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FAILURE OF VAPOR OVERHEADS DISCHARGE LINE FOR A RADIOACTIVE WASTE EVAPORATOR

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Abstract

A 2-inch schedule 40 steel core pipe in an evaporator overheads discharge line broke at several locations downstream from a section of the line where it bridges a road. Fish mouth openings that developed along the pipe seams were initiated at lack of fusion defects in the pipe welds. A vacuum created in the piping upstream of the breaks prevented full drainage of the water upon shut down of the pump. Freezing of water in the pipe (the line was not heat traced) and water hammer effects occurring with pump restart could each contribute to the extensive deformation and tearing observed at the breaks. Both the weld flaws and the over pressure contributed to the outcome. All pipe was replaced and a vacuum break was installed to eliminate the problem.

Background

The Savannah River Site (SRS) has been in operation since the early 1950's as a producer of nuclear fuels for defense applications. Altogether, five nuclear reactors were used during the production years and two chemical separations facilities partitioned, purified and packaged the products. As a result of the processing, millions of gallons of liquid wastes were generated, and reduction of liquid volumes was imperative in order to be able to contain the wastes. Special designed evaporators were put into service about 1960 for this purpose [1].

In the evaporators, volumes of fresh wastes are reduced by 70%. The concentrated wastes are then stored in huge underground tanks built especially for that end use. The water that is boiled off is referred to as "overheads". It is captured and decontaminated, and the effluent is treated before it is discharged to the outfall.

The highly radioactive liquids in the storage tanks are now being put into a stable form by incorporating the material into a solidified molten glass mix. Excess water used in processing the waste must also be eliminated, i.e. evaporated. A new, large evaporator facility designed to handle the additional wastes was recently completed. During trial runs, a failure occurred in the overheads discharge system.

Description

The evaporator overheads line is a jacketed, 2-inch galvanized carbon steel pipe installed above ground and on a pipe bridge between the evaporator and the first downstream manhole. The core pipe is specified as ASTM A53, ASME B31.3, category D, galvanized. The jacket pipe is ASTM A53, ASME B31.3, seamless pipe (not galvanized). Downstream of the evaporator building, the pipeline crosses a roadway via a riser and downcomer approximately 30 ft. high. The pipe otherwise is installed on piers with a typical gravity drain slope of ~3%. With no heat tracing, the above ground layout is subject to the possibility of freezing in no-flow or obstructed flow situations. The pipe had been plugged with a blank flange at the manhole following a hydrotest in October 96. A tie-in of the pipe to the underground main at the manhole was made in September 98. The underground collection system discharges to an effluent treatment plant.

A leak to the annular space of the jacket pipe was discovered during test runs in August 99. The leak was located downstream of the road crossing (high point). Further investigation revealed five additional openings or holes in the pipe, Figure 1. All of the openings were bursts and exhibited a “fish mouth” or “pucker” appearance. The steel was permanently stretched into that configuration, Figure 2. The failures were examined to determine the nature of the breaks.

Inspection and Discussion

As evident in several bursts similar to that in Figure 2, the breaks are very straight and oriented with the pipe axis. The end points are sharp and project axially in both directions in all but one case. Figure 3 shows break #2 from Figure 1, which involved a butt weld joint. In this case, the axial tear, driven by the burst or expansion, continued in the circumferential direction along the edge of the butt weld. The pipe seams for the two pipe joints did not line up axially across the butt joint. Inspection revealed that no significant corrosion had occurred, and the fractured surfaces exhibited only superficial rusting.

Further visual examination revealed, in each case, that the split or tear was aligned with a longtitudinal or axially oriented indication on the internal surface of the pipe. This appeared to be a seam weld. Further inspection of one pipe length revealed an axial defect which was at least 2.5 inches long and had a depth of approximately ½ wall thickness (Figure 4). This defect follows the indication or weld line on the ID surface.

Metallographic study revealed additional smaller linear flaws that had an axial orientation at the weld locations, Figure 5. These are located on the edges of the seam welds and are due to lack of fusion at the weld. The microstructure of the steel is typical for normalized low carbon steel, the heat treatment having occurred at the mill subsequent to welding and perhaps to the sizing operation for the schedule 40 dimensions. The seam appearance is consistent with an electric resistance weld. Grains have a generally radial orientation in the vicinity of the weld, and the weld defects are aligned with the crystal boundaries. Laboratory analysis indicates 0.21% carbon content for the pipe. These data confirm the pipe to be consistent with ASTM A53, Grade A, Type E steel. Note that the flaw dimensions in Figure 5 are within ASTM acceptance limits, but the deep flaw in Figure 4 would be cause for rejection at the mill, had it been seen. Any of the observed lack of fusion imperfections would probably have resulted in failure of an applied cold flattening or "crush" test, in accordance with ASTM A53 criteria. It is presumed that each length of pipe did pass the required hydrostatic test at 2300 psi, though no CMTR's were found in the project file.

Study of Figure 5 shows the ID weld flaw on the right cracked through the galvanized zinc coating, whereas the flaw on the left did not break the external surface of the coating at this specific location. However, it probably penetrates at other locations along the weld line. In most cases, the hot dipped galvanized zinc coating appears to have good bonding to the pipe. Figure 5 shows some cracking and porosity in the iron/zinc layers, but also evidence of good bonding to the steel. Figure 6 shows a case where the zinc has been chipped or has spalled in a small area on the exterior surface of the pipe. Peeling or cracking in the zinc coating extends axially from the chipped area in both directions. The damage is probably due to a combination of poor local bonding and rough handling.

Structural mechanics analysis of the pipe system indicated that the breaks in the line probably resulted from water hammer. Freezing of water in the line could possibly cause initiation of such breaks, though it is unlikely the breaks would develop to the same extent. The location of the first burst downstream from the road crossing (Break #1) is consistent with significant overpressure near this site caused by a column separation mechanism. Prevention of draining of the line by inadvertent sealing upstream was shown to hold the water level at the location in question by means of a vacuum in the piping at the bridge location. When the pump was shut down, forced flow ceased and a vacuum developed in the downcomer, preventing drainage. Placement of a vent at the top of the road crossing is needed to release this vacuum, thereby avoiding the non-drainage problem.

The start-up pressure for the existing situation was reported to be ~3000 psi. Seamless pipe, or pipe without the sharp imperfections found in the failed pipe, would be expected to survive the pressurization. However, weld flaws not only reduce the wall thickness; they also introduce stress concentration effects at the defect locations on the pipe. It is unlikely that the pipe would have failed in the absence of the flaws, even with the overpressure. The hammer effect caused the pipe to break, but presence of the crack initiator for concentrating the stress was critical. A better grade of pipe would have survived the hammer. Moreover, existence of a vacuum relief would have prevented the entire occurrence, so that even the flawed pipe would have worked properly.

It was recommended that a vent be installed at the road crossing. The above ground section of inner or core pipe between the roadway bridge downcomer and the vertical step just upstream from the manhole (Figure 1) was replaced with seamless pipe meeting ASTM A106. This pipe also meets the original A53 specification.

Conclusions

Lack of fusion defects at the toe of seam welds in the pipe used for the evaporator overheads discharge line were the initiation sites for failure. Six fish mouth breaks and leaks were found in the gravity drain section of the line between the road crossing and the downstream vertical step near the outlet manhole. Replacement of this entire section of pipe with seamless A106 was recommended. In addition, it is necessary that a vacuum break be installed at the road crossing high point in order to vent the line and allow it to drain freely.

Reference

1. C. F. Jenkins, "Performance of Evaporators in High Level Radioactive Chemical Waste Service", NACE Corrosion/98, Paper 170, 1998.

Acknowledgements

Assistance was provided by B. C. Miller and J. C. Piercy of the SRS Metallurgical Laboratory at Savannah River Site.

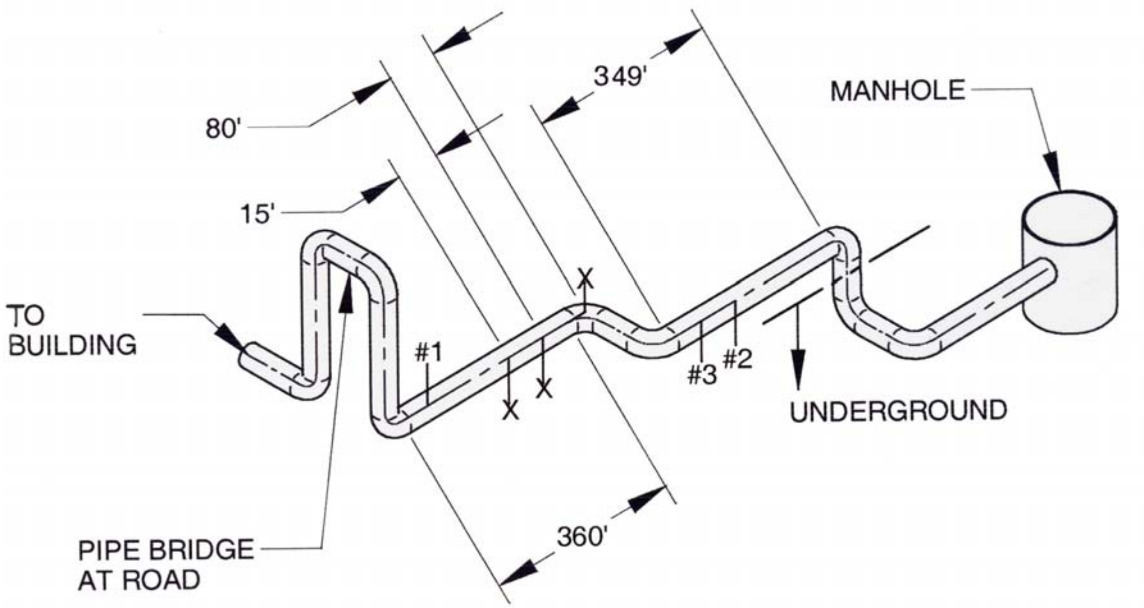

FIGURE 1. Sketch illustrating the non-insulated, above-ground portion of the overhead discharge piping from the evaporator. A simple gravity drain connects to a pipe bridge having a 30-foot vertical rise and drop at a road crossing (on the left) and a 12-foot vertical drop further down stream at the manhole end (on the right). A pump at the evaporator facility forces the liquids across the pipe bridge. "X" identifies locations where breaks occurred in the core pipe of the jacketed line.

FIGURE 2. Fish mouth break in 2-inch core pipe. This is break #3 in Figure 1.

FIGURE 3

Fish mouth break at butt joint. The break on the seam weld continued along the butt weld. This is break #2 in Figure 1.

FIGURE 4. Lack of fusion defect on seam weld on interior wall of the core pipe. Appearance is typical. This flaw is ~2 1/2 in. long and ~0.072 in. deep (wall is 0.154 in. nominal).

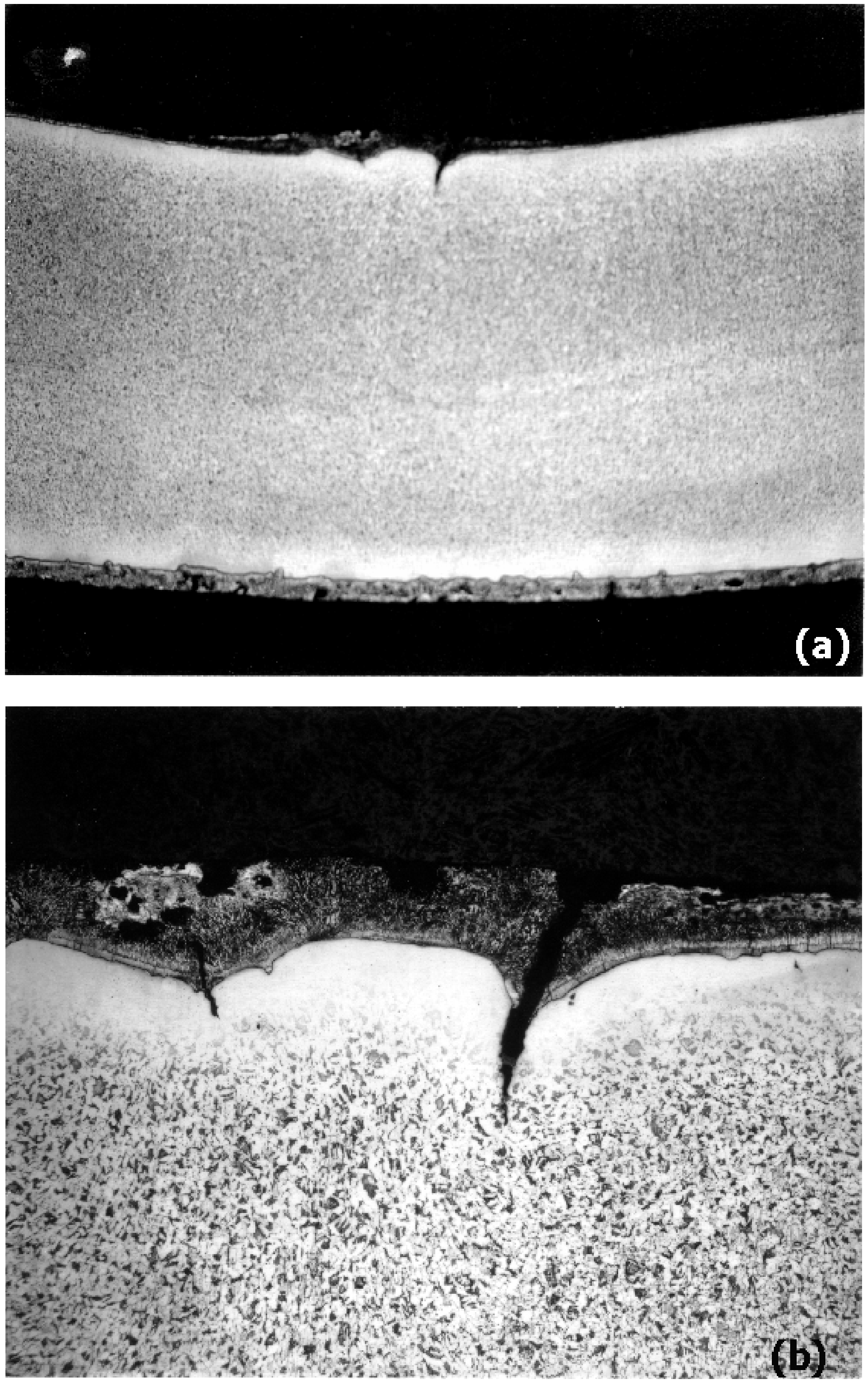

FIGURE 5. Cross section of galvanized A53 carbon steel pipe. Sharp defects occur in the toe of the seam weld on the inside wall of the pipe. Magnification: 16X, 64X .

FIGURE 6. Galvanized pipe from overheads discharge line. A long axial crack and flaking are evident in the zinc coating. Bonding of the zinc is questionable at this location.

Figure Captions

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