REINHOLD ENVIRONMENTAL Ltd.

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HRSG: Makeup Water Treatment for Boilers at Gas Powered Plants

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Introduction

- “The ***feedwater*** used to supply boilers in gas-fired power stations must meet high water quality standards in order to maintain boiler efficiency and to minimize formation of scale and corrosive environments. Production of high purity boiler ***feedwater*** typically involves a variety of water treatment processes, including softening, reverse osmosis, ion exchange, electrodeionization, and other technologies designed to remove ions that may cause damage to system components. This presentation will focus on electrodeionization systems and their application in water treatment systems for production of demineralized water for use in high-pressure steam boilers.”

THE KEY TO HIGH QUALITY FEEDWATER IS HIGH QUALITY MAKEUP WATER

Heat Recovery Steam Generators (HRSGs)

Image Source: https://hrsgusers.org/

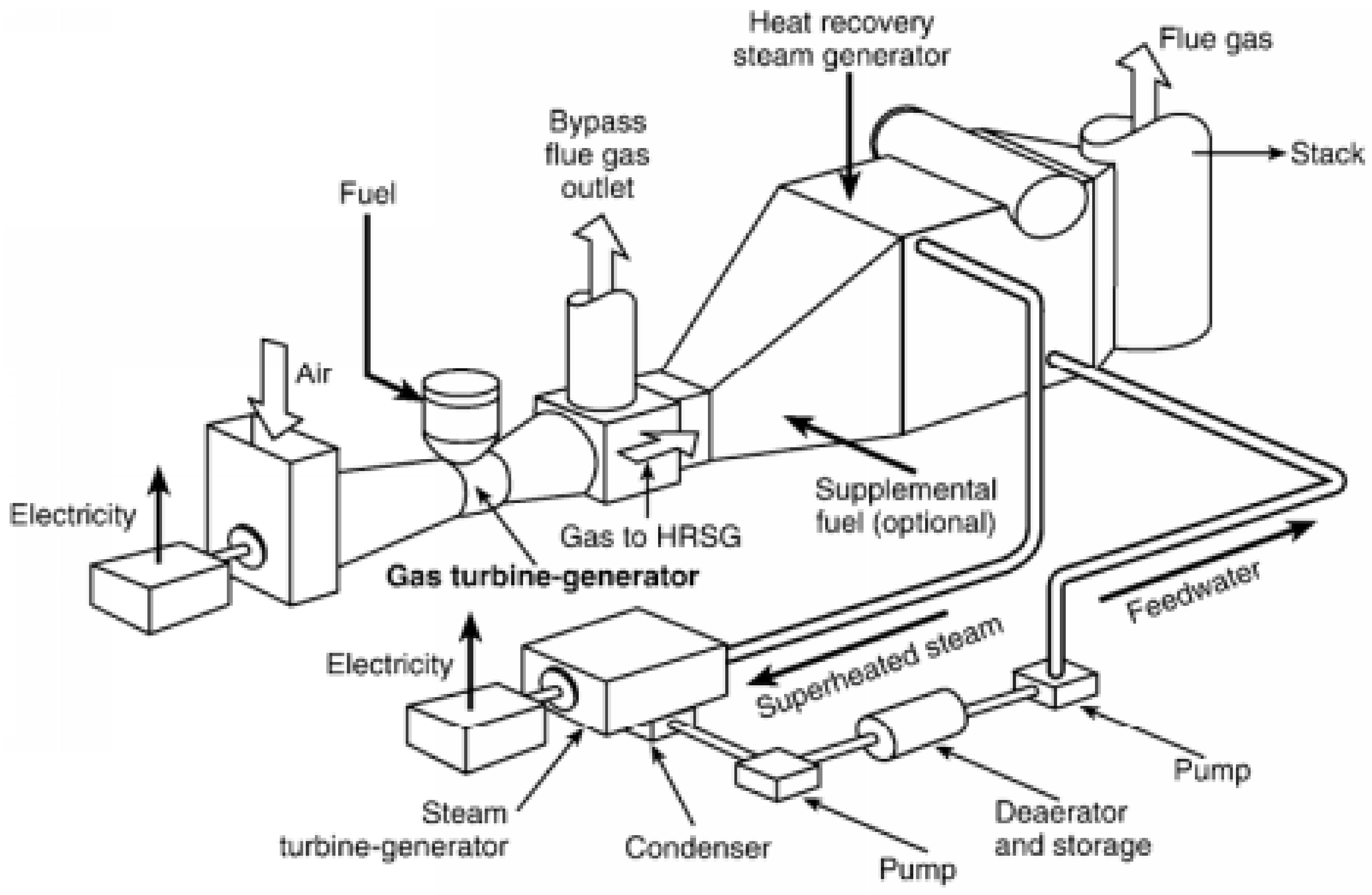

Image Source: *Cycle Chemistry Guidelines for Combined Cycle/Heat Recovery Steam Generators (HRSGs).* EPRI. Palo Alto, CA: March, 2006. 1010438. Page 1-2.

Description

- Utilize waste heat from gas exhaust to produce steam
- Flue gas: Approx. 450 – 650°C (840 – 1200°F)
- Applications:
  - Combined Cycle
  - Cogeneration
- Increase plant efficiency
  - Gas turbine: 35 – 45% efficiency (Simple Cycle)
  - Gas turbine + Combined-Cycle HRSG: 55 – 60% efficiency
  - Gas turbine + Cogeneration HRSG: 75 – 85% efficiency

Source: Ganapathy V. *Heat-Recovery Steam Generators: Understand the Basics.* Chemical Engineering Progress. August 1996.

HRSG Boiler Tubes

- Finned tubes for enhanced heat transfer
- Tubes assembled into coils with a common distribution header: "harps"

Image Source: http://www.kangrim.com/_kang/p76.php

Image Source: http://www.heatechps.ae/usr/pagesub.aspx?pgid=5

Types of HRSG

- Natural Circulation
  - Typically horizontal
- Forced Circulation
  - Typically vertical
  - Smaller footprint
- Once-Through
  - Typically vertical
  - No steam drums

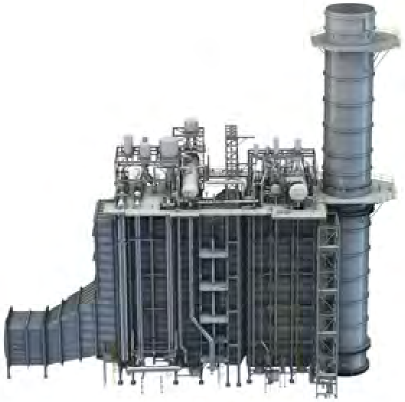

Image Source: https://powergen.gepower.com/products/hrsg.html

HRSGs vs. Conventional Boilers

HRSG	Conventional Boiler
Utilizes waste heat	Utilizes heat produced from a fuel source
Contains only heat transfer equipment	Contains both heat transfer equipment and a furnace
Triple pressure configuration	Single pressure for evaporation and superheating
Output dictated by performance of gas turbine	Output dictated by burner output
Internally insulated to limit impact of expansion on externals	Free to expand; externally insulated

Primary HRSG Components

ECONOMIZER

- Preheats feedwater before it enters the steam drum
- Avoid steam production here
- Recover residual heat

EVAPORATOR

- Receives preheated water from the Economizer
- Vaporizes water to generate steam

SUPERHEATER/REHEATER

- Receives saturated steam from the Evaporator
- Produces dry steam for the turbines

Primary HRSG Components

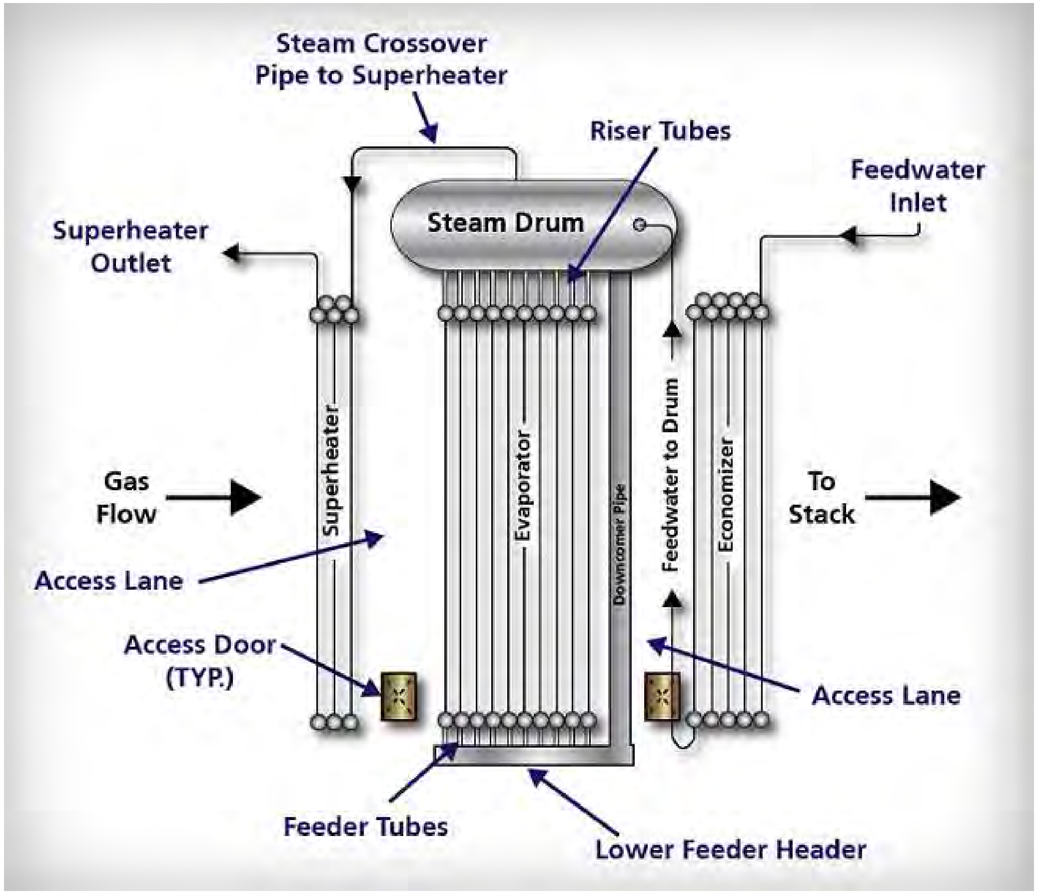

Image Source: https://www.myodesie.com/wiki/index/returnEntry/id/2994

Pressure Modules (Multi-Pressure HRSGs)

HIGH PRESSURE (HP)

- Closest to flue gas entry
- 600 - 1,500 psig

INTERMEDIATE PRESSURE (IP)

- Between HP and IP modules
- 300 – 600 psig

LOW PRESSURE (LP)

- Furthest from flue gas entry
- 100 – 300 psig

Typical Multi-Pressure HRSG Schematic

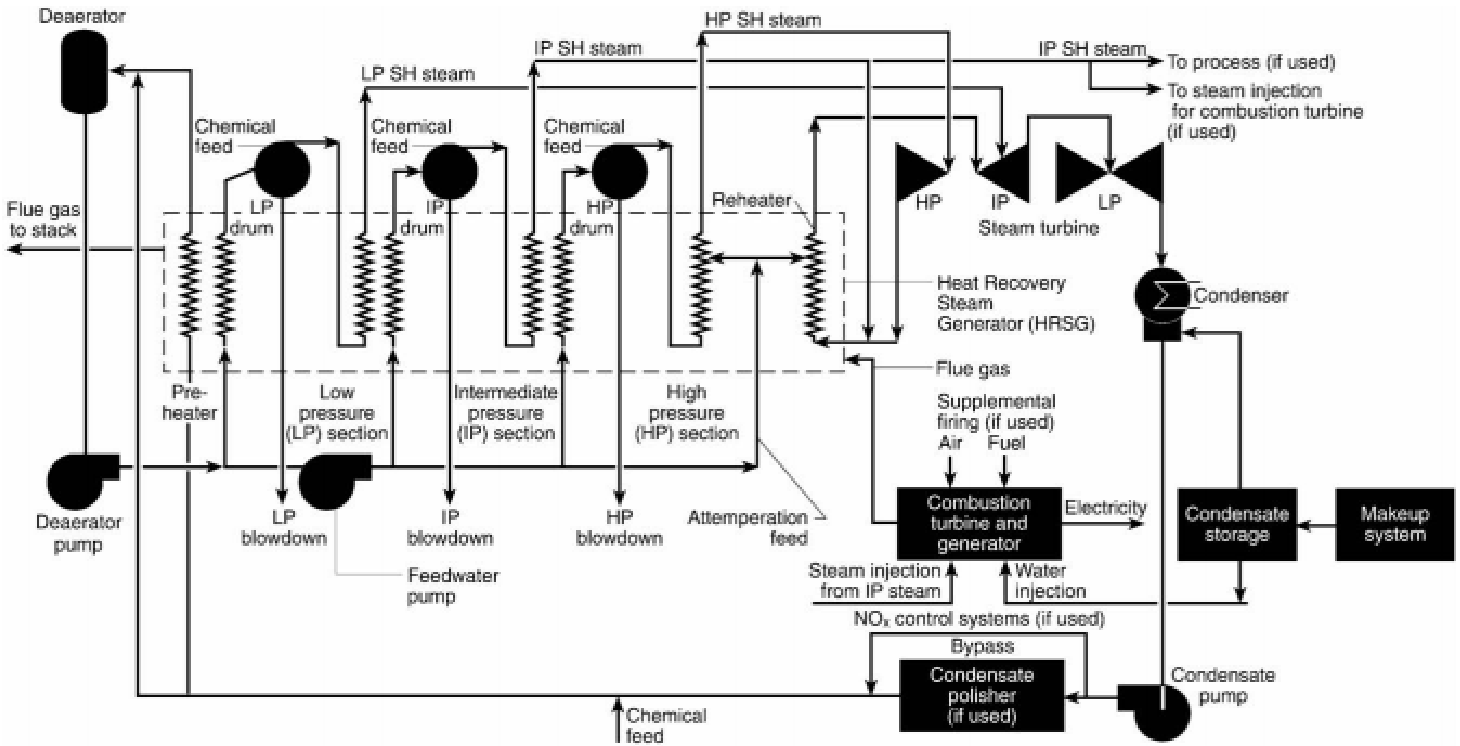

Image Source: *Cycle Chemistry Guidelines for Combined Cycle/Heat Recovery Steam Generators (HRSGs).* EPRI. Palo Alto, CA: March, 2006. 1010438. Front Cover.

Boiler/HRSG Feedwater Quality

Importance of Feedwater Water Quality

- Critical system component
  - Results of Failure:
    - Unplanned Outage
    - Potential Injury to Workers
- Very high quality water needed for proper operation
- Feedwater quality dependent upon makeup water quality
- Makeup water treatment requirements vary depending on source
  - River water vs. drinking water
  - Wastewater reuse

Boiler Deposits

- Scale formation:
  - Constituent solubility limit exceeded, causing surface precipitation
  - Ca/Mg/Al/Fe/Si
- Sludge accumulation:
  - Suspended material adheres to surfaces within the system
  - Material may include corrosion products from within the system

Image Source: https://euroclean.org/dictionary/boiler-scale/

Image Source: http://pe-service.com.ua/en/photo/

Problems Caused by Boiler Deposits

- Reduced boiler efficiency (insulation)
- Tube overheating/rupture
- Plugging of tubes/pipelines
- Unbalancing of steam turbines (carryover)

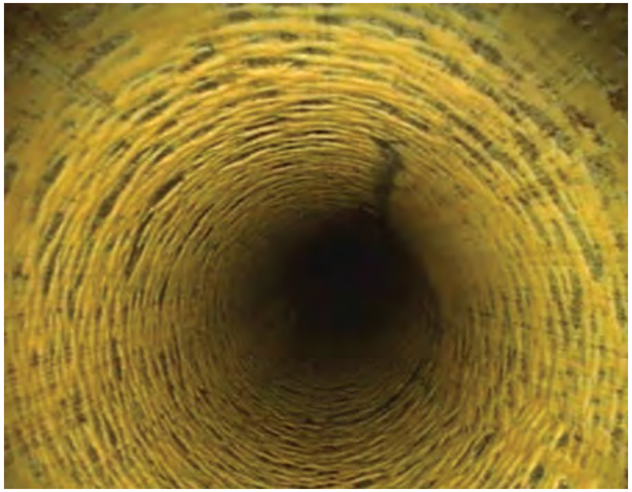

Image Source: http://www.power-eng.com/articles/print/volume-119/issue-7/features/a-journey-to-improve-condenser-performance.html

Image Source: http://www.wikiwand.com/en/Boiler_feedwater

Carryover From Boiler Water to Steam

- Dissolved/suspended materials in boiler circulating water are introduced into steam
  - Mechanical carryover – boiler water droplets enter steam
  - Vaporous carryover – dissolved solids partitioned among the steam
- Leads to fouling/corrosion
  - Boiler drums and tubes
  - Turbine
  - Superheater/Reheater
  - Other parts of the HRSG

Image Source: http://www.ccj-online.com/wp-content/uploads/2016/02/AHUG-fig-4.png

Corrosion

- Metallic degradation
- Complex electrochemical reaction
- Several different causes
  - Low pH conditions
  - Dissolved oxygen
  - Dissolved CO_2
- Can cause serious damage to critical system components

Image Source: http://www.powermag.com/ten-years-of-experience-with-fac-in-hrsgs/?pagenum=1

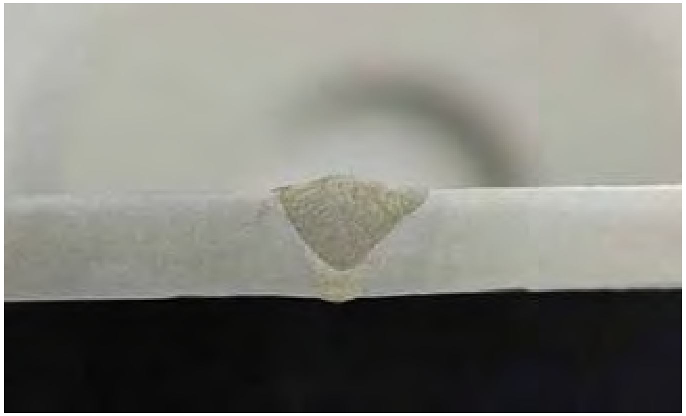

Image Source: http://www.power-eng.com/articles/print/volume-111/issue-7/features/flow-accelerated-corrosion-a-critical-issue-revisited.html

Corrosion: Flow Accelerated Corrosion (FAC)

- Cause of forced outages
- Impacts areas that are vulnerable to flow disturbances (elbows, fittings, etc.)
- Magnetite dissolution – removal of protective coating
- Decreases pipe wall thickness until catastrophic failure occurs
- Exacerbated by inadequate water quality
  - pH/oxygen
  - Reducing environment
- Primarily impacts LP Evaporators & Economizers

Corrosion: Under-deposit Corrosion

- Corrosion that forms underneath deposits
- Hydrogen damage
  - Acid contaminants (chloride)
- Acid phosphate corrosion
  - Phosphates concentrate beneath deposit, forming maricite ($NaFePO_4$)
  - Forms gouges or depressions
- Caustic gouging
  - Excess sodium hydroxide (> 2 ppm) added to the HP drum
  - Similar to acid phosphate corrosion

Image Source: http://www.power-eng.com/articles/print/volume-119/issue-7/features/a-journey-to-improve-condenser-performance.html

Boiler Feedwater Treatment Processes

Deaerator

- Removes oxygen/dissolved gases from feedwater
- Installed on LP module
- Reduces corrosion caused by dissolved O_2, CO_2
- Tray Type (left) vs. Spray Type (right)

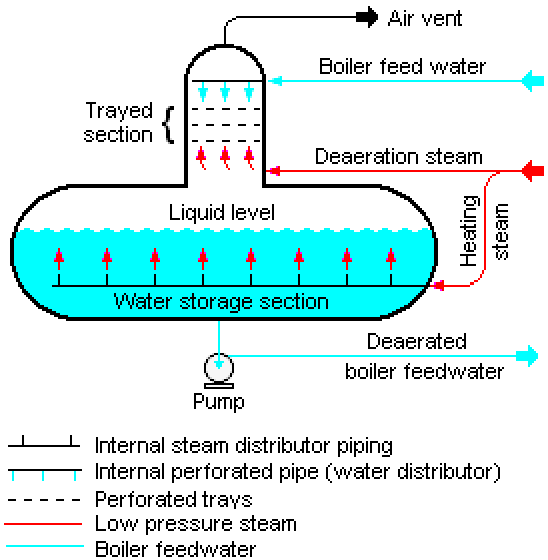

Image Source: https://en.wikipedia.org/wiki/Deaerator

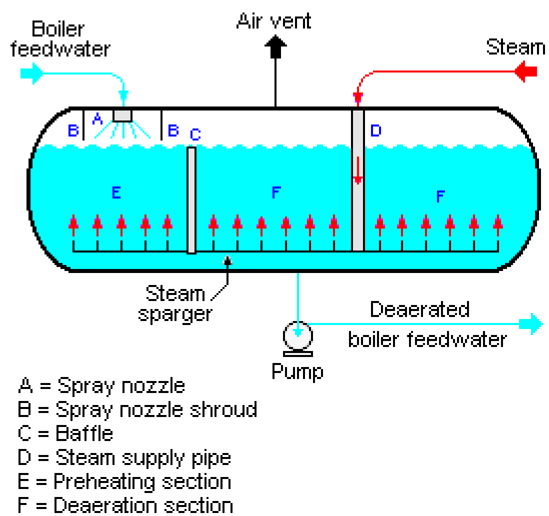

Image Source: https://en.wikipedia.org/wiki/Deaerator

Condensate Polisher

- Ion exchange resin
- For removal of trace minerals/contaminants from within the system
- Prevents concentration of contaminants within the closed loop
- Maintains pH balance
- Reduces corrosion

Image Source: http://www.utamawaterfilter.com/condensate-polishing/

Chemical Treatment Programs

- Drum Style Only
  - Phosphate Continuum
    - Low-Level (Higher quality makeup water)
    - High-Level (Lower quality makeup water)
  - Caustic Treatment
- Once-through Style or Drum Style
  - All-Volatile Treatment (AVT)
    - Oxidizing: Ferrous metallurgy
    - Reducing: Copper metallurgy

Image Source: http://questarusa.com/hazardous-waste-packaging/drums-pails-totes/

Typical Chemical Additives

- Phosphate corrosion inhibitors (trisodium phosphate)
- Sodium hydroxide
- Ammonia/amine
- Oxygen scavengers (hydrazine, carbohydrazine)

Image Source: http://superiorpackagesystems.com/examples/

Boiler Makeup Water Treatment Processes

Benefits of High-Quality Makeup Water

- Reduced Blowdown Frequency
- Better Chemical Control in Feedwater
- Improved System Performance
- Reduced Scaling/Corrosion
- **Reduced Wastewater Production**

Example HRSG Makeup Water Treatment System

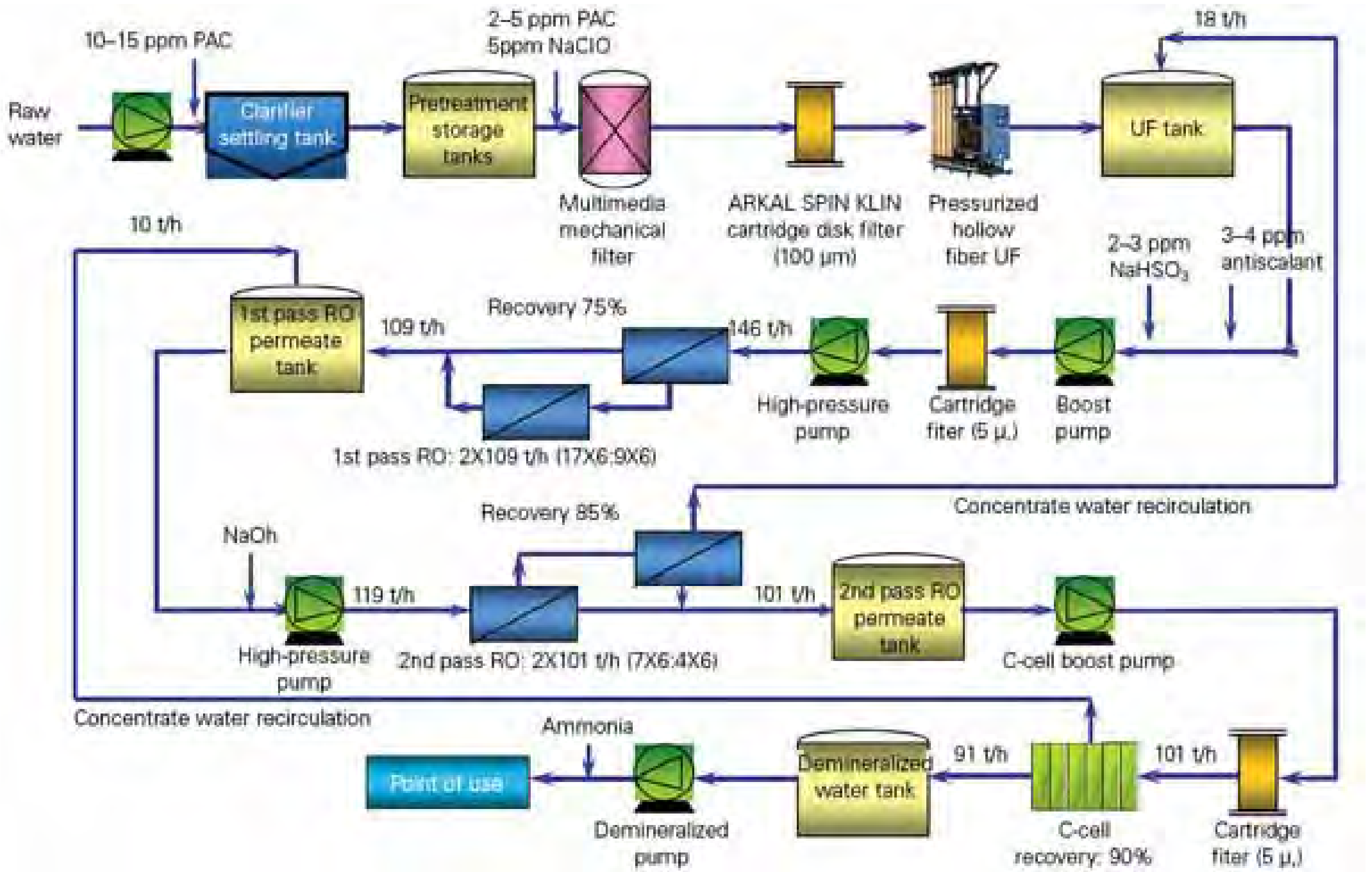

Image Source: http://www.powermag.com/sub-sea-water-treatment-system-provides-reliable-supply-for-the-huarun-power-plant/?pagenum=3

HRSG Makeup Water Specifications

Location	Parameter	Unit	Treatment Program			
			AVT[a]	PC(L)[b]	PC(H)[c]	CT[d]
Makeup	Specific Conductivity	µS/cm	< 0.1	< 0.1	< 0.1	< 0.1
Makeup	Na, Cl, SO_4	ppb	< 3	< 3	< 3	< 3
Makeup	Silica (SiO2)	ppb	< 10	< 10	< 10	< 10
Makeup	TOC	ppb	< 300	< 300	< 300	< 300
Feedwater	Cation Conductivity	µS/cm	0.2	0.2	0.3	0.2
Steam	Cation Conductivity	µS/cm	0.2	0.2	0.3	0.2
Steam	Na, Cl, SO_4	ppb	2	2	3	2

[a] AVT: All-Volatile Treatment
[b] PC(L): Low-Level Phosphate Treatment
[c] PC(H): High-Level Phosphate Treatment
[d] CT: Caustic Treatment
Source: Cycle Chemistry Guidelines for Combined Cycle/Heat Recovery Steam Generators (HRSGs). EPRI. Palo Alto, CA. March, 2006.

Clarification

- Removal of suspended solid material
- Used for untreated surface sources (raw lake/river water)
- May not be needed if source water is potable
- Additives to improve performance
  - Coagulant/Flocculant
  - PAC

Image Source: http://www.ovivowater.com/application/municipal/municipal-wastewater/clarification-sedimentation/clarifier-3/

Multimedia Filtration

Image Source: http://kiblerchemical.com/filter_gallery_pic.php/Automatic-Series-Flow-Multimedia-Filter-followed-by-Activated-Carbon-Filter-ASFCC-5460-2.5_2.5_SS/?filter=2

- Suspended solids removal
- Reduces turbidity, SDI
- Prevents fouling of RO membranes
- Gravel, garnet, sand, anthracite, other media as needed

Ultrafiltration

- Semi-permeable membrane
- 0.005 – 0.5 µm particle removal
- Removal of suspended solids, dissolved materials with high molecular weight
- Further reduces RO membrane fouling

Image Source: http://www.roplant.net/uf-system.html

Reverse Osmosis

Image Source: https://www.kemcosystems.com/portfolio-item/reverse-osmosis-ro/

- Removal of ions and large particles
- Pressure applied to force water across a semipermeable membrane
- 0.0001 – 0.001 µm particle removal
- Produces high quality water for polishing

Boiler Makeup Water Treatment Processes: Demineralization

Two-Bed Demineralizer

- Cation & anion exchange resin beds piped in series
- **Cation Bed:** Replaces positively charged contaminants (i.e. Na^+) with H^+
- **Anion Bed:** Replaces negatively charged contaminants (i.e. Cl^-) with OH^-

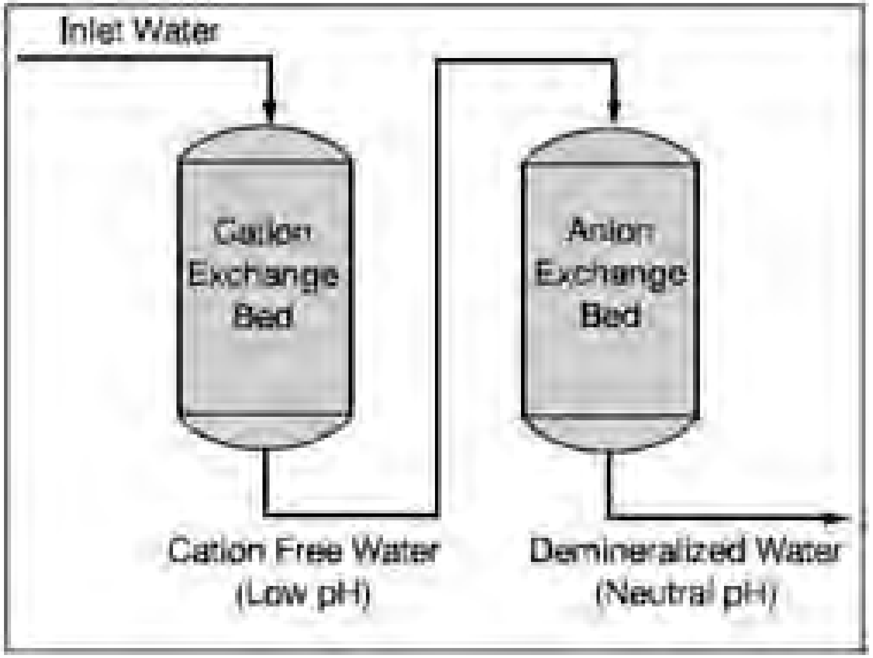

Image Source: http://www.soulwaterfilter.com/tech_2_2.htm

Two-Bed Demineralizer

Image Source: http://industrialsoftener.com/water-filtration-water-softener/

- Must be regenerated occasionally to maintain product water quality
  - Cation Bed: H_2SO_4
  - Anion Bed: NaOH
- Usually regenerated onsite

Mixed Bed Demineralizer

- Cation and anion exchange resins blended
- Similar to two bed system, but more compact
- More complex regeneration process than two bed system
  - Need to avoid contact between improper regeneration solution and exchange resin

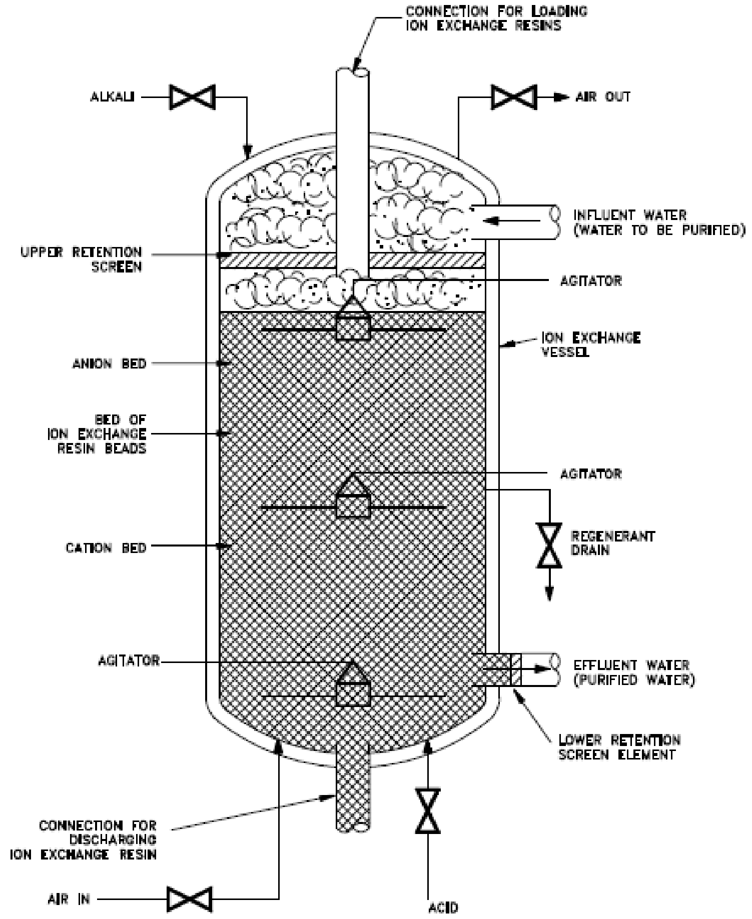

Image Source: http://www.enggcyclopedia.com/2012/03/basics-demineralizers-ion-exchangers/

Mixed Bed Demineralizer

Image Source: http://puretecwater.com/deionized-water/portable-service-di-tank-exchange

- Internal vs. external regeneration
  - External: Resins are physically removed from the vessel, regenerated, and returned
- Can also be rented and switched out for offsite regeneration

Electrodeionization (EDI)

- Also referred to as Continuous Electrodeionization (CEDI) or Continuous Deionization (CDI)
- Modules contain cation and anion exchange resins
- Continuous regeneration via electrical current
- Ion exchange + electrodialysis
- Ion selective membranes
- DC Current

Image Source: http://canpure.company.weiku.com/item/120-T-H-water-treatment-UF-RO-EDI-system-14818599.html

EDI

EDI

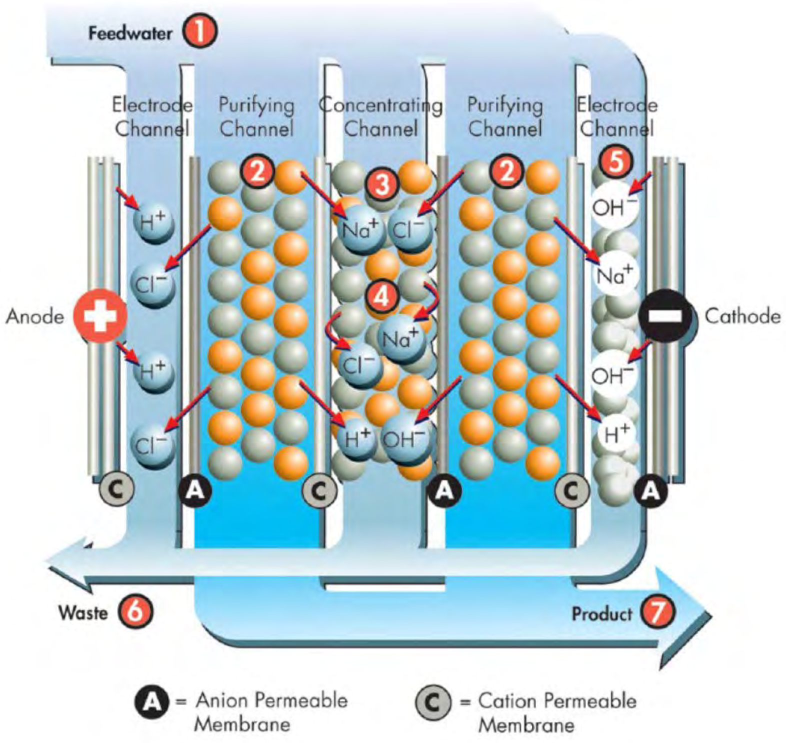

Image Source: http://www.molewater.com/articleShow_31.html

- Ions forced out of feed stream using electric potential
- Resins adsorb ions
- DC field
  - Attracts ions, pulling them into the concentrate stream
  - Splits H_2O into H^+ and OH^-
- Ion-selective membranes act as barriers to water, allow ions through
- Multiple identical layers are "stacked" between two electrodes

EDI Applications

- Power Generation
- Industrial Boilers
- Semiconductors/ Electronics
- Food/Beverage
- Pharmaceuticals
- Manufacturing

Image Source: http://www.floconindustries.net/electrodeionization.html

EDI Supply Water Requirements

Constituent	Concentration Limit
Supply Source	RO Permeate
Supply Conductivity Equivalent, including CO_2 and Silica	< 40 µS/cm*
Dissolved CO_2	< 5 ppm
Silica (SiO_2)	< 0.5 ppm
Fe, Mn, H_2S	< 0.01 ppm
Total Chlorine	< 0.05 ppm
Free Chlorine	< 0.05 ppm
Total Hardness	< 0.5 ppm as CaCO3
TOC	< 0.5 ppm
pH	4 – 11
Temperature	41 – 113°F (5 – 45°C)
Pressure	25 – 100 psig

*Equivalent TDS: < 25.6 ppm

Source: Flynn, Daniel J. *The Nalco Water Handbook, Third Edition.* Nalco Company. New York, NY. McGraw Hill. 2009.

EDI Product Water Quality

Constituent	Concentration Limit*
Product Resistivity	> 7 – > 17 Megaohm-cm
Silica (SiO_2) Removal	90 – 99%
Total Exchangeable Anions (TEA)	< 25 - < 8 ppm ($CaCO_2$)

*Concentration limits are flow dependent

Source: Flynn, Daniel J. *The Nalco Water Handbook, Third Edition.* Nalco Company. New York, NY. McGraw Hill. 2009.

Advantages of EDI Over Other Demineralization Technologies

- No chemicals needed for regeneration; no hazardous waste disposal
- Compact footprint
- No ion "breakthrough"
- High recovery rate (low concentrate volume)
- Electric field creates environment that limits growth of microorganisms
- Decreased capital cost and labor associated with regeneration equipment and process
- Provide removal of silica, CO_2, and TOC

Disadvantages of EDI

- Requires high-quality feed water
- Limited removal of organics
- Susceptible to hardness scaling, organic fouling, and plugging by suspended particulates
- Product water quality dependent on feed water quality
- Susceptible to oxidation from residual chlorine
- Power consumption / need for DC

EDI Power Requirements

- Requires Direct Current (DC) power (Rectifier)
- Current requirement is directly proportional to flowrate and ionic equivalents to be removed
- Practical upper limit: 600 VDC
- EXAMPLE: A unit operating at 500 VDC (26 – 35 GPM) that draws 3 amps costs approx. $5.08 per day to operate if running continuously. (Assumes electricity cost of $0.12/kW-hr and 85% AC to DC conversion efficiency)

Image Source: https://www.gibuys.com/primax-p5500-3-400-9-a-edi-electrodeionization-rectifier-unit-used.html

EDI System Operation & Maintenance

- Monitor feedwater conditions (TOC, hardness, suspended solids, iron)
- Inspect electrode connectors for signs of corrosion or loosening
- Retorque bolts
  - Weekly for first month of operation
  - Whenever product water quality begins to decline

EDI System Clean-in-Place

- Triggered by:
  - Decreased effluent quality
  - Decreased effluent flow
  - Decreased reject flow
  - Increased in ΔP across EDI
  - Increased electrical resistance
- Chemicals Used:
  - Hydrochloric Acid (Ca scale, metallic oxides)
  - Sodium Hydroxide (Organics, biofilm, silica)
  - Sodium Percarbonate (Organics, solids, bacteria/biofilm)
  - Peracetic Acid (Bacteria)

Summary

- High-purity makeup water is needed to maintain boiler integrity and efficiency
- Boiler makeup water treatment includes a series of steps (clarification, filtration, RO) designed to remove suspended and dissolved materials.
- Final polishing (mixed bed ion exchange, EDI) is needed to further reduce ionic concentrations
- EDI combines two existing technologies (electrodialysis and mixed bed ion exchange) to provide ion removal without regeneration.

Thank You!

Questions?

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Title Slide Image Source: https://en.wikipedia.org/wiki/Heat_recovery_steam_generator

Closing Slide Image Source: http://www.cmigroupe.com/hrsg