Testing and Recommended Practices to Improve Nurse Tank Safety, Phase I

This study focuses on determining causes and possible inspection remediation strategies to reduce the occurrence of 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 pressure (see Figure 1). Widely used as an agricultural nitrogen-rich fertilizer, NH_3 is a caustic substance that requires great care when handling.

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 cracking (SCC) is the principal threat to nurse tank integrity, although manufacturing defects and damage from operations are also possible issues.

This study explored possible non-destructive testing methods that could reduce future nurse tank failures by identifying the need for repair or replacement.

Figure 1. Image of a typical nurse tank.

RATIONALE AND BACKGROUND

Past studies of nurse tank failures focused on examining pieces of failed nurse tanks. This was the first comprehensive study of representative NH_3 nurse tanks that were operating satisfactorily in regular service.

This study was designed to determine whether angle-beam ultrasonic testing is a practical non-destructive testing method, as opposed to visual and/or hydrostatic pressure test inspections, both of which are currently used and required for those tanks without legible American Society of Mechanical Engineers (ASME) data plates.

Since the angle-beam ultrasound inspection procedure reveals more information than hydrostatic testing, it may be duplicative and unnecessarily costly for tank owners to perform both types of tests. With angle-beam ultrasound testing, it is not necessary to drain NH_3 from the tank to perform the inspection, and the inspection does not vent air containing oxygen and nitrogen into the tank. The presence of both nitrogen and oxygen is thought to pose the worst SCC challenge to the metal. Nitrogen in the absence of oxygen does not create the oxidation necessary for SCC to progress, and oxygen in the absence of nitrogen more effectively seals the surface of the inner tank wall.

STUDY FINDINGS

The 20 nurse tanks examined were fabricated from steel that in nearly all cases met published design standards for tensile strength and ductility (i.e., the degree to which a material can be deformed, dented, twisted, or stretched without breaking). In the few instances where the steel fell below acceptable performance levels, the measured values were only very slightly lower than expected levels.

- Four of the nurse tanks examined contained cracks detected by external angle-beam ultrasound. Each of these cracks was too small to pose a 10-year safety concern. Nevertheless, such cracks could potentially expand during future service and possibly could cause tank failure.

- Neutron diffraction analysis performed on hoop sections from two nurse tanks (see Figure 2) showed that the unannealed weld seams contained extremely high residual tensile stresses (i.e., the maximum stress a material can withstand while being stretched before failing). These were in the heat-affected zone of the steel immediately adjacent to the unannealed welds. The welds are used to assemble the heads to the shell while manufacturing the tanks. Tensile stress is a necessary factor in SCC, both in crack initiation and growth.

- Test specimens cut from the tanks walls were studied to see if there was significant reduction in carbon content in the steel near the tank's inner wall. This would weaken the steel. This analysis was done using glow discharge spectroscopy. This method bombards the steel's surface with high-velocity argon gas atoms –similar to sandblasting – which allows metal to be removed in thin sections (small fractions of a micron) so that the composition profile as a function of depth can be determined for the metal near the surface. Aside from a very thin (less than 1 micron thick) oxidized layer near the inner tank surface, there were no significant deviations from the expected carbon content of the metal.

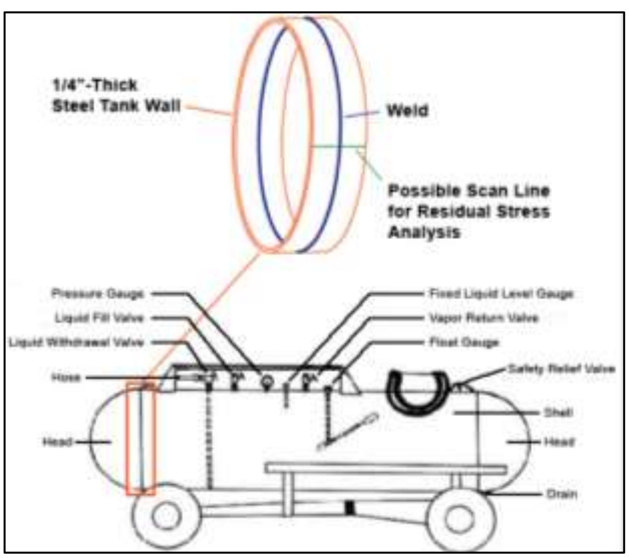

Figure 2. Location of hoop weld sections cut from tanks.

- Test specimens cut from the tank walls were also studied by fabricating them on a lathe (a machine tool which rotates the workpiece on its axis) into round tensile test specimens and pulling them with a tensile testing machine until they fractured. This allowed measurement of the steel's tensile yield strength, tensile ultimate strength, and tensile ductility by elongation. The data acquired by tensile testing were almost entirely within the expected performance range for these steels.

- SCC studies on stressed steel sample test specimens immersed in anhydrous ammonia liquid or vapor generated some cracks that grew in a minority of the specimens; however, most specimens did not initiate or grow cracks. Continued monitoring of the cracked specimens allowed measurement of their crack growth rates under conditions matching actual nurse tank conditions. These data in turn allowed for the formulation of a recommended nurse tank inspection procedure that could mitigate future tank failure rates.

CONCLUSIONS

This project developed a preliminary set of recommended inspection procedures based on the limited data collected in the study. These recommended procedures are based on inspection of the tanks using an ultrasonic angle beam to search for and measure the dimensions of cracks in the high stress areas near unannealed welds. These inspection procedures could be used either in addition to, or as a replacement for, current procedures.

Study findings indicate that a more detailed assessment should be made to determine if there would be a benefit to including a whole-tank stress relief annealing after welding the tanks heads to the shell during the nurse tank manufacturing process. These and other issues are being examined further in two follow-on studies.

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