Managing start-ups & Managing exfoliation in super critical Boilers

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1. Introduction :

Coastal Gujarat power Limited (CGPL) power plant consists of 5X830 MW supercritical units and is the first UMPP. It is the first Green Field Project to have five similar size supercritical units in single phase. The project was executed thru' CGPL, a 100% subsidiary of Tata Power. It is a coastal project using imported coal as primary fuel and sea water for plant use. The fresh water requirement for the plant is met by 25 MLD desalination plant based on Reverse osmosis technology. In supercritical units, the quality of the feed water has long been an important factor in the operation of boilers. Hence utmost care is required not only in design but also in operation and maintenance of the same.

2. Brief Details of water treatment plant

a) RO Stage I

- Overall Recovery: 40%
- No of Streams: 4 X 25%
- Total capacity: 1050 m3/hr

b) RO Stage II

- Overall Recovery: Min 85%
- No of Streams: 2 X 50%
- Total output at outlet: 150 m3/hr

c) DM plant (Mixed Bed units)

- No. of units : 3 X 50%
- Capacity: 160 m3/hr

d) Condensate Polishing Unit

- Type : Deep Mixed Bed Units Vertical (Spherical)
- No. of units: 2 X 50 %
- Capacity : 992.5 TPH each
- Operation: Hydrogen cycle

e) Oxygenated Treatment Plant

Various feed water chemical treatment methods were examined during conceptualization and after thorough analysis, all volatile treatment (AVT) was selected for the start-up, shutdown and condenser tube leakage cases and oxygenated treatment was selected for normal operation.

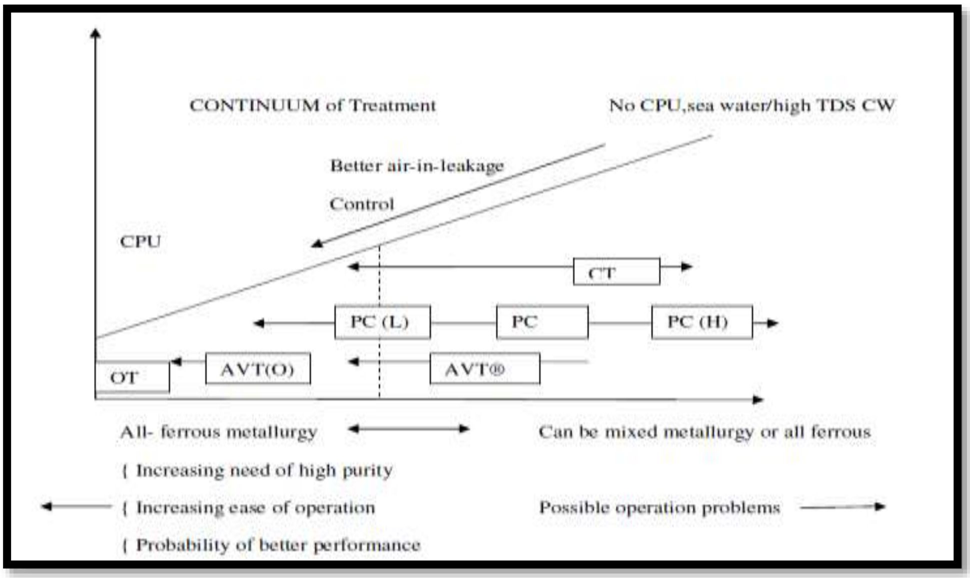


Fig- General guidelines for boiler feed water chemical treatment system

3. Breakthrough Achievements in water chemistry at CGPL

a) **Boiler Clean up during start up:** CGPL team implemented various innovative methods to reduce the time duration for boiler clean up to 3 days (compared to earlier 3 weeks) based on their learnings from the Boiler clean-up process at U# 10. This also helped in optimum utilization of DM water.

The salient features of steps taken are as follows:

- De-aerated water was used for boiler clean-up in place of non de-aerated water.
- The procedure of boiler filling & draining was done simultaneously instead of complete boiler draining & filling (complete draining of boiler was causing oxygen ingress and was leading to degradation of boiler protective layer).

b) **Optimum utilization of DM water during commissioning**: CGPL team carried out detailed strategic planning for DM water generation and consumption during start-up and commissioning to avoid shortage of DM water.

c) **Corrosion tendency of SWRO water**: SWRO permeate which is being used for service water and fire water, showed a reddish brown color post commissioning and eventually leading to minor leakages. CGPL team quickly analyzed the issue and arrived at optimum dosage of calcium chloride and sodium bicarbonate in the service water to make the LSI value slightly positive (neither scaling nor corrosive). Presently Calcium chloride of 75 % purity and sodium bicarbonate in of 99.8% purity is being dosed.

d) **Adoption of Oxygenated Treatment:** CGPL team has been the first adopter of Oxygenated treatment in 830 MW boilers in India.

Following are the limitations with respect to standard plants:

- No Stand by CPU
- No extra Margin in CPU regenerating capacity
- Absence of Condensate dump line
- Absence of pre filter

4. Challenges faced and Mitigations:

4.1 Increased start up time after cold start up:

In supercritical units, the quality of the feed water plays an important role in the efficient operation of the boilers. For this reason, 'Clean-up Process' is being adopted for every cold start up, to obtain the required purity in condensate / feed water. As a part of Re-commissioning activities, after every shut down, prior to taking the system into service, it is ensured that the internals of the piping/equipment are clean and free from any foreign materials, debris. It is also necessary to remove loose dirt and water soluble ingredients in the circuit by mere filling and blow out prior to every startup of the unit, either from cold or long shut down.

However In-spite of having very good chemistry programs in place, it was observed that considerable time is taken for the clean-up cycle in comparison with initial predictions and some of the other super critical units during start up after long shutdown of boiler.

Analysis of Clean up cycle: Cause and Effect Diagram

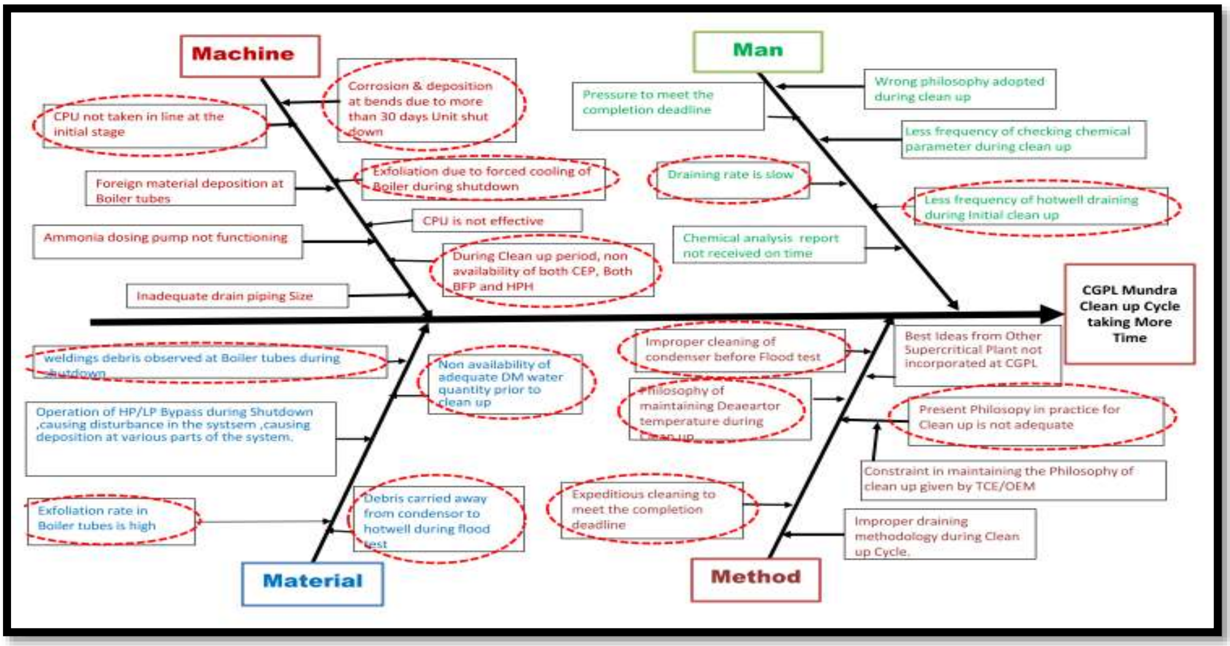


Fig - Cause and Effect Diagram

The problem was studied in detail. Based on brain storming sessions, various Probable Reasons were captured in C & E diagram which is given below:

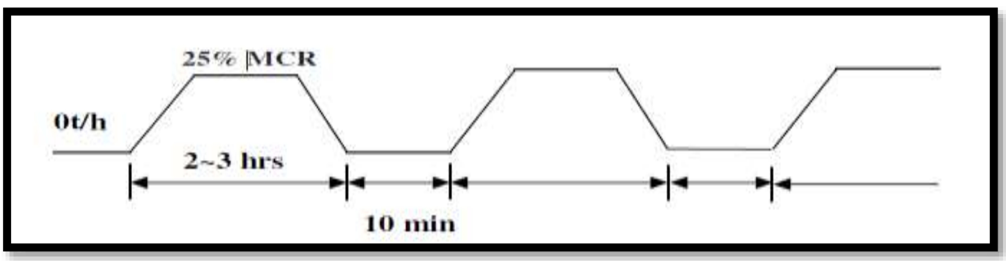
Major observations from cause & effect diagram:

As it could be seen from the Cause and Effect diagram, the major reasons are given below:

a) More rigorous and thorough cleaning regime required.
b) 100 % CPU to be used in pre-boiler clean up also
c) Requirement of Forced cooling of Boiler during Shutdown which may be one of the cause for exfoliation
d) Lower Deaerator temperature during clean up cycle
e) Exfoliation from the super heater tubes
f) Non availability of 100% equipment during start up
g) Inadequacy system Infrastructure

4.1.1 Corrections adopted in start-up cycle:

a) During Condensate Clean-up blow out, complete Hot well filling and draining to be carried out at-least 2-3 times.
b) Manual isolation valve of hot well drain to be opened 100% for effective flushing.
c) Before flood test of condenser, cleaning of hot well to be done by filling hot well to normal level and again draining the hot well completely. After cleaning the Hot well only water filling to be done for Flood Test of Condenser.
d) During condensate system clean up**,** CPU shall be taken in service when iron content of less than 500 ppb is achieved.
e) During feed system clean up cycle, deaerator temperature to be maintained at 130°C to achieve lower levels of DO and iron (During Recent Unit 20 flushing, Deaerator Temperature was maintained at 130 °C and the water chemistry parameters were achieved faster, as compared to earlier start up).
f) Online pH and Dissolve Oxygen parameter should be made available at DCS.
g) For initial clean up (during commissioning or after long term shutdown), carryout “flow swing” (25% MCR for 2 to 3 hrs then 0 t/hr for 10 minutes again 25% MCR for 2 to 3 hrs then 0 t/hr for 10 minutes)



h) During hot flushing, at Boiler Pressure 4-5 Kg/Cm2 before closing the vents, boiler bottom ring header drains to be opened for 10 Mins to have a proper flushing of the system. With this Hot flushing parameter will be achieved in a faster manner.

i) Prior to clean up cycle ensure both CEP/BFP/Boiler Fans are available for operation. All related PTWs must be closed.

j) Condensate Dump Line/ Blow off Line at CEP Discharge shall be provided at a suitable location to take care of high crud burden and reduce the loading on CPU.

k) During clean up, immediately after taking CEP on Recirculation, vacuum pulling and gland steam charging activity shall be carried out (TG should be on barring gear). With this it is expected that turbidity due to gland steam charging will get cleared in the initial stage itself.

l) LP Clean up Recirculation line from D/A to Hot well via FT 1 to be taken in service after getting clean up parameter at Deaerator. Prior to this CW pump to be taken in line and TG gland sealing charging to be done. With this and CPU in service parameter will be achieved faster.

m) The Recirculation line from the separator to the condenser shall be made available and to be used during flushing. This is required for creating proper flow during flushing, which otherwise is dependent on makeup water quantity.

n) Installation of pre-filters and additional regeneration facility for CPU to address the exigencies is being proposed.

4.2 Exfoliation observed in Unit # 20

a) After synchronizing Unit # 20 post annual overhaul, final super heater metal temperature excursion was observed which restricted unit loading.

b) 8 No of Blow outs were carried out by HP/LP Bypass. During the blowout activity, the turbidity level in condenser increased from 10 NTU to 50 NTU which indicated carryover of exfoliated material from super heater/ Re heater

c) Before steam blowing RT was done for the super heater tubes which experienced high metal temperatures. RT revealed deposits in some of the tubes. Suspected tubes were cut which on opening revealed deposits/scales, confirming exfoliation.

d) After achieving chemistry parameters, unit was synchronized and full load could be achieved without any metal temperature excursions.

4.2.1 Mechanism of Exfoliation (as outlined by EPRI)

a) Exfoliation is the expected result of continued oxide growth.

b) The rate of oxide growth increases exponentially with temperature, and also with the steam pressure raise.

c) The major factors associated with scale exfoliation include:

- thick scales;
- rate of temperature change;
- Alloy type (ferritic versus austenitic).

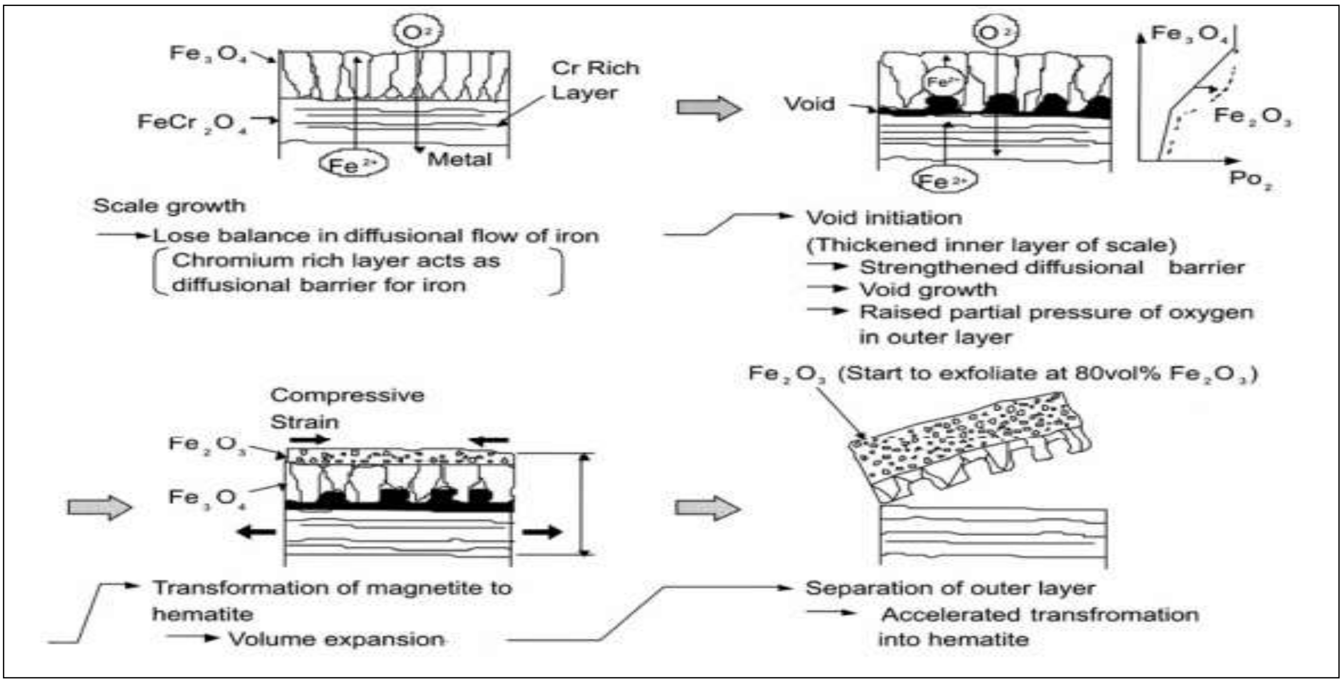
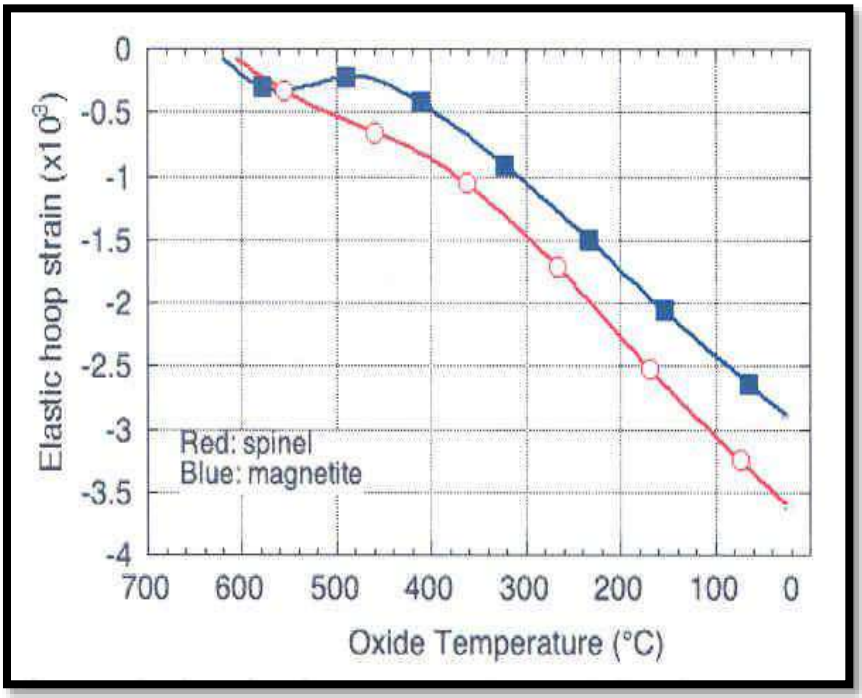


Fig : Schematic Representation of the Usual Sequence of Events in the Exfoliation of Scale

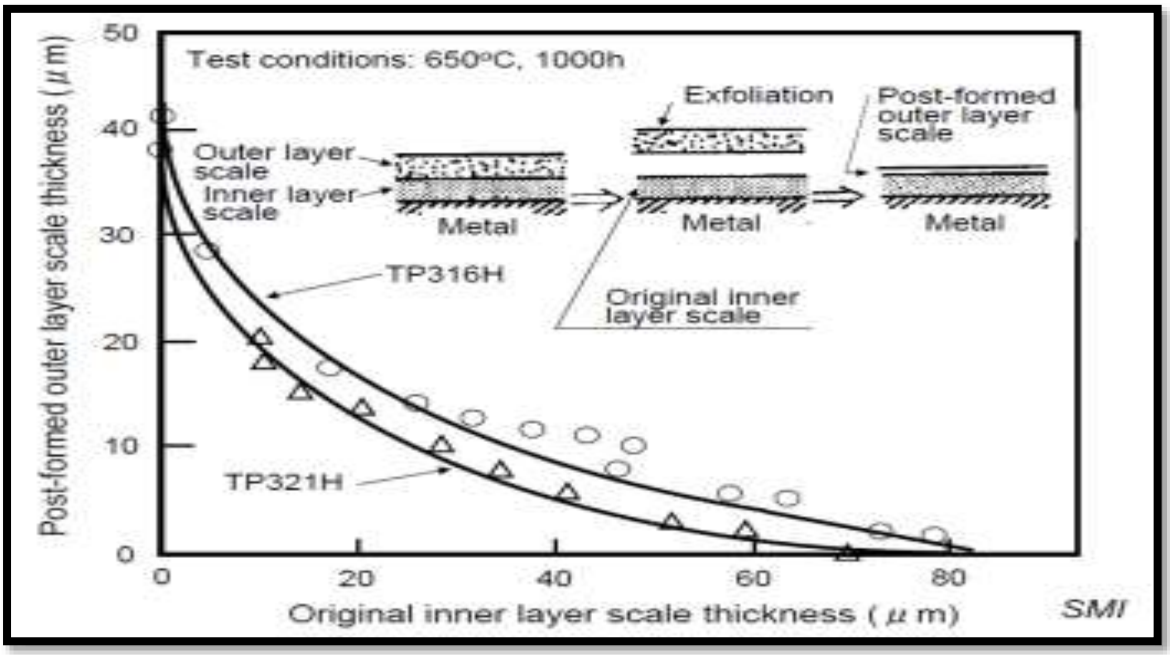
d) Trigger For Exfoliation

- stress differential between the oxide and underlying metal
- large temperature reductions (or increases)
- There may be some other sources of exfoliation that needs to be studied further.



e) The post-formed scale will reduce the growth rate of oxide scale by preventing contact of Fe with O2 in steam.

f) Exfoliation will damage the protective layer of the tube.



g) Exfoliation is the expected result of continued oxide growth. The rate of oxide growth increases exponentially with temperature, and as the steam pressure raised to the power of, for instance, one fifth.

h) Events that can increase the strain differential between the oxide and underlying metal can trigger an exfoliation event; large temperature reductions (or increases) are the most typical triggers.

i) The magnitude of the effect of exfoliation on plant operation depends on the amount of oxide debris released at any given time, the size and shape of the individual oxide flakes, and the part of the operating cycle in which the event occurs.

j) The circumstances that lead to blocking of tubes by exfoliation debris are well understood in principle, and point the way to operating procedures that could be used to "manage" exfoliation; verification is needed through testing.

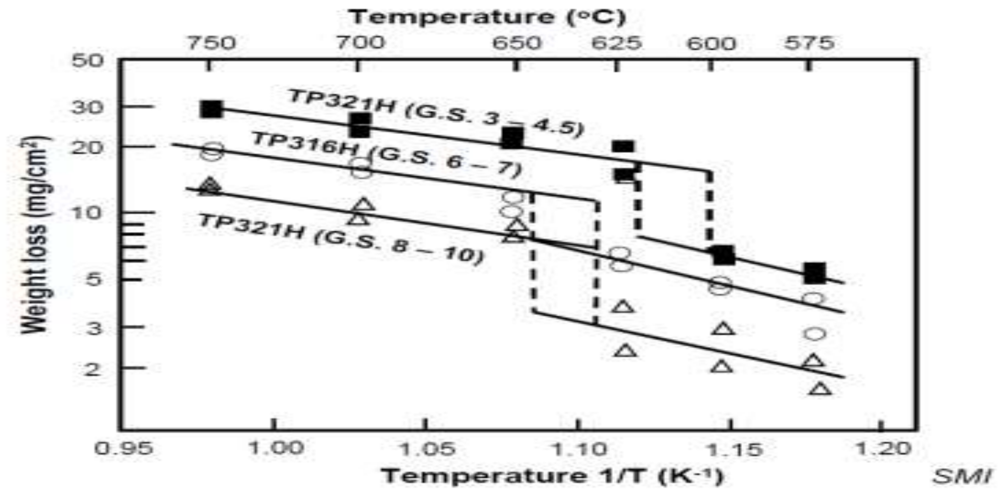
k) The rate of oxide thickening, the type of oxide formed, the conditions under which exfoliation can occur, and the mode of exfoliation (in terms of the size and shape of the oxide flakes) are to a large degree determined by the alloy composition.

4.2.2 Measures being adopted to prevent Exfoliation

a) Detection of blockages by X-ray/radiographic or LFET techniques and removal by mechanical & Initial blowing during start up

b) Better operating practices :

- Maintain temperature within limits as higher temperature can increase exfoliation.
- Allowing Boiler to cool down naturally



Effect of temperature on steam oxidation

c) Steam flow velocity in tubes:
It is understood from the experience of the Japanese plants that super heater tubes operated with a steam velocity of 6 m/s were prone to blockage, whereas super heaters with a steam velocity of 12 m/s did not experience blockages.

d) Avoidance of rapid or extreme boiler transients, and careful control of temperature, especially during start-ups.

e) Limit the introduction of foreign material into the steam path during tube repairs.

f) Steam blowing with HP/LP bypass to be done during boiler pressurization itself, before unit synchronization.

g) After every Shutdown, Hot box up of Boiler to be done, for natural cooling of boiler. Forced cooling will result in Exfoliation and delay in flushing activity.

New Regime Followed:

a) pH to be maintained in Oxygenated Treatment regime shall be between 8.5 to 9. (This is based on EPRI's revised pH limits (8.5 to 9) for Oxygenated Treatment.

b) Maintain oxygen levels as per the pH and Oxygen curve of EPRI (preferably more than 100 ppb)

4.3 Increased regeneration frequency due to high pH operation (as per revised EPRI guidelines):

Presently, the station is operating on oxygenated treatment (OT) with Condensate polishing unit (CPU) to regulate and maintain water chemistry. Each unit is provided with 2X50% CPU vessels with 100% bypass arrangement. As per boiler OEM guidelines, the unit is being operated at pH 8.5, restricting cation conductivity at the outlet of CPU to less than 0.1µS/cm.

The designed service run between regeneration of the CPU vessel is 30 days and accordingly 10 vessels should go for regeneration in 30 days. Considering the regeneration frequency and OEM recommendation, one external resin regeneration facility is provided for the station.

Moreover, EPRI has recently recommended to operate the supercritical units at elevated pH of 8.5 to 9.0 to reduce iron carryover/release compared to earlier guidelines of 8.0 to 8.5. Accordingly EPRI has also revised the dissolved oxygen (DO) level from earlier 30-150ppb to revised 50-200ppb. The table below indicates the earlier and new guidelines.

Parameters of feed water	**OEM (earlier)**	**EPRI (earlier)**	**OEM (New)**	**EPRI (New)**
pH	8.0 - 8.5	8.0 - 8.5	8.4 - 9.0	8.5- 9.0
Dissolved Oxygen ppb	30 - 150	30 - 150	30 - 150	50 - 200
Cation Conductivity (micronS/Cm)	0.2	0.15	0.15	0.15

Table: Parameters for feed water

Before adopting a high pH operation, it was prudent to check its impact on the CPU availability and adequacy of the existing regeneration system. To ascertain this, trial runs were carried by CGPL team for 03 months and the test results indicated that the service run between 02 regenerations for a CPU reduces to approx. $1/4^{th}$ if the unit is operated at pH 9. The test results were further deliberated internally and with OEMs and consultants. After due discussions, it is concluded that for a stable unit operation, the unit shall be operated at pH 8.6 (which is in the range specified by EPRI).

However even with unit operation at pH 8.6, the resin regeneration system will need augmentation. Hence, installation of additional resin regeneration system is recommended in view of following;

a) Reduced service period for CPU resins.
b) Unit operation continuously at elevated pH of 8.6 will further reduce the service period
c) Resin regeneration with existing single regeneration facility will increase the CPU bypass mode operation, which is not recommended.

4.3.1 Existing scheme for regeneration:

The existing resin regeneration facility is a patented technology by the OEM. The system is installed near water pretreatment plant. One resin transfer line is provided for to and fro movement of regenerated and exhausted resin.

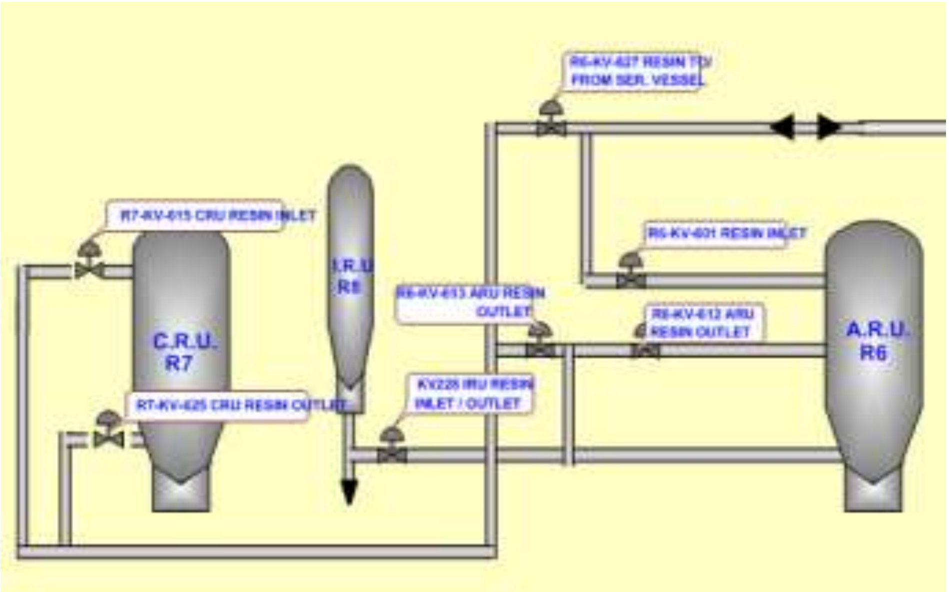


Fig- Resin regeneration vessels

The exhausted resin is hydraulically transferred from service vessel to Anion Regeneration Unit (ARU) through resin transfer line. The mixed resin in ARU is subjected to air scour and rinse operation to clean the charge from crud and then backwashed to separate cation and anion beds. The cation resin, being heavier, collects in the bottom and is first transferred hydraulically to Cation Regeneration Unit (CRU). During transfer, as soon as the presence of interface resin layer is detected, the layer is automatically diverted to Interface Resin Unit (IRU). This resin in IRU is mixed with the freshly transported mixed resin from service vessel to ARU in the next cycle run so that the resin volume in service vessel is not depleted. Now the cation resin in CRU and anion resin in ARU are air scoured and then backwashed to remove any suspended solids.

The cation resin is regenerated with 4-8% hydrochloric acid and the anion resin with 4-10% solution of caustic soda.

After regeneration, the anion bed is further subjected to cleaning cycle consisting of drain down and air scour, before both beds are finally rinsed to drain.

The anion resin is then transferred to CRU, where it joins the cation resin. The two resin beds are then air scoured, which mixes the beds. The resin can now be transferred back to the CPU.

4.3.2 Proposed scheme -

The arrangement of ARU, IRU and CRU vessels in the proposed scheme will be similar to existing scheme. Some of the facilities like acid, alkali storage, resin transfer lines etc will be shared by both regeneration facilities for optimization and simultaneous operation of the systems will also be ensured.

5 Other Recommendations being Adopted:

A proper drain down procedure shall be followed during shutdown. Leaving oxygenated water in any circuit during shutdown will result in pitting and increased levels of corrosion product transport.

6 Conclusion

a) Operating margins in super critical/ ultra-super critical units are much less as the gap between the rated temp and design metal temp is less. Hence efficient control is a must to avoid problems like exfoliation.

b) Adequate measures to be considered during design phase to give operational flexibility, like:

- Proper metallurgy with adequate temp margins
- Pre-filters for condensate.
- Stand by CPU
- Adequate CPU regenerating capacity
- Condensate dump line

c) Clean up/ start up procedures to be reviewed and fine-tuned from time to time based on site experience and shall be strictly followed.

d) Strict adherence to Chemistry regime laid out by OEM/EPRI guidelines.

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