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EXAMINATION OF LUMMUS CONDENSER TUBING

by

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Abstract

Four tubes of Admiralty metal in the Lummus off-hull condenser leaked because of a combination of exposure to mercury and residual stress. 70/30 cupronickel alloy is relatively immune in the same environment.

DESCRIPTION:

Leaks developed in four tubes of the off-hull Lummus condenser after a total service life of approximately 5000 hours. The condenser tube - tube sheet arrangement is shown in Figure 1. Condensing water flows through the interior of the admiralty brass tubes which are 0.642" inside diameter x 0.049" wall thickness. The 2700 tubes are fastened into the Muntz metal tube sheets by cold expanding the inside tube diameter 0.030" and the outside diameter 0.008 - 0.010".. The condenser is constructed of the following materials:

Tubes: Admiralty Tube 70%Cu, 0.05%As, 1%Sn, 0.06%max. Fe, Bal. Zn.

Tube Sheets: Muntz Metal 60%Cu 40%Zn.

Shell, Hot Well: Copper bearing steel.

Water Boxes, Water Box Covers, Baffles, Tube Supports: Steel Plate

During certain phases of S1G operation, the water side Power Plant components were exposed to conditions somewhat different from conventional power plant conditions. Water dissociation by gamma irradiation has increased the hydrogen-oxygen concentration at certain portions of the system since initial operation. Mercury was present in the water-steam-condensate system for about 3800 total hours. During October and November sodium sulphite was introduced into the port loop to help combat oxygen damage. Since saturated steam samples did not contain sulfide, sulfate or sulfite[1], during the sulfite scavenging period, it is probable that these materials were not delivered to the condenser tubes. From October 26, 1956, "Leakure" and "X" Liquid boiler compounds have been present in the starboard evaporator. Subsequent to introduction of these materials into the evaporator but before it had been irradiated, the "X-Liquid" decomposed, and the odor of the decomposition products permeated the entire system.

It is well known that brass of this composition is liable to failure under certain conditions of stress, time, and corrosive media. The action of mercury in causing stress cracking is so well established that condenser tubing specifications require immersion of representative samples from each lot in a standard mercurous nitrate solution to ensure tubing has been heat treated properly for removal of residual stresses. Stress-free tubing will not crack during a 1/2 hour exposure in mercurous nitrate. Tubing samples having residual stresses will crack intergranularly by a stress corrosion mechanism. Stressed brass is also very susceptible to ammonia vapors and presumably other media such as O, H, H_2S, CO, SO_2, SO_3 if present in the condenser during its service may have contributed to the cracking. However, the microstructural evidence seems to indicate that mercury was chiefly responsible.

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(1) Communication from E. L. Brady, 1/23/56

EXAMINATIONS:

General: Three tubes failed near the return water box tube sheet with circumferential cracks at the transition between the expanded portion of the tube and the original tube diameter. The other tube failed 26" from the outlet water box tube sheet. All the four failed tubes were located in an upper quadrant of the tube bundle on the outlet condensing water side of the bundle.

Aside from some erosion probably caused by too high vacuum and excessive velocity during some portion of the operation, the appearance was excellent. The erosion did not contribute to failure in the opinion of a Lummus field representative. The tubes were smooth and unpitted near the failures. There was a considerable variation in the color of the tubes. Tube #4 was silvery near the tube sheet, but had a characteristic yellow brass color 18" from the tube sheet. The #1 tube which failed 26" from the tube sheet was black near the fracture with a gradation to greenish brown near the tube sheet.

Some longitudinal cracks were formed near the primary circumferential cracks. Dycheck examination of the tubes did not reveal any additional cracks along the length of the tube except for those described near the original fracture. Aside from the cracks there was no evidence of poor tube quality; the tubes examined were free of splits, seams, laps, inclusions or any type of defects. The hardness was Rockwell F 79 which is normal for annealed fine grained (0.015 mm) Admiralty metal.

MICROSTRUCTURE:

Tubes identified as #2, #3 and #4 cracked near the return water box tube sheet. Failure in tube #4 occurred circumferentially in the tube as shown in Figure 2. The short section of tubing, originally in the tube sheet, was distorted to facilitate removal. Figure 3 shows the circumferential fracture edge and secondary intergranular cracks. The grains near the cracks show many strain markings probably caused by severe cold working during expansion of the tube into the tube sheet. Figure 4 shows the tip of a longitudinal crack is preceded by an area differing in composition from the matrix. Annealing twins are present in the fine grained matrix which does not show strain markings.

Tubes 2 and 3 show substantially the same type cracks as described for tube 4. The failure location in tube #1 differed from the other three since the leak occurred 26" from a tube sheet. The crack was circumferential and intergranular as were the others. There was very slight evidence of a composition change around the crack as shown in Figure 5.

CHEMICAL ANALYSES:

Spectrographic analyses[(2)] showed evidence of mercury at the edge of tube #4 fracture and 1" from the fracture. The amount of mercury present near the fracture was about four times that found in a sample 18" from the failure. This is in general agreement with the silvery appearance near the tube sheet and preliminary boroscope observations by D.B. Nelson[(3)] of droplets resembling mercury on tube ends near the tube sheet, with a decreasing concentration of droplets toward the midlength of the tubes.

(2) Communication F. P. Landis, 1/27/56.
(3) Communication D. B. Nelson, 1/18/56.

Samples from tube #1 which failed 26" from the tube sheet were examined spectrographically to determine mercury concentration at the fracture and at locations 1 foot on either side of the fracture. One foot from the fracture the concentration was estimated to be 1 - 10 μg/.5 gr sample, while at the fracture the concentration was between 5 - 25 μg/.5 gr sample[2].

RESULTS OF MERCUROUS NITRATE AND MERCURY TESTS[4]

A portion of tube #1 taken approximately one foot from the fracture was subjected to a standard mercurous nitrate test and did not crack.

A tubular specimen taken 15" from the tube sheet was flattened to produce a maximum strain of 0.02", exposed to mercurous nitrate and cracked badly in four minutes. Figure 6 is a photomicrograph of this tube section. There is a marked resemblance of these cracks to those found in tube #1 and shown in Figure 4. A zone of amalgamation apparently is associated with the crack formation.

Another tubular specimen, flattened to produce a strain of 0.011" was exposed to mercury for 170 hours without cracking. However, when an attempt was made to increase the stress, the specimen cracked immediately.

DISCUSSION:

The evidence indicates that conditions for stress corrosion cracking were present in the condenser tubes near the tube sheets. Expansion of tubes into the tube sheet would provide either a level of residual stress or concentration of stresses associated with operation. Mercury will cause stress corrosion cracking and was found near all the cracks. The location of failures in a single sector of the tube bundle may bear some connection with the flow and velocity of mercury droplets.

Cracking of the #4 tube away from the tube sheet is less simple to explain since this section would supposedly be stress-free. Sufficient residual stress to cause cracking in the presence of mercury might have been produced by kinking and subsequent straightening of the tube either during manufacture or installation in the condenser. Microstructural examination cannot affirm the presence of residual stresses required to cause stress cracking.

Other mechanisms which could be considered responsible for the fracture might be excessive tensile stresses introduced by the sequence of tube insertion or fatigue failure caused by inadequate tube support and operational vibration. However, fractures produced solely by these mechanisms would be transcrystalline. Nevertheless, there is no evidence of transcrystalline cracking of the tubes. High temperature fractures can be intergranular but the temperature of the condenser tubes supposedly never reached the threshold temperature required for an intergranular mode of fracture. Some alloys can be embrittled by grain boundary precipitation and subsequently fail intergranularly, but there was no evidence of such a condition in the condenser tubes.

(4) Communication from G. E. Galonian, 1/20/56

RESULTS OF MERCUROUS NITRATE AND MERCURY TESTS ON 70/30 CUPRONICKEL:

Tests are continuing to evaluate the behavior of 70/30 cupronickel in mercury, and the results will be reported later. Thus far preliminary test data support industry wide experience that 70/30 cupronickel is immune to stress cracking by mercurous nitrate or mercury at temperatures below 100C. Laboratory efforts to stress corrosion crack SSTG condenser tubes have been unsuccessful. In addition mercury did not penetrate into the SSTG tube wall.

CONCLUSIONS:

(1) Examination of leaking condenser tube sections reveals the mechanism of failure to have been stress corrosion.

(2) The presence of mercury was either solely or primarily responsible for the cracks. Microstructural evidence of amalgamation in grains contiguous to cracks was found.

REMEDIAL MEASURES FOR LUMMUS CONDENSERS:

The most obvious remedial measure is to reduce the mercury concentration. However, even with less mercury there is no basis for assuming that additional tubes will not fail by the mechanism responsible for the four tubes which have leaked thus far. The evidence to date points to a non-homogeneous distribution of mercury within condensers. It is possible that the remaining tubes will be long lived because of the mercury distribution and the probability that all the tubes do not contain the same level of residual stress.

Should the frequency of failures increase to a point where retubing appears necessary, some choice of retubing materials and procedures will be required. Of the possible retubing materials, 70/30 cupronickel seems a better choice than 90/10 cupronickel, monel, copper, austenitic stainless steel, ferritic steels, nickel, Inconel or the copper zinc brasses.

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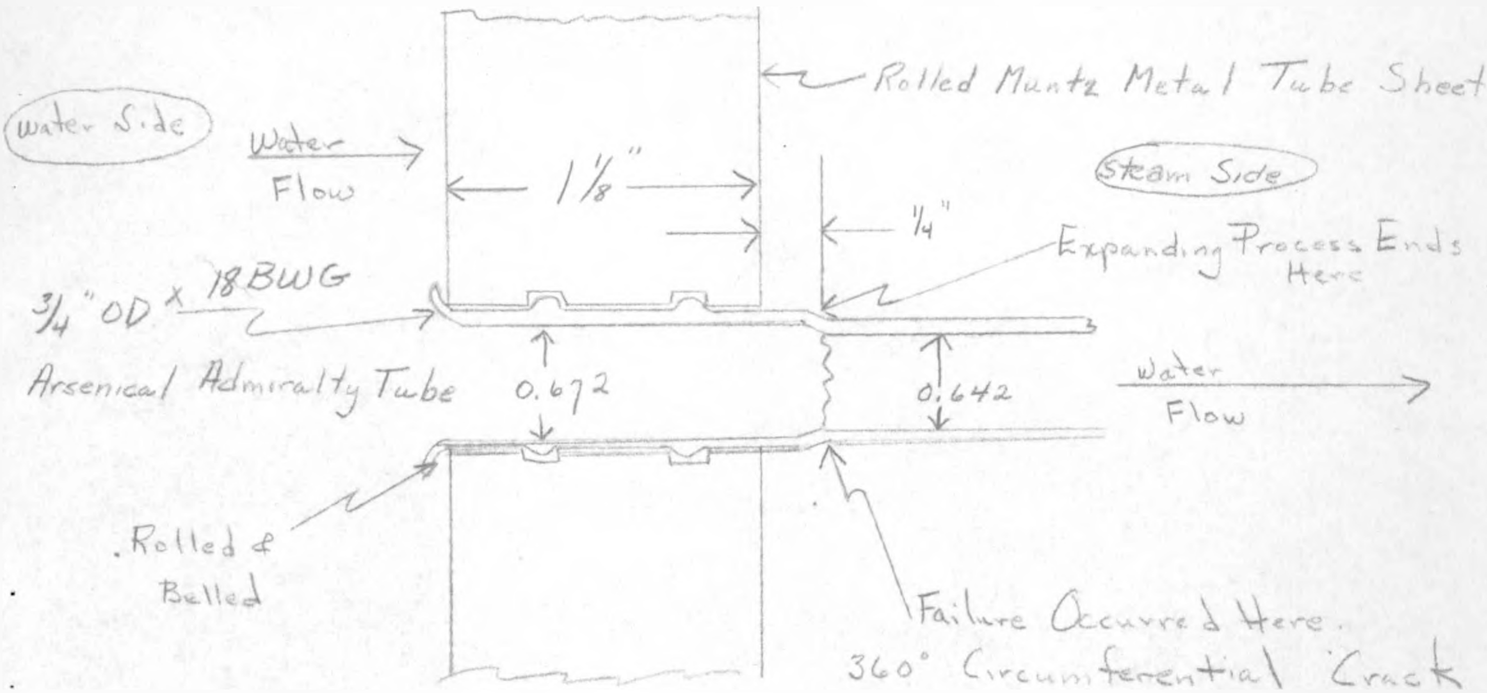

Fig. 1.
Tube - Tube Sheet Arrangement - Lummus Condenser

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Fig. 2. Condenser Tube #4. Right side expanded into tube sheet, circumferential ridges visible. Longitudinal crack and distortion caused during tube removal. Center - primary circumferential crack. Left side is tube section exposed to condensate environment. A small secondary longitudinal crack is visible 1/2" from bottom. 2 X

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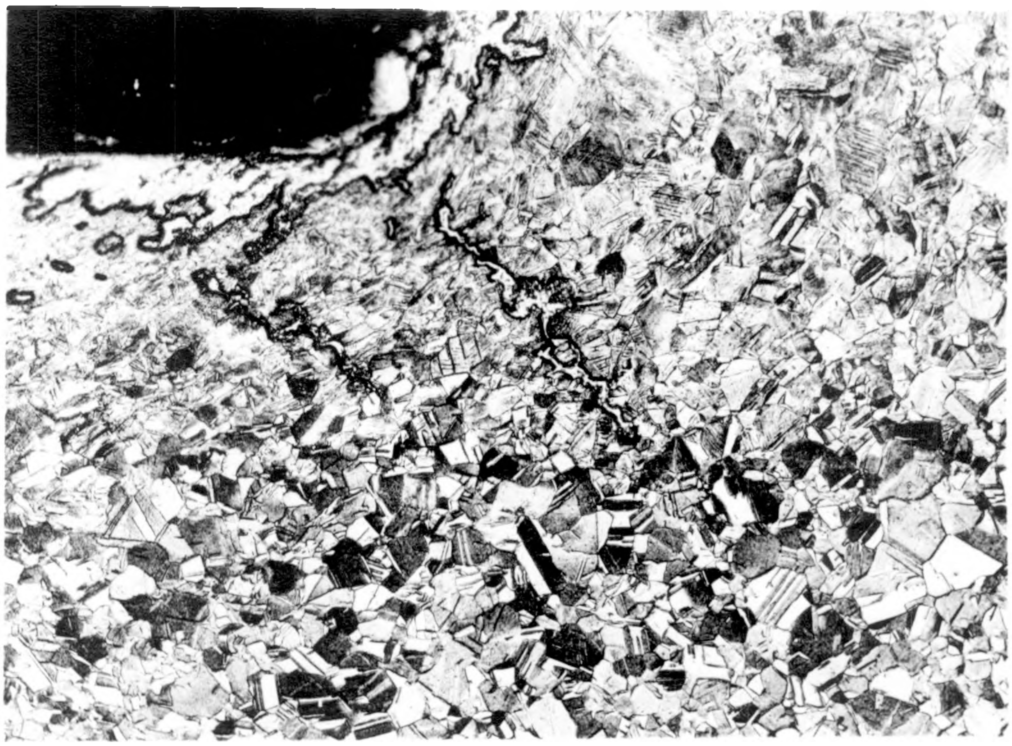

Fig. 3. Condenser Tube #4. Upper left corner is primary circumferentail fracture. Cracks in upper left are longitudinal and intergranular. Strain markings are evident in grains near cracks showing effects of cold expansion into tube sheet. 250X

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Fig. 4. Termination of longitudinal crack in tube #4 showing area of amalgamation around crack. 250X

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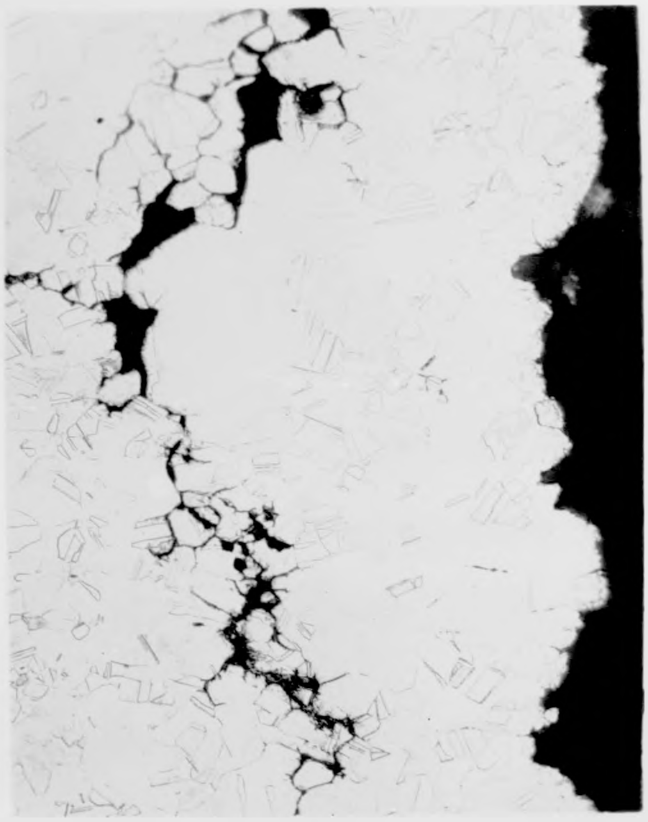

Fig. 5. Tube #1 which failed 26" from tube sheet. Crack is intergranular. Slight evidence of amalgamation.

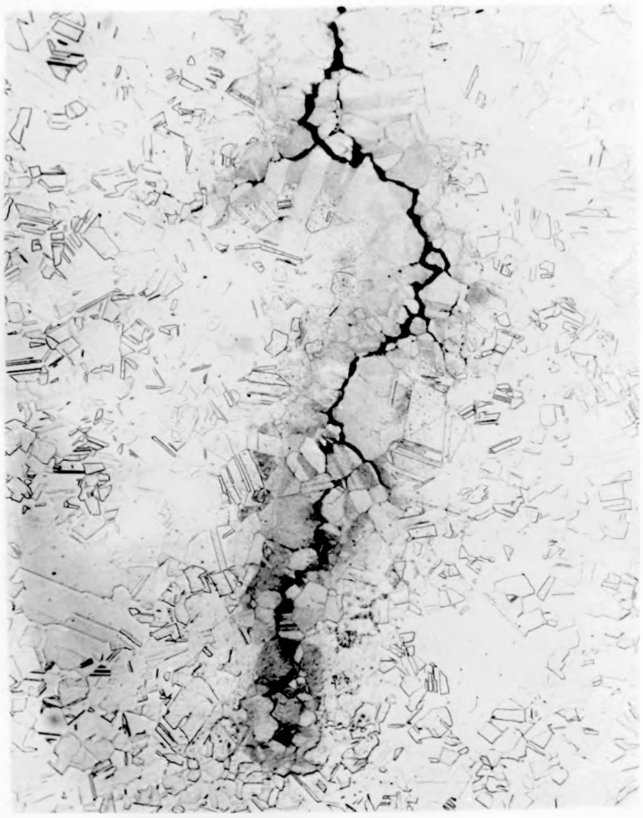

Fig. 6. Section of tube #1 flattened and cracked in mercurous nitrate.

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