AMMONIA REFRIGERATION SAFETY MANAGEMENT

Mark Roxburgh
Mercury Technologies Ltd., Hopps Cottage, Front Street, Hart, United Kingdom, TS27 3AJ
Phone: +44 (0)1429 867 000; e-mail: roxburgh@mercurytechnologiesltd.co.uk

1. ABSTRACT

Ammonia as a refrigerant is an obvious choice in these times of ecological awareness. It is a natural substance and its thermodynamic properties are superior to many of the man-made alternatives. However, its hazardous nature must not be overlooked. End-users are legally and morally obliged to ensure that they have in place safety management sufficient to mitigate the risk associated with their ammonia refrigeration systems. The programme described herein outlines a number of safety management tools that will allow the risk level to be reduced to as low as is reasonably practical.

2. INTRODUCTION

In advocating the use of natural refrigerants, we, as responsible designers, installers and end-users are quite rightly making a stand for the environment. One of these refrigerants, ammonia, is indeed a more ecologically sound alternative to the man-made fluids that have become in-vogue over the past 30 to 40 years. Its favourable specific and latent capacities and its efficient specific energy of compression have been recognised for many years. These positive aspects come, however, at a price. Ammonia is a hazardous substance.

Hence as before, we, as responsible designers, installers and end-users, must advocate the safe use of the refrigerant. We must ensure that our employees, our clients and the surrounding population are protected from the potentially harmful effects of ammonia.

Each country has its rules and regulations regarding health and safety in the workplace and in everyday life. These rules address for example the need for risk assessment, for certain procedures to be followed regarding incident investigation and reporting and possibly training. The EU has certain overarching directives that deal with these and other issues in a more general way, including the ATEX and PED directives. Indeed, these two give quite specific instructions regarding the safe installation, operation and maintenance of plant. National and international codes and standards such as EN 378 give a great deal of further guidance regarding how to safely design, install and operate systems. Finally, national and international professional bodies provide various codes of practice and papers dealing with safe operating practices.

It is difficult for an operator to be certain that he or she is meeting all the requirements of these diverse codes and standards, especially since those responsible for health and safety in some plants may not be familiar with ammonia: in fact they may not be technical persons at all.

3. THE PROGRAMME

In the United States, some 20 years ago, the US government's national safety body OSHA (Occupational Safety and Health Administration) issued a declaration requiring all users of hazardous materials to put in place a safety management programme aimed at mitigating the risk to health and safety associated with that substance. They allowed the various industries to develop their own plans, which OSHA subsequently approved and monitored. The American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE, based in Atlanta, GA) and the International Institute of Ammonia Refrigeration (IIAR, based in Washington DC) were charged with developing a plan for the ammonia refrigeration industry. The plan was implemented in the late eighties and its use has been mandatory since then for all US facilities with more than 5 Tonnes of ammonia on site.

We in Europe and the rest of the world do not have similar legislation. We have, as discussed earlier, a fragmented version, with guidance and requirements scattered throughout multiple national and international codes and standards.
We at Mercury Technologies have taken the broad, comprehensive model developed in the US and adapted it for use in other countries. The methodology was retained as was much of the content, but since, for example, EN 378 differs technically from the various US, AHRAE and IIAR standards, some modifications had to be made. The result is a safety management programme suitable for application, with some minor adjustments, in any EU country.

The programme comprises the following elements

- Documentation
- Mechanical integrity of major hardware
- Mechanical integrity of peripheral hardware and systems
- Offsite consequence analysis
- Operating procedures
- Training
- Permits to work
- Contractor control
- Employee participation
- Incident investigation
- Management tree
- Management of change
- Pre-commissioning review
- Emergency response
- Annual review
- Hazard analysis

Assuming the designer, installer, maintenance contractor and the end-user are all relatively competent, professional people, it is highly likely that most of the items on this list are already in place and meeting all requirements. It is, however, incumbent upon us all, as discussed earlier, as responsible professionals to ensure that ALL items on the list are in order.

3.1 Documentation

From design, through purchasing, installation and commissioning to day-to-day operation, there must be a paper trail. A user must have ammonia charging records, pressure test certificates and drawings to hand. He must ensure that maintenance records are kept, that oil usage is monitored and that inspection authority and insurance certification is up to date. The need for this documentation is not simply to meet legislation. The data is required for maintenance, training and cost projections

3.2 Mechanical integrity of major hardware

Perhaps the most obvious element of the programme is mechanical integrity. The hardware must be designed, specified, installed, commissioned, operated and maintained safely. A detailed inspection of the system by a competent engineer will most likely identify inconsistencies. Each item of equipment and each significant piping system should be surveyed in detail. All nameplate information should be cross-reference with the original design documents as should the operating conditions. Pressure relief and/or protection should be checked. Accessibility, marking and labelling, protection from collision, suitability of supports, ease of maintenance and oil draining; all these issues should be looked into.

An overall plant maintenance programme should be developed. The various codes and standards available to us all, along with the manufacturers recommendations can be used to build-up a schedule that shows maintenance tasks ranging from daily checks, through weekly, monthly services up to annual shutdowns and less frequent rebuilds etc. The maintenance programme must include not only the major hardware components, but also the ventilation/detection /alarm systems and the personal protective equipment (breathing apparatus, showers, emergency lighting etc).

Corroded pipe

3.3 Mechanical integrity of peripheral hardware and systems

There are safety systems and equipment that, although not ammonia-containing, are paramount to the safe operation of the plant, especially during emergencies. Just as with the main hardware, these items must be installed, operated and maintained correctly. A safety management programme such as the one outlined herein must pay due regard to these items. They are made detailed reference to in all relevant codes and standards and include:

Eyewash / shower

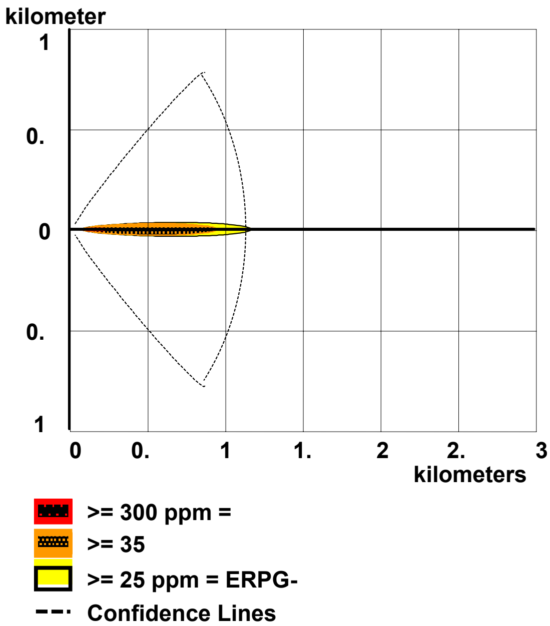
- Ammonia detection
- Ventilation
- Relief valves and associated vent piping
- Emergency lighting
- PPE, Eye wash & showers
- Signage

A thorough survey of all these items should be carried out and shortfalls must be put right. Many of these systems must be covered by the preventive maintenance programme:

3.4 Offsite consequence analysis

If there is a suspicion that an ammonia release may have reach beyond the boundaries of the facility, those consequences should be investigated and quantified, where possible. Only by knowing this can the potential outcomes be known and planned for in an emergency response procedure.

Although there a many ways in which ammonia can be released from a system, in fact there are relatively few ways it can leave the site. If a release is going to occur in a properly designed plant, it is most likely to either



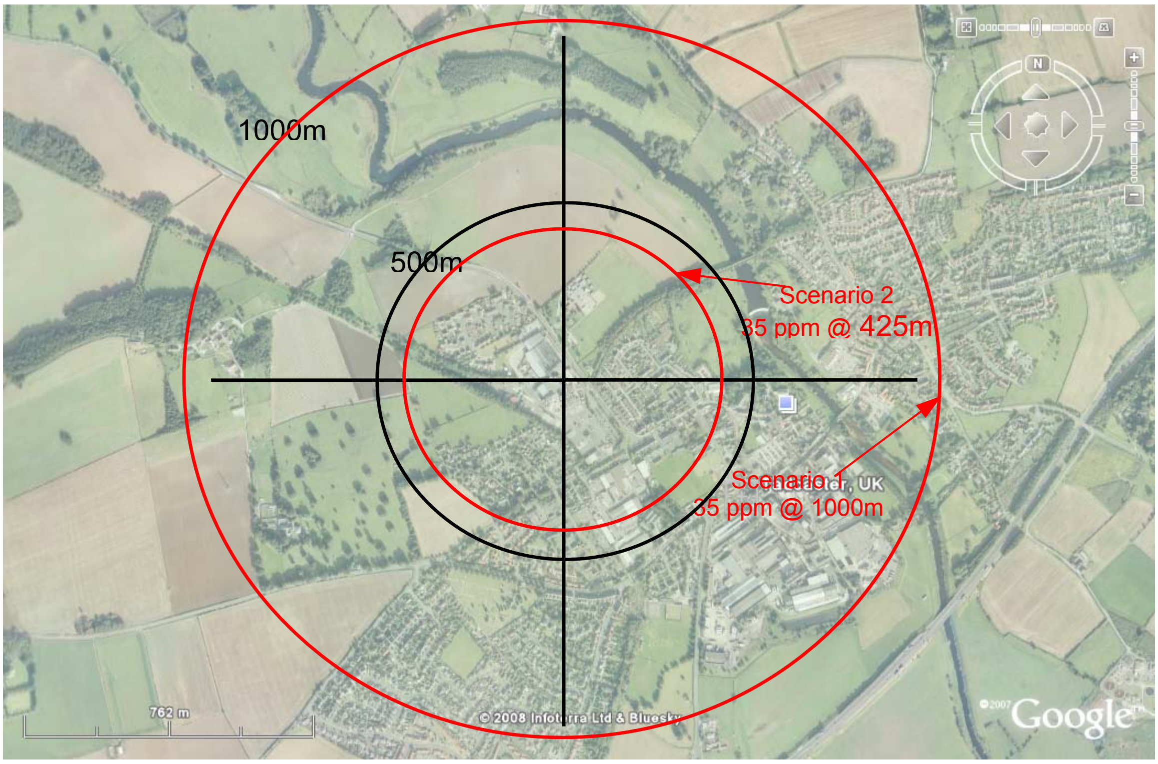
Typical plume dispersal model

- occur in the plant room and be exhausted out through the ventilation system

or

- vent through a pressure relief valve and its associated piping

Other releases, assuming most of the plant is indoors, will be less frequent. By modelling these two more likely events (high frequency, low consequence), most scenarios will be covered. In addition, in order to ascertain the full magnitude of the possibilities of offsite consequence, a worst-case scenario should also be modelled (low frequency, high consequence).



Concentric airborne ammonia overlays

In this, the most likely and the most consequential offsite releases can be modelled. Software like the US Environmental Protection Agency's ALOHA and Screen3 programmes can be used to give indications of worst case airborne ammonia concentrations and various distances downwind. The plume dispersal diagram on the previous page shows distance to various downwind concentration levels. Armed with these approximations, emergency services can be given guidance in their activities in the area. The map above illustrates how the computer model results can be overlaid on aerial maps giving concentric rings of airborne ammonia concentration.

3.5 Operating procedures

Owners, operators and maintenance contractors of ammonia systems must develop operating procedures for all activities associated with the systems. These procedures must be developed in conjunction with those that will apply them. They must be put down in writing, approved and fully adhered to. Some of these must be posted conspicuously in the plant room (start, stop, emergency stop). More specific, technical procedures like draining oil and charging ammonia will possibly be carried out by a contractor and will be required only when those activities are taking place. Others are not directly ammonia related, but important all the same – lock out/tag out, first aid, confined space entry, etc.

3.6 Training

Operators, contractors, first aiders, emergency responders and site personnel in general all must have received a certain level training regarding the ammonia hazard, even if it simply being made aware of its presence on site.
Staring with induction of new staff and basic information being made available to visitors, training continues with emergency response. The general population, the managers, engineers, contractors, first aiders, emergency services and many more all must be fully informed of their duties when a leak occurs, whether it is simply await for an announcement over the intercom or evacuate.
Of course it is important that there be at least some basic level of training amongst employees regarding ammonia handling and plant operation. Contractors who support this and carry out the more complex tasks must provide proof of their qualifications before being given permission to work.
It is important that records are kept, refreshers are given and that job descriptions are drafted making reference to the required level of training

3.7 Employee participation

It is of utmost importance that any safety management system includes input from all levels within the company. There must be clear lines of communication in both directions. Procedures must be drafted with significant input from those that will apply them. There must be a means by which risk information can be made available to all employees and visitors. There should also be a channel by which safety information can be passed form employees back up the chain of command to those in charge of the hazard.

3.8 Incident investigation

Whether it is an ammonia incident or a near miss with a forklift, there should be in place an incident investigation procedure to scrutinise the event, identify the point of failure and redress the deficiency that led to it If the incident has been related to ammonia, those responsible for the management of that particular hazard should be involved in the investigation. Input should be sought from operators, contractors and suppliers. A report should be prepared and the investigation procedure should include a means to resolve the findings in the report. Any resolutions and corrective actions should be documented. This type of investigation is not unique to ammonia; it should be in place in any facility where hazards exist.

3.9 Management systems

Although ultimately the “ownership” of the ammonia hazard on site belongs to the site manager, he will delegate this to his managers. The Health & Safety, Human Resources, Engineering, Maintenance and Production managers may all be responsible for some aspect of ammonia safety. It is important that they are all aware of their responsibilities and that this distribution of ownership is documented.

3.10 Management of change

A safety management programme such as this will become irrelevant if uncontrolled, non-like-for-like changes are made. Whether the changes are mechanical or procedural, unless those managing the hazard are aware of the changes and have adjusted their procedures and hardware accordingly, there may be unseen health and safety consequences. New equipment may require additional training. Additional ammonia containing equipment may require additional ammonia detection and possible rerouted emergency evacuation routes. Outsourcing security may require modified emergency response procedures. As with the incident investigation procedures, management of change may already be part of the company policy production changes. It can easily be modified for use in managing the ammonia hazard.

3.11 Pre-commissioning review

For new facilities, the risks associated with ammonia start to show themselves the moment the ammonia arrives on site. Where possible, all the management tools outlined herein should be in place before the ammonia arrives.

3.12 Risk management review

As with any risk assessment, this assessment and the associated risk management tools should be reviewed regularly to ensure that procedures are being followed and remain relevant. A review should also take place after any significant change or event.

3.13 Permits to work

Any work taking place on the ammonia systems should not take place without a Permit to Work. The permit to work system must be managed in such a way that work scope and work risk are fully understood and planned for. Hot work must be carefully controlled procedures must be clear and training must be in order.

3.14 Contractors

A means by which contractors are assessed, hired and monitored must be in place to ensure that systems are installed and maintained safely and correctly. The owner of the ammonia system and the contractor hired to work on the system have health and safety responsibilities that must be fulfilled. Full details of site hazards must be provided to the contractors who, in turn, must provide the used with details of any hazards he brings to the site. His training records and his health and safety history must be verified

3.15 Emergency response

Many of the preceding management tools have dealt with the prevention of an ammonia release. It must be assumed, however, that failure of one or more of these tools is inevitable in the life of the system. An unplanned ammonia release will occur and a response procedure to this eventuality must be in place.

The plan must include tasks and procedures for all persons on-site and for some off-site (contractors, emergency services, families…). The plan must be valid 24 hrs per day, 365 days per year. Back-ups for all response team members must be assigned, training and refresher training should take place and emergency instructions must be in place.

3.16 Hazard analysis

Once all the above tools are in place and have been assessed, a hazard analysis is carried out, asking what-if questions about all manner of hardware and procedural failure. The analysis must be highly detailed, examining all the hardware, the human interactions, the major procedures and the emergency situation of the system.

4. RESULTS

Whenever a shortfall is discovered in the assessment and hazard analysis, the magnitude of the resultant risk should be determined. The frequency of failure should be estimated and a consequence should also be determined. It is highly unlikely that quantitative data concerning plant failure frequency and consequence will be available; therefore more qualitative judgements should be used. The table below is one example of this method.

		Level 1	Level 2	Level 3	Level 4
Frequency	Level 4	C	B	A	A
	Level 3	C	B	B	A
	Level 2	D	C	B	B
	Level 1	D	D	C	C
		Consequence			

The various levels of frequency and consequence are, by necessity, qualitative in nature and somewhat subjective, but the methodology does allow the end-user to prioritise the residual risk issues. He can then address them in a controlled manner. The frequency and consequence levels outlined below are a suggestion based on the IIAR guidance.

Frequency range	Qualitative frequency criteria
Level 4	Events expected to occur yearly with respect to the refrigeration system. Examples include single instrument or valve error, hose leaks or a human error
Level 3	Events expected to occur several times during the lifetime of the refrigeration system. Examples include dual instrument or valve failure, hose ruptures or piping leaks
Level 2	Events expected to occur no more than a few times during the lifetime of the refrigeration system. Examples include combinations of instrument failures and human errors, or full-bore failures of small lines or fittings
Level 1	Events expected to occur no more than once during the lifetime of the refrigeration system. Examples include multiple instrument or valve failures or human errors, or spontaneous failures of tanks or vessels

Consequence range	Qualitative safety consequence criteria
Level 4	Potential for multiple, life-threatening injuries or fatalities
Level 3	Potential for a single life-threatening injury or fatality
Level 2	Potential for an injury requiring a physician's care
Level 1	Potential to local vicinity, with potential injuries requiring no more than first aid

By identifying each individual shortfall in the safety management system through the risk assessment and hazard analysis and by assigning and frequency, consequence and risk level to each one, a prioritised list of "outstanding risk issue" can be generated. The items on the list can be addressed in order of priority, allowing the end-user to gradually and systematically increase the level of ammonia safety management on his or her site.

For example:

Over-pressure relief valves

The pressure relief valves on the two screw compressors and the high pressure receiver are set to vent at pressure higher than the maximum working pressure (MWP) of the equipment they protect

- *The screw compressor MWP 18 bar. The valves are set at 23 bar*
- *The high pressure receiver MWP is 16 bar The valves are set at 19.3 bar*

Frequency 2
Consequence 3
Risk level B

This final list can be arranged in order of risk severity, and may include such items as those shown below.

Item	Ref.	Scenario	Section	Risk
A.1	3.2	Isolated, live heat exchanger, no PSV	Mechanical integrity	Level A
B.1	3.1	Additional daily checks	Mechanical integrity	Level B
B.2	7.2	Misc. training issues - emergency	Training	Level B
B.3	17.17	Oil draining procedure	Hazard analysis	Level B
C.4	3.9 17.13	Equipment & pipe identification / labelling	Mechanical integrity Hazard analysis	Level C
C.8	4.5	PPE	Safety systems review	Level C
C.13	8.1 17.21	Communication of ammonia risk issues	Employee participation Hazard analysis	Level C
C.18	17.15	Control room ventilation	Hazard analysis	Level C
D.6	3.15	Equipment data sheets	Mechanical integrity	Level D
D.10	5.1	Pressure relief valve offsite consequence	Offsite consequence	Level D
D.14	11.1 17.22	No management of change system	Management of change Hazard analysis	Level D
D.16	15.1	Minor contractor control issues	Contractors	Level D

A list of outstanding issues such as this can become an action item list and the various issues can be addressed in order of severity.
By carrying out a risk management assessment such as this, an owner can assure himself that all the safety management tools at his disposal are complete and in place. He can be certain that he is meeting his legislative responsibilities without the doubt that one or more piece of law or good practice has been overlooked.

5. REFERENCES

1. EN 378, 2008, *Refrigerating systems and heat pumps – Safety and environmental requirements*
2. Directive 1999/92/EC, *ATEX Workplace Directive*
3. Directive 1994/9/EC, *ATEX Equipment Directive*
4. Directive 1997/23/EC, *Pressure Equipment Directive*
5. United States Environmental Protection Agency, 2000, *Risk Management Program Guidance for Ammonia Refrigeration (40 CFR Part 68)*

(May 2009)