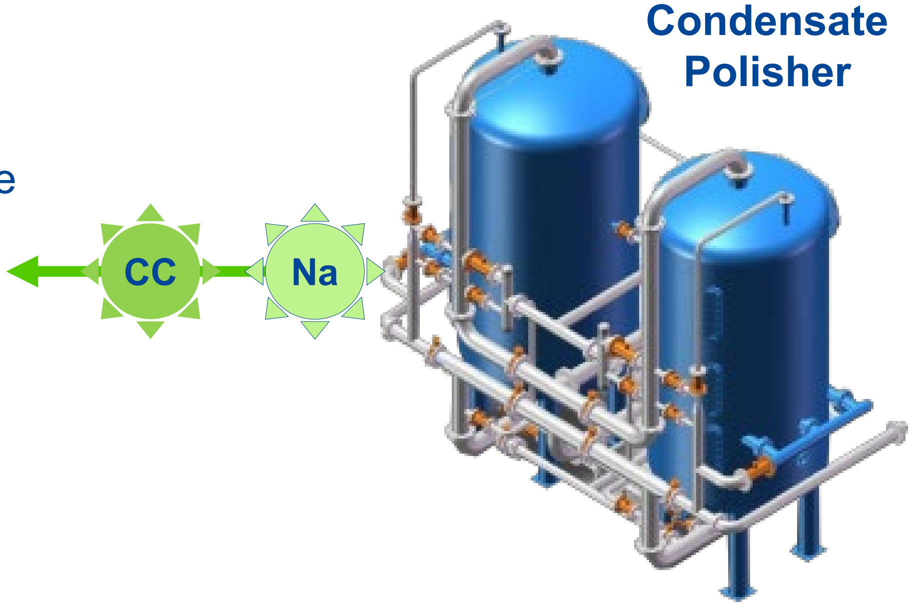
At condensate polisher outlet

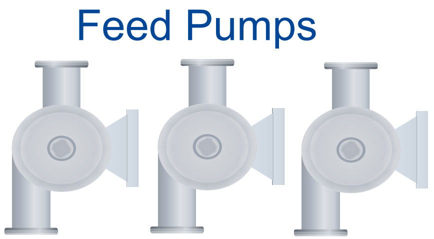
- **Cation Conductivity**
  - most important parameter because it rapidly alerts the operator to ingress of potentially corrosive anions and is more sensitive than conductivity.
- **Sodium**
  - rapidly alerts the operator to cation breakthrough and the need for regeneration of the resins. Again, it is more sensitive than conductivity
- Optional Conductivity
  - provide confirmation of the effective operation of the polisher and to "back-up" the Sodium measurement

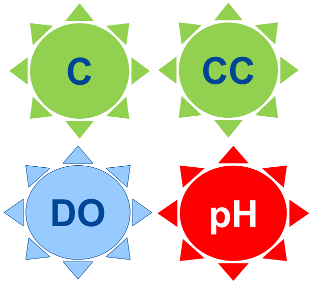


Feedwater without Condensate Polisher

Downstream of feed pumps on HRSG Plants

- **Conductivity** - essential to give a rapid indication of the successful operation of dosing systems to control feedwater pH
- **Conductivity after cation exchange** is also monitored at these locations in order to confirm that no contaminants have entered the feedwater with the dosed alkali (ammonia or amine), through condenser leakage or via any other route.
- **pH** measurement (or assessment from conductivity and conductivity after cation exchange) provides further confirmation that the dosing regime specified for the plant is being achieved
- **Dissolved oxygen** is measured to confirm its within control of targets for the plant**. In those units where oxygen dosing to the feedwater is used, it is essential** to confirm that the target range is being achieved
- Optional ORP with Copper Alloys in the feedwater circuit

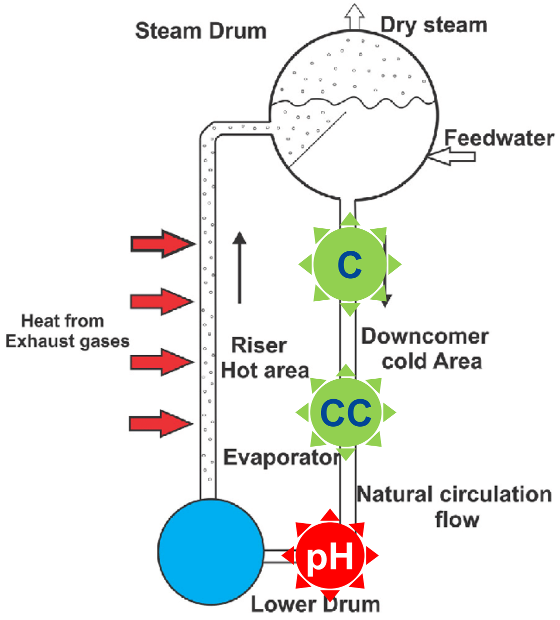




Drum Boiler/HRSG Evaporator Water

Plants running AVT (no alkali added)

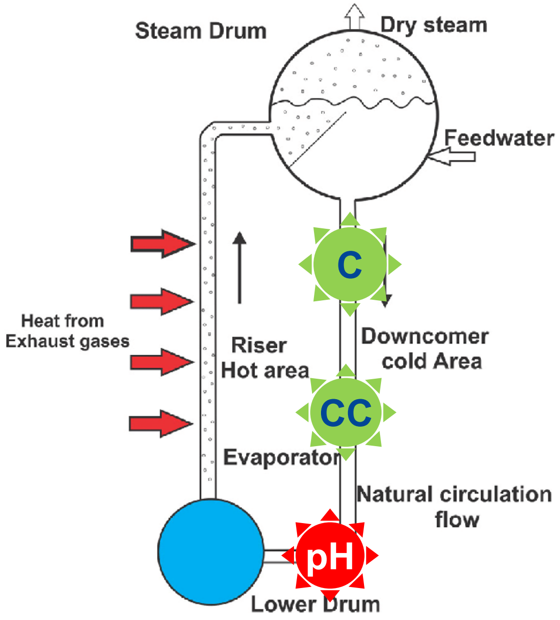
- Samples from Boiler downcomers preferred
- **Conductivity** measurement is valuable to provide a warning of deviation from the normal operation of the boiler. In sliding pressure operation, it must be recognized that volatile dosing agents will favor the steam more strongly as pressure falls and thus the equilibrium state of the boiler dosing will be pressure dependent.
- **Conductivity after cation exchange** is monitored in order to confirm that no contaminants are accumulating to an excessive level in the boiler water and to guide the operators on the adjustment of blowdown rates.
- **pH** measurement provides further confirmation that the dosing regime specified for the plant is being achieved.
- Optional Silica: may be measured in the boiler water if the relationship between its concentrations in water and steam are known. (Although the aim is to control silica levels in steam, the measurement in boiler water may be more reliable in some circumstances.)



Drum Boiler/HRSG Evaporator Water

Plants running on Caustic Treatment

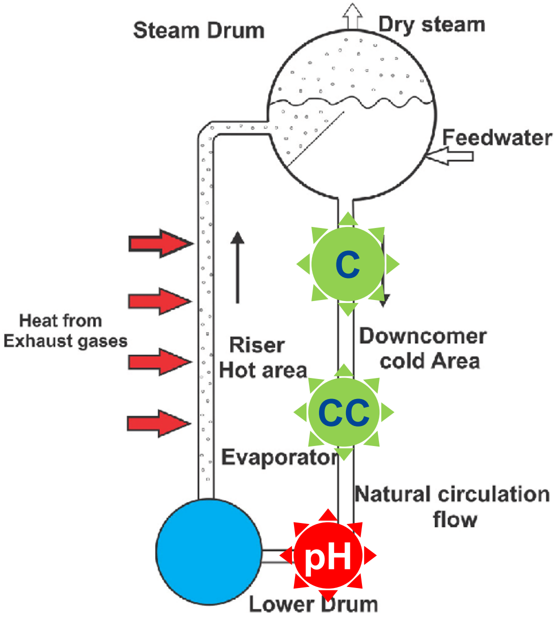
- **Conductivity** measurement generally provides a direct indication of the dosed concentration of hydroxide. Its measurement can be used as a key parameter in the adjustment of boiler blowdown rates and dosing system setting.
- **Conductivity after cation exchange** gives a clear indication of the accumulation of impurity anions in the boiler water and therefore provides additional information on which to base control of the blowdown system.
- **pH** measurement provides confirmation that the target dosing regime is being achieved.
- Optional Silica may be measured in the boiler water if the relationship between its concentrations in water and steam are known. **Note that silica is less volatile in boilers with caustic dosing than in AVT dosed units.**



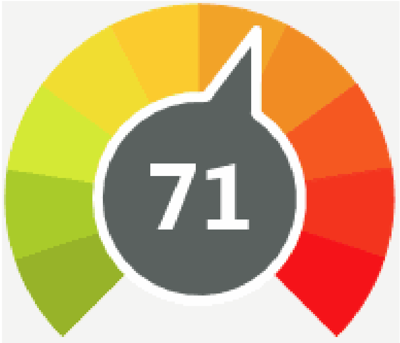
Drum Boiler/HRSG Evaporator Water

Plants running on Phosphate

- A multidimensional measurement challenge to manage pH, sodium, phosphate, chloride, sulfate and others while minimizing risk of hideout
- **Conductivity** measurement again provides a warning of deviation from the normal operation of the boiler. In boilers where high levels of phosphate hideout occur, there can be large increases in conductivity during periods of low load operation.
- **Conductivity after cation exchange** complicated by the contribution from phosphate, but can alert to increases of chloride, if vigilant
- **pH** can be helpful because it shows that the phosphate present in the boiler water is within the right range
  - however, at lower phosphate levels pH is driven more by ammonia
  - At higher phosphate levels, small condenser leaks may have only a very minor effect on the pH of the bulk boiler water. So, pH measurement alone is an insensitive indicator of corrosion risk in phosphate dosed boilers



Phosphate Target = 50

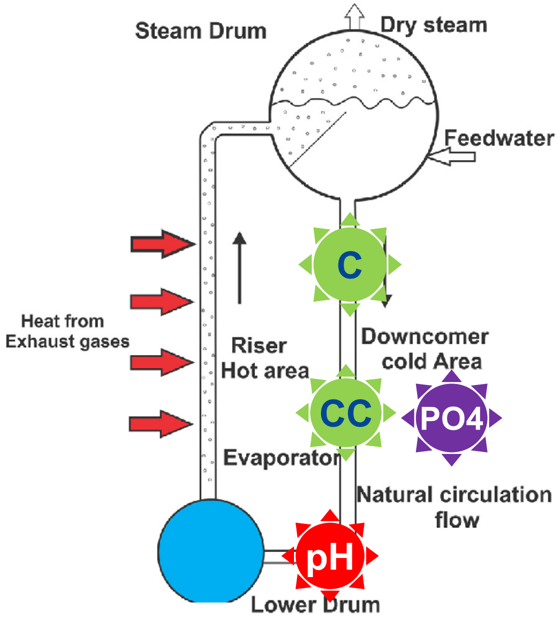


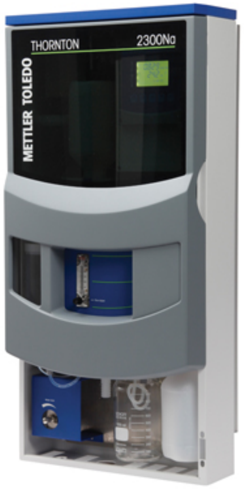
Phosphate levels with hideout and return

Drum Boiler/HRSG Evaporator Water

Plants running on Phosphate Continued

- **Phosphate** measurement is necessary to enable unambiguous control of dosing in boilers that are subject to hide-out and to allow the interpretation of the conductivity after cation exchange in terms of other contaminants.
- Optional Sodium In circumstances where it is necessary to achieve a fuller understanding of the boiler chemistry (specifically the [sodium]:[phosphate] molar ratio which can be strongly related to corrosion risk), it becomes essential to monitor **sodium as well as** phosphate concentrations.
- Optional Silica may be measured in the boiler water if the relationship between its concentrations in water and steam are known. (Although the aim is to control silica levels in steam, the measurement in boiler water may be more reliable in some circumstances.)





Steam Measurement Overview

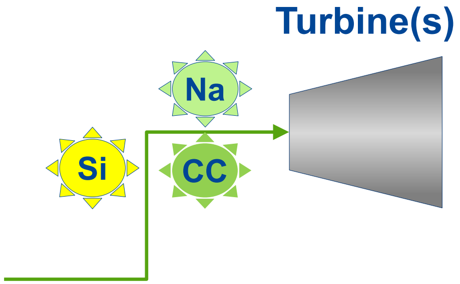
Objective and suggestions on sampling locations

- **Protect the turbine from:**
  - Excessive carryover from drum boilers
  - Contaminated attemporator spray water
  - Concentrations of silica that could form deposits on the turbine blades
- Note : Appropriately designed AND located representative sample extraction probes are required, especially for saturated steam
- **Typical measurement locations**
  - Upstream of the superheaters providing saturated steam
    - Important for frequent carryover measurements but does not need to be continuously measured when plant is well under control
  - Downstream of superheaters, providing superheated and reheated measurement points, which WILL catch the possible contamination from the attemporator spray
    - Generally preferred for on-line monitoring
    - Special considerations needed for the sample cooling requirements

Main Steam – Superheated & Reheated

Minimum Key Measurements

- **Cation Conductivity:** Monitor for level of carryover of all ionic contaminates
- **Sodium:** More accurate monitor for corrosive salts
- **Note:** If either of these show persistent high levels, this is strong indication of mechanical boiler drum damage OR signification feedwater contamination. Both require operator intervention to identify and solve the problem!
- **Silica**: If the make-up water has or is suspected to contain non-reactive silica (often varies with the seasons), this is the most important measurement point for monitoring for levels that would cause deposition
- Optional for fast start or frequently cycled plants: **Degassed Cation Conductivity** can provide useful additional information to distinguish air in-leakage from other forms of contaminant ingress such that a relaxation in CACE associated with the former can be determined to prevent delay in starting a unit.



If time allows…

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