Steam Turbines and the Challenges of Lumpy, Corrosive Steam

Geothermal Steam Chemistry

Michael Caravaggio
Director Thermal Fleet R&D

November 2023

Geothermal Steam Turbines

Steam Chemistry Point of View

Competing processes:

.. Corrosion vs. Scale Mitigation (lumps) ..

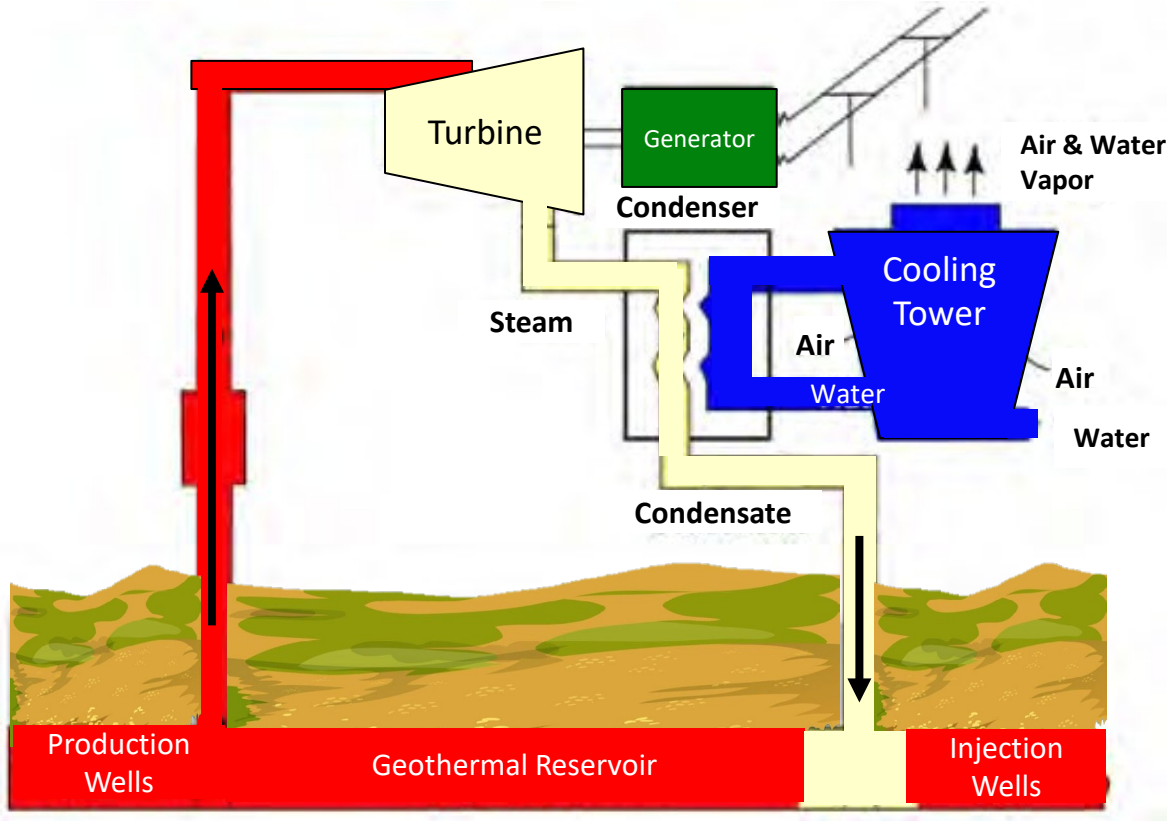
Costs of getting scale mitigation wrong seen to be higher than that of corrosion. Alloy up in the right places.

S. Addison – New Zealand

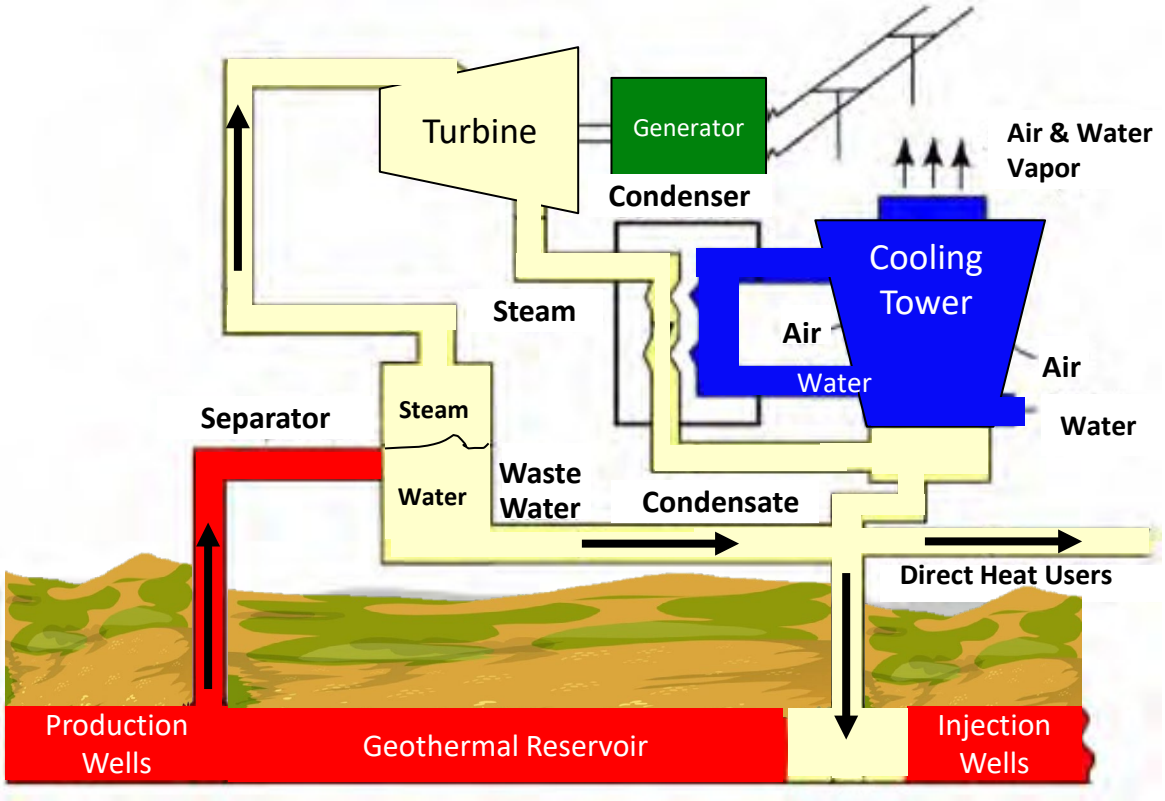
Lumpy, Corrosive Steam ~200ºC

Lumps: Silica, Iron oxides
Corrosive: Sulfate, Chloride

Direct Steam (Lumpier)

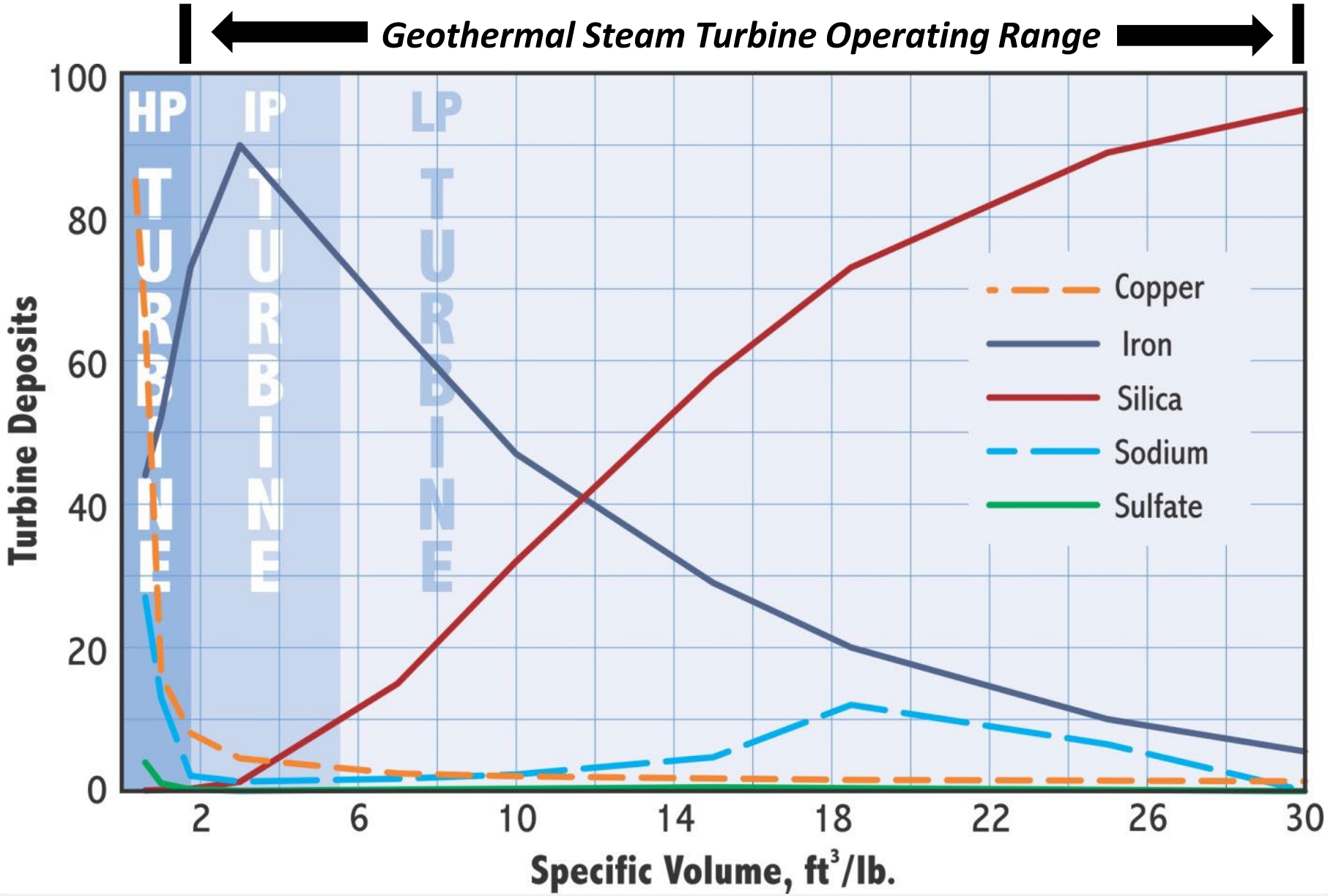


Flash Steam (Less Lumpy)



(Adapted from: Geo-Heat Center, Oregon Institute of Technology)

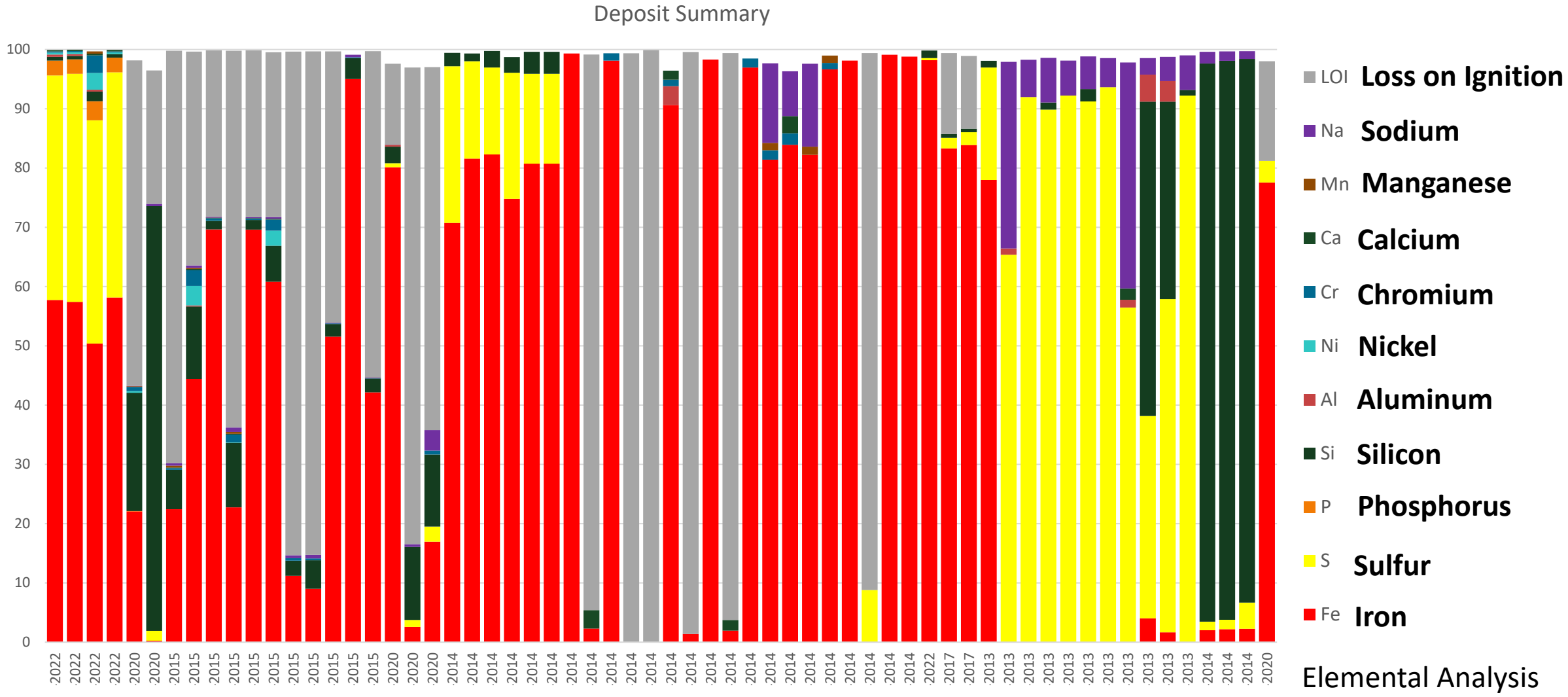
Turbine Deposits Thermal Power Plants



Typical Inlet Condition
200-300°C
near saturation
(moderate superheat)

Corresponds to
specific volume
2-1.4 ft^3/lb.

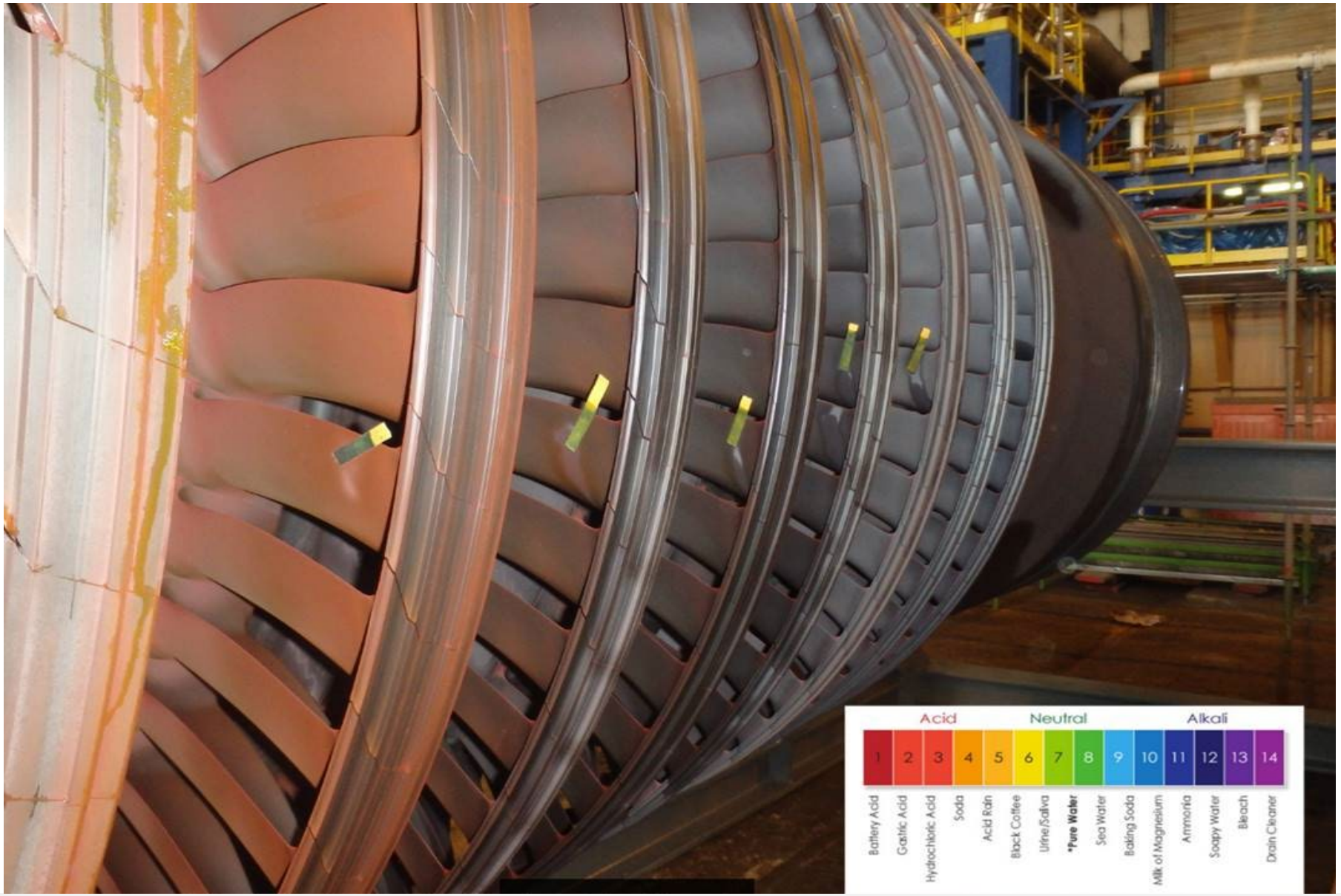
Recent Geothermal Steam Turbine Deposits



Photos, Turbine Stage, Turbine inlet temperature / pressure and out temperature / pressure

Guidelines for Turbine Deposit Collection and Analysis 1023064

Check the pH before you sample



$$pH = -\log[H^+]$$

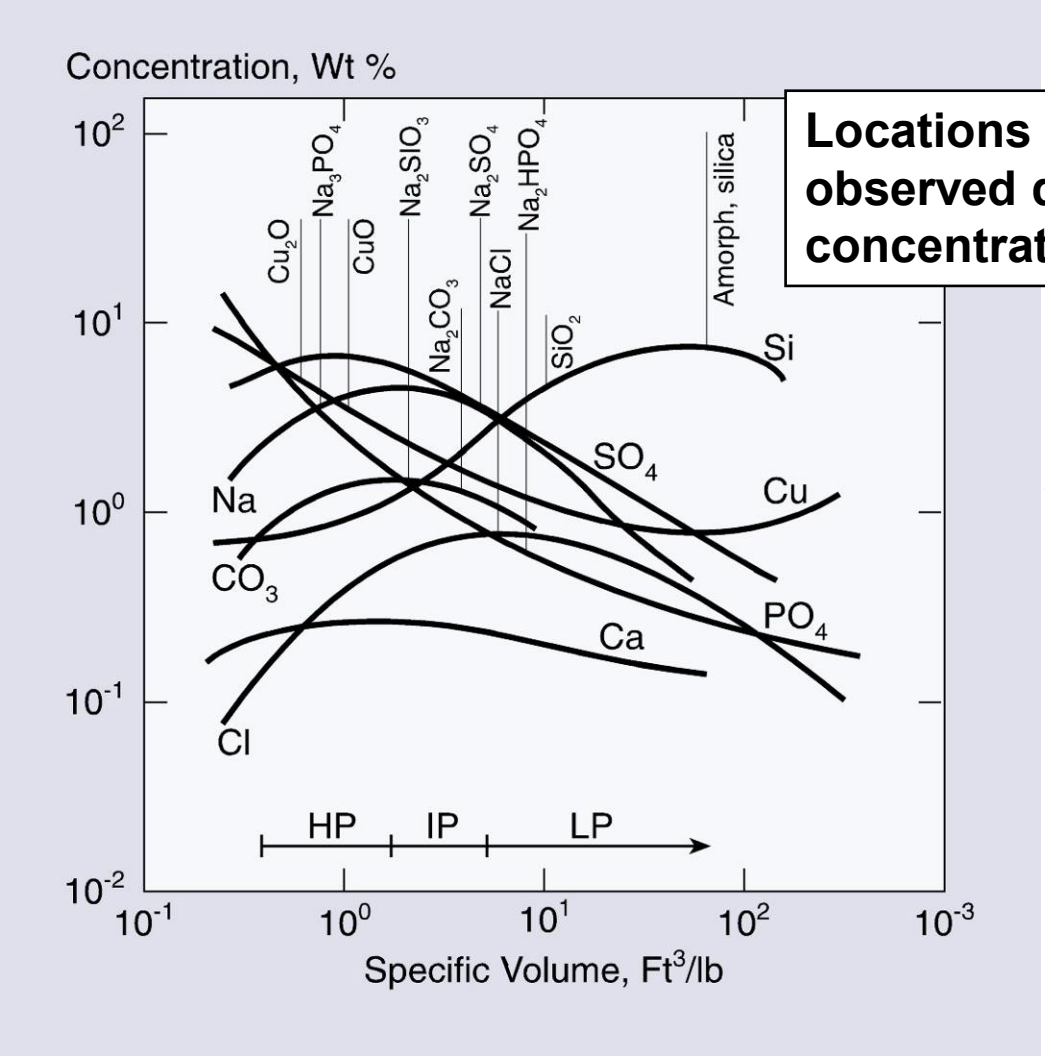
0	10^{0}	1
1	10^{-1}	0.1
2	10^{-2}	0.01
3	10^{-3}	0.001
4	10^{-4}	0.0001
5	10^{-5}	0.00001
6	10^{-6}	0.000001
7	10^{-7}	0.0000001
8	10^{-8}	0.00000001
9	10^{-9}	0.000000001
10	10^{-10}	0.0000000001
11	10^{-11}	0.00000000001
12	10^{-12}	0.000000000001
13	10^{-13}	0.0000000000001
14	10^{-14}	0.00000000000001

Wet the surface with Demineralized water and check the pH!

The more acidic the more offline protection and washing is necessary

Ideally neutral to slightly alkaline

What deposits where



Locations of peak observed deposit concentration

Copper (Cu) – HP turbine

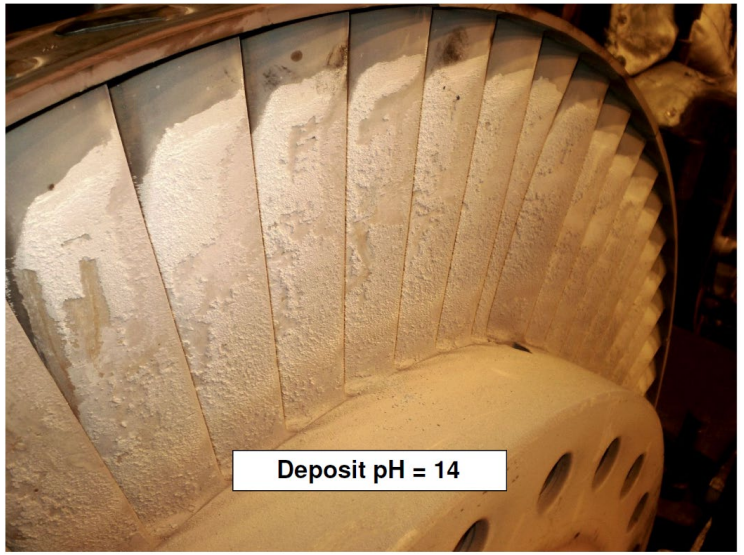
Sulfate (SO4) – HP/Reheater/IP turbine

Chloride (Cl) – IP/LP turbines

Silica (Si) – LP turbine

Sodium (Na) – Entire turbine susceptible

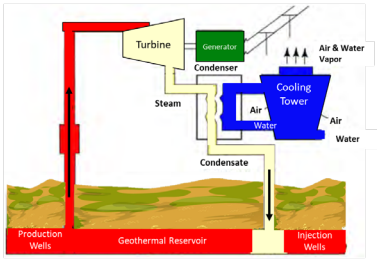
LP Turbine Deposits – nearly 100% NaCl



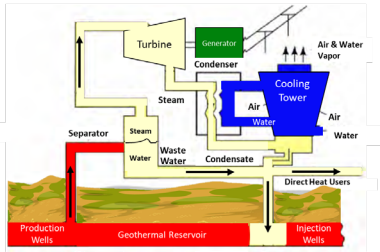
pH of >12 is concerning and a strong indicator of caustic

Lumpy Parts

Direct Steam (Lumpier)

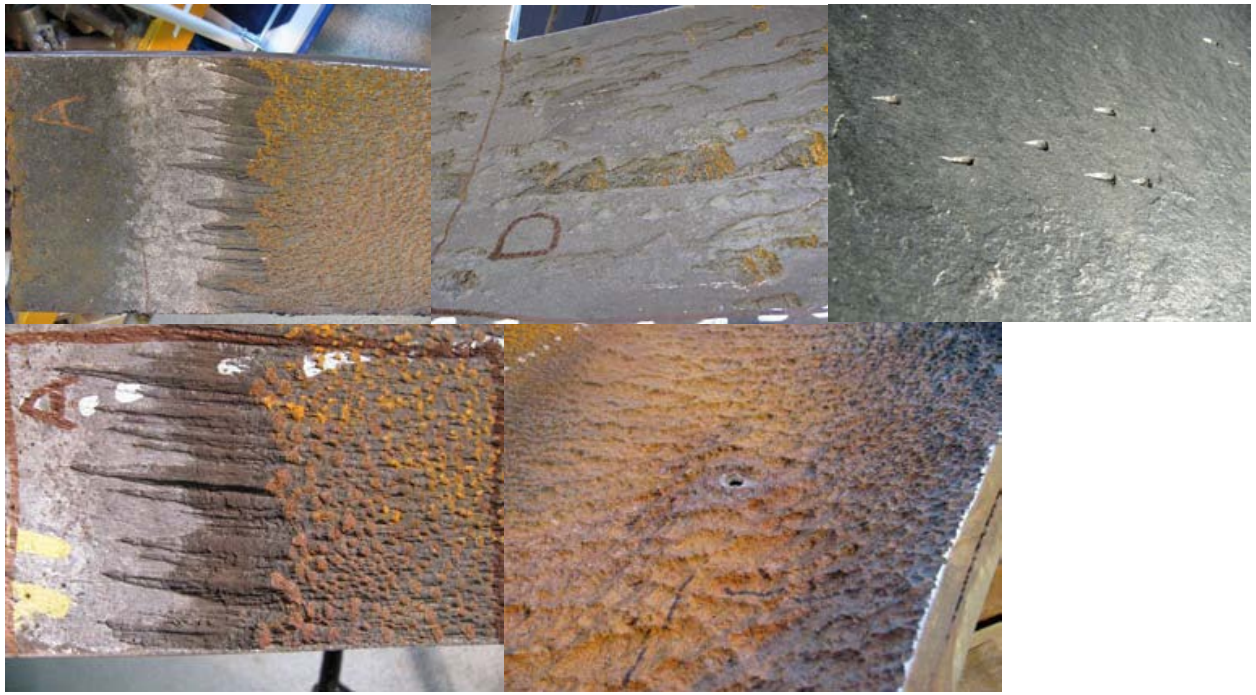


Flash Steam (Less Lumpy)



Lumps 1

- Corrosion of Iron upstream of Turbine

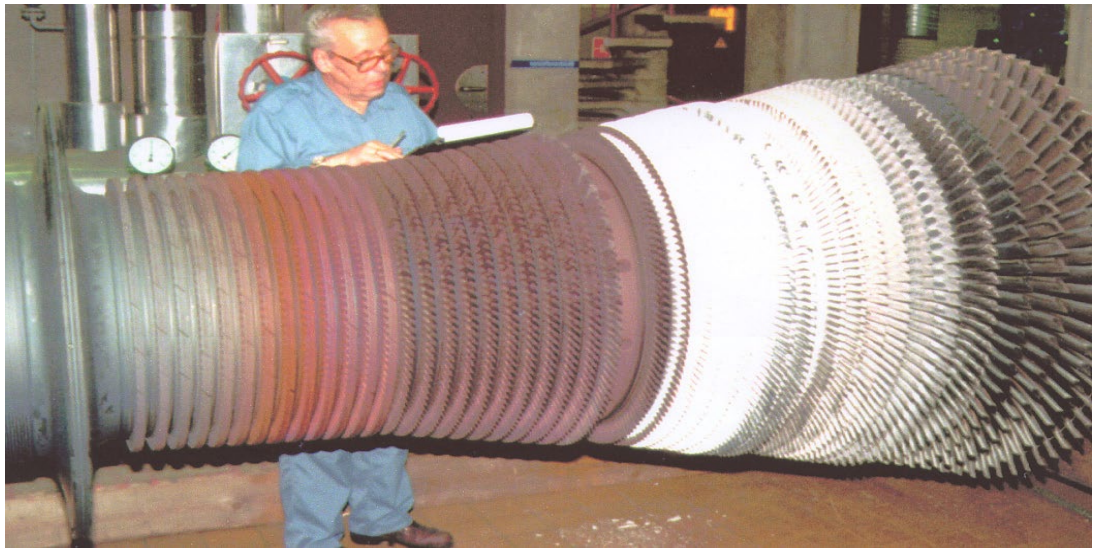


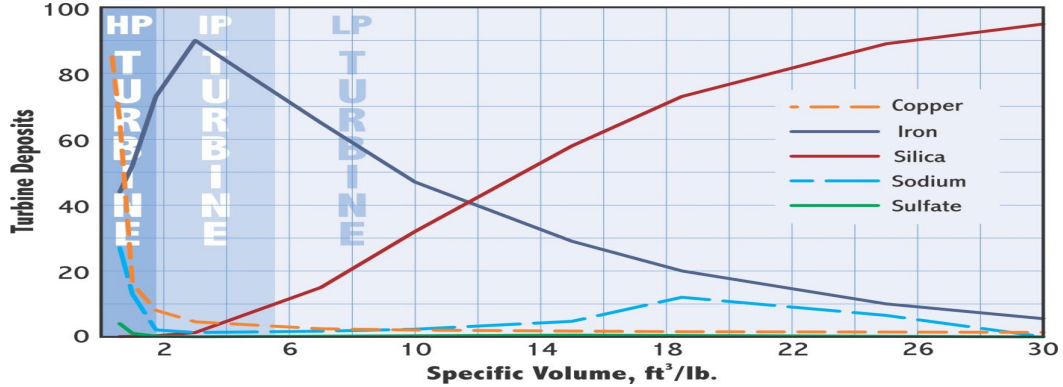
The Challenging Chemistry of Geothermal Generation
Addison 2012 – EPRI Workshop

Wetness of Steam and pH of Wetness

Lumps 2

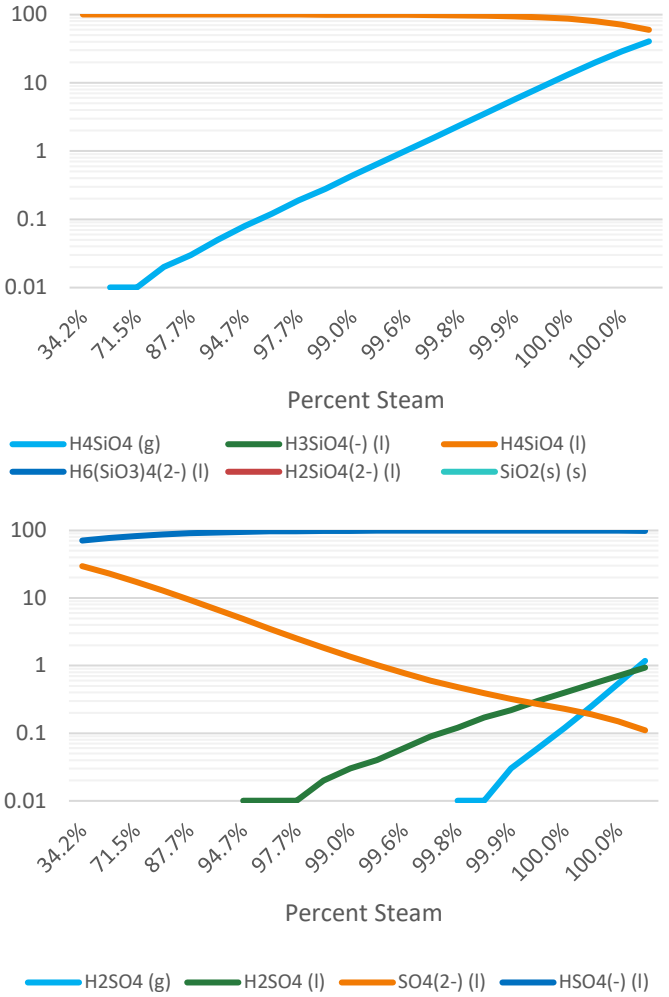
- Silica Volatility



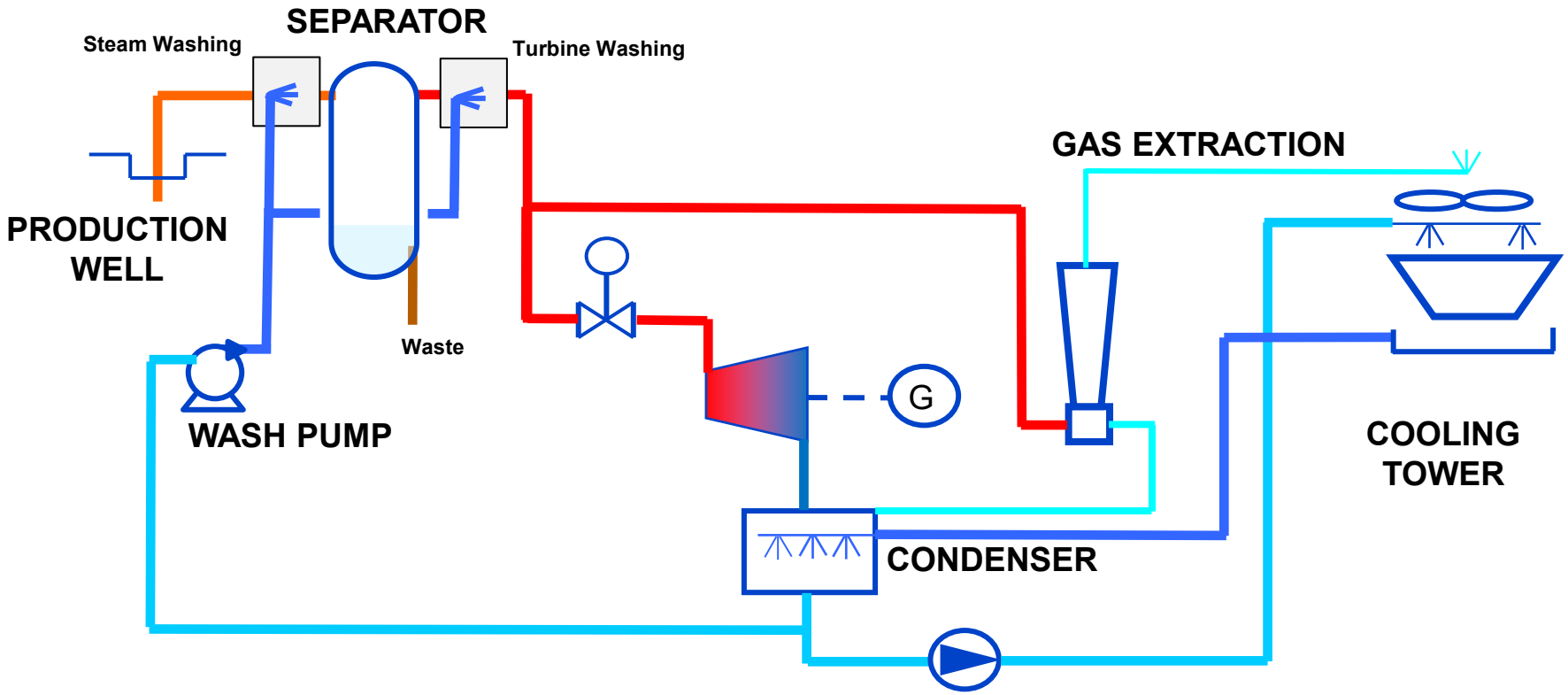


Steam Washing

MULTEQ Simulations

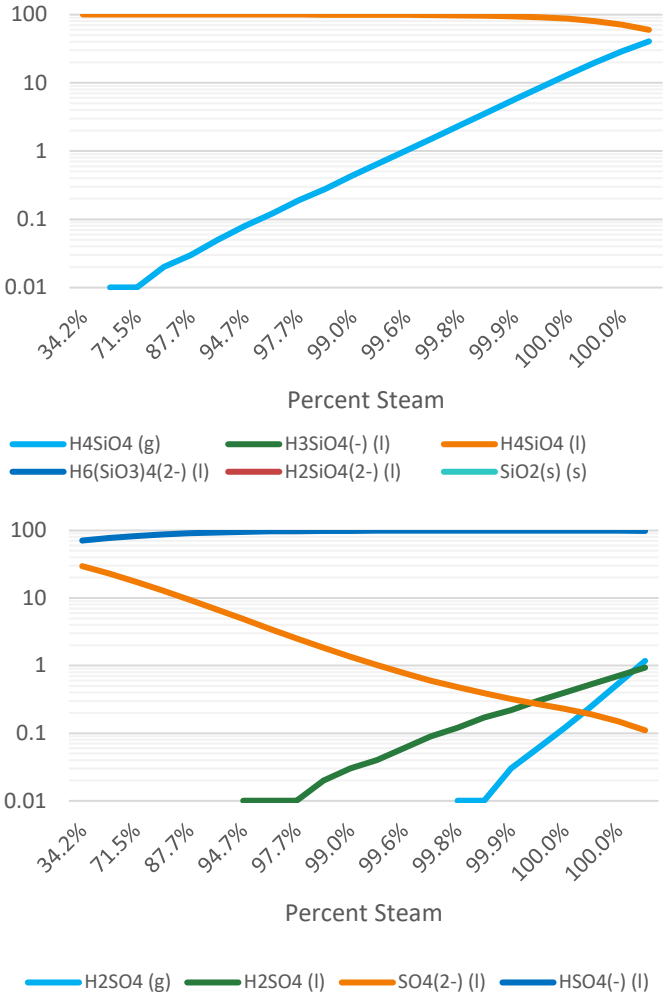


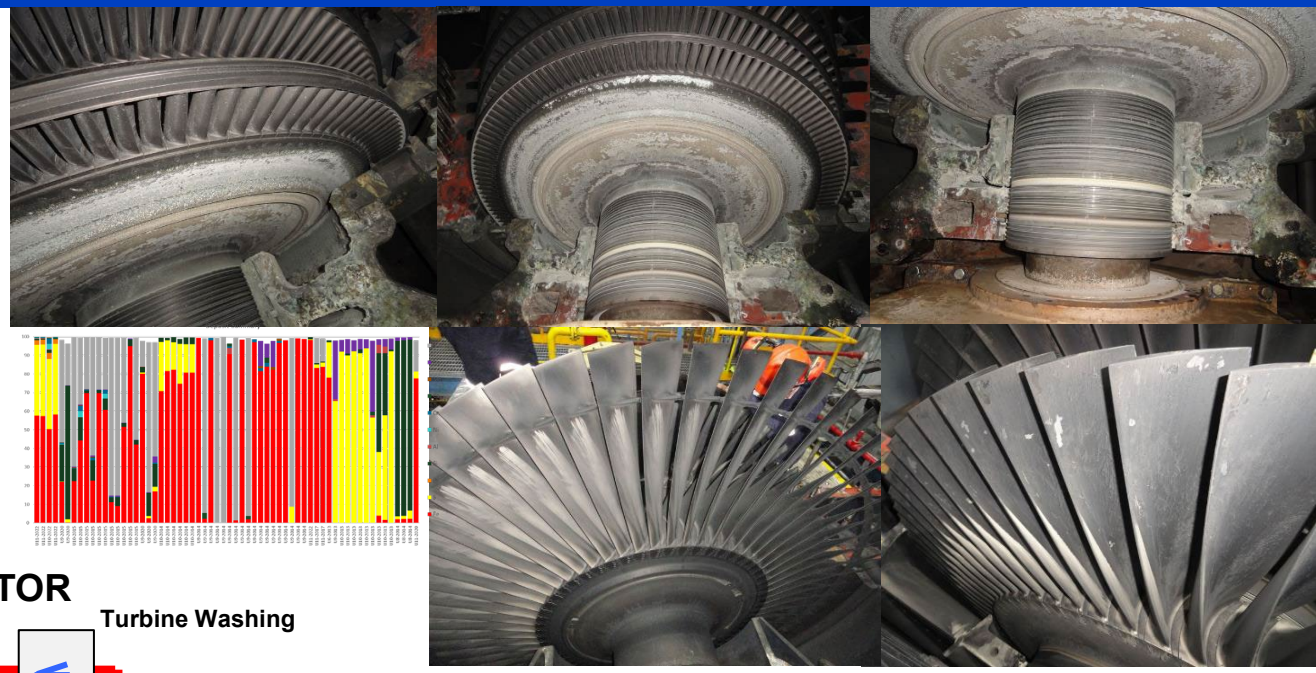
In theory washing should be very effective at reducing lumps and many corrosive elements – MULTEQ Calculations

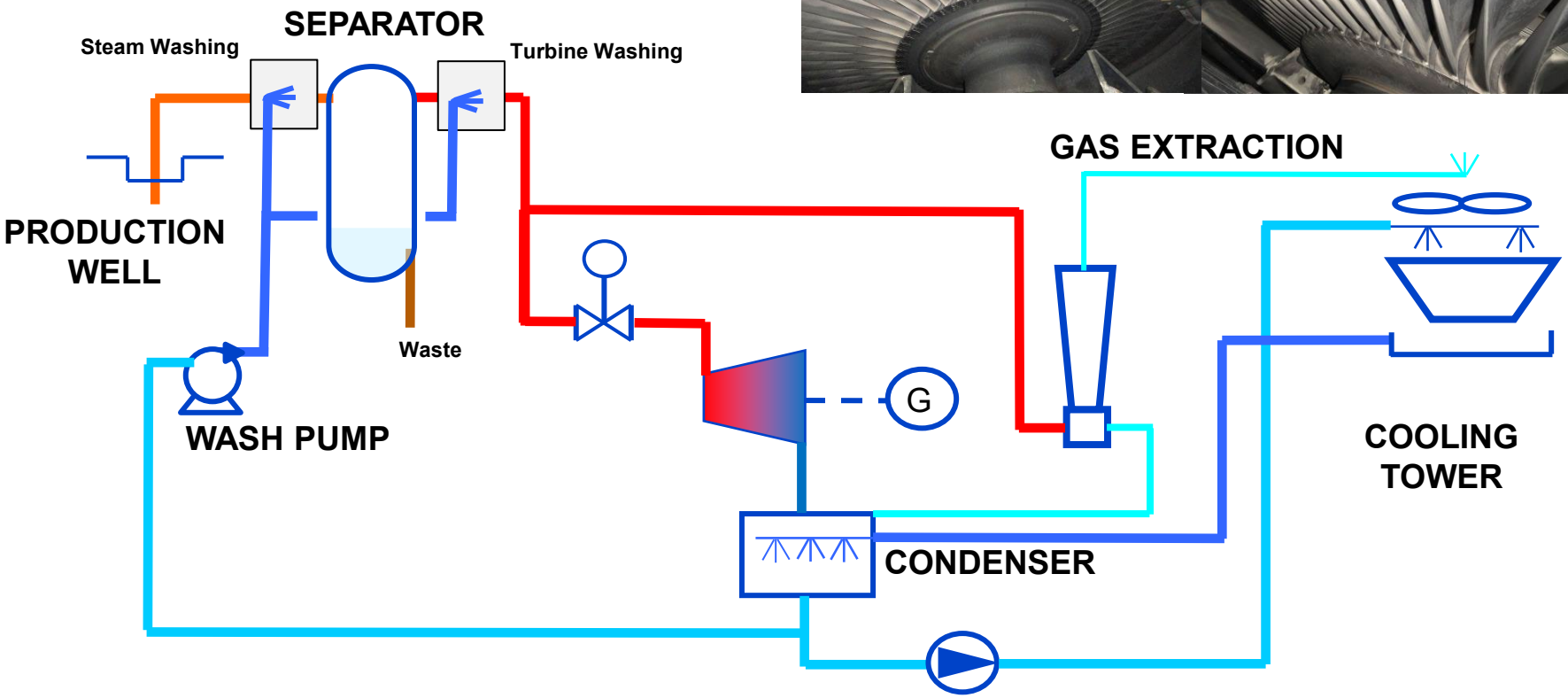


Steam Washing

MULTEQ Simulations

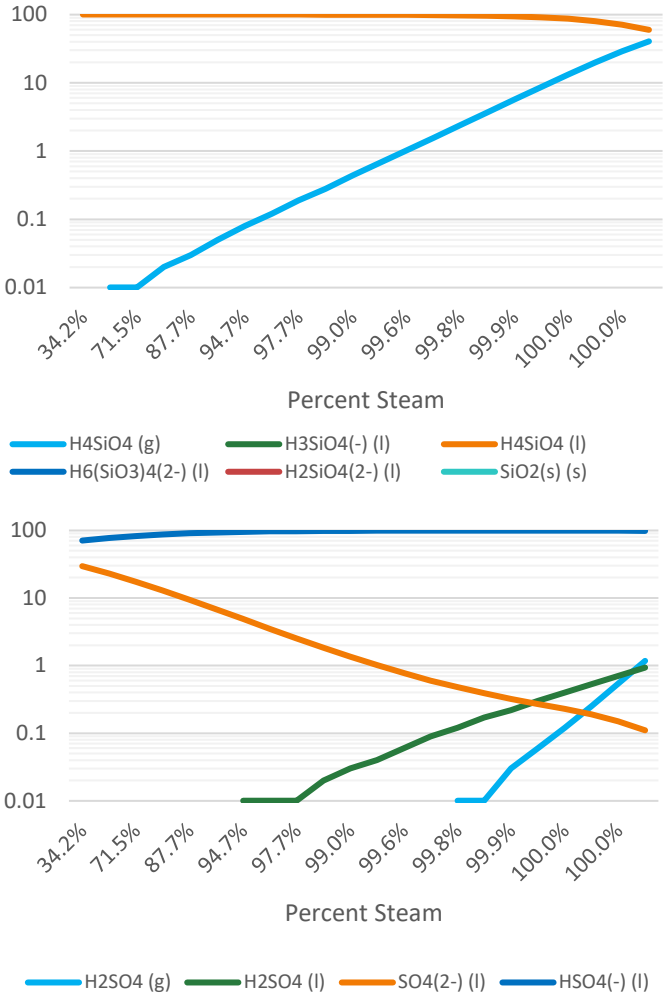


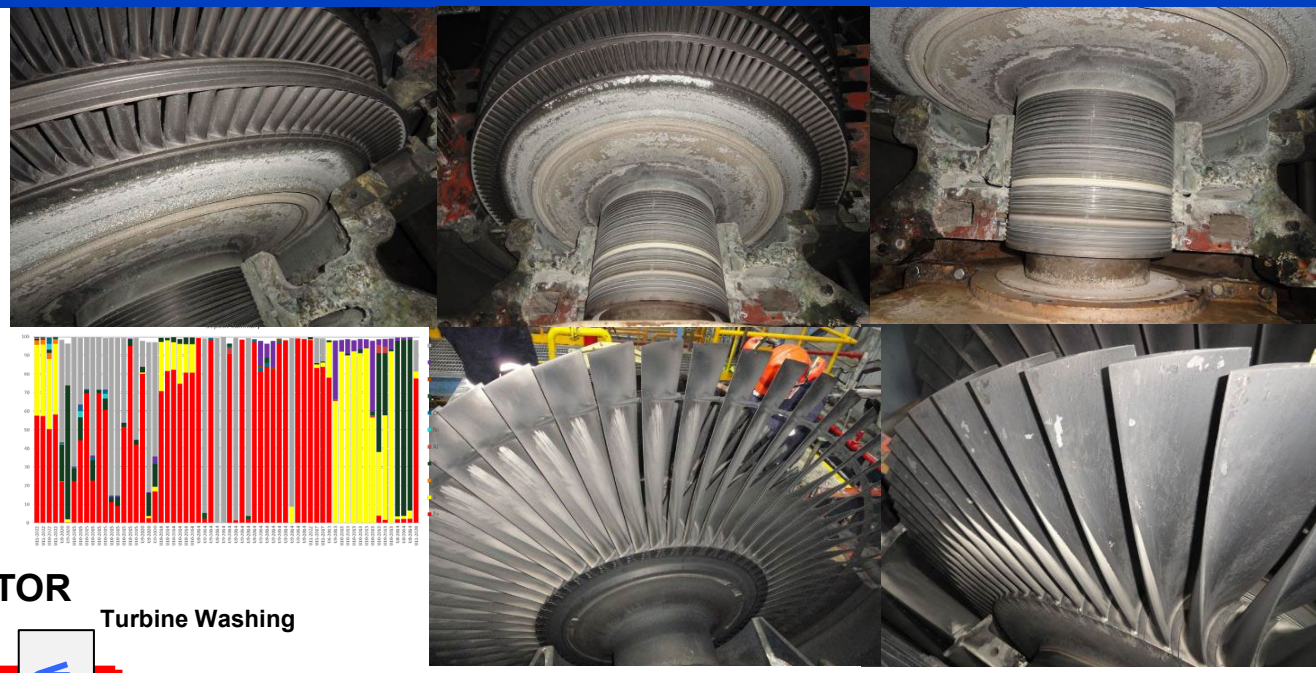


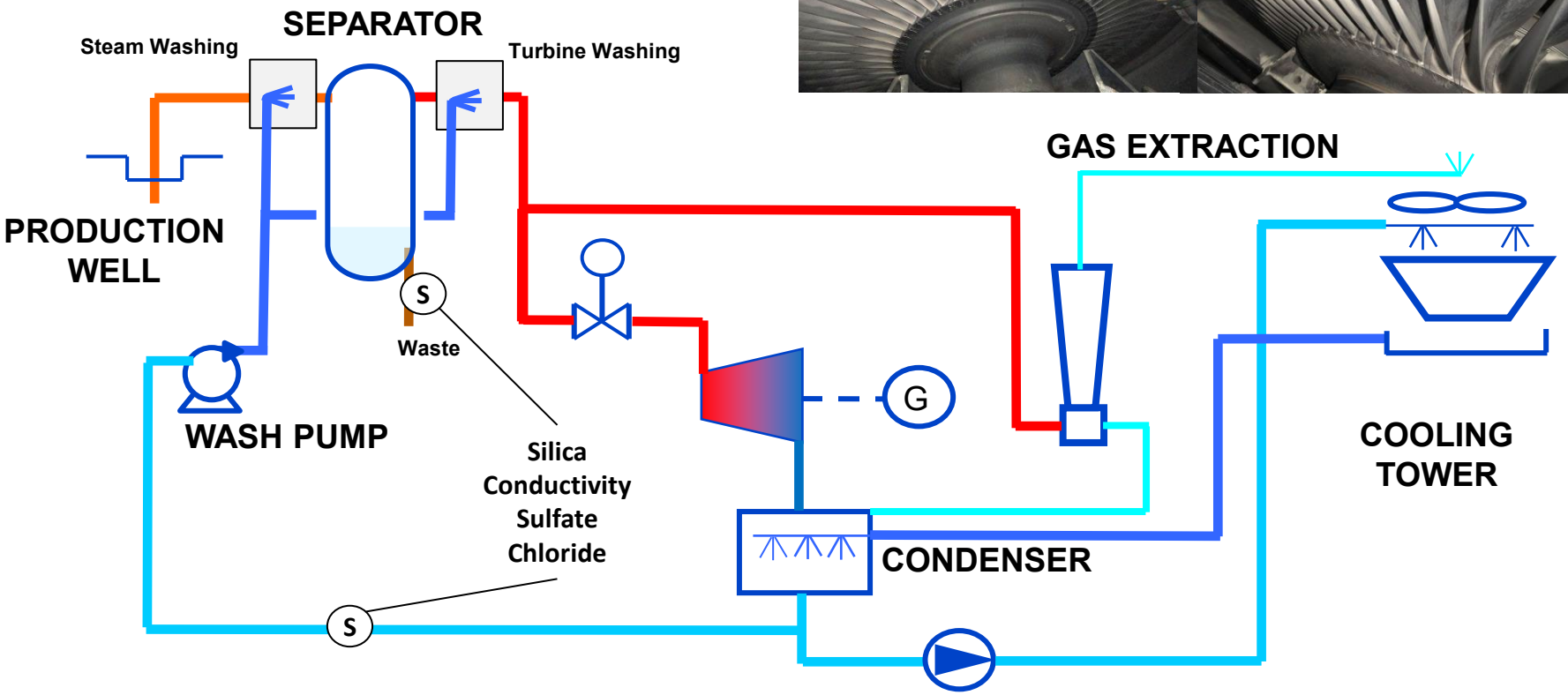


Steam Washing

MULTEQ Simulations





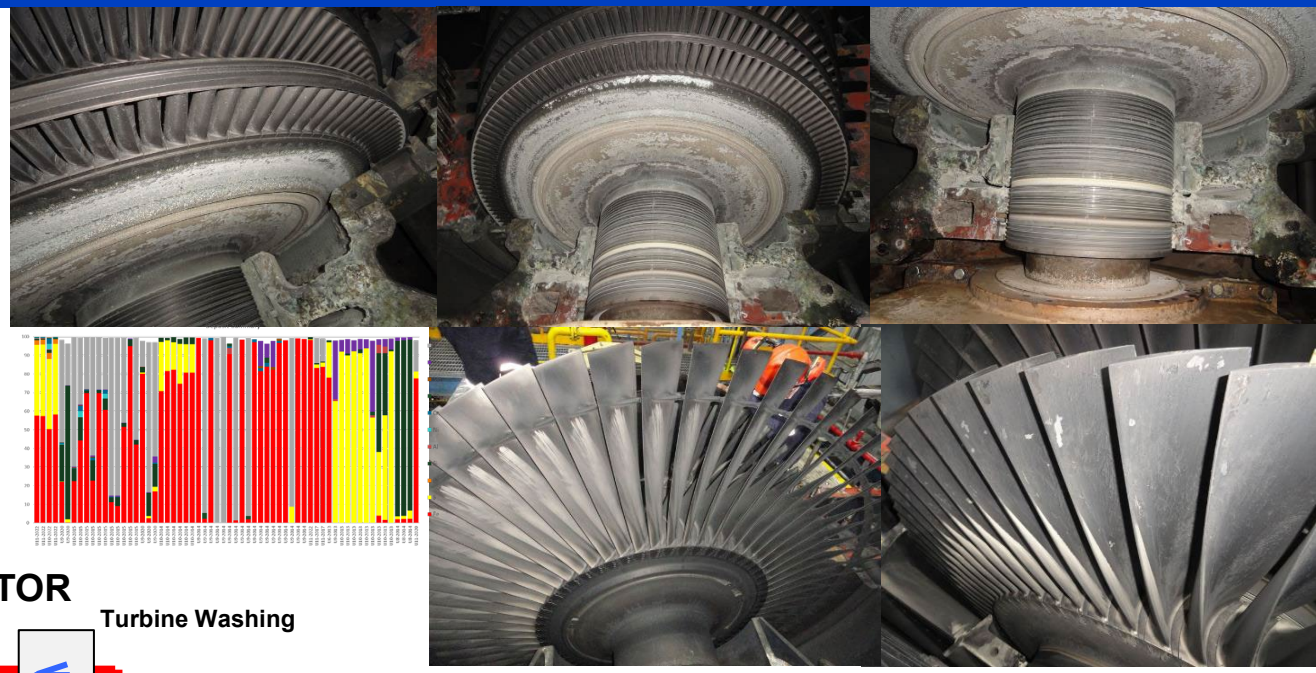


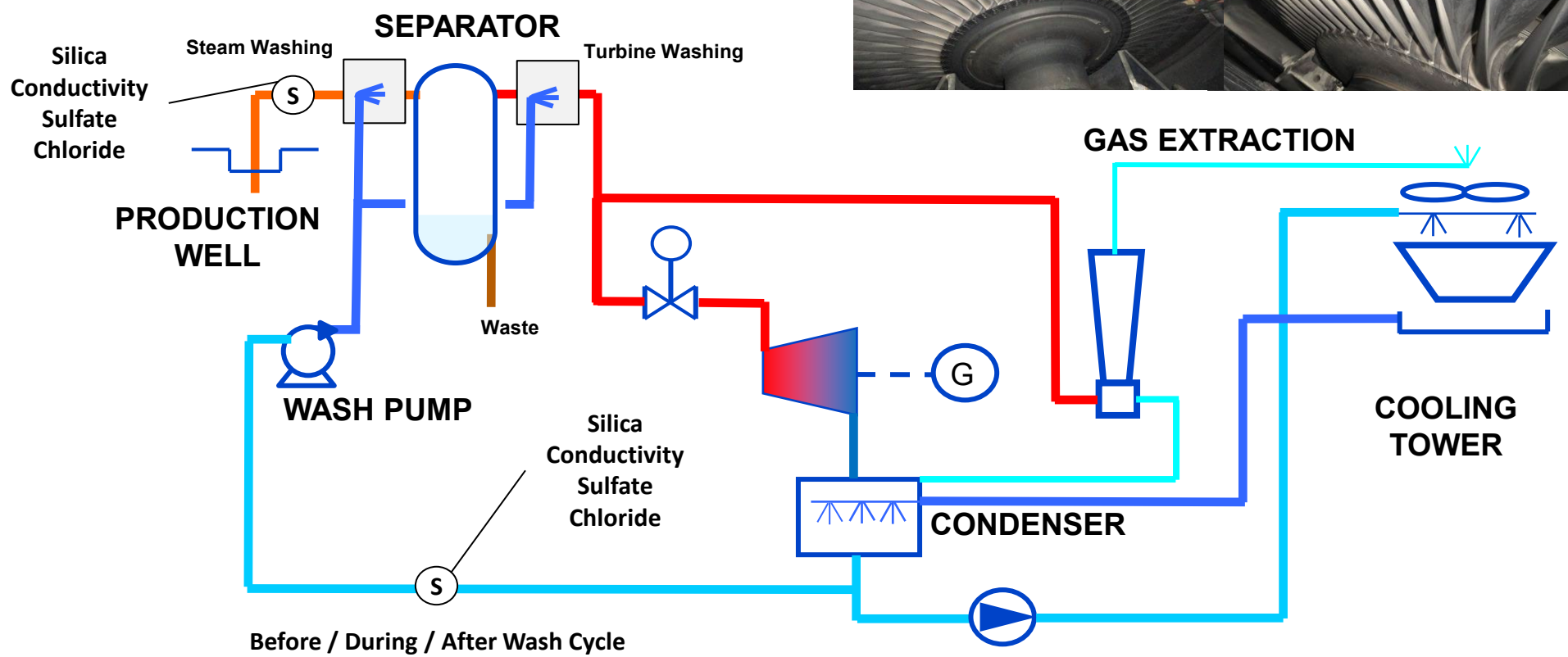
Turbine Washing

Dissolve corrosive salts

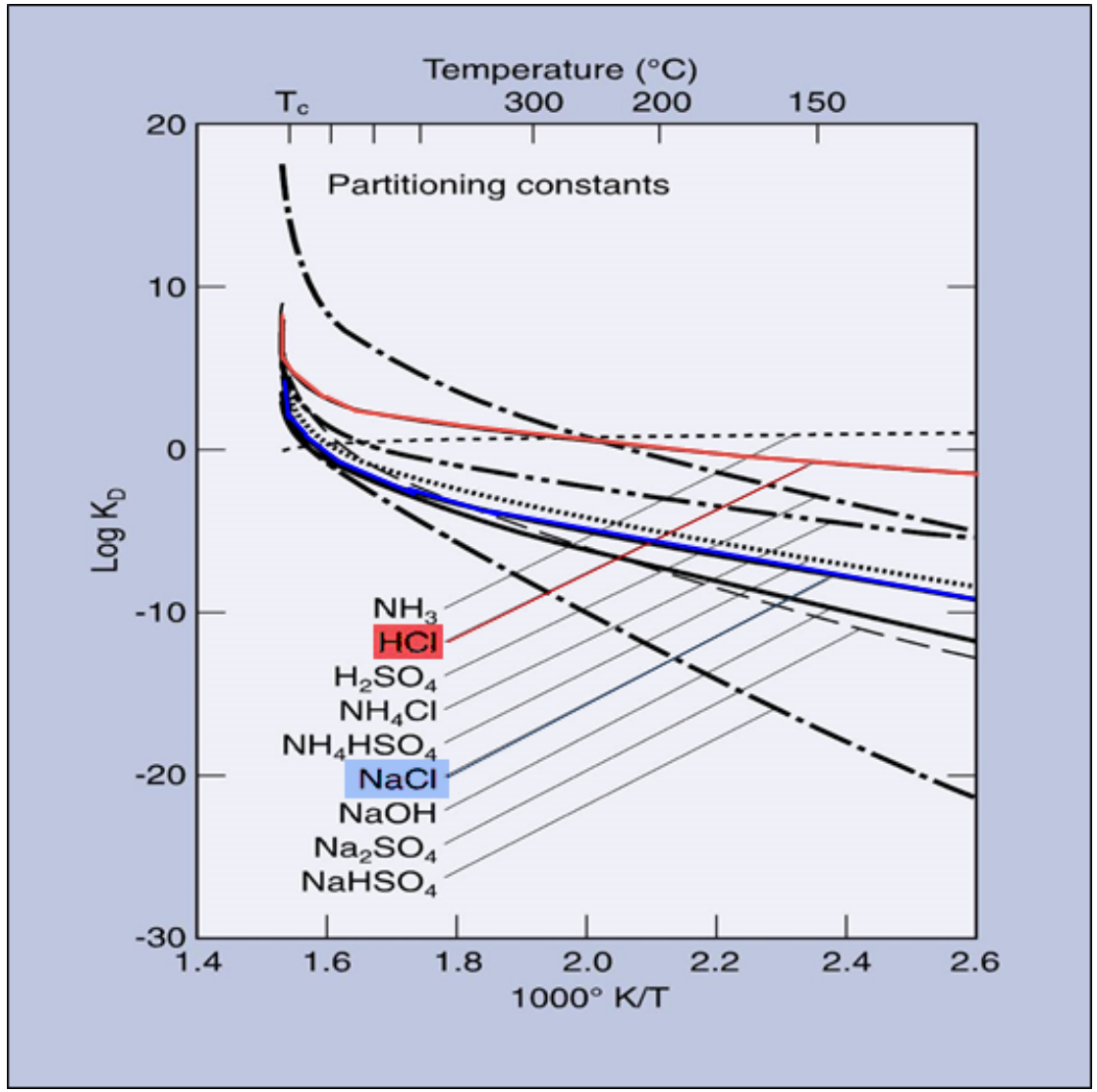
Loosen and remove lumps (silica, corrosion products)

Less corrosive (neutral to alkaline) surfaces





Down Well Treatment



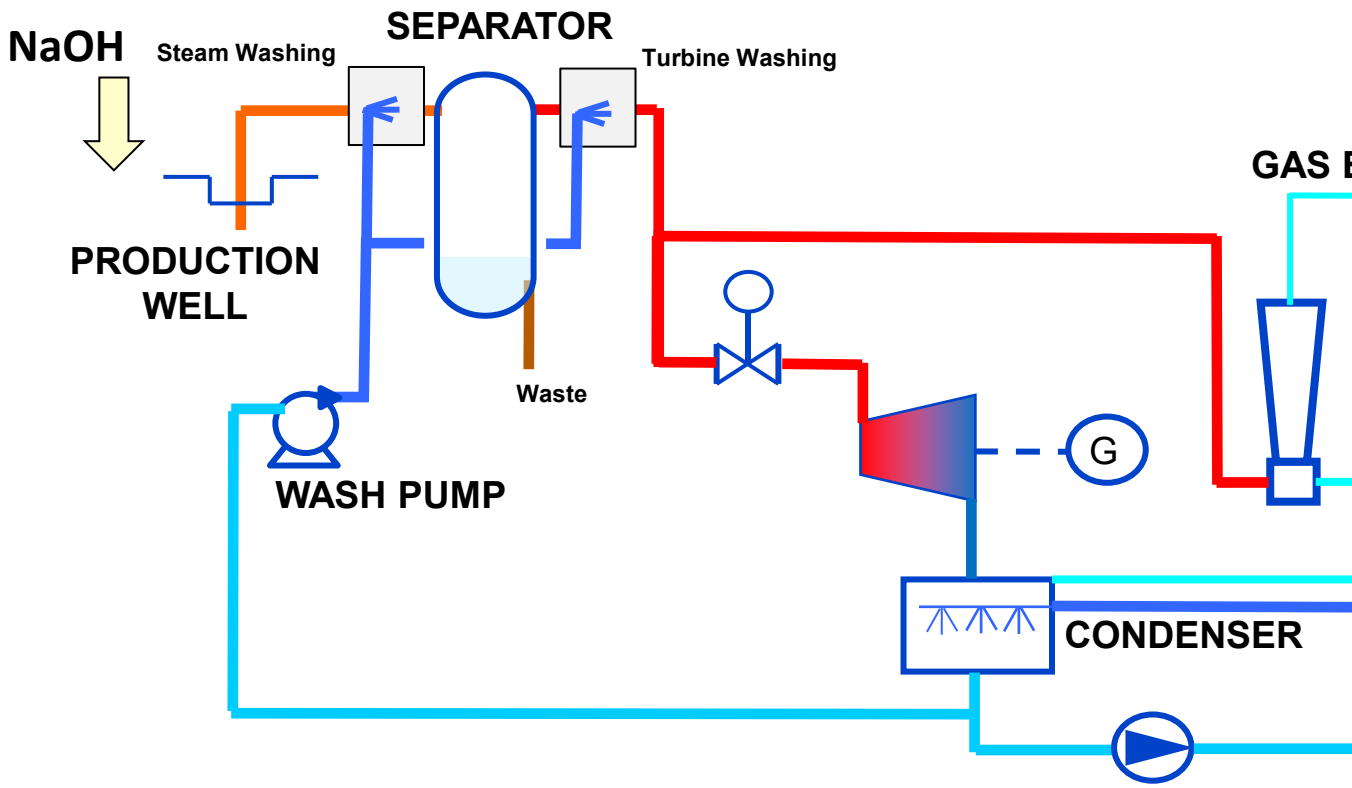
Relative Volatilities of Acid / Ammonia Salt / Sodium Salt

In most cases, acidic brine can be treated by downhole injection of sodium hydroxide (NaOH)

Presence of Ammonia (NH_3) can lower dewpoint of Chloride in Superheated Steam

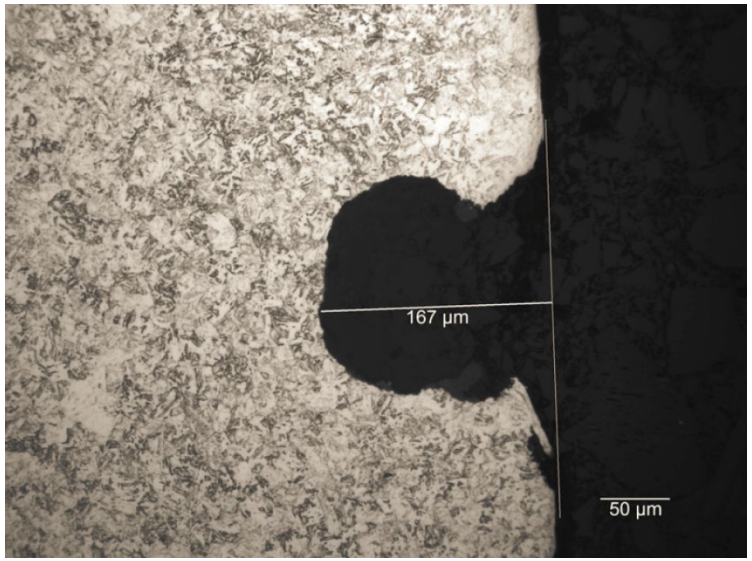
NH_3

$$HCl + NaOH \Rightarrow H_2O + NaCl$$

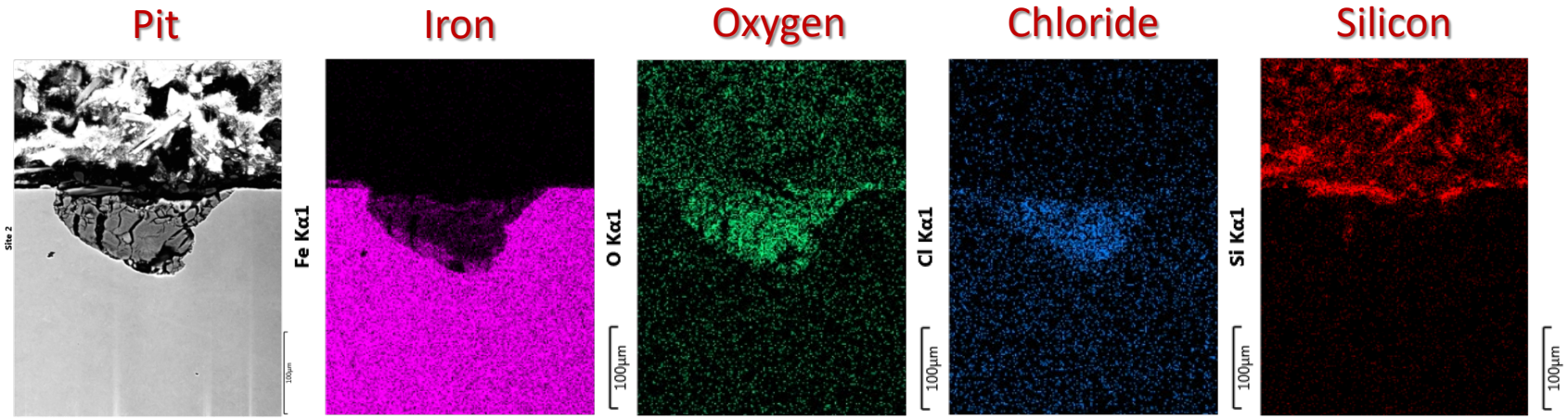


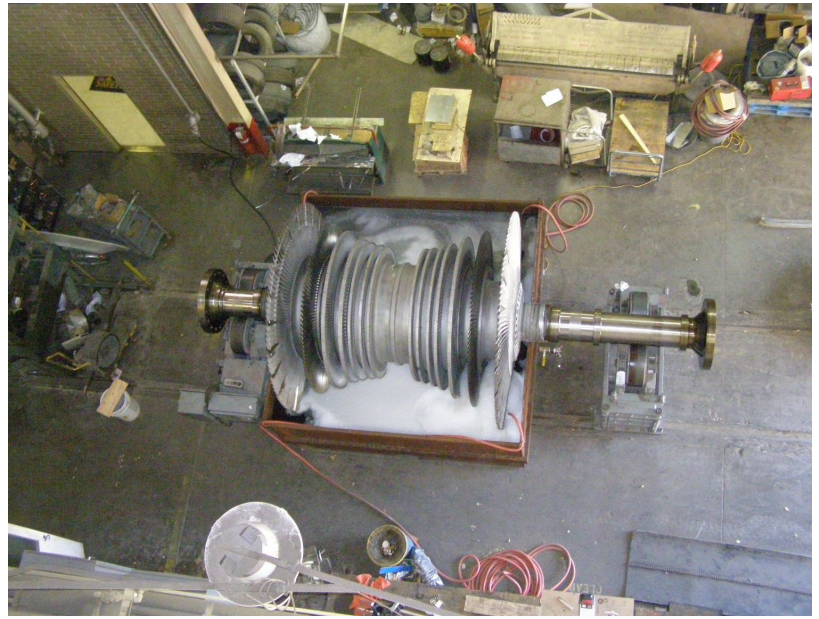
For Turbine Pitting Chloride is Normally the Culprit

- **Chloride deposits on turbine blades breakdown passivity**
  - **Typically during shutdown**
  - **Chloride migrates into the forming pitting driving pit growth**



- Once corrosion occurs – corrodents concentrate within pits and crevices and are often nearly impossible to remove
- Must remove defect
- Must wash with DI or ammoniated DI

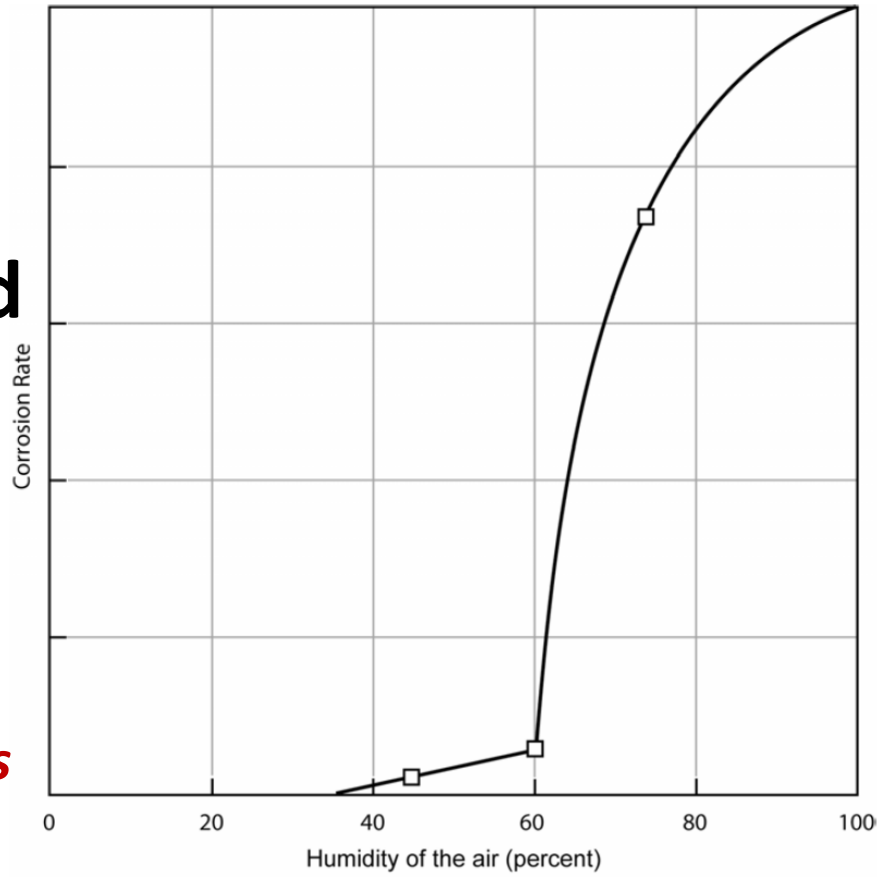




EPRI Guiding Principles for Equipment Protection

Guiding Principle #3:

Keep Water and Moisture out of Steam Touched Components and any Water Touched Surfaces to be Maintained Dry During the Shutdown Period



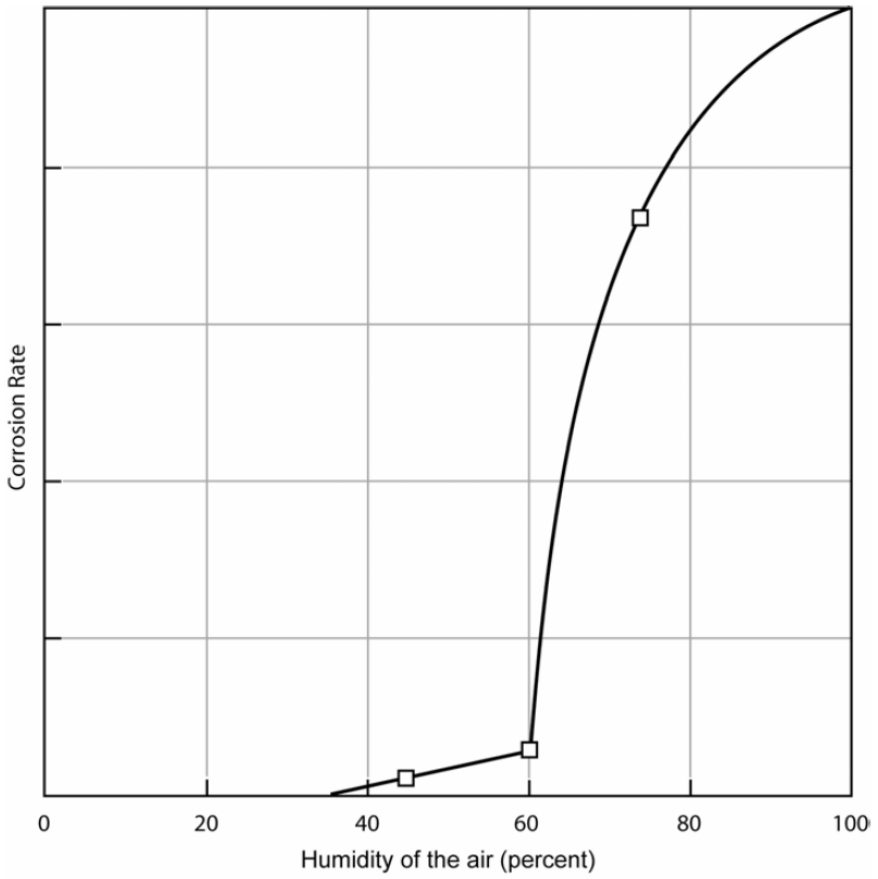
- ***Use Dehumidified Air to Protect Steam Turbines and Reheaters***
- **Drain Equipment Rapidly While Hot prior to Dry Layup and when Inspection and Maintenance are Needed**

Dry Layup

Cannot Meet 35% Relative Humidity

Component	Layup Type	Parameter	Target Value
Turbine Boiler / Condensate / Feedwater	Dry with Dehumidified Air	Relative Humidity	< 35%

- Near term and Long term
  - Adjust Air flow, try once-thru, adjust flow path
- Remember <60% huge improvement
  - Use Iron Corrosion Product Transport on startup to verify relative success



Examples of Dehumidification Systems

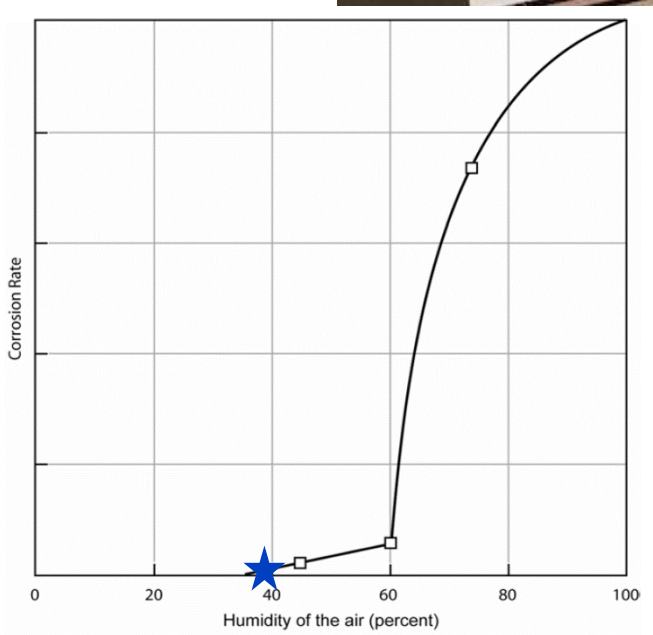
Conventional Drum Unit

Supercritical Once-Thru Unit

Combined Cycle Plant

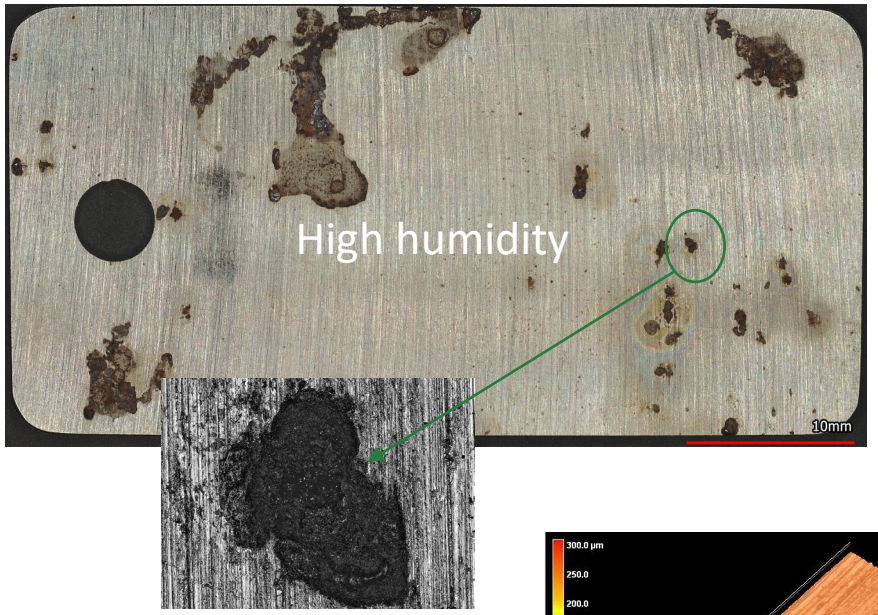
Offline Protection

- Attached are heaters installed in 2 LPs, they are 60KW heaters .
- Removed the duct from access door and lay the wand inside the hood approximately 3 ft away from L-0 buckets.
- RH reading was 39% after it had been in the hood for about 7-8 min and was still dropping

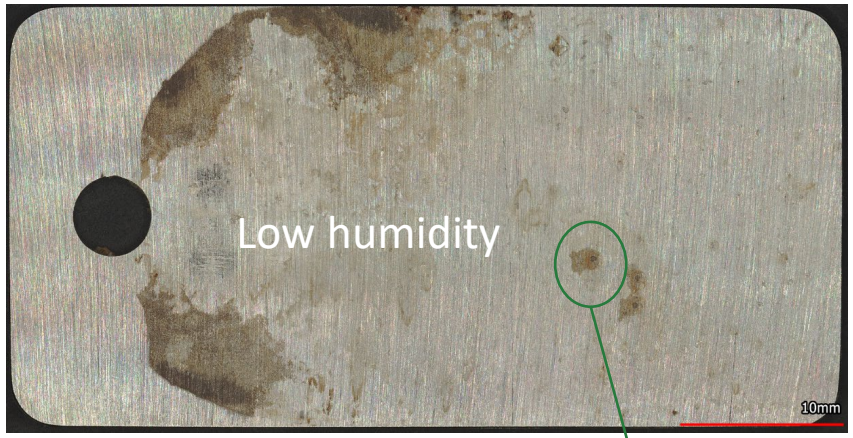


410 SS Coupon with NaCl Deposits exposed to Relative Humidity Conditions

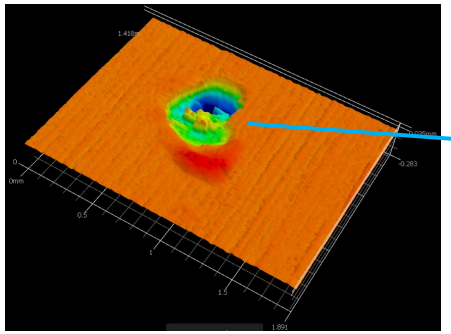
Pitting Comparison

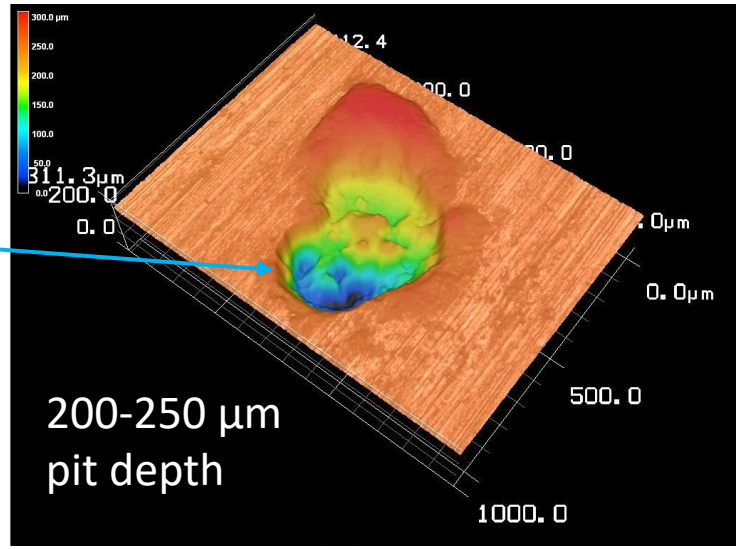


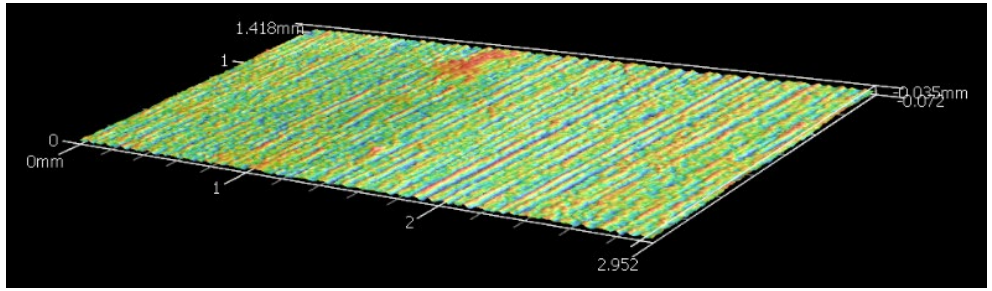
0.656 mg/cm² NaCl, 80% RH, 30°C, 1 month



1.48 mg/cm² NaCl, 35% RH, 30°C, 1 month



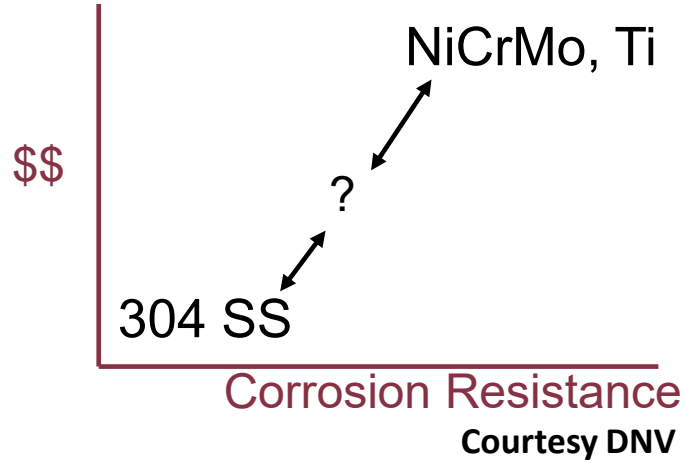




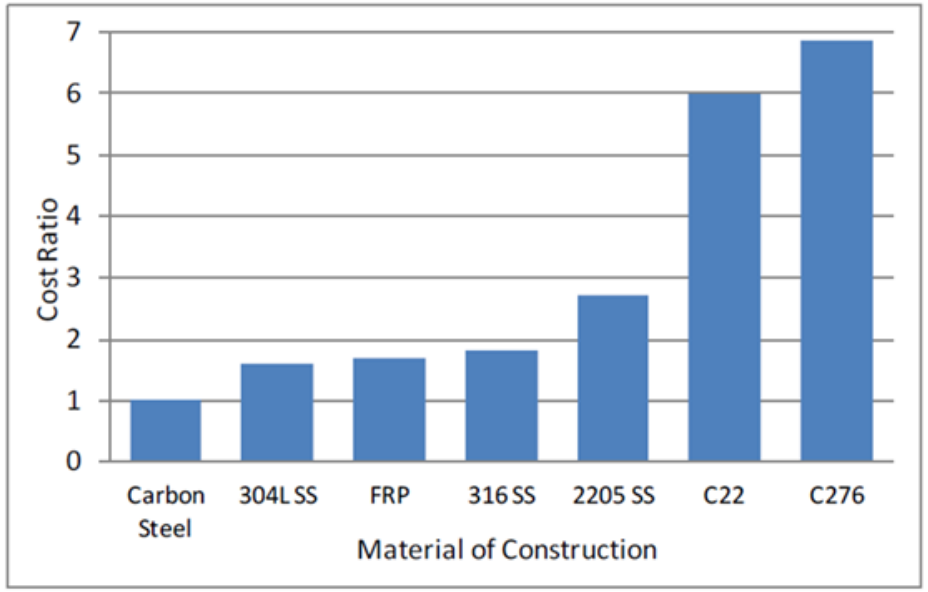
No pits, stain only

Alloying Up (Corrosive Steam)

- Cracking resistance of intermediate corrosion resistant alloys is not well defined for some geothermal environments
- Cracking and corrosion primarily influenced by:
  - pH
  - **Chlorides**
  - Oxygen
  - Temperature
  - H_2S partial pressure
  - CO_2 partial pressure
  - Stress vs. Yield strength

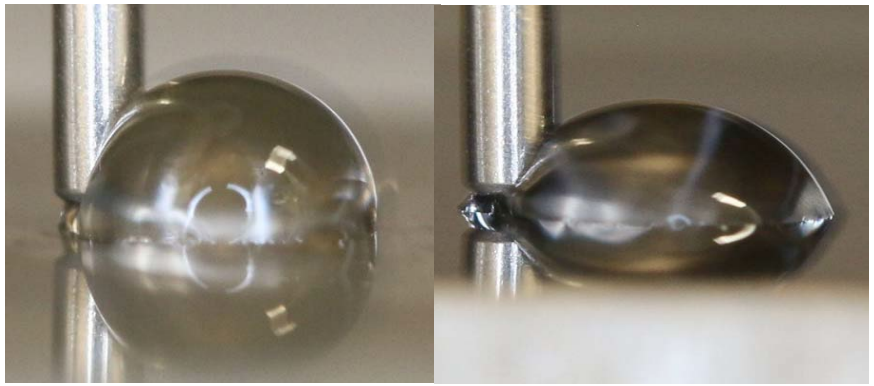


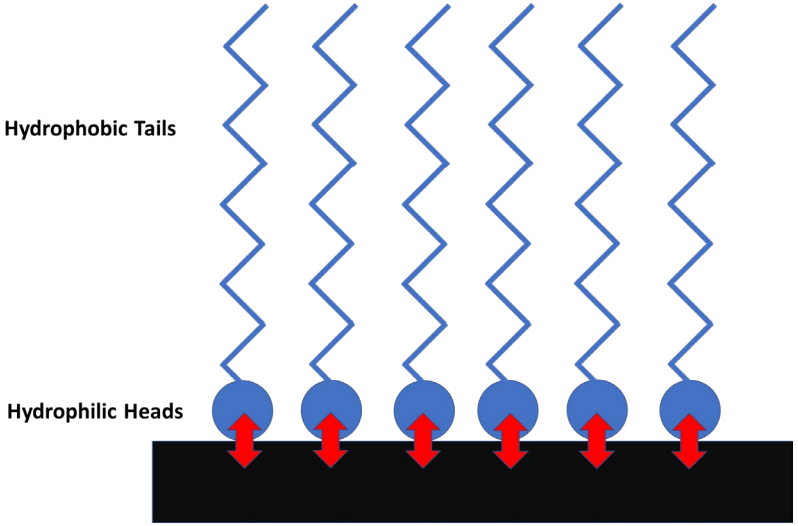
Courtesy DNV

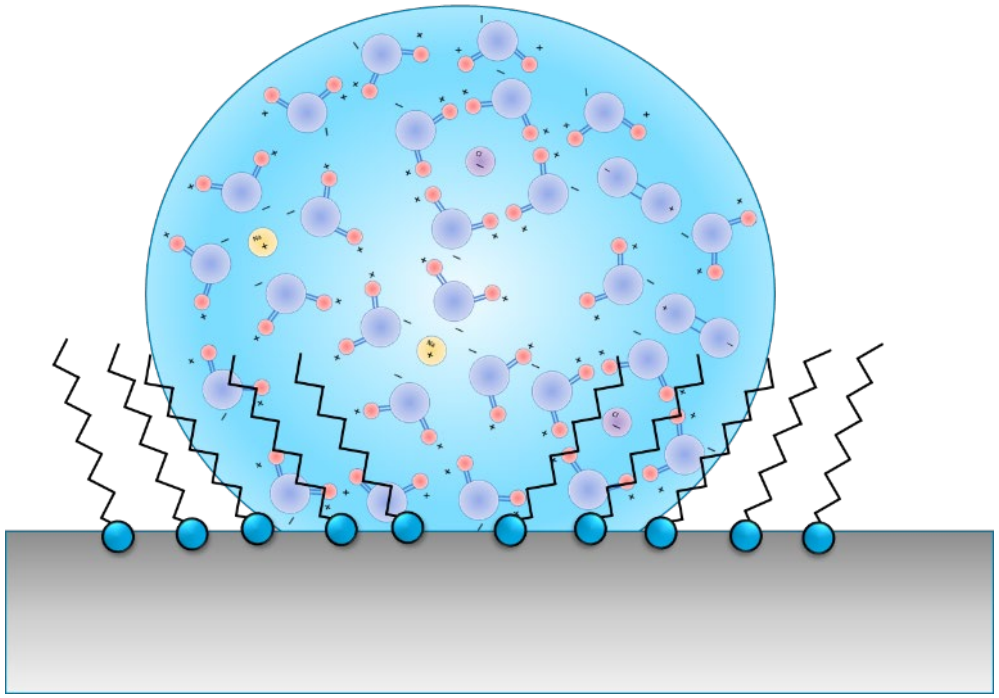


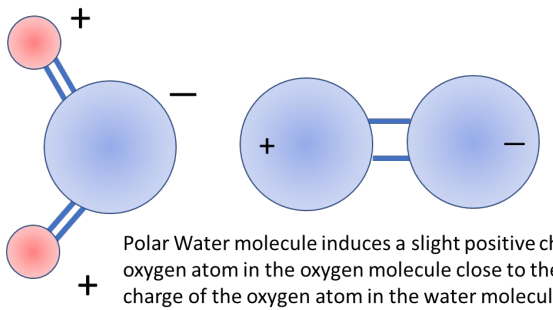
Corrosion of Materials Used in Geothermal Power Generation: Review of Materials and Treatment Technologies 3002007966

Film Forming Products





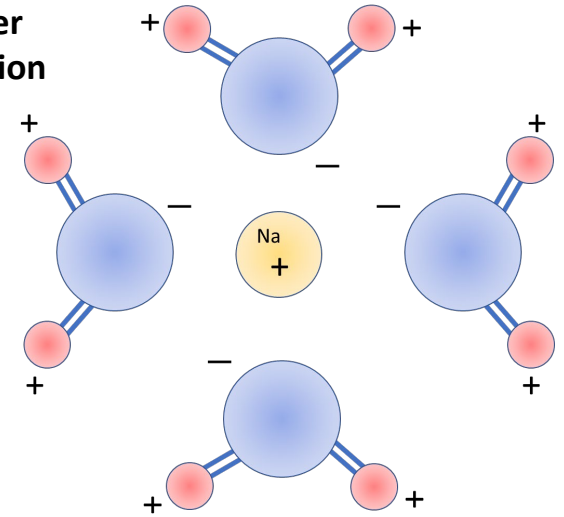




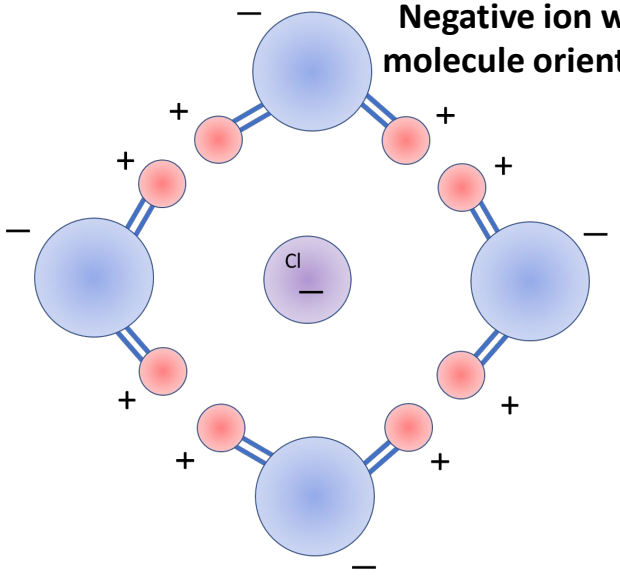
Polar Water molecule induces a slight positive charge on the oxygen atom in the oxygen molecule close to the negative charge of the oxygen atom in the water molecule

Water / Oyxgen

Positive ion water molecule orientation



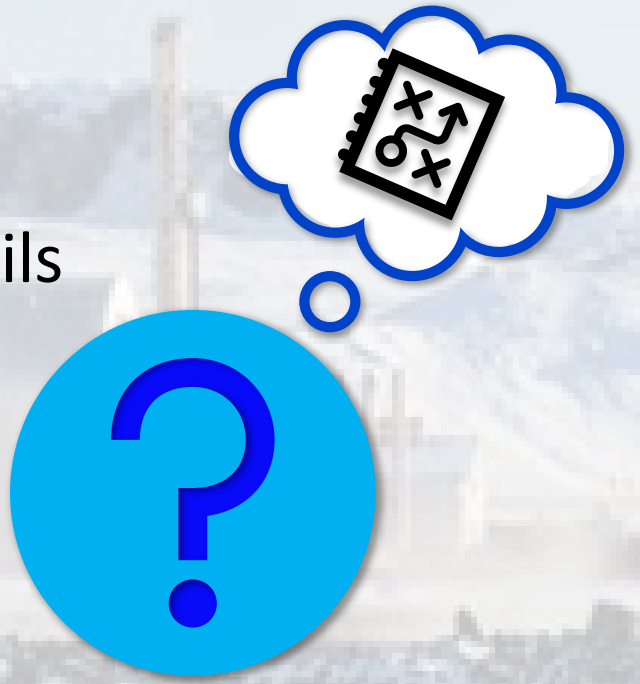
Negative ion water molecule orientation



Can prevent salt and oxygen from interacting with filmed surface

Summary

- Geothermal Steam is lumpy and corrosive
  - Monitoring and careful analysis can help develop strategies to optimize and minimize issues
    - Down well options
    - Chemistry of wash waters in and out
    - Details on Turbine Deposit
      - Pictures of pre-sampled material with location details
      - pH of deposit prior to sampling
      - Composition detail and loading estimation
    - Evaluation of preservation needs



Together...Shaping the Future of Energy®