

AN INNOVATIVE APPROACH TO MITIGATING SULFUR DEPOSITION IN THE CONDENSER AT MAHANAGDONG GEOTHERMAL POWER PLANT

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ABSTRACT

CalEnergy International Ltd. is currently operating three geothermal power plants in Leyte with a total gross capacity of 546 MW. These plants were built and are operated under the Build Operate Transfer (BOT) scheme in partnership with the PNOG Energy Development Corporation.

The Mahanagdong power plant of CE-Luzon Geothermal Power Company with a gross capacity of 180 MW (164.7 MW net) has experienced sulfur build-up in the main condenser and heat exchangers. The build-up of sulfur is quite alarming and continued accumulation leads to fouling and backpressure build-up within the condenser. As a result, condenser efficiency decreases, and both turbine performance and unit efficiency are adversely affected. To address the problem, several options were evaluated and the most practical solution was adopted to mitigate sulfur deposition.

Ways to remediate sulfur build-up are presented in this paper. Results of the recent inspections of the critical exchangers are compared with those of last year.

1.0 HISTORICAL BACKGROUND

The Mahanagdong project is a 180 MW geothermal facility on the island of Leyte, Philippines. The facility was completed in July 25, 1997 and sells 100% of its capacity to the PNOG-Energy Development Corporation (PNOG-EDC) for resale to the National Power Corporation (NAPOCOR) and distribution to the Luzon grid.

The power plant consists of three 60 MW Toshiba turbine units located at two sites approximately two kilometers apart. Site A houses two of the units and Site B houses the third unit (Fig. 1). Geothermal steam at 5.94 kg/cm²a is supplied to the plant. The steam contains up to 2.9% NCG in Site A and 3.8% NCG in Site B with 1.6% of the NCG is hydrogen sulfide. After passing through the turbine, the steam is condensed in a shell-and-tube condenser under vacuum. Noncondensable gases (NCG) contained in the steam are

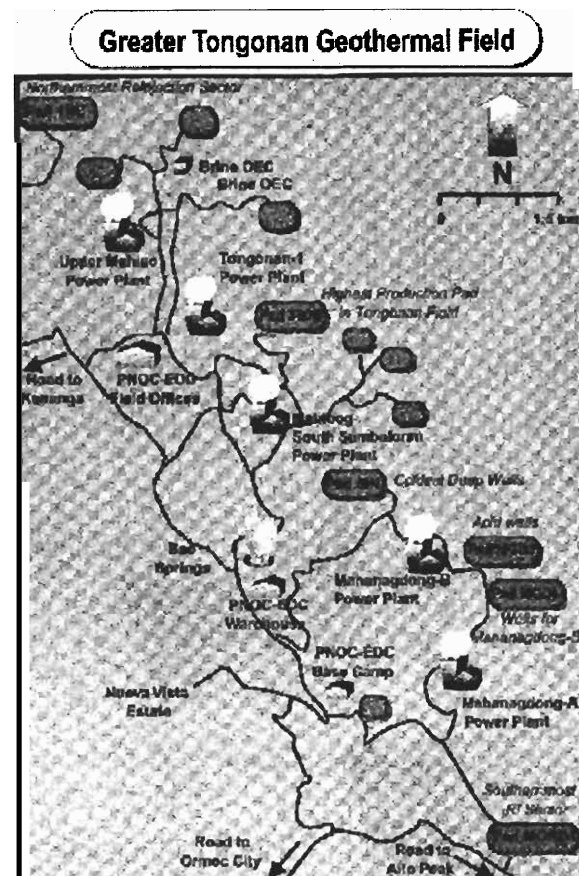


Figure 1. Location map Mahanagdong power plant

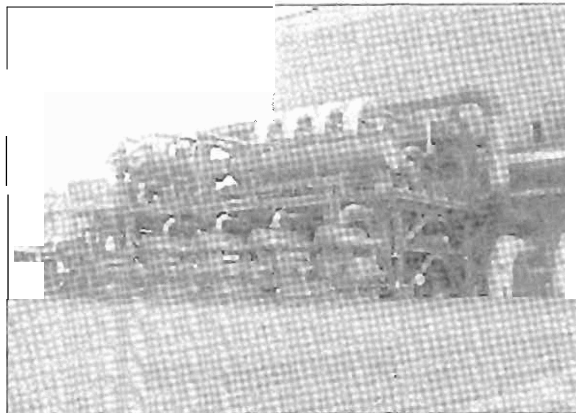
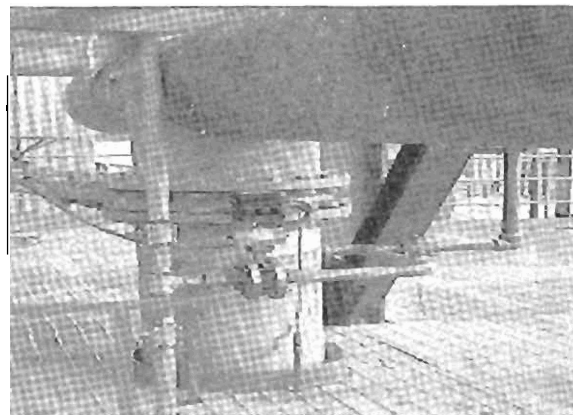


Figure 2. Vacuum system - steam jet ejectors for the 1st stage and liquid ring vacuum pumps for the 2nd stage.



Anti-cavitation protection.

withdrawn from the condenser by a vacuum system. The main vacuum system consists of steam jet ejectors for the first stage and liquid ring vacuum pumps for the second stage (Fig. 2). The noncondensable gases (NCG) from inter-condensers are compressed at the vacuum pumps at 0.15 to 0.16 kg/cm²a. Under certain operating conditions, cavitation may occur in the compression chamber and may cause damage to impellers, port plates, and plate-types valves. To avoid such damage, automatic air valve (Fig. 3) was installed in 1999, as anti-cavitation protection utilizing ambient air as the media.

The automatic air valve (Fig. 3) improved vacuum pump performance. However, two years after, Unit 1 condenser efficiency, and both turbine performance and unit efficiency are adversely affected. On investigation, it was found that the deposits consisted of elemental sulfur and were severe enough to interfere with the normal operation of the condensers.. Inspection of other critical auxiliaries during the "2001 warranty" inspection showed excessive sulfur build-up at the shell side of the gland steam condensers. The deposits were confined mainly to the throat and region downstream of the control valves. As the deposits grew, the control valve opened to compensate for the reduction in flow area.

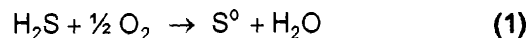
Heightened concerns about the associated voluminous sulfur buildup and its impact on condenser efficiencies have prompted CalEnergy to take immediate measures to remediate the problem. This paper describes the investigation that was performed to identify

the root cause of the deposits and the remedial action taken to eliminate the problem.

A key to eliminating the deposit formation is an understanding of the deposit mechanism and physical properties of sulfur. It is sufficient to say that sulfur is a complex substance that may have many different forms and properties depending on the surrounding pressure and temperature and the rate of cooling.

2.0 PROBABLE CAUSE

The main source of sulfur deposition in the critical heat exchangers is the conversion of hydrogen sulfide (H₂S) to sulfur at the vacuum pump. Hydrogen sulfide (H₂S) in noncondensable gases (NCG) reacts with induced air from automatic air valve (Fig. 3) thus, forming sulfur as shown in reaction 1:



Another factor that contributes to sulfur formation is the solubility of hydrogen sulfide in water. According to Perry, H₂S solubility decreases with increasing water temperature. The water supply to the vacuum pump is 27.6°C while discharge temperature is at 37.8°C. This means that H₂S dissociates to sulfide ion at the vacuum pump carrying the same into the cooling water return where the temperature is higher. Formation of sulfur is further enhanced at the cooling tower since cooling water is saturated with dissolved oxygen. The sulfur enriched cooling water is redirected back to the main condenser, inter-condensers, and generator air

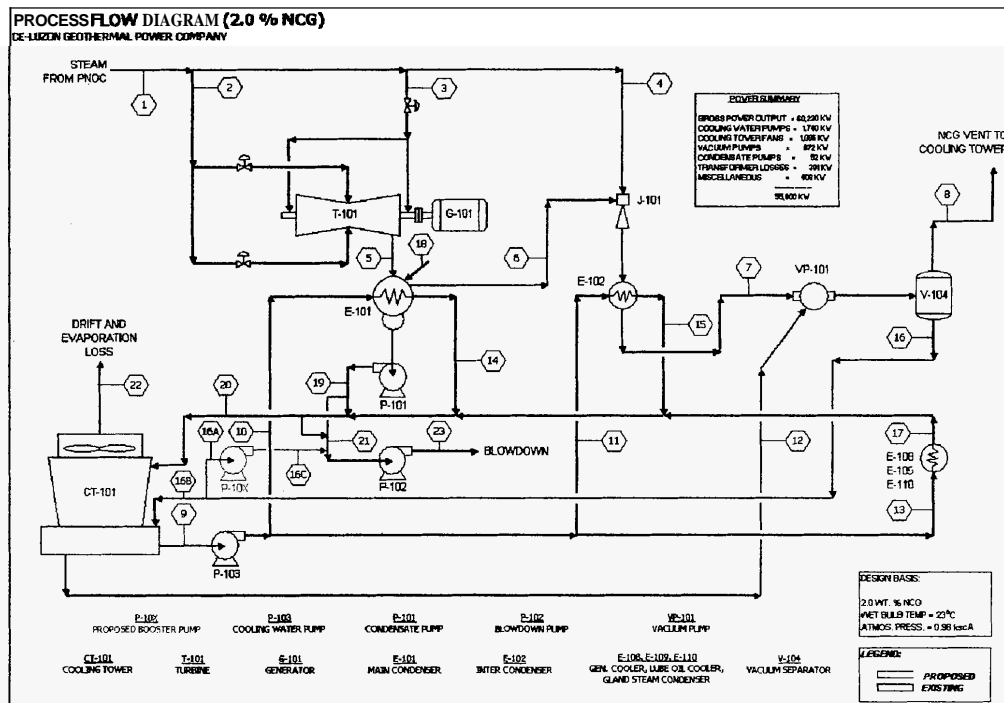


Figure 4. Proposed scheme to re-route vacuum separator discharge into the re-injection lines.

coolers. The conclusion is further validated in the case of sulfur build up at the gland steam condenser. The oxygen in air that is drawn to the gland steam condenser together with gland steam reacts with the hydrogen sulfide in the NCG as shown in equation 1.

3.0 APPROACH TO REMEDIATE DEPOSITION

To address sulfur deposition, corrective measures were initiated. Sulfur deposition in the critical heat exchangers depend on the amount of H_2S present in the system and how it partitions between the condensate and the NCG. Study was undertaken to survey first the available commercial scavenger technologies, identify their process capabilities and limitations and then establish the relative investment and operating cost associated with the technologies. The information resulting from this evaluation was used to screen those technologies with the greatest potential technical and economic merit for field evaluation program.

3.1 Chemical

1. Sulfur reduction. A sulfite usually in the form of sodium sulfite is added to the

cooling water. The sulfite reacts with sulfur as shown in equation 2 to form a water-soluble thiosulfate, which can be removed through blowdown.



- Use of dispersant Drewspense 739 (DS 739) to keep sulfur in suspension. The dispersant will dislodge and remove the sulfur in the condenser back to the cooling tower. DS 739 is a surfactant having hydrophobic and hydrophilic ends. The hydrophobic end attached to the sulfur while the hydrophilic end acts as a barrier to other suspended particles preventing their agglomeration and drawing the solid into a stable dispersion in water. The particles are then easily kept dispersed by water velocity and ultimately removed through blowdown.

3.2 Mechanical

- Re-route vacuum separators discharge into the re-injection lines (Fig. 4). Present configuration, vacuum pump cooling water is returned directly to the cooling tower basin without flowing through the cooling tower fill.

2. Re-route vacuum separators discharge piping to cell A. Present setup vacuum separator discharge piping near cooling tower basin suction pit as shown in Figure 5.
3. Modification of anti-cavitation system (Fig. 3). Existing setup utilizing ambient air as the media to prevent pump cavitation.

4.0 IMPLEMENTATION OF SOLUTION

A relative Screening Index (SI) was developed. The SI took into account: Investment and operating costs, and subjective weightings of process reliability, ease of operation, operator acceptance, ease of spent material disposal, and terrain requirements. Based on the weighting factors used, results indicated that a combination of both chemical and mechanical approaches would be the option for Mahanagdong case. A dispersant approach along with some mechanical modification had the best rating and lowest total plant investment. The overall combination had the lowest long term operating cost. The sodium sulfite approach was eventually dropped due to concern on its long-term impact on the wooden structure of the cooling tower.

4.1 Chemical

Use of dispersant to keep sulfur in suspension. Drewspense 739 is feed once a week at 20 ppm or equivalent to 96 kilos to mitigate sulfur deposition in the system. The method used to treat the system is by slug dose of 76 kilos into the cooling tower basin and the remaining balance of 20 kilos is thru the satellite injection as shown in Figure 6. The rationale behind the scheme is to maintain a concentration of 20 ppm in the system. Dosage rate is calculated based on the system volume per tower.

4.2 Mechanical

Figure 7 shows the modified vacuum separator discharge line header. The installed 12" diameter valve is the tapping point for the modification in re-routing vacuum separator discharge to cell A. With this approach, sulfur will settle at the basin thus minimizes sulfur deposition in the system.

Figure 8 shows the modified anti-cavitation system. Noncondensable gases were utilized



Figure 5. Vacuum separator discharge at the cooling tower basin.

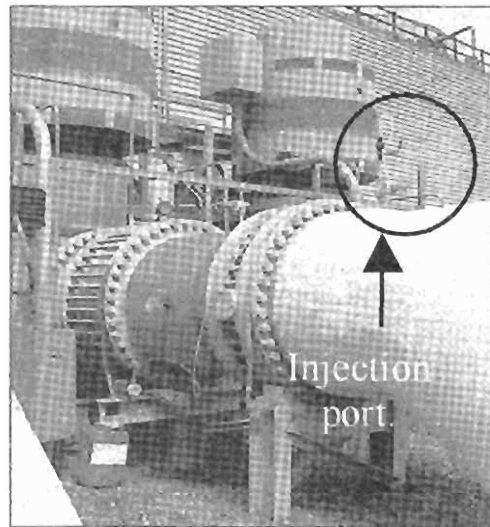


Figure 6. Cooling water supply line injection to maintain 20-ppm concentration in the system.

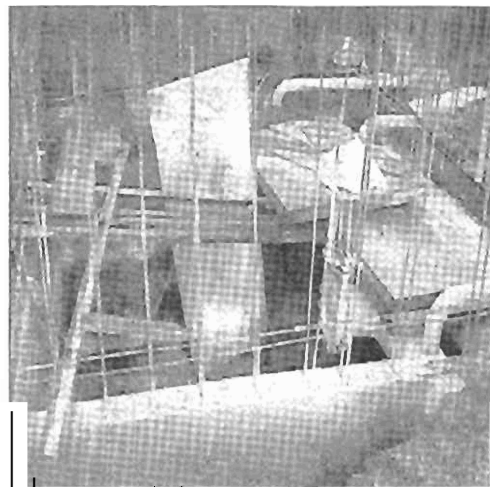


Figure 7. Tap point (12" diameter) valve to re-route vacuum separator discharge to Cell A.

as the anti-cavitation media to prevent vacuum pump cavitation. This set up will eliminate sulfur build-up in critical heat exchangers.

5.0 RESULTS AND MONITORING

After four months of commercial operation from annual warranty inspection, Unit 1 was down due to turbine blade problem. With this opportunity, inspection at main condenser was initiated to evaluate the extent of sulfur buildup after program implementation. The result was somewhat expected. Inlet water boxes indicated very thin sulfur deposition at both the shell and tube side as shown in Figures 9 and 10. The deposits can easily be removed by mere flushing. The amount of dirt is not significant compared to last inspection. A total number of 16 drums of sulfur deposit were removed from the condenser during the 2001 warranty inspection. Outlet water boxes are relatively clean as shown in Figure 11.

To ensure that sulfur buildups can be detected early, the plant installed online monitors in the common cooling water return header and provided sample connections at different return sub-headers for easy fouling identification

Figures 12 to 14 are the different monitoring instruments installed to monitor system fouling and sulfur build-up:

Visual Corrosion and Fouling Monitor (VCFM) are installed to simulate critical heat exchanger conditions and indicate if fouling occur (Fig. 12). This early warning device allow us to respond before any problem occur.

The Ashland Biofilm Monitor, as shown in Figure 13, is used to collect and monitor any biofilm formation in the system. We adjust the treatment program to eliminate biofilm before it becomes a problem.

Figure 14 shows a sidestream tower film fill-monitoring device. Used to ensure fill remains clean.

6.0 EARLIER INSPECTION RESULTS

Pictures taken during the previous warranty inspections showed progressive clogging of heat exchanger tubes over the last two years. Shown below (Figs. 15a - 22b) are pictures of some heat exchangers:

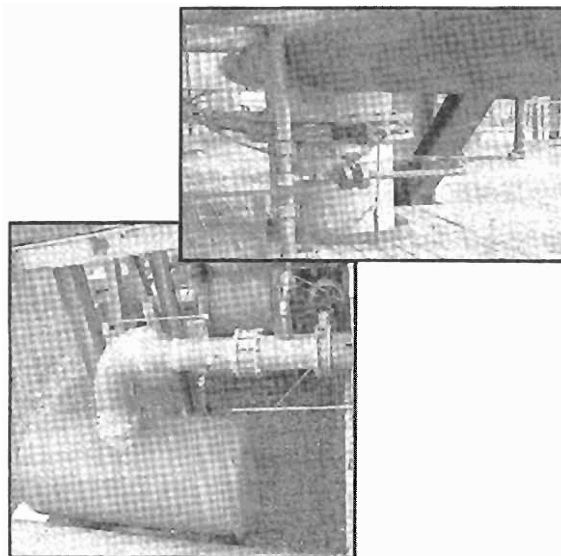


Figure 8. Show the modified anti-cavitation system. Set-up is utilizing NCG as the anti-cavitation media.

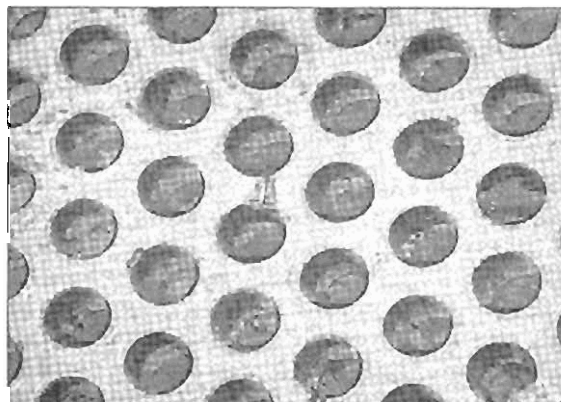


Figure 9. Very thin sulfur deposit at shell side inlet water box.

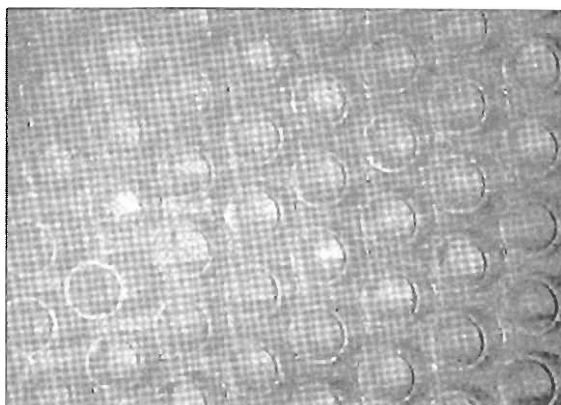


Figure 10. Very thin sulfur deposit at tube side inlet water box.

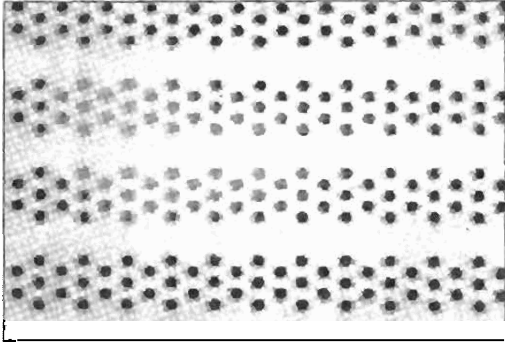


Figure 11. Main condenser outlet water box is clean.



Figure 12. Visual Corrosion and Fouling Monitor (VCFM).

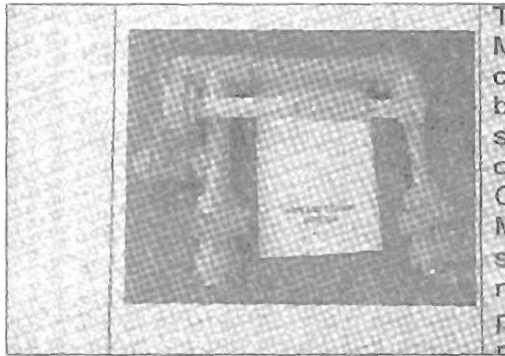


Figure 13. Biofilm monitor.



Figure 14. Tower film fill-monitor.

A. Year 2000 warranty inspection

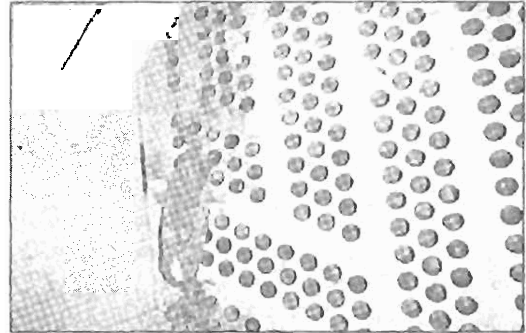


Figure 15a. Minimal sulfur deposit inside Unit 1 main condenser tubes.



Figure 15b. Sulfur deposit main condenser water inlet box.

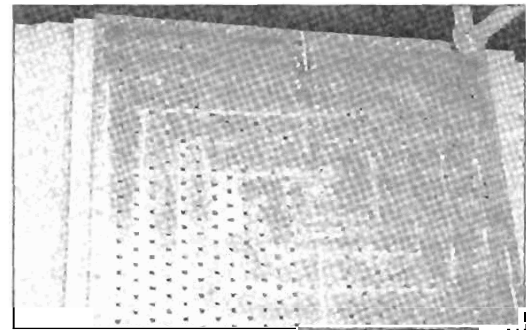


Figure 16a. Minimal deposit accumulated at Unit 1 generator air cooler.

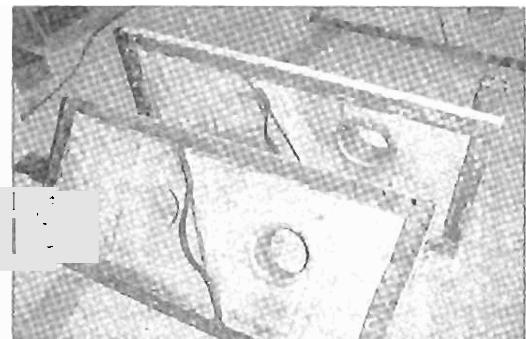


Figure 16b. Slime deposit in the head cover generator air cooler.

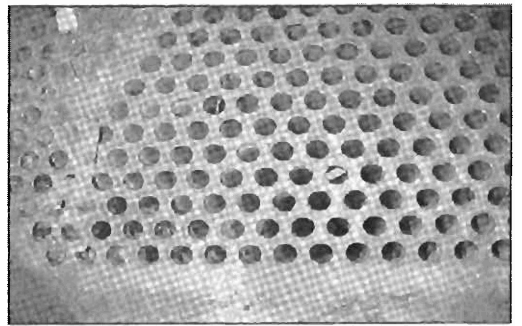


Figure 17a. Deposit accumulates at Unit 1 inter-condenser tubes interior wall.

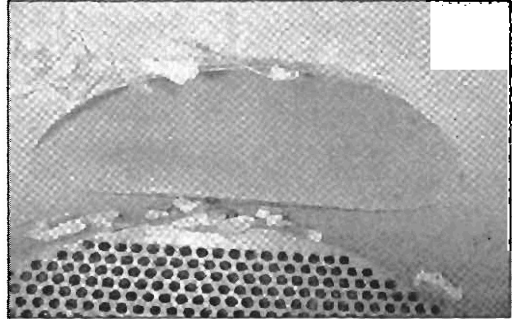


Figure 17b. Deposit at the lower portion of shell.

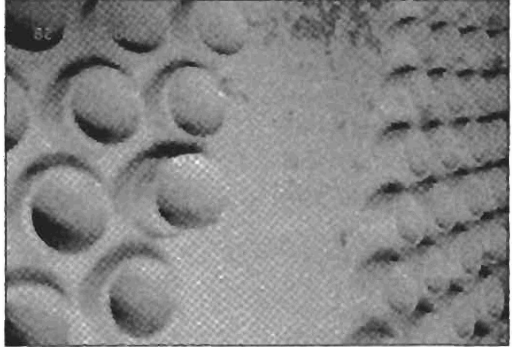


Figure 18a. Sulfur buildup heavy at main condenser water outlet box.

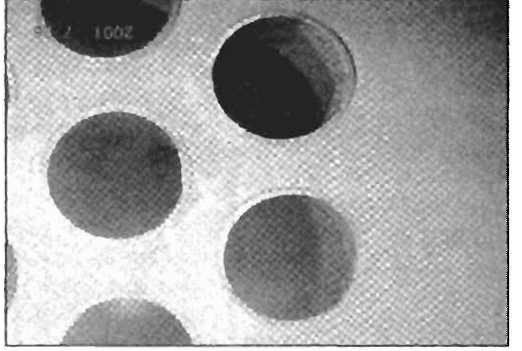


Figure 18b. Condenser tubes heavy sulfur deposit

B. Year 2001 warranty inspection

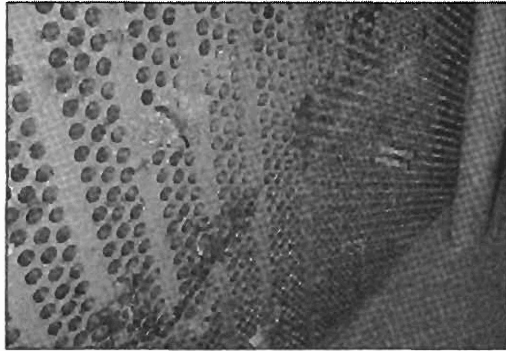


Figure 18c. Sulfur buildup main condenser water inlet box.

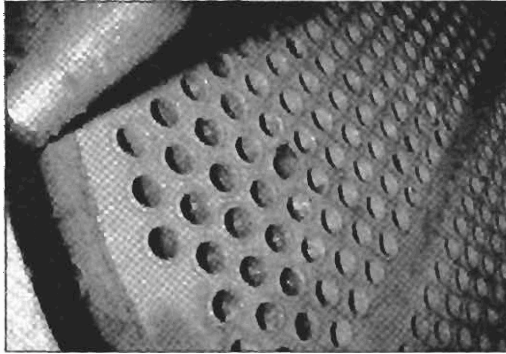


Figure 19. Oil cooler water box side buildup.

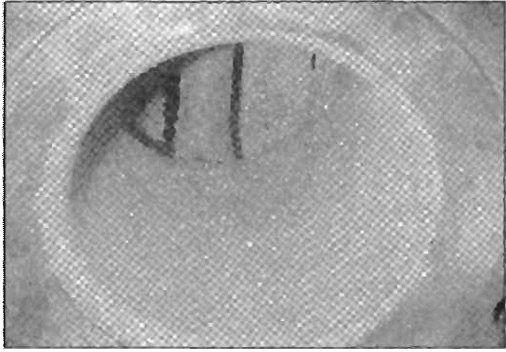


Figure 20a. Sulfur deposit heavy at gland steam exhauster shell side.



Figure 20b. Tube side gland steam exhauster.

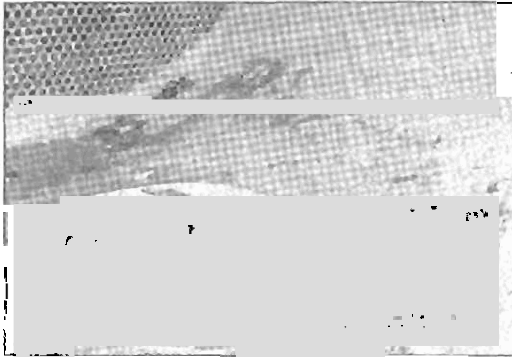


Figure 21. Sulfur deposit inter-condenser.

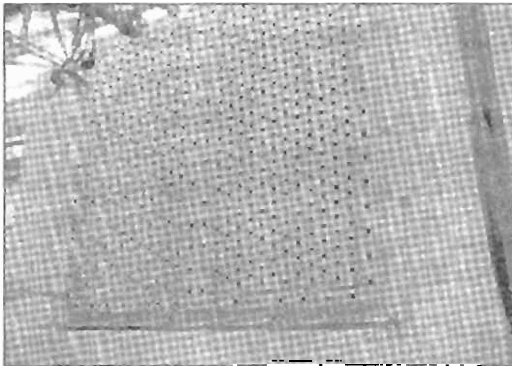


Figure 22a. Sulfur deposit generator air cooler.

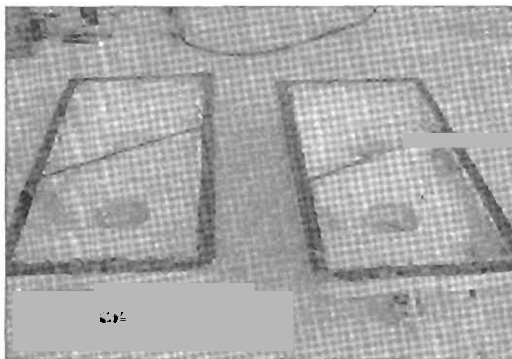


Figure 22b. Sulfur deposit at air cooler end covers.

Drewspense 739 has proven to be a cost effective and efficient means to reduce sulfur build-up in the system. Recent main condenser opportunity inspection validates the result.

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7.0 CONCLUSION

In a surface type condenser more hydrogen sulfide (H₂S) will partition into the noncondensable gas (NCG). Hydrogen sulfide in noncondensable gas reacts with oxygen at the vacuum pump to form sulfur. The installation of modified anti-cavitation system helps eliminate sulfur formation at the vacuum pump and avoid sulfur build-up related emergency shutdowns.