HOW TO SELECT THE BEST NDT Method for Your Company

Developed Specifically for the Ammonia Refrigeration Industry
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As an ammonia refrigeration system user, your company is responsible for the reliable operation and maintenance of a complex piping system. Determining the best method of inspection to ensure the reliability of your system can be difficult.

With a brief overview of several NDT (Nondestructive Testing) technologies, this paper will highlight factors to be considered as you and/or your mechanical contractor select the most appropriate technique for your company.

A properly conducted inspection of your piping system, performed by qualified experts who are trained and skilled in specific methods, should do two things. First, it should support regulatory compliance with complete documentation and reporting of results. Second, it should support operational efficiencies and help identify priority areas in your system for repairs and preventative maintenance.

REGULATORY REQUIREMENTS

Owners/operators of facilities with ammonia refrigeration systems face an increasingly difficult regulatory environment, and penalties associated with inaction or insufficient action are real and increasing. The use and storage of anhydrous ammonia in refrigeration facilities is governed by either (or both) of the following:

Clean Air Act (CAA) and the EPA’s efforts to help refrigeration facilities comply with CAA requirements highlight the following aspects of the CAA’s Chemical Accident Prevention Program: the risk management program (RMP) regulations, the general duty clause (GDC), industry standards and an enforcement focus on accident prevention.

29 CFR 1910.119 Occupational Safety and Health Administration (OSHA) – Process Safety Management (PSM) of highly hazardous chemicals (HHC). As part of a company’s PSM program, the mechanical integrity of systems used to process or store covered chemicals must be maintained (and inspected) to reduce the possibility of accidental release or exposure.

While the OSHA PSM/HHC and the EPA RMP regulations apply to anhydrous ammonia used or stored in quantities in excess of 10,000 lbs., the CAA’s GDC covers any refrigeration facility using anhydrous ammonia in quantities less than 10,000 lbs. Regardless of the amount of ammonia in your system, there is a regulatory expectation of preventative maintenance, including inspection.

Fines associated with non-compliance are rising, making regulatory requirements for inspection of your system very compelling. However, they are not necessarily the most prevalent considerations in your day-to-day operations.

OPERATIONAL REQUIREMENTS

Operating and maintaining ammonia refrigeration systems efficiently and cost effectively while maintaining regulatory compliance is a significant challenge.

Refrigeration systems are complex collections of specialized components (compressors, condensers, vessels and valves) connected by custom-crafted piping. The specialized components in this system are identifiable by their manufacturer and include operating, repair, maintenance and inspection instructions. The piping connecting all of these subsystems is not branded; it does not come installed with recommended maintenance or inspection guidance.

To date, the ammonia refrigeration industry as a whole has been unable to provide guidelines related to inspection and maintenance. The basic question regarding refrigeration system piping is this – At what point is a pipe considered to be unsafe and declared unfit for use? How much wall loss is too much?

While trade associations are making efforts to provide some guidance in this area, today each company is responsible for determining its own criteria regarding when repair of piping is possible or if replacement is required. There are several factors which make this a perplexing challenge:

- As a general rule, ammonia is a non-corrosive, non-erosive chemical which typically does not cause damage to the inside of pipes found in the system.

- The most common damage mechanism of refrigeration piping is external corrosion, caused by moisture in contact with the external surface of the pipe.

- Properly coated (painted) pipe, in the absence of moisture or any physical damage, would last indefinitely

Further, the lack of a standard for repair vs. replacement of piping presents a myriad of recommendations. At one extreme are the operators, contractors and suppliers who suggest that any uncertainty is too much. If the pipe looks rusty (“it's brown”), then it should be replaced – even if there has not been any appreciable wall loss. At the other end of the spectrum are those that will try to extend the life of the pipe to the extreme, without any intervening maintenance. These opposing perspectives can be resolved by employing the proper NDT technique, which will afford a more balanced approach.

NDT provides information about the condition of piping that can be used in several ways. First, pipe with initial signs of corrosion are identified so that they may be rehabilitated (cleaned and coated/painted) to arrest any active corrosion. External corrosion detected earlier is easier and less expensive to repair. Second, for more extensive damage, NDT inspection results can be used to prioritize more expensive repair and replacement projects; pipe which has wall loss due to corrosion beyond the point of repair can be scheduled for replacement.

Maintenance budgets are limited and funds should be directed where they are needed most. A well-designed and executed NDT inspection program supports efficient operation of the system and will help you get the most ‘bang for your maintenance buck’.

With numerous NDT methods available today to help you with your pipe inspection requirements - how do you choose which to employ?
We will examine the nondestructive testing (NDT) options for pipe inspection so that you may determine the best method to help you and/or your mechanical contractor identify areas of concern in your system. We will explore the most relevant and widely used methods and their applicability to refrigeration piping — Visual, Ultrasonic (including Long Range UT), Radiographic (traditional, digital and real-time), and Radiometric Profiling.

All of the applicable NDT test methods discussed here result in collected data, which is then interpreted by someone trained and familiar with the applied technique. None of the techniques applicable to refrigeration piping systems inspects 100% of the system. All of the techniques are applied at specified locations - test measurement locations (TML) - along the piping.

VISUAL

Visual inspection is as direct as it sounds – an inspector looks at the pipe to see if it is in good condition.

Taking notes and pictures can help document what was seen when the inspection was performed. Naturally, visual inspection works best for failure mechanisms which occur on the outside of pipes. Though as it applies to refrigerated piping, visual inspection comes up short.

When visual inspections are conducted, nothing inside the insulation is seen and it is impractical to assume that the inspector is able to examine the top, bottom, and both sides of every length of pipe in the system. Additionally, picture and note taking for all sides of all pipe would be exhaustive.

Applicability to ammonia refrigeration piping:

+ Easy to understand. Seemingly fast.
- Uncertain effectiveness. Oftentimes, the most extreme cases of failure exhibit outwardly indications only after much damage has occurred. Some of the more common indications such as wet insulation may often not be evident from the outside, allowing for corrosion to remain undetected for long periods of time.
- Record keeping can be difficult. Photos, notes and conclusions drawn from observations make this technique more time-consuming than expected. During audit, visual inspection record keeping is subject to a lot of scrutiny.
ULTRASONIC

UTT
ULTRASONIC THICKNESS TESTING

UTT is one of the more common NDT techniques due to ease-of-use. Ultrasonic thickness testing measures the wall thickness of a properly prepared sample (pipe) by touching the transducer to the surface of the pipe. Similar to a submarine sonar unit, the equipment uses sound energy and timed measurements to calculate the thickness of the sample being tested.

This method is very good at measuring the thickness of a single-layer sample – optimally, a clean, flat, sample at moderate temperature. However, its use in refrigeration systems is burdened by the pipe preparation required and the operating conditions typically found in refrigeration systems. When other techniques are not possible, UTT, even with its inherent limitations, may be the only technique reasonably available.

Generally, UTT is a go-to method for many NDT inspection companies primarily because of the availability of UTT technicians (not the benefit or disadvantages of the technology itself). Historically, NDT companies have used UTT to measure wall thickness of piping in industries such as petrochem or chemical where the damage mechanisms are internal to the pipe.

In ammonia refrigeration, damage mechanisms internal to the pipe are rare. Ammonia is non-corrosive and non-erosive under normal operating conditions. The most common pipe damage mechanism in ammonia refrigeration systems is external corrosion due to water being trapped inside the insulation and held in contact with piping. UTT is not a particularly effective technique when measurement is required ‘through’ the corrosion or in the pit left in the pipe by the corrosion.

In this instance, standard practice requires: 1) the use of a pit gauge to measure the depth of the corrosion, 2) UTT to determine the wall thickness of nearby, unpitted pipe wall, and 3) an estimation of the remaining wall thickness using these two values. These operations are difficult at best to perform in the limited confines of the typical access hole (cut with a ‘hole saw’) into piping insulation.

For each location where the wall thickness of the pipe is being measured, a single location on one side of the pipe is recorded with the transducer. For multiple measurement locations, insulation needs to be removed and another measurement made by touching the transducer to the pipe at that location.

UTT applicability to ammonia refrigeration piping:

- Can inspect both thin and thick materials
- Allows for high sensitivity and resolution
- Insulation must be cut or removed to allow for contact between the transducer and pipe, introducing atmospheric water (condensation) into insulation/vapor barrier. Insulation must then be replaced or repaired after inspection.
- Pipe surface must be cleaned/prepped to allow for transducer contact
- Common couplant use can result in transducers being frozen to cold piping and/or incorrect measurements obtained.
LRUT
LONG RANGE ULTRASONIC TESTING

Much like UTT, LRUT utilizes sound energy and time measurements to calculate the condition of straight, long runs of pipe. In LRUT, the transducer used in conventional UTT is replaced by a collar which fits around the pipe so that long runs of straight piping (up to 100 meters or 300 feet) are measured at one time.

Insulation must be removed for collar placement, but may be left in place on the remaining pipe being measured. Pipe diameter is also a factor in LRUT effectiveness, with 4 inch diameter pipe being the average minimum limit in size which may be measured. Due to these limitations, LRUT has not found practical application in the testing of ammonia piping systems.

LRUT applicability to ammonia refrigeration piping:

- Faster results – this method can provide wall thickness assessments over great lengths of piping
- Size limitations – pipe smaller than approximately 4 inch diameter is not a good candidate for LRUT
- Measures only straight runs of pipe. Refrigeration systems routinely have many tees, elbows, valves and other components breaking up long, straight runs of pipe.
- Insulation must be cut/removed for installation of the collar. While only one section per measurement location must be removed compared to each testing location with UTT, it is still destructive to the insulation and vapor barrier. Insulation must then be replaced or repaired after inspection.

RADIOGRAPHIC

RT
RADIOGRAPHIC TESTING

Much like a familiar medical x-ray, RT uses radiation to capture an image, or an x-ray, of the pipe. An x-ray film or a digital plate is located near the pipe to be inspected and an x-ray or gamma ray energy source is located some meters away. The film or digital plate is then exposed to the radiation, resulting in an x-ray image² of a portion of the pipe. Safety regulations require that a safe working area be established during the creation of the images. This often means that a barrier will be identified, inside of which all personnel will need to be evacuated during the exposure.

RT applicability to ammonia refrigeration piping:

- Truly nondestructive - X-Ray images can be produced with the insulation in place and do not require preparation of the pipe surface.

²The typical image created in RT is the width of the pipe by the length of the film or digital plate, typically on the order of 17 inches. When the layperson looks at an x-ray image, it would be to assume that the image represents 100% inspection of the length of pipe covered by the film. However, while some indications seem to be visible in the image, the practice of radiography does not support the quantification of corrosion except in the plane parallel to the film. That is, measurements of wall thickness may only be made at the top and bottom of the pipe in the image for a shot setup where the source is pointing at the pipe from the side.
Pitting and corrosion located on the pipe section most nearly perpendicular to the plane of the film (or digital plate) may be quantified as to severity.

Additional inspection results, such as confirmation of pipe size and schedule and severely water-soaked insulation may also be evident in the x-ray image.

Inspection setup, establishment of safe working area (evacuation of plant personnel and erection of barricades) and creation of the image are time-consuming, resulting in a low number of test locations completed during a given inspection period.

Pitting and corrosion located on a pipe section that is not oriented perpendicular to the plane of the film (or digital plate) is not able to be quantified as to severity.

Physical pipe rack construction often limits or eliminates the possibility of creating the x-ray image. Multiple parallel pipes, supports, catwalks and other obstructions often prevent positioning the film or digital plate in the optimal position for an x-ray image. Additionally, placement of the x-ray source may be limited for a given shot.

Results are not real-time. X-Ray film must be developed and digital plates must be scanned for the digital image information they contain.

When Ir-192 or Se-75 are used as the source, there are limitations as to the pipe size and schedule which can be interpreted for wall thickness.

The RTR system is moved along the pipe and the image updates in real time. Insulation does not have to be removed to use these systems and there is no pipe preparation required. However, RTR systems are not powerful enough to x-ray through the pipe as RT systems do. Each scan of the system along the pipe produces images of one edge of the pipe - the image is produced through the insulation of the outside edge.

In other industries, RTR is very successful at locating weld locations, thus, if the pipe has severe enough corrosion or significant rust scale buildup, it may be visible in the image. Corrosion in ammonia piping generally occurs at the top and bottom of the pipe; due to gravity, wet insulation typically occurs in the bottom half of the pipe. To collect readings on the top, bottom, front, and back edge of the pipe, four (4) scans would be required.

RTR applicability to ammonia refrigeration piping:

Results are real-time. Images can be reviewed as they are produced, allowing for immediate analysis and additional inspection, if warranted.

Truly nondestructive - RTR can be applied with the insulation in place and does not require preparation of the pipe surface. This method is truly nondestructive.

Requires significant corrosion scaling to be evident.

Additional inspection results, such as confirmation of pipe size and schedule, are not normally evident in the x-ray image.

RTR systems typically need to be positioned perpendicular to the pipe run and positioned so that the beam and detector align with the tangent edge of the pipe, as viewed in profile. Pipe run construction or other obstructions may limit the ability of the test personnel to properly position the RTR system for imaging.

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RTR
REAL-TIME RADIOGRAPHIC TESTING

There is a category of radiographic testing (RT) which uses real-time imaging systems. These systems have an x-ray tube on one end of the device which is aimed at a detector to produce an image.

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3If the system is scanning the top of the pipe (and the system beam is parallel to the ground on a horizontal pipe) then only the top edge of the pipe is being seen and evaluated by the inspector. If the bottom edge of the pipe is to be inspected, that requires a different scan using the system. If someone refers to the system as scanning 100% of the pipe, they are referring to 100% of the length of the pipe while monitoring a single edge of the pipe, depending upon positioning. As the system is real-time, videos of all the scans are not typically saved and evaluated later.
- Pitting and corrosion located on a pipe section that is not at the pipe tangent edge being imaged will not be detected.

**RTR+ REAL-TIME RADIOGRAPHY SUPPLEMENTED WITH RADIOGRAPHIC TESTING**

In an attempt to address some of the costly limitations of RT (relatively low number of test locations per inspection day), some NDT vendors have created a hybrid technique – initial scanning with RTR identifying areas of interest with follow up RT at these selected locations.

RTR can be an effective pre-screening tool for RT, as long as the equipment positioning difficulties and limited scanning area of RTR do not prevent comprehensive inspection. Once RT locations are determined using RTR, the same benefits and limitations of RT techniques apply. This approach results in fewer locations receiving RT application.

**RADIOMETRIC**

**RP**

**RADIOMETRIC PROFILING**

RP is a fast, real-time testing technique. This application measures changes in a beam of gamma-ray energy as it passes through the sample being inspected. The beam source is positioned on one side of the pipe with the detector on the other side of the pipe, measuring everything between the source and detector⁴. In refrigeration piping, this includes insulation, foreign material inside the insulation, one pipe wall, pipe contents, the other pipe wall and anything else ‘in the beam’.

The radiation exposure from the gamma source is extremely low. Special radiation safety barriers and direct vicinity evacuation are not required for its use.

**RP Applicability for ammonia refrigeration piping:**

+ Results are real-time – data can be reviewed as it is collected allowing for immediate analysis.

+ Truly nondestructive - RP can be applied with the insulation in place and does not require preparation of the pipe surface.

+ Up to 3X to 10X more inspection locations per inspection day than other NDT methods

+ Safe - low intensity, low exposure. No radiation safety barriers are required, thus there is less impact on facility operations.

+ RP system is unaffected by temperature – the application is effective on frozen or hot piping.

+ Perpendicular scanning techniques (slice scan) results in 100% of pipe, insulation and contents being included and measured at that test location.

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⁴Data is collected with the RP system by scanning with the system in 2 primary directions. Either parallel to the centerline of the pipe (axial scan) or perpendicular to the centerline of the pipe (slice scan). Axial scans with the beam oriented vertically, allow for rapid measurement of both the top and bottom of the pipe, along with the insulation and pipe contents. Data is collected along 100% of the length of the axial scan. In the case of a slice scan, the data is recorded as the beam passes through 100% of the cross section of the insulation, pipe and contents.
SELECTING THE METHOD FOR YOU

When considering the best method of pipe inspection for your company, there are several considerations to take into account:

EFFICIENCY

a) How quickly does the inspection need to be completed?
b) Will the method selected disrupt daily operations?
c) Are you up against a deadline or scheduled auditor visit?
d) Are there indications that there may be an issue within your system that needs immediate attention?
e) Do you have the resources (time, manpower and money) to prepare your pipes for NDT methods which require preparation?

COMPLETENESS, ACCURACY, DETAIL

NDT methods vary in the amount of information and detail that are provided in the results. Further, technology limitations, piping system layout and configuration, pipe size and coatings will affect access and accuracy.

Depending upon your refrigeration system piping, a single NDT method may provide a sufficient and full reporting of the system’s condition. Where a more complete assessment of system condition is critical, multiple methods may be used to balance the limitations of individual methods, resulting in a more robust analysis.

An efficiently operating system is about more than just the amount of wall loss on the piping – wet insulation, blockages and unexpected pipe contents (liquid where vapor is expected) are all examples of conditions which affect performance, efficiency and safety. To the extent that an NDT method highlights these conditions in addition to pipe thinning, that method should be used.

COST

There are several factors to consider when comparing quotations from NDT suppliers and considering the cost effectiveness of the methods they use. The most obvious consideration is the bottom line price on the NDT service quotation – this is the amount paid to the vendor for the inspection only. Additionally, there may be costs associated with preparation or repair/replacement of insulation upon completion of the inspection.

Consideration should also be given to the completeness of the inspection: How many test locations are included in the inspection? Other factors being equal, more test locations mean better, more complete results. What type(s) of indications (potential problems) will be identified and reported? Ideally, the method selected will highlight areas of concern other than just pipe wall thickness. How would an evacuation of the testing area impact your operations?
A detailed comparison of the technologies will help you select the best NDT method for your company. While considering specifications and configuration of your system, the following *NDT Technology Detail Comparison* will provide helpful information:

<table>
<thead>
<tr>
<th>NDT TECHNOLOGY DETAIL COMPARISON</th>
<th>UTT</th>
<th>RTR</th>
<th>RT</th>
<th>RTR+ (Prescreening)</th>
<th>RTR + RT</th>
<th>RP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Applicability to Ammonia Refrigeration Piping</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>No insulation removal or surface cleaning / preparation required.</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Easy-to-use</td>
<td>✓</td>
<td></td>
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<td></td>
<td></td>
<td>✓</td>
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<tr>
<td>Flexible positioning for measurements on all parallel and nested or congested pipes</td>
<td></td>
<td>✓</td>
<td></td>
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</tr>
<tr>
<td>Safety – doesn’t require radiation barriers</td>
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<td></td>
<td></td>
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<tr>
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<tr>
<td>Test locations / inspections per day</td>
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<td>Varies</td>
<td>X</td>
<td>N/A</td>
<td>½X to ¾X</td>
<td>3X to 10X</td>
</tr>
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</table>

Ultimately, you may determine that one of the NDT methods discussed is clearly best for your situation — or several of the techniques are potential candidates. If you have a mechanical contractor, it can be helpful to get their input as you make a determination on your choice of NDT method.

Don’t leave the health of your system – as well as that of your company and community – to chance. NDT inspection is a powerful, proactive way to help manage your refrigeration system. Identify areas of possible concern, target limited resources to the areas they are most needed and ensure regulatory compliance.