

A CASE STUDY ON MANAGING TROUBLE SHOOTING IN PRIMARY WATER SYSTEM IN 500 MW UNIT

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ABSTRACT

Direct water cooling of stator windings has been common since the early 1960s. In general these windings have performed well, although as would be expected in any liquid systems involving many varied components, there have been problems with leaks, leaks both large and small. Perhaps less expected have been problems with copper oxide formation within the hollow copper strands which carry the water (as well as electrical current). Two types of oxide can be produced, cupric (a black compound, CuO) and cuprous (a red compound, Cu₂O). Though copper is known as passive metal but under varying pH ranges coupled with different level of dissolved oxygen, there are different phenomenon which may occur in stator water system.

This paper will deals with stator water system in 500MW thermal plant unit, corrosion mechanism and a case study related to initiation of copper corrosion. The importance of sensors and alarms in auto control system is also felt while dealing the issue. The learning's along with suggestive measures which could be beneficial to operation team dealing with primary water system (PWS) has also been talked in paper.

INTRODUCTION

Effective heat dissipation of power generator stator windings is a key component to maintaining generator power output and winding performance. Therefore, maintaining the operational reliability of the stator cooling system is very important.

The power generator stator cooling system is a group of small diameter copper tubes (strands) that carries water around the generator stator windings. Corrosion in the system is exhibited as copper oxide flakes in the strands which reduces water flow and inhibits the cooling efficiency of the system. This can lead to de-rating the generator and eventually may necessitate cleaning or replacing the strands. Plugged strands often lead to winding "hot spots" which can ultimately cause generator failure. Traditional methods of cooling water quality control measure the dissolved oxygen concentration.

Systems use deaerated water with a DO level held to less than 20 ppb wherein a thin layer of copper oxide forms on the tubing creating a protective (passivated) barrier against damaging corrosion. At the higher DO level cupric oxide forms (CuO) while cuprous oxide (Cu₂O) forms at the lower DO levels. If the process can be maintained at DO levels the integrity of the copper in the system can be satisfactorily maintained. The process of copper flaking called spalling occurs when copper oxides on the strand walls change from cuprous oxide (Cu₂O) to cupric oxide (CuO), or the reverse, from to cupric oxide (CuO) to cuprous oxide (Cu₂O). It is the transition between copper oxide states that causes the problem. Stresses incurred

during the transition cause the copper oxide to flake off.

Monitoring dissolved oxygen levels alone does not provide an indication of the copper oxide state. Therefore, large swings in the corrosion potential of the copper tube can occur while the measured DO level maintains the appearance of a balanced system. Recent EPRI studies confirm that significantly higher rates of copper loss in the stator cooler occur at the intermediate dissolved oxygen concentrations of 100-1000 ppb. In addition, strainer clogging and strand plugging significantly increase during transitions from high to low or from low to high dissolved oxygen concentrations.

The dissolved oxygen mainly ingress through make-up to stator primary water system. So the quality of makeup water is very important. It can be either fully demineralised water from the station demineralisation plant having a maximum direct conductivity of 1.5 μ S/cm at 25°C and conductivity after strong acidic cation resin is not more than 0.2 μ S/cm. The disadvantages associated with use of demineralised water are high dissolved oxygen content (between 6-8 ppm depending on temperature of water) and low pH of 7.0 or ii) Turbine condensate taken from the extraction pump discharge. The advantages associated with the use of turbine condensate are low dissolved oxygen content about 50 ppb and relatively high pH suitable for copper and copper bearing alloys of the system (pH between 8.8 and 9.0). While using turbine condensate, it will be ensured that it is not contaminated and that it complies with the specified

control limits. The situation is likely to arise when there is condenser leakage and during start-up of the plant when oxides of iron and copper are usually present in excess of the control limits. Experience and opinion in CEGB, U.K. is that, risk involved due to ammonia, normally present in turbine condensate to cause stress corrosion cracking of copper and its alloys within stator primary water system, is negligible. However, as per the view of some vendors, the turbine condensate should be used only after complete removal of ammonia by passing all make up through CPU/stator water polishing unit and in conjunction with alkaliser retrofitting for their 500 MW units.

Electrical conductivity is the basic criterion of quality for the stator primary water and it must always comply with the specified limits. By maintaining low conductivity and design water flow rate, the risk of flash over, in a clean water circuit, is eliminated.

In the absence of any remedial measure, the conductivity of primary water, will normally, rise slowly because of the impurities e.g. carbon dioxide and perhaps because of insufficiently good quality of makeup water. Control of conductivity is normally achieved by continuous /intermittent operation of stator polishing unit and by maintaining inert atmosphere in the system by use of suitable grade of nitrogen gas.

MECHANISM OF CORROSION IN PWS CIRCUIT

In general, the amounts of copper in the stator primary water will depend on the following factors like quality and frequency of blow down &make up water; concentration of dissolved oxygen gas, operation of alkaliser system, operation of stator water polishing unit, PSW Cooler leakages (ingress of impurities). Presence of Fe ions may increase Cu ions in PSW system.

It must be ensured that the storage tanks and pipelines, handling DM water or condensate, as make up to stator primary water system should be suitably lined. The rate of corrosion is minimum when the stator primary water system is tight i.e. when neither water is lost from the system nor the makeup is taken into the system. Practically, this is not possible as water is taken out for manual testing of the constituents and sometimes lost due to leakages. It is desirable that manual tests are carried out once in every two months, so that minimum water is taken out from the system. The makeup is taken by operation staff by passing 100% through polishing unit.

Dissolved oxygen in stator primary water is main reason for corrosion. In order to avoid dislodging of

passive oxide layer from the surface, leading to the blockage of bars, it is necessary to regulate the makeup water flow in a manner that dissolved oxygen does not abruptly increase. It is recommended that a suitable on line dissolved oxygen monitor with recorder is provided for the system. Till then manual analysis shall be carried out i.e. once in two months.

The severity of the corrosion attack can be largely reduced by alkalisng, low dissolved oxygen water. This system then becomes less susceptible to disturbances resulting from air leakage. Stator primary water system between pH 8.5 and 9.0 and conductivity between 1.0 and 2.2 $\mu\text{S}/\text{cm}$ for improvement in its reliability and availability. The corrosion products in stator primary water when detached from the metal surfaces, deposit on the tube ends and also on inlet and outlet hoses of water cooled generator windings, resulting in flow rate restriction. In order to get timely indication of flow restriction, it is essential to provide individual pressure gauges at inlet and outlet of water flowing through stator windings. Also provision of differential pressure indicator gauge with suitable alarm setting will ensure proper attention of operation staff for corrective measure, avoiding long shut down sets are working on DP- 1 Kg/cm^2 where as others around 3 kg/cm^2 across windings.

Stator water polishing unit with 2 to 5% polishing is provided in the system controls conductivity by eliminating electrolytes from the system and additionally, traps some suspended matter. The unit contains mixed Ion Exchange Resins of nuclear grade. The exhausted MB resins are regenerated and put back in SPU. The extent of corrosion can be assessed by eluting the resins and analyzing the filtrate when the resins are getting frequently exhausted.

Chemistry of copper

Corrosion of copper is dependent on pH and dissolved oxygen content of (PSW) cooling water. There are two regimes in which the corrosion rate is minimum:

Low Oxygen Regime where corrosion is inhibited by formation of passive layer of cuprous oxide (Cu_2O) and High Oxygen Regime where formation of passive layer of cupric oxide (CuO) inhibits corrosion.

As it is common with metals that form soluble oxide layers, the copper release rate increases with water velocity. This is due to a more rapid mass transfer from the oxide layer into the bulk liquid, resulting in an increased dissolution rate of the oxide layer. The copper is released from surfaces as:

- dissolved copper ion (Cu^+ and Cu^{++})

- Particle or as colloid (CuO , Cu_2O , and possibly also Cu)

The blue colour of spent ion exchange resin from generator cooling systems is evidence of the release of copper ions, whereas the clogging of strainers and fouling of mechanical filters is a result of particle release. The particle release seems to be connected to phase changes between Cu_2O and CuO , possibly

by stresses from the change of structure. Such phase changes are initiated by variations of the electrochemical potential. They take place, for example, when the oxygen concentration is changed from its normal range (either less than 20 ppb or greater than 2 ppm) to intermediate concentrations (100 - 500 ppb). Fig-1 depicts Copper Release Rates at Various Water Chemistry Conditions

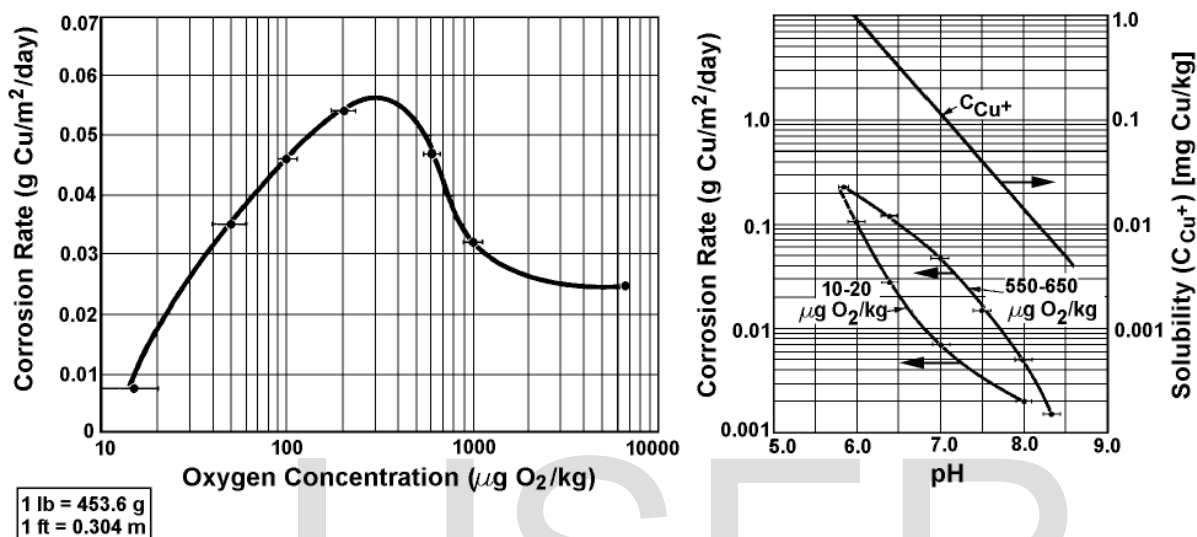


Fig-1: Copper Release Rates at Various Water Chemistry Conditions

The metal potential may be altered by the amount of dissolved oxygen present. Under conditions of low oxygen (<100 ppb) and neutral to alkaline pH, the formation of red Cu_2O is favoured. However, once air is introduced and dissolved oxygen increases, it rapidly changes to the black CuO or a mixture of oxides. The following Pourbaix diagram (Fig-2) shows the different phases of copper and its oxides with respect to its metal potential and the pH of the aqueous medium.

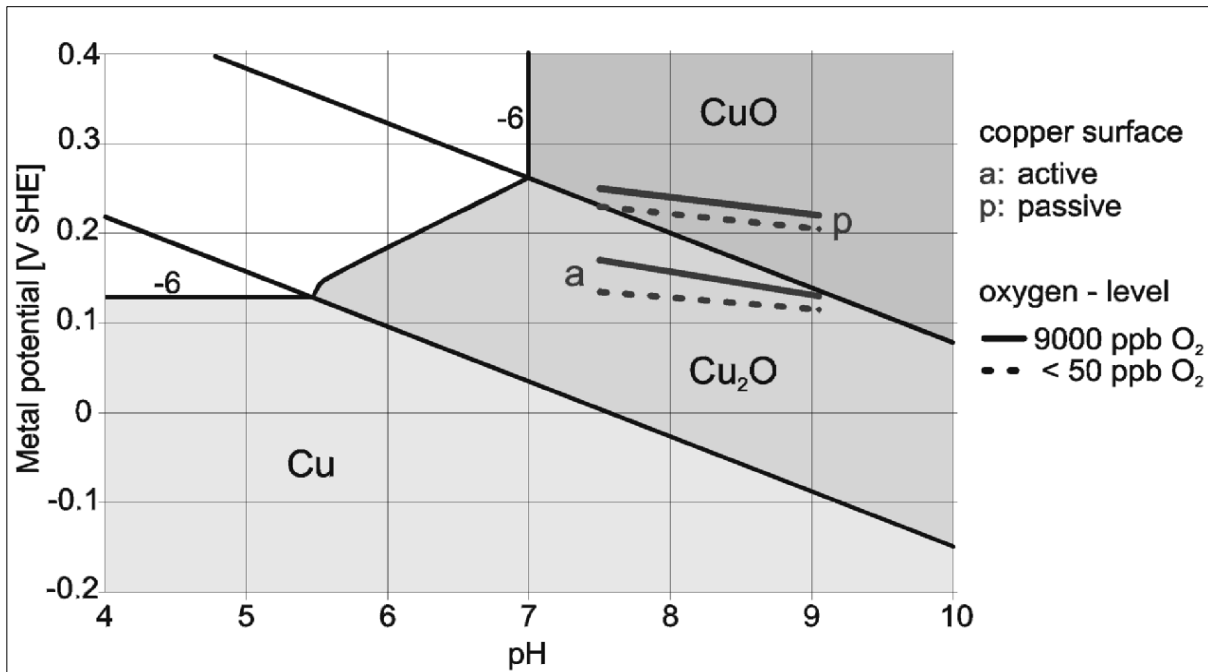


Figure 2: Potential of Passivated (Black CuO Layer) and Active (Freshly Pickled) Copper

Either oxide forms a stable layer. However, altering either pH or dissolved oxygen or both may shift the equilibrium to a point where a mixture of oxides is found, resulting in instability. This causes the oxide to lose its adherence resulting in migration and deposition elsewhere in the water circuit. Under generator cooling water conditions the solubility of copper oxides is dependent on pH and also, to a lesser degree, on temperature. Fig-3 analyzes the conditions in pure water Neutral pH is 6.64 at 50°C, and 6.13 at 100°C, but the dissolution of Cu₂O and CuO produces OH⁻ ions and the water will therefore be slightly alkaline. It is seen that the solubility of both CuO and Cu₂O at 100°C are higher than at 50°C, but the change is less pronounced for CuO. This dependence of solubility on temperature is also seen at slightly acidic and at moderately alkaline pH values, such as encountered with neutral or alkaline generator water treatment.

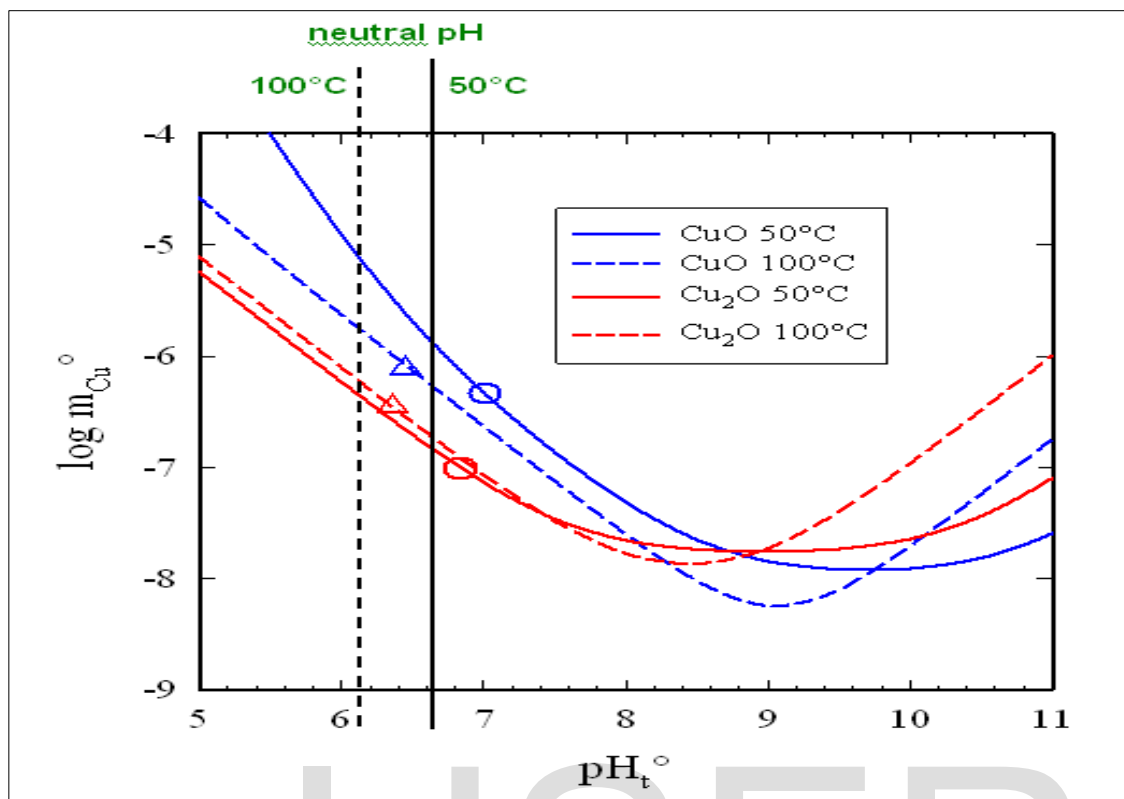


Fig-3: Solubility of Cu_2O and of CuO as a function of the pH at temperature. The vertical lines indicate the neutral pH at 50°C and 100°C , resp. The circular and triangular points indicate the solubility limits in pure water at 50 and 100°C , resp. Because the dissolution of Cu_2O and CuO produces OH^- ions, these points are at a slightly higher pH than neutral.

The low DO and high DO regimes with pH and conductivity requirements are summarized in Table-1.

Table-1: Dissolved oxygen based regimes

Regime-I(ST-I)	Regime-II(St-II)
DO ($\mu\text{g/l}$): >2000 to < 5000 (high)	DO ($\mu\text{g/l}$): < 20 (LOW)
pH: 6.0 – 7.5	pH: 8.5 – 9.0
Conductivity at 25°C , $\mu\text{S/cm}$: < 2.0	Conductivity at 25°C ($\mu\text{S/cm}$): 1.8-2.2
Passive layer of CuO	Passive layer of Cu_2O

CASE STUDY:

Recently a problem was faced in primary water system in 500MW unit of station which could have led the tripping of unit but swift action of O&M team averted the happening. The details of problem, action taken and further suggestions provided are summarized in following text.

System description

The line diagram, photograph and chemical specifications are given Fig-4 & 5 and Table-2 respectively:

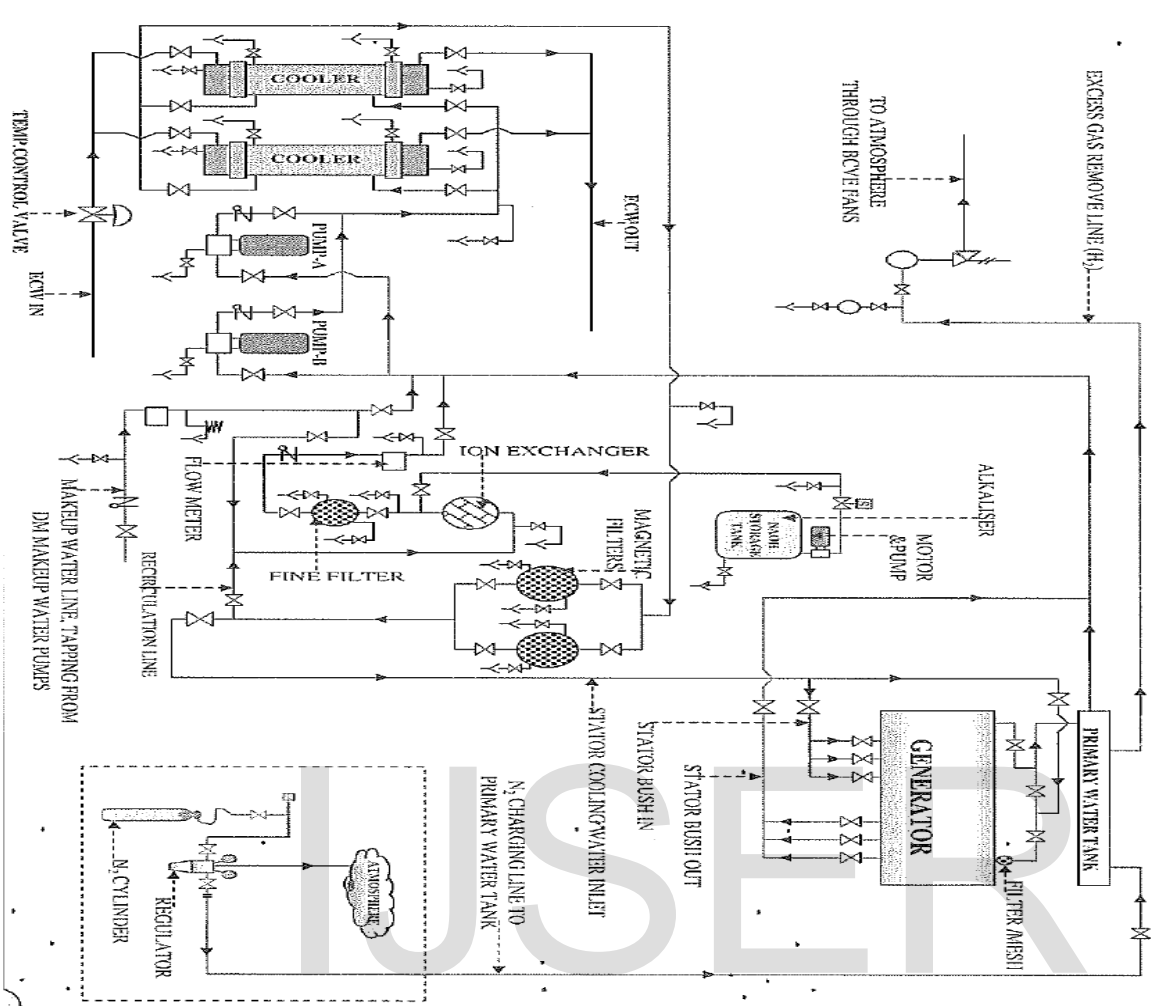


Fig-4: Line diagram of Primary Water System in 500MW unit



Fig-5: Photograph of Primary Water System in 500MW unit

Table-2: Chemistry specifications (Parameters) in PWS

SN	Parameter	Unit	Limit	Value
1	Sp. Conductivity at 25°C	μS/cm	<2.2	
2	Dissolved oxygen	Ppb	<20	
3	Total copper	Ppb	<20	
4	Total Iron	ppb	<20	
5	pH at 25°C		8.5-9	

The upper limit of direct conductivity in normal operation, is 1.5 μS/cm at 25°C, preferably 0.5 μS/cm or below when operating without alkaliser system in circuit, 2.2 μS/cm at 25°C with alkaliser system in circuit lower limit being 1.0 μS/cm. The values of conductivity i.e. 1.5 μS/cm (with alkaliser system not in circuit) should not be exceeded during generator commissioning tests.

Issue:

It was noticed that DP across the primary water winding was in increasing trend and flow was reduced to 50 to 55 M³/hr. instead of normal circulation flow 60-64 M³/hr. The conductivity was not rising and it was 1.4 μS/cm. Primary water samples were taken to monitor the check list parameters. It was found that sp. conductivity, iron and DO were within limits but copper was very high (527.73 ppb) and pH was found to be 6.8 to 7.0.

Root cause:

Since conductivity was not rising so it was thought that resin based exchanger was not exhausted. Conductivity at the resin based exchanger outlet was 1.4μS/cm and did not showing decreasing trend either. But as the caustic pump was not working (conductivity was not coming below 1.0 μS/cm) which is very rare, above all its annunciation was coincidentally not active at unit control room to indicate not running of caustic pump for 3 days. As per logic at conductivity below 1 μS/cm, pump would take a start and at value exceeding 3 μS/cm it would trip. But due to resin exhaustion the conductivity did not decrease so caustic pump did not take start. Also partially the cations (Cu ions) were exchanged by resin, the corresponding anions leached resulting in decrease in pH. Due to this stator winding faced corrosive environment and further leaching of copper took place in specific pH zone.

Indications which were missed:

1. Caustic tank level was 80% full and it was constant for last few days. Concerned operator overlooked it.
2. The alarm was not working and desk engineer could not notice it.
3. There is no alarm if pump stops running more than one hour. Only visual monitoring was there.
4. As such no alarm for resin exhaustion.
5. Caustic tank level non marking and level monitoring.

Actions taken:

Frequent analysis of PWS samples for Cu and other parameters was carried out. The presence of high copper indicated leaching of stator winding.

Immediately the pump was checked by EMD and found OK.

Logic was set resulting in starts and stops of pumps as per normal logic.

Fine filter and magnetic filters were cleaned. It indicated that the exchanger resin was exhausted, changed immediately. The graph after cleaning the filter and changing the resin is depicted in Fig-3.

pH of the system resorted to 9.0 and DO was maintain below 20 ppb.

Copper value normalized i.e. <20 ppb after four days of operation.

The analytical results for samples drawn are summarized in Table-3. The copper was analysed with Ion Chromatogram (IC; Metroham Make) present in Chemistry Lab (Shwn in Fig-6). The peaks and IC photo is shown in Fig-7,8.

Table-3: Analytical data during revival of PWS

Time	Cu		
After 3 days of reporting(Mechanical filter)	543(ppm)		

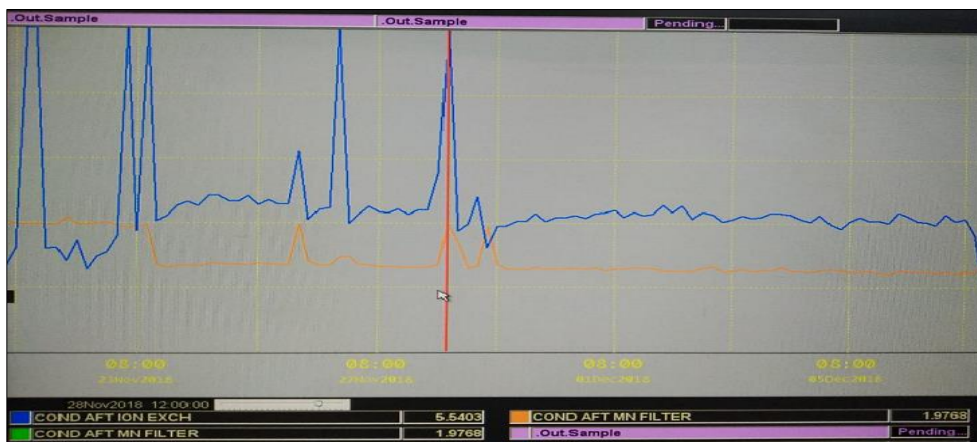


Fig-6 Conductivity trend after main filter and Ion exchanger changing

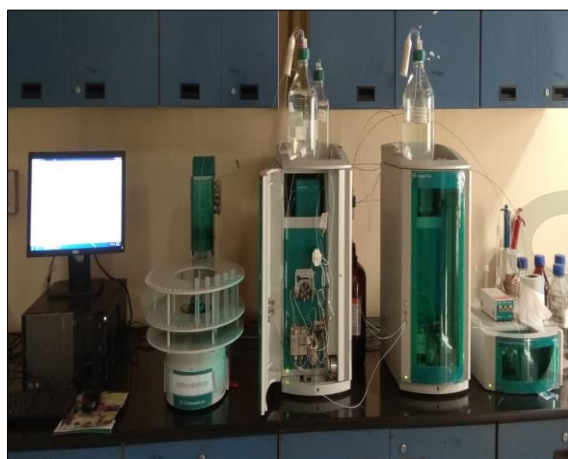


Fig-7: Ion Chromatograph Equipment

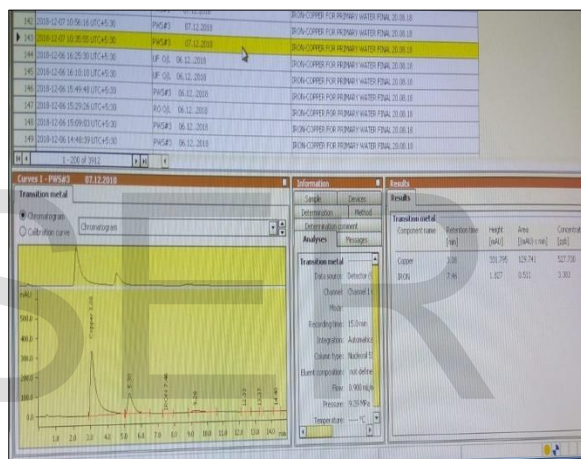


Fig-8: Cu peak (527.73 ppb) in IC

FURTHER ACTION:

To ensure that such lapse may not happen again the detail discussion within O&M Departments including Electrical, C&I, Operation and Chemistry was made and check list primarily focussed on implementation of auto system was prepared. It was implemented within two days. The main points of check list are given in Table-4:

Table-4: Checklist and activities to perform for maintaining healthiness of PWS

SN.	Description of activity	Why required
1.	After Ion exchange resin regeneration final conductivity will be jointly checked by Chemistry and EMD.	Confidence building and avoidance of lapse
2.	Caustic pump not running for > 01 hrs. Logic to be prepared.	Alarm in control room followed by pump status
3.	Ion exchanger conductivity remains between 1 to 1.5 μ S/cm more than three hours	Alarm in control room, resin exhaustion indication
4.	Caustic tank level monitoring once a day by operator	Level drop of tank needs to top up
5.	Make up water intake should not be more than 10 litres at a time under nitrogen pressure min.0.2ksc	DO control

6	Resin replacement in presence of all concerned parties	Process improvement
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Additional suggestions

1. Level transmitter for tank level monitoring and alarm on low level.(fig-01)
2. Ion exchanger vessel should be transparent and coloured resin may be used wherein with resin exhaustion colour will change.(fig-2)
3. One stand by exchanger with auto service facility to be provided to avoid fresh resin emergency.(fig-3)
4. Proper regeneration assembly for resin (under procurement).
5. In place of flow gauge, flow transmitter to be introduce in the system for better flow measurement and enhance resin life.(fig-4)

Implementation

Date 15.05.19, after implementation of **Table-4: Checklist and activities to perform for maintaining healthiness of PWS, especially 03, 04 and 05.**we are able to manage the resin change process much easier as shown in Fig.9.

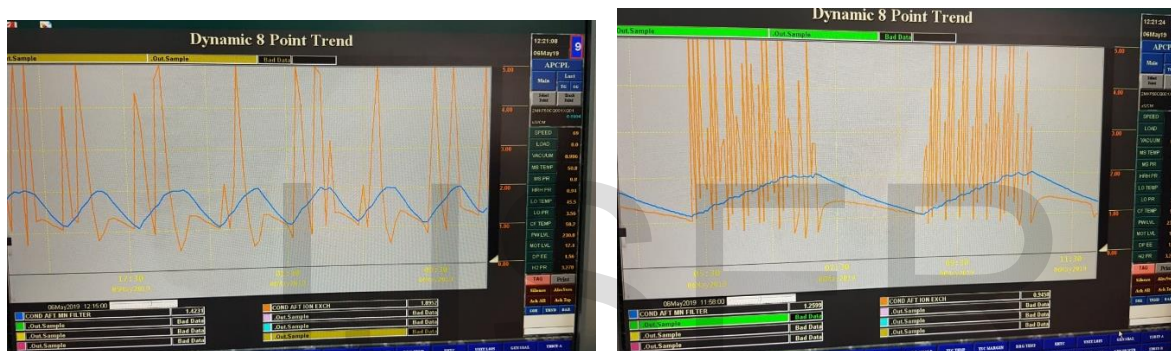


Fig 9.1 Normal Operation of Caustic pump start and stop **Fig 9.2** Annunciation in control room for resin exhaust as the Pump takes one hour for start

CONCLUSION:

1. The healthiness and continuity of primary water system is very crucial for generator, all efforts must be made to ensure to keep Cu in adhered/ stable form.
2. The logics/ automation such and Chemical parameters monitoring and alertness in reporting helps the team to solve the problem of stator Polishing Unit.
3. Continuous monitoring of PWS samples for Cu and Fe by IC are required.

REFERENCES:

1. EPRI. (2013). *Report TR-074532: Turbine-generator Auxiliary System Operation & Maintenance Guide - Volume 4: Stator Cooling Water System - UPDATE*. EPRI.
2. IGSTPS Control for providing screen shots of Primary eater system after modification.

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