Testing and Recommended Practices to Improve Nurse Tank Safety: Phase II

Phase II of this study continues multi-year research related to the occurrence and potential methods of remediating anhydrous ammonia (NH_3) nurse tank failures. Nurse tanks are cylindrical steel tank shells with hemispherical or elliptical end caps referred to as heads, designed to hold NH_3 in liquid form under significant pressure (see Figure 1). Widely used as an agricultural nitrogen-rich fertilizer, NH_3 is a caustic substance that requires great care when handling.

Figure 1. Photograph. Image of a typical nurse tank.

RATIONALE AND BACKGROUND

In Phase I of this study, a variety of metallurgical tests were performed on 20 used nurse tanks and on laboratory specimens cut from these tanks. Testing corroborated the conclusion from other studies that stress corrosion cracks (SCCs) are the principal threat to nurse tank integrity, although manufacturing defects and damage from operations are also possible issues.

Study findings from Phase I indicated that a more detailed assessment should be made to determine the benefit of performing whole-tank stress-relief annealing (heating the welded tank in a furnace) after all seams are welded, including the tank heads to the shells during the nurse tank manufacturing process. In addition to investigating the effectiveness of this potential step in the manufacturing process, this report also addresses the unprecedented appearance of pinhole leaks in newer nurse tanks. Finally, researchers performed extensive SCC tests on 200 nurse tank steel samples over a 12–15 month period while also surveying 532 in-service nurse tanks for various types of cracks using ultrasound equipment.

STUDY FINDINGS

Pinhole Leaks

This study concluded that the principal cause of pinhole leaks next to welds is interconnected porosity in welds. Such porosity usually results from welding steel with surface contamination from water, mill scale, rust, and other contaminants. Such pinhole leaks can be avoided by following the welding procedures laid out by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code.

Stress-relief Annealing

Residual tensile stress is a key factor in initiating and enabling SCCs to grow in nurse tanks. SCCs are a primary cause of tank failures, which lead to injuries and fatalities. Residual stress occurs from the thermal stress induced by welding the tanks during manufacture. It has long been known that stress-relief annealing assists the atomic structure of the stressed steel to relax some, thus lowering residual tensile stress in such heat-treated steel. In this study, the head-to-shell stress in a tank with ASME protocol stress-relief annealing was measured by neutron diffraction analysis to determine the residual tensile stress levels. These measurements were compared to previous measurements made on two unannealed tanks, and it was found that the ASME-recommended protocol for stress-relief annealing lowered the residual tensile hoop stress (the largest stress in the tanks) by two-

thirds. It lowered the axial residual tensile stress by one-third. These stress reductions put the remaining residual stresses well within the elastic range of the steel and thus are predicted to greatly extend tank lifetimes and lower risks related to stress corrosion cracking. The field testing (described below) for cracks in unannealed and annealed nurse tanks significantly supports this.

Nurse Tank Crack Survey

A side-angle ultrasound survey of 532 in-service nurse tanks was performed to measure ultrasound indications, most of which were indicative of cracks in the tanks' steel walls (see Figure 2). This survey showed that many tanks contain indications, but nearly all of these are too short and too shallow to pose a risk of tank failure. The 104 tanks that had received stress-relief annealing had dramatically reduced numbers and sizes of indications. The majority of ultrasound indications were found in the heat-affected zone (HAZ) near welds (i.e., the metal that got hot during welding but did not actually melt). Most indications lay perpendicular to head-to-shell welds. Likewise, most of the indications occurred at or above the 80-percent fill line. In this portion of the tank, ammonia vapor (with no water) contacts the tank's inner wall surface. Below the 80-percent fill line, liquid ammonia with water contacts the tank's inner wall surface.

Figure 2. Photograph. Close-up of the ultrasonic unit used to conduct nurse tank inspections.

Stress Corrosion Cracking Study

This study exposed 200 steel specimens for 12–15 months to various environments while holding the steel under high tensile loads for the entire time period. It was expected that the test would cause some specimens to initiate and grow SCCs. Three different environments were tested: ammonia + 0.2 percent water, ammonia + 0.2 percent water + N-Serve (an additive that improves the fixing of nitrogen to soil particles in environmental conditions when it would otherwise be rapidly lost), and ammonia + 0.2 percent water with the tank purged with pure nitrogen gas each time before the tank was loaded. In each test, some specimens were immersed in liquid ammonia, while other specimens were exposed to the vapor in the tank space above the liquid. Specimens were removed from the ammonia and examined periodically to note crack formation and growth rates, then returned to the test environment for further exposure. Compared to what was observed in Phase I, the amount of crack initiation and growth in Phase II was less than anticipated in all six environments. The data obtained from this portion of the study (for both Phase I and Phase II) are not adequate to allow confident predictions of crack growth rates in actual tank service. The study did show that tanks containing N-Serve experience higher uniform corrosion rates and should be monitored for minimum wall thickness. Additional study of SCC propagation rates in ammonia is desirable.

RECOMMENDATIONS

The following recommendations were developed for best manufacturing and inspection practices for nurse tanks:

- Stress-relief annealing should be performed on all new nurse tanks as a part of the manufacturing process to reduce the occurrence of SCC failure.
- Pinhole leaks can be avoided by assuring that welds are made only on clean, dry metal.
- Nurse tank owners should avoid storing ammonia that contains N-Serve in nurse tanks for long periods of time (i.e., months or years). It is understood that the trend is to separately inject N-Serve at the time of application rather than premixing it in the ammonia and dispensing via the nurse tanks, so this risk is decreasing.

Ultrasonic testing is an effective method for determining the location and size (though not the depth) of potential cracks. Ultrasonic testing should be performed on the HAZ and the fusion zones of all nurse tank welds as a routine, periodic inspection procedure. If inspection of all welds on tanks is deemed too costly, the majority of SCC problems could be identified by inspecting the circumferential welds above the 80-percent fill line.

To read the complete report, please visit: http://www.fmcsa.dot.gov/facts-research/art-publicreports.aspx.