Journal of
Energy
Technology

JET Volume 17 (2024) p.p. 11-19
Issue 1, 2024
Type of article: 1.01
http://www.fe.um.si/si/jet.htm

DAMAGE ANALYSIS OF CONDENSER COOLING TUBES IN A THERMAL POWER PLANT

ANALIZA POŠKODB HLADILNIH CEVI KONDENZATORJA V TERMOELEKTRARNI

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Keywords: ammonia, cooling, cracks, tubes

Abstract

A steam turbine condenser (STC) is a surface, shell, and tube type vacuum condenser, cooled by a water system supplied from a river. The STC consists of two water passes and two water flows. Its condenser shell is constructed from carbon steel, and contains 4910 cooling tubes made of CuZn28Sn1As brass, each with dimensions of 23.0 x 1.0 mm and a length of 6,400 mm.

Three new steam dump devices (SDDs) have been installed on the condenser. Two SDDs are designated for high-pressure (HP) steam, while one is allocated for intermedia-pressure (IP) steam. The primary function of the SDDs is to divert steam from the boiler through the bypass system into the STC. The bypass system is utilised primarily during start-up, shutdown, and for managing excess steam transfer.

The Commissioning and Trials Board conducted tests on the new SDDs, which lasted for five hours. However, during the commissioning phase, high condensate levels in the STC caused trips. Additionally, online monitoring indicated high condensate conductance. Upon opening the condenser water chamber doors and filling the steam side of the condenser with water, it was discovered that twenty-eight of the cooling tubes were leaking. These leaking tubes were subsequently plugged. For further analysis, four cooling tubes were extracted, and two condensate samples were obtained. While extracting the cooling tubes, the other tubes were inspected visually using a borescope to assess their internal condition.

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The analysis results indicated that all the cracks on the extracted tubes were located approximately 5 mm from the tube sheet on the front side of the condenser, where the cooling water inlet and outlet are situated. Furthermore, grooves were observed on all the other tubes at the same location, characteristic of stress-corrosion cracking influenced by ammonia.

Povzetek

Kondenzator parne turbine (STC) je površinski, lupinasti in cevni vakuumski kondenzator, hlajen z vodnim sistemom, ki se dovaja iz reke. STC je sestavljen iz dveh vodnih prehodov in dveh vodnih tokov. Ohišje kondenzatorja je izdelano iz ogljikovega jekla in vsebuje 4910 hladilnih cevi iz medenine CuZn28Sn1As, vsaka z dimenzijami 23,0 x 1,0 mm in dolžino 6400 mm.

Na kondenzatorju so bile nameščene tri nove naprave za izpust pare (SDD). Dva SDD-ja sta namenjena za visokotlačno paro (HP), eden pa je dodeljen za paro srednjega tlaka (IP). Primarna funkcija SDD je preusmeritev pare iz kotla skozi obvodni sistem v STC. Obvodni sistem se uporablja predvsem med zagonom, zaustavitvijo in za upravljanje presežnega prenosa pare.

Komisija za zagon in preskušanje je opravila teste novih SDD, ki so trajali pet ur, vendar so med fazo zagona visoke ravni kondenzata v STC povzročile izklope. Poleg tega je spletno spremljanje pokazalo visoko prevodnost kondenzata. Ob odpiranju vrat vodne komore kondenzatorja in polnjenju parne strani kondenzatorja z vodo je bilo ugotovljeno, da pušča osemindvajset hladilnih cevi. Te puščajoče cevi so bile nato zamašene. Za nadaljnjo analizo smo ekstrahirali štiri hladilne cevi in pridobili dva vzorca kondenzata. Med ekstrakcijo hladilnih cevi so bile druge cevi vizualno pregledane z uporabo boroskopa, da se oceni njihovo notranje stanje.

Rezultati analize kažejo, da so vse razpoke na izvlečenih ceveh približno 5 mm od cevne pločevine na sprednji strani kondenzatorja, kjer sta dovod in odvod hladilne vode. Poleg tega so na vseh drugih ceveh na istem mestu opaženi utori, značilni za napetostno korozijsko razpokanje pod vplivom amonijaka.

1 INTRODUCTION

A steam turbine condenser (STC) is a critical component in a power plant's water-steam cycle system. Its primary function is to condense the steam exiting the turbine into water, which can then be pumped back into the boiler to be reheated and reused in the water-steam cycle. Steam from the boiler is directed into the steam turbine, where it expands and generates mechanical energy as it passes through the turbine blades. This energy turns the turbine shaft, which drives a generator to produce electricity. After leaving the turbine, the steam enters the STC at a lower pressure and temperature. Inside the STC, the steam comes into contact with tubes or surfaces cooled by water. This cooling process causes the steam to condense back into water.

The STC bypass system plays a vital role in optimising the performance, stability, and safety of power plant operations by regulating the steam flow through the condenser during various operating scenarios. This system allows for the controlled diversion of steam around the condenser, bypassing the main steam`s flow path when necessary. It helps manage the steam flow rates, controls the HP and IP steam pressure, and ensure stable operation during start-up, shutdown, and load changes. The bypass system is complemented by SDDs, which are used to reduce steam pressure before it enters the STC. The SDDs are shown in Fig. 1.

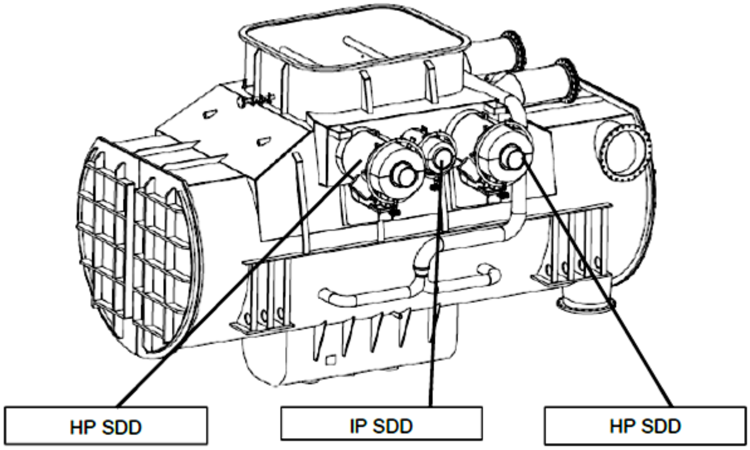

Figure 1: The SDDs integrated on the STC

The STC tube bundle is divided into left and right sides, and each side of the tube bundle are divided into 3 sectors: upper (U), middle (M) and lower (L). The tube bundle sides, tube bundle sector, damaged tubes, and plugged tubes for inspection are shown in Fig. 2.

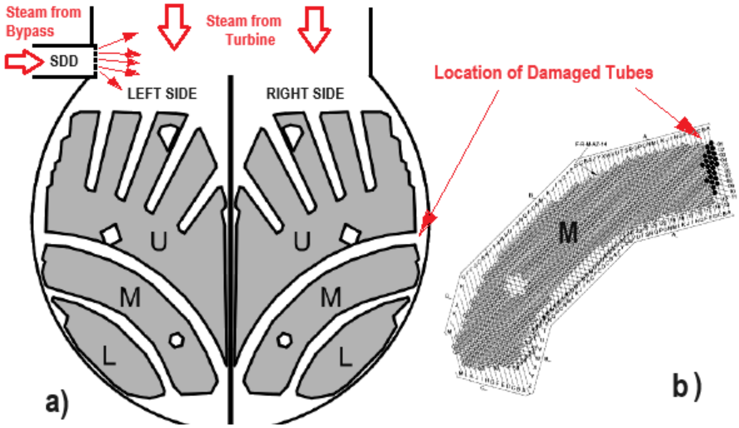

Figure 2. a): *Tube bundle sectors, and b) Damaged tubes and plugged tubes for inspection*

After the fifth hour of test operation, the Commissioning and Trial Board found a leakage in the STC cooling tubes. Additionally, online monitoring indicated high condensate conductance. Two condensate samples were taken from the STC for chemical analysis. One sample was taken before testing, and the second sample was taken during the testing procedure.

For analysis, four cooling tubes were extracted, two condensate samples were obtained, and the steam flow velocity was calculated from the SDDs. While extracting the cooling tubes, other tubes were inspected visually using a borescope to assess their internal condition.

2 RESULTS OF TUBES AND WATER ANALYSIS

All the extracted tubes were examined visually for any cracks or holes. In addition, their inner and outer surfaces were examined, and special attention was given to the outer surfaces of the tubes in places of tube sheets and support plates.

All tubes have a thin, approximately 0.1 mm, nonuniform layer of dry mud spread throughout. This mud layer may be attributed to low cooling water velocity through the condenser tubes, rough filtration of cooling water, or a combination of both factors. Cleaned surfaces show a uniform layer of red-brown oxide, indicating that a naturally forming layer has been established and is serving its purpose of protecting the inner surfaces of the tubes.

All the extracted tubes that were leaking and subsequently plugged were examined, to determine the source of the leaks. Circumferential cracks were found only at the beginning end of the tubes, near the front side. These cracks appeared approximately 3 to 5 mm after the tube sheet and were straight or slightly branched. Additionally, grooves were discovered on other tubes in the same location as the cracks found on the leaking tubes. These circumferential transverse grooves near the tube sheets are indicative of trans-granular stress-corrosion cracking, likely caused by excessive ammonia. The location of tube cracking and the cracks on the front end of the tube are show in Fig. 3.

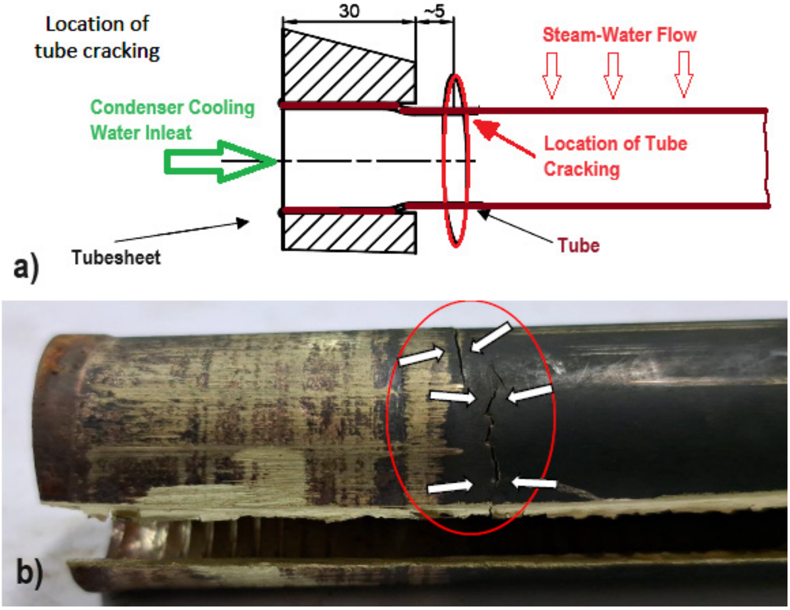

Figure 3. a): Location of tube cracking and b) Crack on the front end of the tube, approximately 5 mm after the tube sheet

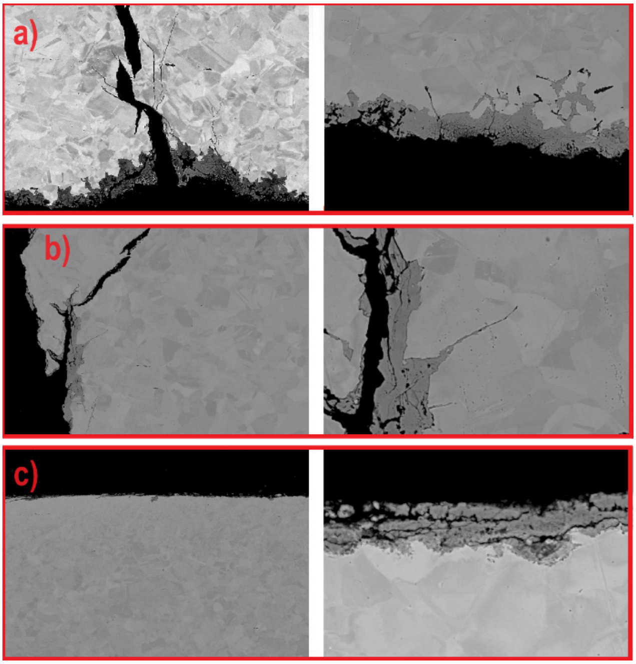

Figure 4: Examination under a microscope revealed: a) Transcrystalline progression, b) Additional cracks branching from the main crack, and c) Oxidation on the outer surface

Analysis of the tube also involved examination under a microscope. From Fig. 4, the following observations were made:

- a) The initiation of cracks on the inner surface of the pipe;
- b) The presence of multiple transcrystalline cracks;
- c) Oxidation of the outer surface with no visible marks;
- a) and b) Branched secondary cracks observed adjacent to the main crack and
- a), b) and c) Oxidation to a thickness of 50 µm.

Also, two condensate samples were provided for chemical analysis. The results of the chemical analysis of the condensate are presented in Table 1, along with the safe operating values for steam turbine steam-water cycles where heat exchangers with brass tubes are installed.

Table 1: *Chemical analysis of the condensate*

No.	**Sample name**	**pH**	**λ Electrical conductivity (µS/cm)**	**NH3 Ammonia (ppb)**
1	Before start	8.2	59.3	6135
2	During operation	9.6	7.8	1827
a	Values considered safe during commissioning	Min. 5.0	Max. 1.0	Max. 1000
b	Values considered safe during normal plant operating modes	9.0 to 9.3	Max. 0.25	250 to 700

From the results of the analyses, it can be summarised that the cracks initiated on the inner surface of the tube and progressed transcrystallinely throughout. Multiple visible cracks were observed, characterised by branching and the presence of oxides, which are common indicators of stress corrosion cracking.

All the cracks on the tubes that were extracted were found at the same position, approximately 5 mm from the tube sheet on the front side of the condenser, where the cooling water inlet and outlet are located. Grooves were also found on all other tubes at the same location, characteristic of stress-corrosion cracking influenced by ammonia.

These cracks and grooves were found primarily in places where the tubes were rolled into the tube sheets, indicating high stress. It is assumed that these grooves may also be caused by stress corrosion cracking under ammonia, but were either self-healed, or had not progressed to cracks yet.

No other areas on the tubes showed signs of damage, and there were no damages on the tubes where the tube bundle support plates are located. Chemical analysis of the condensate samples revealed an extremely high concentration of ammonia.

3 RESULTS OF THE HP SDDs PERFORMANCE ANALYSIS

In addition to analysing the STC tubes and condensate quality, we also conducted a performance analysis of the HP SDDs. We obtained data on the quality and quantity of steam entering the HP SDDs device using the Supervisory Control and Data Acquisition (SCADA) system (see Fig. 5).

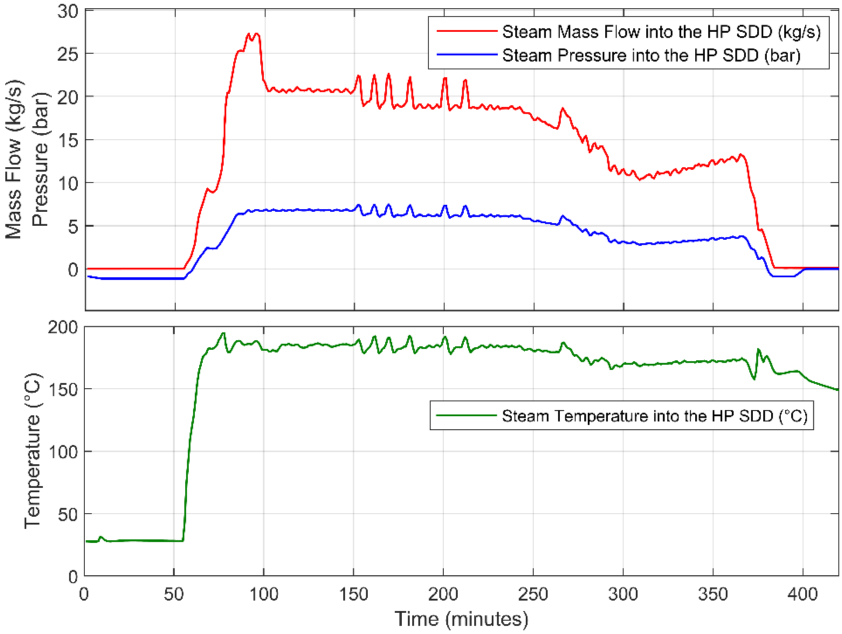

Figure 5: *Quality and quantity of steam entering the HP SDDs device*

Fig. 5 illustrates that, during HP SDD device operation, the incoming steam reached a maximum flow rate of 26 kg/s, with a pressure of up to 9 bar and a temperature of up to 190°C. The steam exit velocity from the HP SDD device, also known as the steam velocity entering the STC, was calculated using these data. The steam velocity from the HP SDD device was calculated using the Mach number equation. The steam Mach number is defined from the total pressure difference of the dumped steam flow and the isentropic exponent n. The velocity is calculated of the steam exiting the HP SDD device:

$$v_4 = M \cdot v_{ss} = \sqrt{\frac{2}{n-1} \cdot \left(\left(\frac{p_3}{p_4} \right)^{\frac{n-1}{n}} - 1 \right)} \cdot v_{ss} \tag{3.1}$$

where v_4 is the velocity of the steam exiting the HP SDD device, M is the Mach number, v_{ss} is the sound speed of the steam, p_3 is the steam pressure in the rear chamber of the HP SDD device, p_4 is the steam pressure entering the STC, and n is the isentropic exponent. The results of the steam speed calculation from the HP SDD, depending on the load, are shown in Fig. 6.

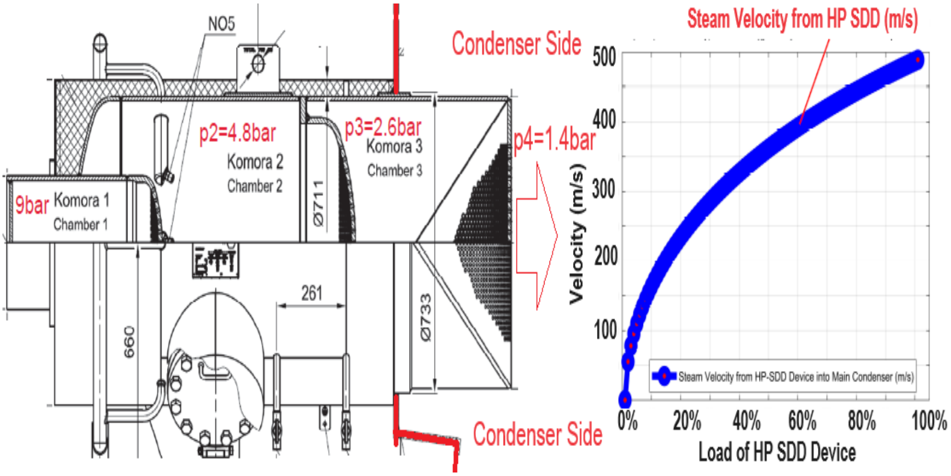

***Figure 6:** Design and steam velocity from the HP SDD*

The results of the analysis (see Fig. 6) show that, at full load of the HP SDD, the steam velocity entering the STC was 490 m/s, exceeding the recommended steam velocities significantly. Bypass steam with excessive velocities can cause severe damage to the condenser internals. The Heat Exchange Institute (HEI) Standards for steam surface condensers provide limits for maximum enthalpy, pressure, and velocity of bypass drain or bypass steam allowed to enter into the condenser. According to the HEI, the maximum enthalpy is 2850 kJ/kg, the maximum pressure is around 18 bar, and the maximum steam velocity is around 155 m/s. Wet steam is not permitted. Damaged bypass headers, sheared tubes, and damage to internal structural members have been encountered frequently during bypass operation.

4 CONCLUSIONS

Based on the results of the analysis, it can be concluded that the damage to the STC cooling tubes was attributed to a combination of circumstances that led to stress corrosion cracking. Excessive steam inlet velocities in the STC caused large surface and resonance loads on the cooling tubes. Additionally, the excessive amount of ammonia in the condensate contributed to surface corrosion. As the cracks propagate from the inner tube to the outside, it is necessary to maintain a constant flow of cooling water.

Measures to prevent damage to the STC tubes:

- About three rows of tubes around the affected area, including the affected area, should be replaced with thicker tubes, 23.0 x 2.0 CuZn28Sn1As;
- The ammonia content in the steam should be monitored carefully, and should be kept to 250 ppb up to 700 ppb, and the pH maintained between 9.0 and 9.3;
- The steam velocity from the SDDs should be reduced to the HEI recommended velocity.

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