In-service inspection of welds in atmospheric ammonia storage tanks

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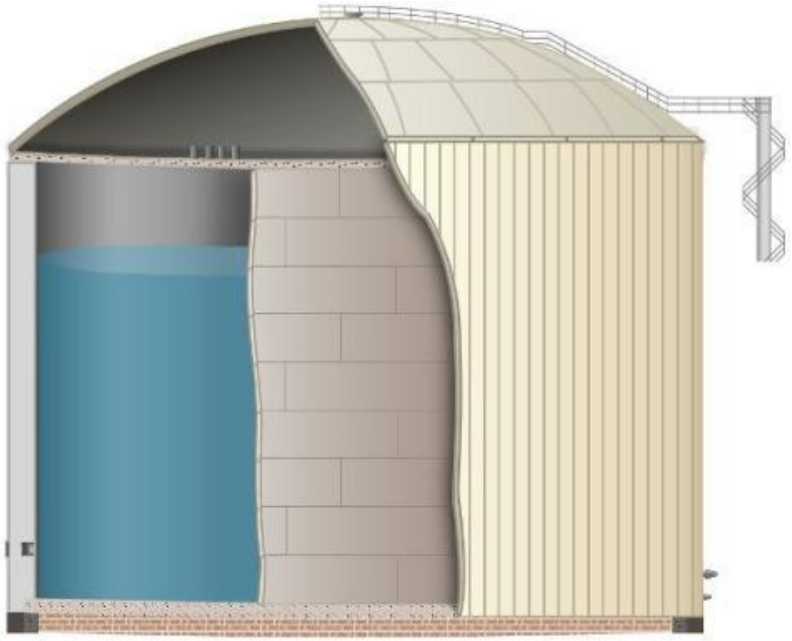
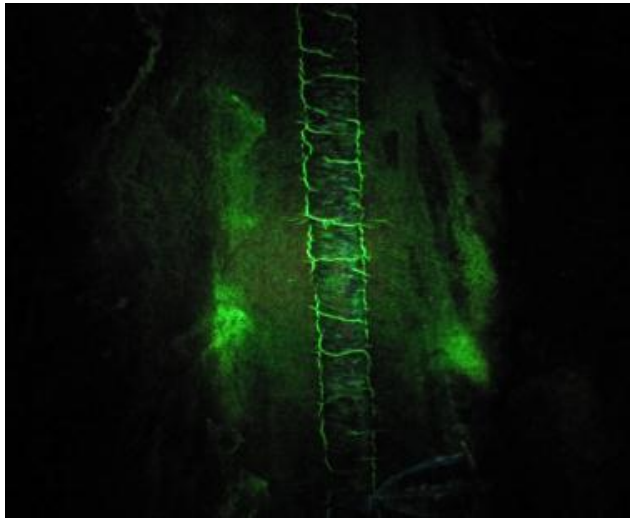
Ammonia storage tank design

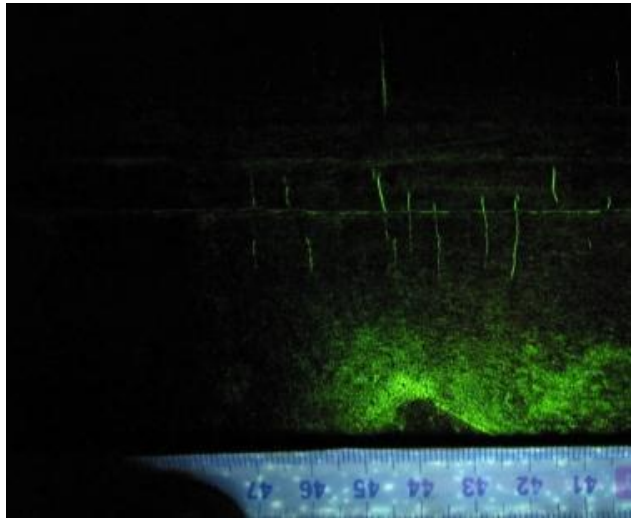
- "Cup in a Tank" is a double wall ammonia storage tank
  - Designed with an insulated outer steel tank and an open inner steel tank holding the liquid ammonia
  - The annular space between the outer and inner tank is filled with ammonia vapour



NH_3 – Stress Corrosion Cracking (SCC)

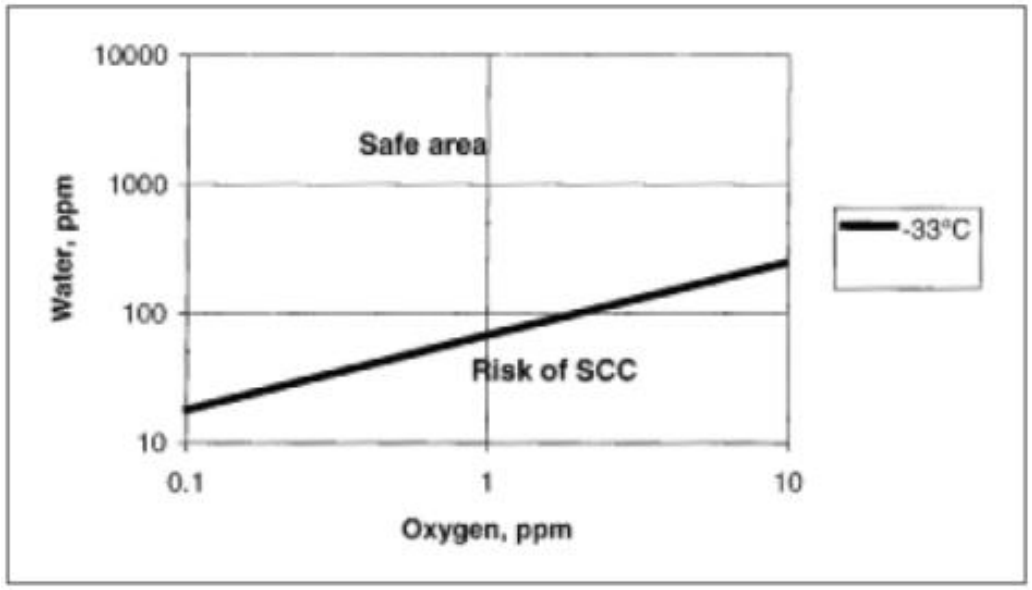
- Ammonia Stress Corrosion Cracking (NH_3-SCC) is the damage mechanism that is a threat to the mechanical integrity of the tank
  - Liquid ammonia in the presence of oxygen can cause NH_3-SCC in carbon steel
- NH_3-SCC occurs at the internal surface of the inner tank
  - General phenomenon that can occur on all weld seam areas, driven by environmental conditions (oxygen and water content) and residual stress
  - Cracks can be parallel and transversal to the welds





NH_3 – Stress Corrosion Cracking

- NH_3-SCC initiation requires high residual stress levels
- NH_3-SCC depends on the water content and the oxygen concentration
  - NH_3-SCC initiation requires the presence of oxygen
  - The presence of water inhibits the formation and growth of NH_3-SCC



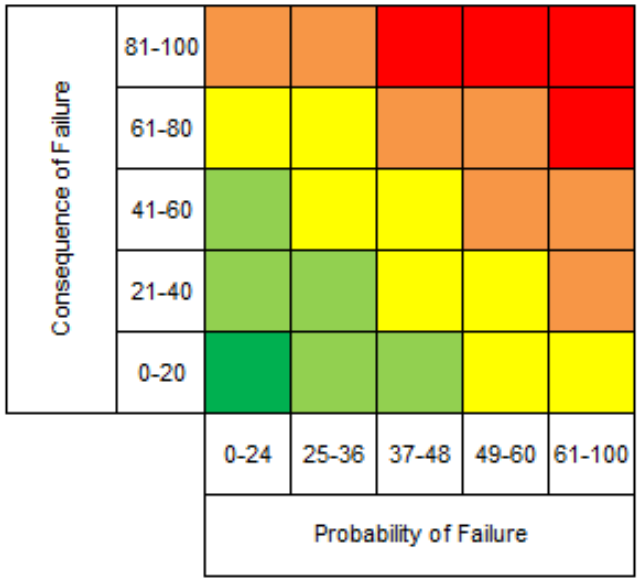
Benefits of non-intrusive inspection

- Tank decommissioning and re-commissioning are critical phases in the formation of cracks: potential for increased oxygen level inside the tank

- Non-intrusive inspection advantages
  - It does not affect the integrity of the tank (avoiding the negative effect of opening the tank for internal inspection, which causes thermal stress and allows the ingress of oxygen)
  - It is less hazardous to carry out than the internal inspection (dangerous operations like emptying and filling up the tank are not required)
  - It may be carried out more regularly than traditional internal inspection

Benefits of non-intrusive inspection

- European Fertilizer Manufactures Association (EFMA, nowadays called Fertilizer Europe, FE) guidelines allow for non-intrusive inspection of ammonia storage tanks provided that
  - Risk Based Inspection assessment places the tank in the inspection frequency area of at least 10 years: tank cannot be in the High risk (red) area of the risk matrix
  - The used NDT technique is able to detect and characterize cracks below the calculated maximum tolerable defect

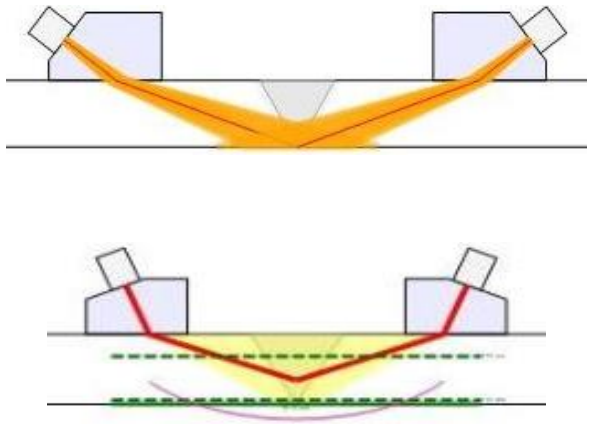


RED	High risk, Immediate mitigation actions shall be taken
ORANGE	Medium High risk, Limited inspection interval, maximum 5-10 years
YELLOW	Medium risk, Average inspection interval, maximum 10-15 years
GREEN	Low risk, Extended interval, maximum 15-20 years
DARK GREEN	Very Low risk, Extended interval, 20-25 years

Selection of NDT technique

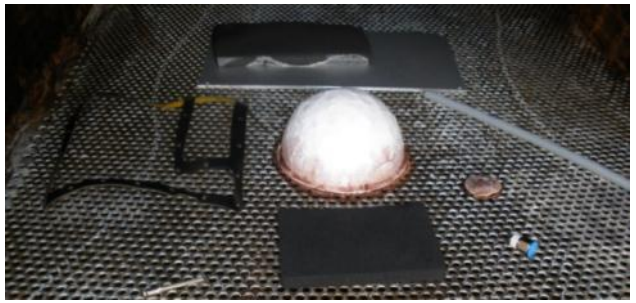
- Selected NDT technique has to be able to
  - Detect cracks with dimensions less than the calculated maximum allowable defect sizes
  - Detect and determine the size of cracks which can run both parallel and perpendicular to the weld

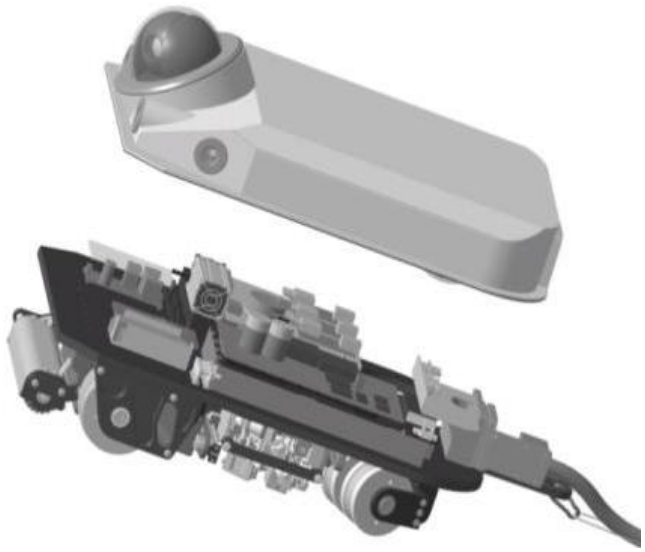
- Ultrasound technique is chosen, with
  - Two sets of shear wave probes
    - One set perpendicular to the weld
    - One set in a small skewed angle to the weld
  - Time Of Flight Diffraction (TOFD) probes for sizing of cracks



Automated ultrasonic inspection

- Inspection robot
  - All materials have been tested to ensure they can withstand ammonia atmosphere and low temperature
  - Designed as one enclosed unit connected with an umbilical cable (optical fiber for communication)
  - It runs on magnetic wheels
  - It is fitted with cleaning brush and cameras
  - Ultrasound probes installed for detection and sizing of cracks
  - Remote controlled deployment tool developed for placing the robot inside the outer tank wall (on the external surface of the inner tank wall)





Preparation for Inspection

- Ground foundation for habitat
- Placing habitat with platforms and scaffolding
- Removal of insulation from the tank manhole and cleaning of the cover
- Installation and alignment of the habitat
- Sealing around manhole
- Nitrogen supply for flushing of habitat and equipment
- Connection of oxygen analyzer
- Preparation for gas divers (fresh air supply and water supply for washing ammonia off)
- Placing container with electronics and glycol supply
- Placing container with control room

Habitat in position at outer manhole

Inspection execution

- Inspection is carried out by a team of specialists consisting of:
  - NDT technicians
  - Mechanics
  - Fire fighters especially trained for working under toxic atmosphere
- Inspection sequence
  - Ammonia tank is opened in nitrogen atmosphere
  - The deployment tool with the remote controlled hatch is mounted
  - Hatch is closed
  - The atmosphere is normalized and the remaining equipment is mounted and tested
  - The habitat is filled with nitrogen and the inspection robot is placed on the external surface of the inner tank wall ("cup") with the deployment tool
  - Hatch with cable reel is closed and the inspection begins

Inspection execution

Inspection execution

- All inspection data are digitally stored
  - They can be retrieved at a later date for re-evaluation or comparison with new inspection data
- The inspection locations and findings are plotted on a map
  - Full traceability is ensured
- All relevant findings (cracks) are reported to the client for evaluation
  - The findings are evaluated against the maximum allowable defect sizes calculated by client