White Paper

FMCSA/PHMSA Nurse Tank Safety Project

August, 2013

Purpose

The purpose of this paper is to articulate the research effort to determine a baseline performance standard for the manufacturing, re-qualifying and maintenance of nurse tanks, and provide information to enhance the requirements within the regulations used to mitigate the risks associated in the transportation of anhydrous ammonia for agricultural purposes.

Background

On February 1, 2011 PHMSA published a final rule HM-245-"Incorporation of Certain Special Permits into the HMR" which integrated two longstanding nurse tank special permits. Specifically, DOT SP-13554 was used by thousands of grantees and authorized nurse tanks with missing or illegible ASME Specification plates to be continued in service if specified conditions were met. The final rule specified conditions for nurse tanks which required them to be periodically inspected and tested every five years. The periodic inspection consisted of an external visual inspection, thickness test, and pressure test in order for continued use in service. The nurse tank periodic inspection and test must be conducted in accordance with the appropriate sections of Part 180 of the hazardous materials regulation. In April 2011, PHMSA conveyed its' action with a letter to NTSB to address the nurse tank issue with an emphasis placed on collaborating with the Federal Motor Carrier Safety Administration.

PHMSA currently has two petitions from the agricultural industry requesting the same periodic inspection and testing requirements for new and in-service nurse tanks that is required by HM-245 (for existing nurse tanks??). The rulemaking, HM-245, was considered a partial response to the NTSB recommendation noted above. NTSB recommended continue its efforts to address the Non-Destructive Examination (NDE) methods for nurse tanks.

Nurse Tank Research

<u>Stress Corrosion Cracking</u>
SCC Crack Growth Testing initially began during the summer of 2011 with more than 200 hundred samples being manufactured from existing nurse tank. The specimens were machined with small flaws simulate initial cracking. During this summer, these SCC specimens were divided into groups of 66 specimens per group and loaded into one of the following test situations: normal ammonia-0.2% H_2O solution, ammonia-0.2% H_2O solution containing N-Serve additive, or NH_3 in a tank that was backfilled with 99.95% pure N_2. The specimens were removed from the nurse tank environment and crack measurements were recorded. Analyze data on SCC specimens and develop new plots for SCC crack growth rates as functions of N-Serve content and purging vs. no purging during refills. SCC samples tested in the vapor space above the liquid formed more cracks and longer cracks than SCC samples immersed in liquid

NH_3. The vapor space contains NH_3 vapor with little or no H_2O vapor. This is a more aggressive SCC corrosive medium than liquid NH_3 containing the required 0.2% H_2O. The 168 tanks examined that were manufactured on or after 1999 with no annealing and thinner steel accounted for 74% of the indications found in the heat affected zones (HAZ), even though those tanks comprised only 32% of the tanks examined.

Effects of the Annealing Process

When welds are used to join two pieces of metal, the heated regions of the metal expand as the temperature rises while the cooler regions distant from the weld do not expand. The head-to-shell circumferential welds in nurse tanks are butt welds with one side offset. The offset results in a one to two inch long flange on the inner surface of the tank which obscures both the weld and the heat affected zone (HAZ). These differences in expansion generate stresses in the metal that (unless relieved by annealing) remain essentially unchanged from the moment the weld is completed until the tank is retired from service. When tanks are pressurized with ammonia, additional stresses are imposed on the metal such that the yield strength of the metal is exceeded, and the ultimate strength that the metal can hold is approached. Thus, the combination of the high residual stress near the weld and the pressure of the ammonia, places that metal at nearly the highest possible tensile stress state, making it especially susceptible to SCC initiation in these regions.

It is significant that the highest tensile stresses are found in the HAZ, not in the weld's fusion zone. This information can guide future inspection methods, indicating that the most productive search for cracks would be performed along the HAZ. The residual stress in the heat affected zone was reduced from a high of 346 MPa to a high of 118 MPa. This residual stress when annealed is a 66% reduction. The axial stress is the highest for the annealed tank, with a high of 166 MPa, but this has been reduced from a high of 251 MPa in the unannealed tank. These results demonstrate the effectiveness of annealing in relieving the residual stress in a nurse tank. Coupled with the angle beam ultrasound inspection survey, these results indicate the usefulness of annealing in reducing stress levels that drive stress corrosion crack initiation.

Angle Beam Ultrasonic Testing

Angle Beam Ultrasonic Testing a typical nurse tank consists of the following welds: three circumferential welds; one longitudinal weld; welds associated with the attachment of the feet; and welds associated with the valves and monitoring apparatus of the anhydrous ammonia. For these tanks the welds were inspected on both sides in the heat affected zone and on the weld itself. In this way large cracks both perpendicular and parallel to the weld could be found if present.

Neutron Diffraction Analysis of Residual Stresses Near a Pinhole Leak Location. The goal of this analysis is to verify whether the residual stresses in the weld metal around the pinhole leak are as found in the previous neutron diffraction analysis, i.e., less than in the steel immediately adjacent to the weld.

Summary

Pinhole leaks in nurse tanks result from the formation of pores, bubbles, and/or voids created during welding, where the webbing between them can fail due to metal fatigue, thus joining the voids to form wormholes. These flaws can be eliminated by assuring that only clean, dry surfaces are welded.

- Pinhole leaks in a nurse tank are substantially smaller than critical-sized cracks and thus are unlikely to lead to catastrophic tank rupture.
- SCC test samples placed in the vapor space above the ammonia's liquid surface displayed more cracks and longer cracks than SCC samples immersed in liquid ammonia. This is consistent with the theory that ammonia vapor, which does not have water vapor in it, is a more aggressive SCC corrosive medium than liquid ammonia, which contains the required water.
- The process of pumping out the air and performing an N2 gas purge prior to tank refilling did not lower the incidence of SCCs; thus, N2 gas purging during nurse tank loading would not lower the risk of SCCs in nurse tanks.
- N-Serve additions to ammonia did not cause more SCCs; however, N-Serve did increase the uniform corrosion rate of the tank's interior wall, forming rust (Fe(OH)x, where x=2 or 3).
- The ASME PWHT (annealing) applied to a 1,000-gallon tank for this research reduced the residual tensile hoop stress near welds by two-thirds and reduced the residual axial tensile stress by one-third. Hoop and axial tensile stresses are the primary drivers of SCC initiation and growth in nurse tanks, so their reduction (following PWHT) to ranges well within the elastic stress range of steel indicates that PWHT greatly reduces the risk of SCC development in nurse tanks. Thus, performing PWHT on all newly-manufactured nurse tanks would greatly reduce the occurrence of SCC failure in nurse tanks. This is even more critical given the trend toward purchasing larger tanks (which hold larger amounts of NH3 and thus pose a higher risk of damage or injury in the event of catastrophic failure).
- Ultrasonic testing is an effective method for determining the location and size of potential crack indications.
- A sample of 532 in-service nurse tanks were examined by side-angle ultrasound and found to contain 3,326 total indications. Most indications were cracks, but some may have resulted from weld geometry or non-crack internal flaws. The great majority of indications were located in the HAZ beside the weld, but a significant minority were found in the weld-fusion zone. About three-fourths of the indications were perpendicular to the weld line, and one-fourth lay parallel to the weld line. More than three-quarters of 80 documented indications were located in the tank heads; only about a fifth of indications were found in the tank shell.
- The circumferential welds that join the heads to the shell accounted for the great majority of indications, and most of those indications were located in the vapor space above the 80-percent fill line.
- The 168 examined tanks that were manufactured during or after 1999 accounted for 74 percent of the indications found in the HAZ, even though those tanks comprised only 32 percent of the total tanks examined.