

RECOMMENDATIONS FOR THE SAFE AND RELIABLE INSPECTION OF
ATMOSPHERIC, REFRIGERATED AMMONIA STORAGE TANKS 2002



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Users of this Booklet are advised to consult their latest national regulations before carrying out their own inspections, as changes in the regulations may have been made since its publication.

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1. SCOPE

This document, produced by EFMA, provides guidance and an optimum basis for the periodic inspection of fully refrigerated anhydrous liquid ammonia storage tanks, operated in Europe. The recommendations and guidelines provided are applicable to those tanks, which operate at or near atmospheric pressure and -33°C.

The guidance uses a risk based inspection approach requiring the evaluation of the probability and consequences of failure for each individual tank. The underlying intention is to maximise operational safety and reliability of these tanks.

2. INTRODUCTION

The practice for the inspection of storage tanks, which contain anhydrous liquid ammonia at atmospheric pressure, is different in the different countries in Europe. Some examples of the requirements and codes of practice of national authorities and industry associations for inspection in the different countries are shown in Appendix 1. In addition to the specific national regulations or codes of practice, some companies supplement these with their own internal code of practice. Ammonia storage tank systems also have to comply with a number of other, more general, safety regulations in the respective countries.

In Europe, there are approximately 50 refrigerated ammonia storage tanks in operation.

The main purpose of this document is to provide guidance and recommendations for the periodic inspection of fully refrigerated anhydrous liquid ammonia storage tanks. The guidance is based on experience from inspection of ammonia tanks and the knowledge of related failure mechanisms, in particular stress corrosion cracking induced by anhydrous liquid ammonia under certain conditions. The need for a change in inspection philosophy is, to a large extent, initiated by the identification of stress corrosion cracking (SCC) during the inspection of refrigerated ammonia storage tanks and the result of extensive research work on the phenomena of stress corrosion cracking in ammonia storage tanks.

The guidance uses a risk based inspection (RBI) approach to optimise the inspection programme between the need for knowledge about the condition of the tank and the negative effects of opening the tank for inspection which could increase the potential for SCC.

Risk based inspection involves the planning of an inspection on the basis of the information obtained from a risk analysis of the equipment. The purpose of the risk analysis is to identify the potential degradation mechanisms and threats to the integrity of the equipment and to assess the consequences and risks of failure. The inspection plan can then target the high risk equipment and be designed to detect potential degradation before fitness for service could be threatened.

The process of risk based inspection should form part of an integrated strategy for managing the integrity of the systems and equipment of the installation as a whole.

Application of these recommendations requires an appropriate level of competence and experience of ammonia storage tank design and operations.

3. DESCRIPTION OF SPECIFIC AREAS OF CONCERN

3.1 Ammonia storage facilities

Liquefied ammonia is mainly stored either at ambient temperature under high pressure or at -33°C under atmospheric pressure. In some cases, it is also stored at intermediate temperatures and pressures (semi-refrigerated). For pressure vessels, the inspection requirements in most countries are governed by the respective pressure vessel codes and regulations. The recommendations provided in this document are therefore limited to atmospheric ammonia storage tanks, which operate at -33°C .

3.2 Types of ammonia storage tanks

Illustrations of different types of storage tanks are shown in Appendix 2. The main types of atmospheric tanks operating at -33°C are:

- A **Single wall tanks**, which are tanks with one steel bottom and wall designed to contain the full liquid level of ammonia.
- B **Double wall tanks**, which are tanks with double steel bottom and wall, each designed to contain the full liquid level of ammonia.

For reasons of better understanding the differences between single and double wall, and the meaning of full containment, one or more of the following barriers can be considered:

1. Inner steel tank designed for full containment of liquid ammonia.
2. Outer steel tank designed for full containment of liquid ammonia, the roof may be separate for each inner and outer tank or common.
3. Concrete or steel wall designed as extra tank protection, not designed for containing liquid ammonia.
4. Bund wall (or dike) with height and distance designed to contain liquid ammonia that may be released from the ammonia tank in an accidental situation. Examples of different constructions of bund walls are shown in Appendix 3.

3.3 Operation

It is expected that the tank operation is in accordance with best available operating procedures based on HAZOP or similar process risk evaluation tools. The design of individual storage tanks and their associated ancillary equipment varies between installations. Typical items that require systematic focus during operation may include:

- Relief valves.
- Nozzles.
- Drainage systems.
- Insulation, both at the roof, wall and in the bottom.
- Roll-over protection, proper circulation.
- Heating system for foundations (where installed).

The procedure described in this document is not considered to be valid if these items are not effectively operated and maintained. Where appropriate they should be included as part of a systematic schedule for maintaining the tank and its associated ancillary equipment.

3.4 Design and materials of construction

Tanks for the storage of anhydrous ammonia at or near atmospheric pressure and -33°C will normally be designed to a suitable design code such as API 620 R: Design and Construction of Large, Welded, Low-Pressure Storage Tanks; BS 7777: Flat-bottomed, vertical, cylindrical storage tanks for low temperature service; or similar. Materials for atmospheric ammonia tanks are normally selected to satisfy the requirements specified in these design codes. The standard type of material is low temperature certified carbon manganese steel, impact tested at or near -40°C . The susceptibility to stress corrosion cracking increases with increasing yield strength of the steel. Materials with a specified minimum yield strength (SMYS) between 290 and 360 MPa are often used.

Various types of welding materials are used in construction, but often with a considerably higher strength level than the base material. Compatibility of yield strength level between weld and base material is an important parameter for resistance against ammonia stress corrosion cracking. Some typical data for welding consumables are shown in Appendix 4.

It is important that detailed records of tank construction and fabrication are kept in order to enable an accurate RBI evaluation to be carried out.

3.5 Factors affecting ammonia storage tanks

As with all other constructions, ammonia tanks can be affected by their internal and/or external environment. Ammonia is not generally corrosive to the materials selected for tank construction. The contaminants normally found are oil and water, but the quantities are normally small and the effect is positive to service life. Operating stress levels are normally low, as the density of ammonia (0.66 g/cm^3) is lower than that of the fluid used for testing the tanks (water), although operating stresses higher than those anticipated could occur.

3.5.1 Original weld defects

Ammonia storage tanks are constructed according to appropriate design standards, such as API 620 R; BS 7777; or equivalent. These standards have requirements for inspection of welds by radiographic (RT) and magnetic testing (MT) to ensure the good quality of the welds. The quality and integrity of the welds prior to first commissioning are vital for the future life of a tank, particularly in the initiation and propagation of SCC under ammonia duty. Residual stresses and local hardness peaks should be minimised by sound welding procedures.

3.5.2 General corrosion

External corrosion due to atmospheric conditions is prevented by the application of insulation containing a vapour membrane that reduces the ingress of atmospheric moisture, and at the storage temperature of -33°C the corrosion rate is negligible. The roof may be attacked externally by general corrosion. The roof should be regularly inspected, and where possible repaired by the plant personnel without interruption of service. It is important that the condition and integrity of the insulation and vapour membrane on all areas of the tank are considered as part of the overall inspection assessment.

The ingress of oxygen during the emptying of the tank, or caused by leakage in the safety valves can theoretically cause some corrosion in the upper part of the wall. However, in practice, oxygen is effectively removed because of the continuous cooling by compression. No detectable deterioration has therefore been found internally due to general corrosion.

3.5.3 Stress corrosion cracking

Stress corrosion cracking is a phenomenon which can occur in metals exposed to a combination of stress and corrosive environment. The corrosive environment will, under certain circumstances, destabilise the protective oxide layer, without causing general corrosion. This destabilisation is sufficient to prevent the reformation of oxide after a crack, caused by stress.

Liquid ammonia in the presence of oxygen can cause SCC in carbon steels. The potential problem of SCC increases with increasing yield strength of the plate material, increasing strength of the weld metal and local hardness in the welds.

The applied stress levels required to initiate such cracking are high, and are not experienced during normal operations. However the residual welding stress levels in high and medium strength materials or welds with over matched strength, together with the applied stresses, can be enough to initiate SCC if oxygen is present in sufficient quantities.

Since the late 1980s stress corrosion cracking has been detected in some storage tanks operating at -33°C . Based on experiences from findings and extensive international research work, it appears that the commissioning and to an even greater extent recommissioning are critical phases in the formation of cracks. This is due primarily to the potential for increased oxygen levels inside the tank and temperature variations causing increased stress levels.

The main conclusions concerning SCC in ammonia tanks from research work carried out combined with practical experience is:

1. SCC is difficult to initiate at -33°C .
2. SCC initiation requires applied plus residual stress levels above yield.
3. SCC initiation requires the presence of oxygen.
4. The presence of water inhibits the formation and growth of SCC.

5. Where SCC is found in low temperature tanks the defects are in general very small (less than 2 mm deep) and transverse to the weld. However, a few exceptions with larger defects have been reported.
6. Commissioning and in particular recommissioning is a critical period for the formation and growth of SCC.
7. Knowledge and experience of SCC has led to the improved operation of ammonia storage tanks. Due to this, recent experience indicates that the problem is decreasing, even in tanks where extensive cracking has been detected earlier.

Actions to improve service life by shot-peening or cathodic protection are considered to be non proven technology and hence have not been included as beneficial for protection against SCC in ammonia tanks.

The phenomenon of SCC is rare in low temperature tanks due to the need for the presence of oxygen to catalyse the process and the low temperature that slows the process.

Quantification of the probability that a critical crack may develop is based on documented experience with ammonia tanks. World wide, about 1000 tanks are in operation, representing about 20,000 tank years. Although properly documented inspection results have only been published for relatively few tanks, limited statistics indicate that about 10% of all fully refrigerated ammonia storage tanks may develop ammonia stress corrosion cracks after some years in operation.¹

It should be noted however that critical defect sizes can vary between tanks due to variations in strength and fracture toughness properties of the actual weld and plate materials, applied stress and residual stress levels.

SCC in fully refrigerated ammonia storage tanks is still a phenomenon which has to be taken into consideration when ammonia storage tanks are inspected. In fact SCC is the main *internal degradation* mechanism which has to be taken into consideration when planning and executing an inspection programme. However, external factors for degradation, such as external corrosion, settling etc., have also to be considered.

A list of literature on stress corrosion cracking is included in Appendix 5.

3.5.4 Fatigue

Fatigue has been raised as a possible failure mechanism that may occur because of the long lifetime of an ammonia storage tank. Typical import tanks are filled and emptied every 1-2 weeks. The number of cycles during a lifetime is in the range 50 times/year times 40 years = 2000. Provided there are no significant defects present, this is far below the number of cycles that would be required to cause fatigue under normal operating conditions. Fatigue is therefore not considered to be relevant, unless special conditions may change the number of cycles or the stress levels are far above design.

¹ Meeting between European ammonia tank operators about ammonia storage tank experiences, Oslo 8-9 November 1999.

4. INSPECTION PHILOSOPHY

Inspection of low temperature ammonia tanks is a compromise between a need for knowledge about the tank condition and the negative effects of opening the tank for inspection, which will cause thermal stress and ingress of oxygen. For ammonia tanks, it is known that decommissioning and recommissioning tends to increase the risk for SCC initiation. The need for inspection and the method, type and scope of inspection therefore have to be evaluated dependent on the risk and consequence of a failure. Applying RBI means that these factors can be considered and the inspection programme can be established for each individual tank.

The application of RBI to an ammonia tank requires an evaluation of the following:

Failure Probability:

1. Operating experience.
2. Additional stress, internal and external (settling, snow or similar).
3. Leak before break properties.
4. Pipe connections.
5. Stress corrosion cracking, oxygen and water content.
6. Other materials degradation phenomena.
7. Plate and weld material properties.
8. Pre-commissioning control.
9. Repairs.
10. Commissioning and recommissioning procedure (inert purging, cooling rate).

Failure Consequences:

11. Single vs. double wall tank.
12. Extra external safety (bund wall or dike).
13. Location of the tank.

Shot-peening and cathodic protection are considered to be non proven technology and are not regarded as beneficial in terms of failure probability. They have therefore been excluded from the RBI evaluation

5. INSPECTION

RBI is one element of an overall inspection strategy for each individual tank. RBI and associated structural integrity calculations should help to establish a tank inspection strategy that includes:

- Definition of the most appropriate inspection methods.
- Determination of the most appropriate tank monitoring requirements including internal and external inspection aspects.
- Establishment of prevention and mitigation steps to reduce the likelihood and consequences of a tank leak or failure.

Different storage tank applications have unique conditions that must be considered when evaluating the tanks. It is therefore very important that experienced and competent engineers and inspectors are involved in evaluating existing tanks.

It is essential that the design and operating history of the tank are reviewed with the responsible engineers and operators during the formulation of an inspection strategy.

It is also important to be familiar with and consider any local conditions that may influence the tank inspection programme: e.g. ambient conditions, local soil conditions, etc.

5.1 Competence and independence

A high level of competence and experience is required in order to execute a thorough and effective assessment. It is important that reliable data is used for the evaluation and it is essential that those involved have the required knowledge and experience to assess the influence of any uncertainties in the data used on the accuracy of the calculation.

The application of fracture mechanics codes requires a high level of technical expertise and practical experience. Great care is essential in the selection of personnel to carry out such work.

A group of people covering the areas of inspection, engineering/maintenance, operation and process safety should be involved in the evaluation. This team should have an appropriate degree of independence necessary to act impartially in all matters relating to the inspection of the tank.

5.2 Pre-evaluation

The purpose of pre-evaluation is to establish the basis for a risk based inspection programme. The pre-evaluation will cover the relevant parameters that affect failure probability and failure consequence, as described in section 3.

The evaluation will position each tank in an inspection frequency zone in the Inspection Frequency Diagram below.

The Inspection Frequency Diagram has been developed and evaluated based on current regulations and standards and on a survey of the status of 37 ammonia tanks representing approximately 75% of European capacity. Analysis and validation of the Diagram was also carried out in conjunction with regulatory and engineering research organisations using two specific tanks that had a detailed inspection history available.

Whereas national codes are normally based on setting maximum limits for inspection periods, the Diagram also provides a means of evaluating tanks that may have a higher potential of risk, where an improvement programme is required and where the period between inspections may need to be reduced.

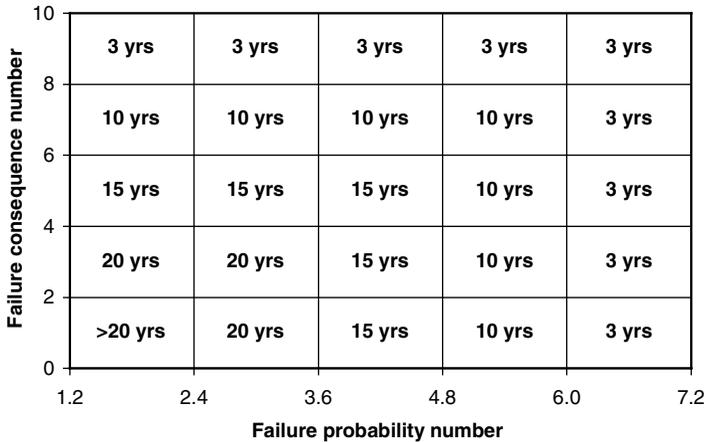
The diagram therefore provides a means of optimising the tank inspections based on RBI techniques and practical experience of most European tanks.

The Inspection Frequency Diagram is based on standard RBI processes that have been modified and developed to give a suggested inspection frequency for ammonia tanks based on an evaluation of failure probability and failure consequence factors.

The process of evaluation is given in Appendix 6 and is based on a questionnaire covering the factors related to failure probability and consequence. The questions in the evaluation are weighted depending on the relative influence of the different factors and the number of total

points is calculated for both failure probability and failure consequence. These total points values translate directly to the x and y axes of the Inspection Frequency Diagram and allow each tank to be positioned in one of the inspection frequency zones.

Inspection Frequency Diagram



>20 Years:

Indicates an ideal situation, where tank properties are state of the art and consequences of a failure are at a minimum.

10-20 Years:

The tank has good properties and the consequence of a failure is well taken into account. Details about properties and location determine the given inspection interval.

3 Years:

The probability for and/or consequence of a failure is not considered to be in accordance with the industrial standard. It is recommended that the tank should be subject to an improvement programme.

It should be noted that these inspection frequency positions on the Diagram provide guidance on internal tank inspection and that this is only one element of an ongoing programme for ensuring the integrity of the systems and equipment of the storage installation.

5.3 Procedure for structural integrity calculations and definition of inspection programme

The main purpose of structural integrity calculations is to determine the maximum tolerable defect sizes at relevant locations in the tank wall. Typical assessment locations and defect orientations considered in such calculations are defined in Appendix 7. In practice, these

calculations are usually carried out when one or more of the following beneficial reasons apply:

1. To justify and support the use of non-intrusive non-destructive testing (NDT) inspection methods from the external wall of the tank to check for any significant SCC on the internal surface.
2. To improve the assessed criticality position of the tank on the RBI diagram and to predict the likely failure mode (Leak Before Break, LBB, or Break Before Leak, BBL), if SCC takes place, and hence the likely consequence.
3. To provide additional confidence in the inspection method and inspection coverage selected; or in the selection process of the most cost effective inspection plan.
4. To provide further confidence in the selected inspection interval.
5. To assess the significance of cracks found by either internal magnetic testing (MT) or external non-intrusive NDT methods.

Established fracture mechanics codes such as BS 7910: 1999: Guide on method for assessing the acceptability of flaws in metallic structures [Level 2 method] should be used for the calculation of maximum tolerable defect sizes. Ideally, it is useful to calculate tolerable surface breaking as well as fully penetrating defect sizes. The latter is included so that the likely failure mode (LBB or BBL) can be predicted for the defect locations selected.

The required data for the fracture mechanics calculations should be established for all the assessment locations and the relevant defect orientations selected. One of the main input data for these calculations is applied stress due to maximum operating height of liquid ammonia and hydro test conditions. It is also useful to calculate the relaxed welding residual stresses resulting from the initial hydro test, so that the beneficial effect of this can be included in the tolerable defect size calculations. The other key input data required are fracture toughness or Charpy impact energy, yield and tensile strengths of the welds and plate materials. In the absence of fracture toughness properties, the derivation of such data from known Charpy values is detailed in BS 7910.

It is useful to produce the results of the fracture mechanics calculations in a tolerable defect depth vs. defect length graphical format for each of the defect orientations and assessment locations considered. Such a presentation will help the interpretation of results and the subsequent decision making process.

5.4 Inspection programme

The integrity of all ammonia tanks should be assessed by a systematic inspection programme.

5.4.1 External inspection

The external monitoring and inspection of the tank and associated equipment is an extremely important part of the overall inspection programme for ensuring tank integrity.

Operating personnel should routinely monitor the external surfaces of the tank for cold spots, bulges, leaks or any unusual conditions. Changes and unusual occurrences in the tank operation should be recorded and evaluated with respect to the tank inspection programme.

Periodic external inspections of the tank should be carried out by an appropriately qualified and experienced inspector as part of the overall inspection programme.

It is assumed that items such as relief valves, pumps, insulation, foundations, external piping, instrumentation, electricity supply and other important items relevant for the safe operations are appropriately designed, systematically maintained and documented.

5.4.2 Internal inspection

If, based on the evaluation procedure in section 5.2, the conclusion is to carry out an internal inspection of the ammonia tank, a certain procedure should be followed. This is detailed in Appendix 8. If the tank has to be opened for any other reason, an internal inspection according to Appendix 8 is recommended.

5.4.3 Internal inspection from outside

The conclusions based on the evaluation procedure defined in section 5.2 may be to implement non-intrusive inspection methods in lieu of an internal inspection. The inspection to be carried out will be from the external surface of the tank wall, for example using an ultrasonic flaw detection method, to check for any significant SCC that could be present internally at the weld seam areas.

Whichever non-intrusive inspection technique is used, the method has to be fully validated for the relevant inspection locations and applicable successfully at -33°C. It must be sufficient for the detection of the type, size and shape of cracks that are acceptably below the calculated maximum tolerable defect sizes [section 5.3]. It is also necessary to define a map, which clearly identifies those areas of the tank that are to be inspected by such methods.

Internal inspection from outside is an opportunity that may extend the inspection interval or replace internal inspection, but this is not covered by this document.

5.5 Reporting

All reports from inspections of the tanks should, as a minimum, include the following items:

1. Tank identity with information about materials, welds etc.
2. Date of inspection and years since the last inspection.
3. Areas of the tank inspected (map, drawing, description).
4. Map of identified defects from earlier inspections, both repaired and not repaired defects (weld defects from construction etc.).
5. Inspection method.
6. Inspector qualification data (if relevant).
7. Qualification information for the inspection method.
8. Reference to the evaluation report and/or inspection programme.
9. Findings with a map where defects are identified.
10. Reference to further investigations (if relevant).
11. Conclusion and recommendations for future inspection requirements.

5.6 Repairs

Repairs, both grinding and rewelding, introduce local high stress levels. Before possible repairs, and in particular those by welding, tolerable defect size calculations should be carried out, in order to evaluate if repairs are needed. Grinding may be necessary to establish typical and maximum defect depths. It is strongly recommended not to carry out weld repairs if sufficient material thickness is in the area of the defect location. Any repairs should be documented in detail (location, repair method, depth, weld materials and procedures, welder qualifications, thickness tests, etc.) to provide information for later assessments and inspection.

If welding is required, it is vital to use a low strength weld deposit and carry out all necessary actions to avoid local high hardness.

5.7 Corrective actions

Repairs may increase the risk of initiation of cracks. Areas that have been subject to weld repair require adequate follow up. Repairs may move the tank into an area where more extensive inspection is required. Hence, other actions such as the reduced operating level of ammonia liquid, should also be considered.

5.8 Commissioning, decommissioning and recommissioning

Commissioning, decommissioning and re-commissioning have to follow a procedure which ensures the efficient removal of oxygen and a careful and uniform cooling and warm up. This is important in order to keep the thermal stress to a minimum level and to reduce the risk of initiating stress corrosion cracking. The procedure should be well documented and records of actual measurements should be maintained for future reference. Minimum requirements for these procedures are described in Appendix 9.

6. APPENDICES

1. National rules or recognised standards for the inspection of atmospheric ammonia storage tanks in Europe.
2. Ammonia storage tank design.
3. Bund wall (dike) design.
4. Welding consumables for ammonia tank construction.
5. Ammonia stress corrosion cracking literature.
6. Risk based inspection evaluation.
7. Crack configurations that should be evaluated by structural integrity calculations.
8. Internal inspection recommendation.
9. Commissioning, re-commissioning and de-commissioning procedures.
10. Relationship between water and oxygen content of ammonia and the risk of SCC.

APPENDIX 1

National rules or recognised standards for the inspection of atmospheric ammonia storage tanks in Europe.

Country	Maximum inspection interval for atmospheric, refrigerated tanks
Austria	12 years
Belgium	20 years, but a notified body can decide shorter intervals
Denmark	Follows the UK recommendations (CIA)
Finland	12-16 years, depending on tank design
France	Local authority requirements
Germany	None (VAWS, water protection act, states 5, 10 or 15 years)
Greece	None
Ireland	None
Italy	None
Netherlands	12 years, max. 18 years
Norway	Ensure safe operations
Portugal	None
Spain	10 years
Sweden	Ensure safe operations
UK	First inspection after 6 years, then every 12 years depending on inspection results, according to CIA* recommendation

* Chemical Industry Association: Guidance for the large scale storage of fully refrigerated anhydrous ammonia in the UK, June 1997.

Reference: European ammonia storage meeting Oslo, November 1999 and information from EFMA members.

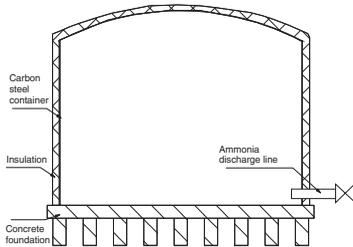
In addition to the national regulations, the large industrial companies often have corporate requirements for inspection intervals and practices.

APPENDIX 2

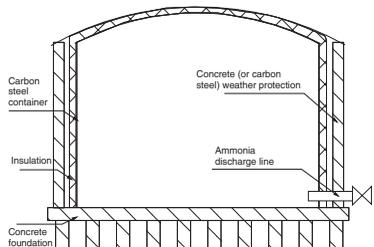
Ammonia storage tank design

Only tanks suitable for low temperature atmospheric storage are included in this appendix.

A. Single wall tanks

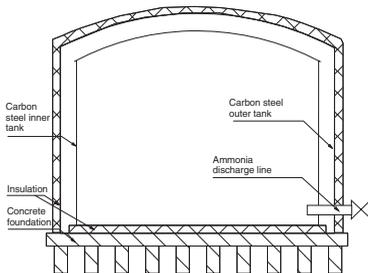


A1. Single wall with external insulation.

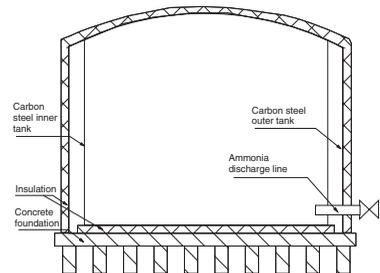


A2. Single wall with external wall.

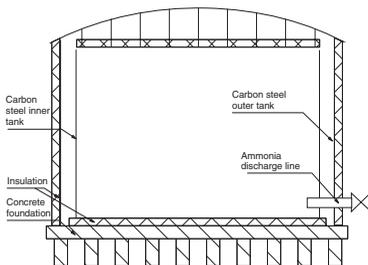
B. Double wall tanks



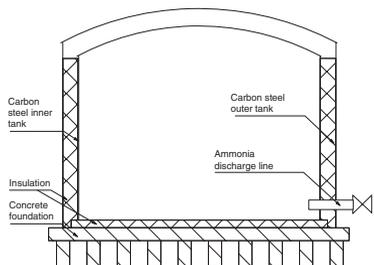
B1. Double wall tank.



B2. Double wall tank with common roof.



B3. Double integrity tank.

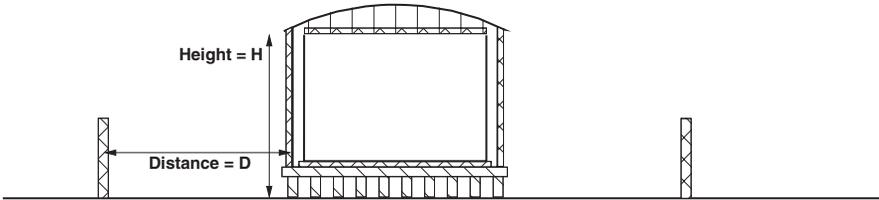


B4. Double wall tank with perlite insulation.

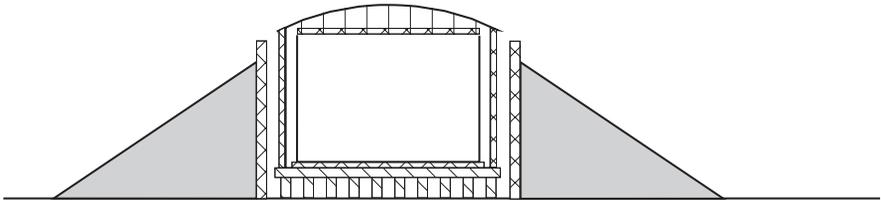
APPENDIX 3

Bund wall (dike) design

Designed to contain the contents of the tank in the event of failure. Capacity and strength to be capable of containing liquid ammonia that may be released from the tank in an accidental situation by arrangements such as those detailed in the examples below.



Bund wall at a distance not to be damaged by the tank, $D > H$.



Bund wall with extra safety.

APPENDIX 4

Welding consumables for ammonia tank construction

STRENGTH LEVEL	TYPE OF WELDING CONSUMABLES	STANDARD/ GRADE/ DESIGNATION	TYPICAL YIELD STRENGTH [MPa]	TYPICAL TENSILE STRENGTH [MPa]
“LOW” STRENGTH	SMAW	AWS E60xx	min. 331	min. 414
	FCAW	AWS E6xT-x	min. 345	min. 428
	SAW	AWS F6x-Exxx	min. 330	415-550
	SMAW, FCAW and SAW	EN E 38 x x x x	min. 380	470-600
“MEDIUM” STRENGTH	SMAW	AWS E70xx	min. 390	min. 480
	FCAW	AWS E7xT-x	min. 414	min. 497
	SAW	AWS F7x-Exxx	min. 400	480-650
	SMAW, FCAW and SAW	EN E 42 x x x x	min. 420	500-640
“HIGH” STRENGTH	SMAW	AWS E80xx	min. 460	min. 550
	SMAW, FCAW and SAW	EN E 46 x x x x	min. 460	530-680

APPENDIX 5

Ammonia stress corrosion cracking literature

1. "On the structural integrity of a refrigerated liquid ammonia storage tank at Norsk Hydro Fertilizers Ltd", R. A. Selva, C.M. Dickson, NV Report SS/8703057/RAS, April 1987.
2. "Stress Corrosion Cracking in Low Temperature Ammonia Storage Tanks", R. Nyborg, P. E. Drønen, L. Lunde, AIChE Ammonia Safety Symposium, Vancouver, 1994.
3. "Integrity of Ammonia Storage Vessels – Life Prediction Based on SCC Experience", R. Nyborg, L. Lunde, M. Conley, Material Performance, November 1991, p. 61 ff.
4. "Stress Corrosion in a Fully Refrigerated Ammonia Storage Tank", J. R. Byrne, F. E. Moir, R. D. Williams, AIChE Safety in Ammonia Plants and Related Facilities Symposium, Denver 1988.
5. "New Cases of Stress Corrosion Cracking in Large Atmospheric Ammonia Storage Tanks", M. Appl, K. Fässler, D. Fromm, H. Gebhardt, H. Portl, AIChE Safety in Ammonia Plants and Related Facilities Symposium, San Fransisco 1989.
6. "Structural Integrity of a 12,000-Tonne Refrigerated Ammonia Storage Tank in the Presence of Stress Corrosion Cracks", R. A. Selva, A. H. Heuser, AIChE Safety in Ammonia Plants and Related Facilities Symposium, San Fransisco 1989.
7. "Inspection of an Anhydrous Ammonia Atmospheric Pressure Storage Tank", S.B. Ali, R. E. Smallwood, AIChE Safety in Ammonia Plants and Related Facilities Symposium, San Diego 1990.
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9. "Measures taken to ensure safe operation of ammonia storage tank", M. Walter, R. Lesicki, Ammonia Technical Manual 1998, p. 127 ff.

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11. No. 308, 1991: "Ammonia Storage Inspection", S. Hewerdine.
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APPENDIX 6

Risk based inspection evaluation

Item	Failure probability		Failure consequence	
	Weight	Point	Weight	Points
1. Operating experience	2	5		
2. Additional stress, settling, snow etc.	5	5		
3. Leak before break assessment	5	5		
4. Pipe connections	2	5		
5. Stress corrosion cracking, oxygen and water	10	5		
6. Other materials degradation phenomena	1	5		
7. Material properties	5	5		
8. Pre-commissioning control	3	5		
9. Repairs	4	5		
10. Commissioning procedure	6	5		
11. Single vs. double wall tank			4	5
12. Bund wall (extra external safety)			5	5
13. Location of the tank			3	5
Total points	215		60	
Probability or consequence number (0-10)		5.0		5.0

The points range for each question is 0-10:

0 = Excellent, 5 = Normal operations, 10 = Operating conditions affects the tank integrity negatively.

The probability and consequence numbers are obtained by dividing the total weighted points scored by the total weight for each section.

The different items are given points according to the following explanation:

1. Operating experience (weight 2)

- a. Is your ammonia produced at the site or imported by ship or rail? (0)
(4)
- b. Is the ammonia level in the tank constant? (0)
or does it change frequently (≥ 15 times per year) (2)
Not frequently (< 15 times per year) (1)
- c. Have you experienced operating problems that may have resulted in unfavourable conditions in the storage tank (e.g. lifting of relief valves, high oxygen concentration, complete failure of refrigeration system, overpressure etc)?
No (0)
Yes (1)
- d. Did accidents occur?
No (0)
Yes (1)
- e. The number of internal inspections was
Zero (0)
A few (1-2) (1)
Several (> 2) (2)

2. Additional stress, settling, snow etc. (weight 5)

- a. Are there external factors like extreme weather conditions (heavy snow, hurricanes and earthquakes) that may lead to additional stress?
No (0)
Yes, but we have considered additional construction improvements or can predict the influence on stress by simulation (2)
Yes (4)
- b. Have you observed settling phenomena?
No (0)
Yes, but we have considered additional construction improvements or can predict the influence on stress by simulation. (4)
Yes (6)

3. Leak-before-break assessment (weight 5)

- Has a leak-before-break assessment been performed? (10)
- No
- Yes
- If yes, does this conclude with leak before break for the crack configurations shown in Appendix 7?
- No, major areas of the tank will give break before leak (10)
- The result of the assessment is non conclusive (5)
- Yes, all areas of the tank are shown to give leak before break (0)

4. Pipe connections (weight 2)

- a. Are all pipe connections pre-made and stress relieved? (0)
- Yes
- No (4)
- b. Are the pipe connections made flexible? (0)
- Yes
- No (4)
- c. Is the manhole pre-made and stress relieved before installation? (0)
- Yes
- No (2)

5. Stress Corrosion cracking, oxygen and water (weight 10)

- a. Do you add water (0.2%) to the ammonia? (0)
- Yes
- No
- If no, is the combination oxygen/water content such that it is above the safe line (see Appendix 10)?
- Yes (2)
- No (4)
- b. Have you experienced SCC before? (6)
- Yes
- Yes, but reduced number of SCC findings due to improvements (4)
- No, but no proper inspection (3)
- No, and the tank is properly inspected (according to the practice described in Appendices 7 and 8) (0)

6. Other material degradation phenomena (weight 1)

Did you observe other material degradation phenomena?

- a. External corrosion
 - No (0)
 - Yes
 - If yes, have you installed some kind of corrosion protection?
 - No (4)
 - Yes (2)
- b. Mechanical Damage
 - No (0)
 - Yes
 - If yes, have you made repairs?
 - No (6)
 - Yes (4)

7. Material properties (weight 5)

- a. Plates
 - LS (SMYS<300 Mpa) (0)
 - MS (SMYS>300 and <360 Mpa) (1)
 - HS (SMYS>360 Mpa) (2)
- b. Welding consumables (ref. Appendix 4)
 - LS (0)
 - MS (2)
 - HS (3)
- c. Do you have material certification, or have you performed a Charpy test at -33°C (or lower) using material with the same charge number that satisfies the requirements in the design code?
 - Yes (0)
 - No (5)

8. Pre-commissioning control (weight 3)

- a. Have you performed and documented internal welding control before commissioning the tank for the first time?
 - Yes (0)
 - If repairs (2)
 - No (5)
- b. Is the tank hydro tested?
 - Yes, to 100% volume (0)
 - Yes, but only to 100% weight (70% volume) (3)
 - No (5)

9. Repairs (weight 4)

- Have you ever repaired your tank since its first commissioning?
- No (0)
 - Yes
- If yes, were the repairs
- a. without welding (5)
 - b. with welding
 - minor repairs with stress relief heat treatment (2)
 - minor repairs without stress relief heat treatment (6)
 - major repairs with stress relief heat treatment (4)
 - major repairs without stress relief heat treatment (10)

Minor means only a few locations and limited depth/area.

Major means extensive areas or deep grinding (more than 20% of the wall thickness).

10. Commissioning procedure (weight 6)

- Do you have a procedure for the commissioning/decommissioning?
- No (10)
 - Yes
- Is it documented that the commissioning (or recommissioning) is in accordance with the recommendations detailed in Appendix 9?
- Yes (0)
 - Partly, the items in Appendix 9 should be considered (cooling rate and oxygen removal are the vital items) (2-8)
 - No (10)

11. Single vs. double wall (weight 4)

What is the kind of ammonia tank you have (see Appendix 2)?

- Single wall, A (10)
- Double wall, B (0)

12. Extra external safety (weight 5)

- No bundwall (10)
- Bundwall

- a. 100% containment, no discharge line through the bundwall and the bundwall in accordance with Appendix 3. (0)
- b. as item a, but bundwall without earth protection closer to the tank (2)
- c. as item a, but with discharge line through the bundwall (2)
- d. Less than 100% containment (6)

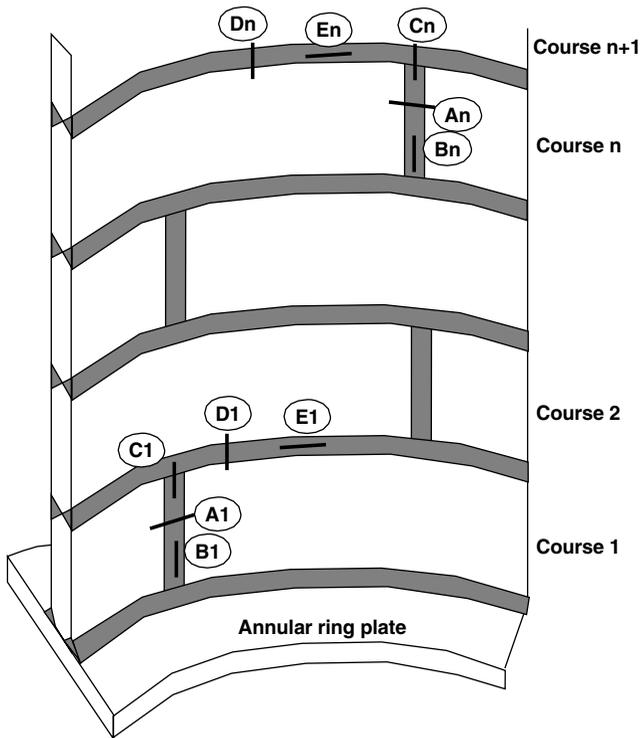
13. Location of the tank (weight 3)

Where is the tank located?

- a. Not close to external population, not close to water and no access by other public than staff; (0)
- b. Close to population
 - less than 1 km (7)
 - between 1 and 2 km (5)
- c. Close to water, less than 500 m (2)
- d. Access by public other than staff (1)
- e. Close to population, close to water and access by public other than staff (10)

APPENDIX 7

Crack configurations that should be evaluated by structural integrity calculations.



The sketch above illustrates the typical defect orientation and locations which should be considered when maximum tolerable defect size calculations are carried out. When necessary, the calculated results for these locations can be interpolated for shell courses 2 to n-1.

A1 (n): Transverse cracks in vertical welds in course 1 (course n).

B1 (n): Longitudinal cracks in vertical welds in course 1 (course n).

C1 (n): Transverse cracks in horizontal welds between courses 1 and 2 (courses n and n+1), located at a T-weld.

D1 (n): Transverse cracks in horizontal welds between courses 1 and 2 (courses n and n+1).

E1 (n): Longitudinal cracks in horizontal welds between courses 1 and 2 (courses n and n+1).

Course n is at a level higher in the tank wall, e.g. with lower strength material.

APPENDIX 8

Internal inspection recommendation

Internal inspection should be carried out with magnetic testing method (MT), with either wet fluorescent or contrast paint. The inspectors should be qualified according to EN 374.

The extent of the inspections should depend on the findings, and follow a stepwise approach. If no significant defects are identified in step 1, this should be sufficient to consider the tank free from critical cracks. If defects are found, which cannot be explained as insignificant fabrication defects, it is necessary to move to step 2.

As for step 1, if defects are found in step 2, which cannot be explained as insignificant fabrication defects, it is necessary to move to step 3.

Area	Step 1	Step 2	Step 3
Bottom to shell weld	100%		
Annular ring	100%		
Bottom plates	50%	100%	
Shell plates, T-welds in courses 1 and 2	100%		
Shell plates, horizontal and vertical welds in courses 1 and 2	10%	100%	
Shell plates, T-welds in course 3 to top	10%	50%	100%
Shell plates, horizontal and vertical welds in course 3 to top		10%	100%
Manholes, pipe connections, pump sink and other special details	100%		
Clamp marks or temporary fabrication weld marks		10%	100%
Roof, nozzle penetration welds	100%		
Areas subject to previous repairs	100%		

The content should be considered as a minimum requirement. As decommissioning, recommissioning, cleaning operations and preparation work such as scaffolding etc. are often far more time consuming, it is reasonable to extend the inspection programme in phase 1.

In addition spot checks of the thickness of the bottom and wall plates, and vacuum box testing of the tank bottom are recommended.

APPENDIX 9

Commissioning and recommissioning procedure

1. Hydrotest, either up to 70 or 100%, depending on the design code.
2. Purge with nitrogen until the measured oxygen in the discharge gas is less than 4%.
3. Before purging with ammonia, leave a certain level of ammonia containing water¹ (20% or more) in the bottom of the tank. The amount depends on the flatness of the bottom and should as a minimum cover the whole tank bottom.
4. Purge with ammonia gas until the measured oxygen in the discharge gas is less than 0.5%.
5. Cool the tank down to as low a temperature as possible, at a cooling rate lower than 1°C/hour.
6. Measure the temperature in the bulk volume of the tank, away from the gas inlet.
7. Within one week after commissioning and when conditions are stable, take samples for water and oxygen analysis from the ammonia liquid in the tank and analyse them.

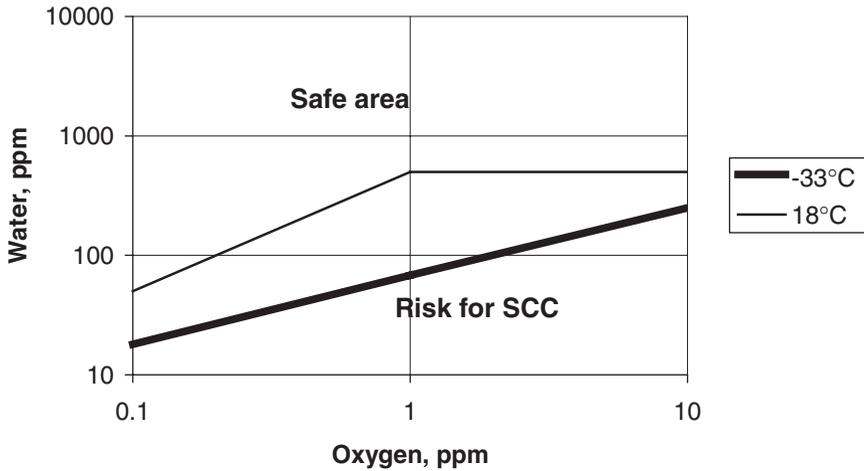
Decommissioning procedure

1. Empty the tank to the absolute minimum liquid level.
2. Evaporate the remaining ammonia in a way that ensures uniform and slow heating, not exceeding 1°C/hour.
3. Measure the temperature in the bulk volume of the tank, away from the gas inlet. Give careful consideration to temperature measurements at the lower levels of the tank during decommissioning.
4. Purge with warm ammonia gas or nitrogen until all liquid ammonia is removed. The bottom area may need to be cleaned before it is possible to get all the ammonia gas out.

¹ It is recommended that ammonia is added to the remaining water to avoid extensive absorption of ammonia gas when starting ammonia purging.

APPENDIX 10

Relationship between water and oxygen content of ammonia and the risk of SCC



The normal operation area for a refrigerated ammonia tank is below 0.5 ppm oxygen and between 100 and 1000 ppm water.

The graph is an extract from the results given in Appendix 5, reference [8].

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