The knowledge hub for refrigeration, air conditioning and heat pumps

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Ammonia leakage, dispersion and risk assessment

Why this topic?

You should read this paper if you work with or are considering working with ammonia refrigeration systems.

It provides a unique insight into:

- Current legal frameworks related to classification of hazardous areas.
- How the potential release of ammonia has been modelled to provide new calculation methods for hazard range.
- New industry guidance which will impact design, construction, operation and maintenance of these systems.

1 Introduction

Ammonia has been considered to be an excellent choice of refrigerant for industrial applications for more than 150 years even though it is toxic and flammable. It requires careful safety consideration in the design and operation of refrigeration systems and it has a good safety record. Ignition of ammonia is a very rare occurrence and is virtually unknown in systems which comply with recognised European Standards. However, compliance with the requirements of the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002 in accordance with the EU ATEX Directives requires a different approach.

The primary purpose of DSEAR is to protect workers and others who may be at risk from dangerous substances that can cause a fire, explosion or similar energy-releasing event, such as a runaway exothermic reaction. DSEAR is therefore primarily concerned with situations where there may be a flammable release during normal operating conditions. DSEAR is not concerned with the risks related to toxicity nor is it concerned with 'worst case' or catastrophic failures that might be reasonably envisaged, although these are covered in other health and safety regulations. DSEAR does however require that appropriate assessments are carried out, potential risks are identified, and areas of the workplace classified where explosive atmospheres may occur to avoid ignition sources (from unprotected equipment, for example) in those areas.

Recently a 'Joint Industry Project' [1,2] has sought to provide practical guidance to ensure ammonia refrigeration plants are fully compliant with DSEAR because the Health and Safety Executive (HSE) had determined that regulatory requirements are not always being fulfilled in the case of ammonia refrigeration systems.

This paper provides an overview of the current legal framework and explains the procedure to be followed in classification of hazardous areas in accordance with IEC EN 60079-10-1. An approach using new software to model potential releases and calculate the hazard range, is described and new guidance is introduced for those involved in the design, construction, operation and maintenance of ammonia refrigeration systems.

2 Background

The significant gap between the requirements of UK legislation [3] and the European Standard on Refrigeration Safety and the Environment (EN378 - Parts 1,2, 3, and 4:2008) [4] has been previously described by the authors at this year's International Congress of Refrigeration [2]. EN378:2008 does not attempt to align with the ATEX directives because they are enacted slightly differently in each country. The most obvious difference between the law and the standards, which has become even more marked in recent years, is that the standard considers several classes of flammability whereas the law only differentiates between flammable substances and non-flammable substances. Any refrigerant which is "*a substance or preparation which meets the criteria in the approved classification and labelling guide for classification as a substance or preparation which is explosive, oxidising, extremely flammable, highly flammable or flammable*" would be covered by DSEAR. The separation of refrigerants into different classes of flammability (lower flammability, flammable and higher flammability) provided by BS ISO 817:2012 [5] does not make any difference to the way in which fluids are treated in DSEAR, and it is a mistake to try to correlate the DSEAR listing of "extremely flammable, highly flammable or flammable" with the ISO 817 listing of "higher flammability, flammable or lower flammability". For example R-32 and R-1234yf (both listed as A2L refrigerants and therefore in the ISO 817 "lower flammability" class are considered under DSEAR to be "extremely flammable", with the assigned hazard statement H220. In contrast ammonia has the assigned hazard statement H221, "flammable" although it is also class 2L in ISO 817. Conversely, R-1234ze(E) which is "lower flammability" class in ISO 817 is not flammable according to the test method referenced in HSE's Approved Classification and Labelling Guide [6]. It has been made clear by HSE that refrigeration systems using substances covered by the Guide are required to meet the requirements of the ATEX directives [3]. There are no exceptions, and furthermore the requirements are retrospective. As new information about safety comes to light, for example in the revision of a safety standard, HSE would expect machinery being maintained in a safe condition to be kept in line with up to date standards where appropriate.

A further discrepancy between the law and the standards which has recently been highlighted by HSE is that the law applies to the whole system whereas the standards are focussed on occupied spaces and machinery rooms, leaving parts of the system which are not in either of these designations loosely defined. This challenge is addressed later in this paper.

3 Relevant Legislation

In general UK law imposes a range of duties of employers, the self-employed and employees as well as others such as designers, manufacturers or suppliers of articles and substances for use at work. These are expressed as broad general duties in the Health and Safety at Work (HSWA) Act 1974 but are spelt out in more detail in subsidiary regulations such as those dealing with the management of health and safety and specific health and safety issues

HSWA was enacted as a result of the need to codify much of the pre-1974 legislation with the principal aim of creating a single comprehensive system of regulatory law. There are three primary aims of HSWA:

1. To secure the health, safety and welfare of persons at work.
2. To protect persons other than persons at work against risks to health or safety arising out of or in connection with the activities of persons at work.
3. To control the keeping and use of explosive or highly flammable or otherwise dangerous substances, and generally preventing the unlawful acquisition, possession and use of such substances.

The Management of Health and Safety at Work Regulations 2002 (The Management Regulations) require employers to make and implement effective arrangements for assessing the risk and planning, organising, controlling, monitoring and reviewing the preventive and protective measures necessary to meet the specific requirements contained in relevant health and safety regulations.

For ammonia systems these requirements are contained mainly in the Provision and Use of Work Equipment Regulations 1998 (PUWER), the Pressure Equipment Regulations 1999 (PER), the Pressure Systems Safety Regulations 2000 (PSSR) and DSEAR. However, this list is not exhaustive and in some instances other regulations may also apply.

In recent years much of the UK's health and safety law has originated in Europe. Proposals from the European Commission may be agreed by Member States, who are then responsible for making them part of their domestic law. Modern health and safety law in the UK, including much of that from Europe is based on the principle of risk assessment.

ATEX is the name commonly given to the European framework for controlling explosive atmospheres and the standards of equipment and protective systems used in them. It is based on the requirements of two European Directives.

1. Directive 99/92/EC (also known as 'ATEX 137' or the 'ATEX Workplace Directive') on minimum requirements for improving the health and safety protection of workers potentially at risk from explosive atmospheres.
2. Directive 94/9/EC (also known as 'ATEX 95' or 'the ATEX Equipment Directive') on the approximation of the laws of Members States concerning equipment and protective systems intended for use in potentially explosive atmospheres.

The ATEX 137 Workplace Directive (1999/92/EC) has been implemented in the UK as DSEAR and by similar regulations in other EU Member States. These regulations require 'Hazardous Area Classification' to be carried out where there may be a risk of explosion due to the presence of flammable substances in the form of gases, vapours, mist or dust. The regulations also require that to ensure safe operation, any equipment (both electrical and non-electrical) used in a classified area falls within the scope of the regulations and must therefore be suitable for use in the respective zone.

The specific DSEAR requirements dealing with explosive atmospheres came into effect at different times depending on when the Workplace (equipment) was first used and can be summarised as shown in Table 1 below.

Table 1 showing the different times from which DSEAR applies in the United Kingdom.

Workplace	Date when DSEAR/ATEX requirements must be met
Workplace in use before July 2003 (Equipment already in use before July 2003 can continue to be used indefinitely provided a risk assessment shows it is safe to do so.)	Workplace must meet requirements by July 2006
Workplace in use before July 2003 but modified before July 2006	Workplace must meet requirements from the time the modification takes place
Workplace comes into use for the first time after June 2003	Workplace must meet requirements from the time it comes into use

Accurate, documented area classification is now not just a technical safety requirement but also a legal requirement that should be carried out by a competent person in accordance with the relevant regulations and standards. The concept is not new. The control of sources of ignition by the use of specially protected equipment in areas where flammable gases or vapours may arise has been a fundamental safety measure for many years. However, to ensure safety and also legal compliance, the method used in establishing area classifications needs to be both proven and reliable, recognising that the highest level of protection is required where the risk of a release is 'high' and that lower levels of protection can be implemented where the risk of a release is lower without compromising overall safety.

Currently hazardous areas are classified into zones based on the anticipated frequency of occurrence (releases) and the estimated duration of an explosive gas atmosphere. There are three defined grades of release; continuous, primary and secondary. Generally, these three defined grades give rise to hazardous areas classified as Zones 0, 1, and 2 respectively.

The zones are defined in the relevant International Standard IEC EN 60079-10-1:2009 [7] as follows:

Zone 0 - a place in which an explosive gas atmosphere is present continuously or for long periods or frequently. Note that Zone 0 hazardous areas are not normally used in ammonia refrigeration systems because of the toxicity of ammonia.
Zone 1 – a place in which an explosive atmosphere is likely to occur occasionally in normal operation, (Examples include sampling points, relief valves, drainage points).
Zone 2 – a place in which an explosive atmosphere is not likely to occur in normal operation but, if it does occur, will persist for a short duration of time only. (Examples include near flanges, pipe fittings, valve stems, pump glands).

In addition, ammonia suppliers have a requirement to classify ammonia, provide hazard information (safety data sheets) and provide safe packaging in accordance with the European Regulation on Classification, Labelling and Packaging of Substances and Mixtures (EC No

1272/2008) which came into force in all EU member states, including the UK, on 20 January 2010. The intention of the CLP Regulation is very similar to the Chemicals (Hazard Information and Packaging for Supply) Regulations 2009 which they replace – substances and mixtures that are placed on the market should be classified, labelled and packaged appropriately.

Ammonia is classified under these Regulations as flammable and toxic, to be labelled with the following hazard statements:

H221	Flammable gas.
H280	Contains gas under pressure; may explode if heated.
H314	Causes severe skin burns and eye damage.
H331	Toxic if inhaled.
H400	Very toxic to aquatic life.
EUH071	Corrosive to the respiratory tract.

The HSE publication PM81, Safe Management of Ammonia Refrigeration Systems, was considered to be a useful guide since it pulled all relevant information together in one easy to use reference document. However the first edition was withdrawn many years ago as it was somewhat out of date. Over the past year the HSE in conjunction with industry stakeholders including the Food Storage and Distribution Federation (FSDF), RSA Group and the Institute of Refrigeration (IoR) have been working together to produce a second edition of PM81 [8]. This is currently undergoing a final review process before it is published later this year. This new edition applies to new and existing installations (whether permanent or temporary) and indicates the precautions which the HSE believes would be identified in a risk assessment as reasonably practicable to achieve compliance with the detailed legal provisions.

The forthcoming edition of PM81 clearly states that "both new and existing workplaces, where dangerous substances are used, must be assessed and classified into hazardous places (zones) and non-hazardous places in accordance with Regulation 7(1) of DSEAR. Although ammonia is difficult to ignite it is classified as flammable and can give rise to flammable mixtures and hazardous Zone 1 and 2 area classifications".

4 Relevant Standards

The requirements for refrigeration safety are detailed in the four parts of EN378:2008 but as previously stated these do not address dangerous substances and explosive atmospheres as required by DSEAR. There is a great deal of valuable, useful and practical safety guidance in EN378 but it misses some key points. For example the location of mechanically actuated equipment such as valves or pumps, and equipment requiring routine maintenance such as filters or strainers is not considered by the standard unless they are in a machinery room.

Some further insight into the steps that need to be taken in order to comply with the requirements of DSEAR can be found in BS EN 60079-10-1:2009 [7] and BS EN 1127-1:2011 [9]. EN 60079 gives guidance on the calculation of the hazardous zone which is created by the leak of a flammable substance. It tabulates the size of hole which should be considered when evaluating the leak rate and introduces the concept of a zone being "of negligible extent" (NE). This means that the consequences of ignition of a cloud of flammable gas would not be significant provided the cloud was smaller than the limit imposed by the zone volume. The consequences arise either from the energy released by combustion (the burning effect) or from the sudden increase in air pressure caused by the heating (the pressure effect). If the zone is less than 1% of the room volume then the pressure effect can be neglected and only the burning effect needs to be considered. It follows that the recent emphasis placed in the refrigeration standards on "burning velocity", as described by Kataoka [10], does not help to define whether the hazardous zone defined by EN 60079 is "NE" or not. EN 1127 gives further guidance on the likelihood of leakage and once again a significant difference from EN 378 is apparent. Whereas EN 378 only considers joints as being either "permanent" or "non-permanent", EN 1127 distinguishes between joints which are designed to emit some fluid in normal operation, joints which are "technically tight" and those which are to an even higher standard, which it describes as "durably technically tight". It is apparent from careful reading of EN 60079 and EN 1127 that the great majority of all non-permanent joints used in refrigeration systems are "durably technically tight". This leads to the conclusion that, when assessing the probability of leakage and the severity of the consequences it is not necessary to consider the worst possible leak scenario imaginable, but simply to consider what the effects of a leak of magnitude indicated by EN 60079 from a technically tight joint would be. However EN1127 also makes it clear that pipes shall be considered to be potential sources of leakage even if there are no non-permanent joints if the pipe is located in a position which might make it vulnerable to mechanical damage during routine operations. Where a joint is intended to be periodically detached, for example to gain access to a filter or strainer, then an appropriate supervisory regime is required to ensure that this does not give rise to a flammable atmosphere, for example by stipulating that a high ventilation rate is applied during the operation.

5 Development of the Modelling Software

Ventilation is a critical factor in area classification. BS EN 60079-10-1:2009 defines the degree of ventilation on the basis of the calculated value Vz and contains a numerical method for indoor and outdoor situations. It also allows the use of alternative methods such as 'computational fluid dynamics' (CFD). The numerical method in the standard has no scientific basis. It is actually based on the assumption that the ratios between a) the actual ventilation rate and the ventilation rate required to dilute the release down to a specified level, and b) the enclosure volume and V_z are equal.

As reported by Santon *et al*, [11] area classification studies carried out by the Health and Safety Laboratory (HSL) at a large natural gas site in 2005 indicated that the numerical methods in BS EN 60079-10-1 provided grossly conservative values of V_z. Following those studies, work presented to Hazards XIX by Gant *et al* [12] in 2006 showed that the numerical values of V_z calculated from the standard were typically between 100 and 3,000 times greater than values obtained by using CFD. Importantly, the work by the HSL also confirmed the validity of classification of the $0.1m^3$ limit for V_z as the criterion for Zone 2NE through practical experiments. This work was subsequently incorporated by the Institute of Gas Engineers and Managers into a revision of their guide to hazardous area classification of natural gas installations, IGEM/SR/25 [13] with the concept of Zone 2NE being introduced into the gas industry's standard for the first time.

Having developed a scientifically-based solution for natural gas, it became clear to HSL that a generic alternative to the numerical methods in IEC EN 60079-10-1 was required for the area classification of other gases including releases both indoors and outdoors. One of the first gases selected by HSE and HSL was ammonia. One of the main reasons for ammonia being selected was because the HSE reported at the time that they had identified in the UK a number of broad areas, particularly within the food and drink industries, where existing management of ammonia refrigeration systems by some designers, installers, contractors and site staff had been found wanting. These include:

- A lack of understanding of the science of ammonia refrigeration and the implications for design and modification.
- Failures to select, install, maintain, check and use systems correctly.
- Failures to identify through assessment the likely sources of gas escape so that appropriate plant modifications may be made or appropriate plant checks instituted to detect likely sources of leakage at an early enough stage.
- Failures to prepare and rehearse emergency procedures to limit the effect of leakage if one occurs.
- Failures to train personnel

Another reason was that the HSE were concerned that many operators of ammonia refrigeration plants had failed to understand and therefore fully implement the requirements of DSEAR. The HSE's concern regarding this lack of DSEAR compliance led to a Joint Industry Project (JIP) being agreed with the objective of providing practical guidance to

a) address these general concerns and
b) ensure legal compliance in the area classification of ammonia refrigeration systems.

The model used by the JIP is a simple, scientifically-based, integral model for the release of a flammable gas in a ventilated enclosure. The model, which was developed by HSL, is described by Webber et al [14] and Young [1] and is hereafter referred to as the modelling software. It is further explained by HSL on their website [15].

There are however certain limitations that should be noted when carrying out area classifications using the modelling software:

1. The size of hole selected for consideration in leakage calculations is critical. It determines the release rate of the flammable substance and thus eventually the type of zone and the extent of

the zone. Release rate is proportional to the square of the hole radius. The volume of the hazardous zone which arises is proportional to the cube of the hole radius. A modest underestimate of the hole size will therefore lead to a gross underestimate of the calculated value for release rate and zone extent volume, (hazardous range), which should be avoided. Over-estimation of the hole size will lead to a conservative calculation which is acceptable for safety reasons, however the degree of conservatism should also be limited because it results in overlarge zone extents. A carefully balanced, realistic approach is therefore needed when estimating the hole size.

2. The build-up of flammable gas following a release from a pressurized system can be strongly affected by local obstructions to the resulting jet and to the ventilation flow. Both have a very significant effect on the dispersion of the flammable gas and the resulting size of gas cloud. It is therefore important that the effect of this congestion/confinement is accounted for in an area classification.
3. A preliminary assessment of the effects of confinement on the gas cloud build-up can be carried out by assigning an appropriate value to the efficiency of mixing. A value of $\epsilon = 1$ represents an unobstructed release, $\epsilon = 0.5$ represents a moderate degree of obstruction and $\epsilon = 0.3$ represents a significant obstruction to the ventilation flow. These figures have been taken from Ivings et al [16]. In addition for large enclosures this might not be sufficient on its own and an assessment of local ventilation effectiveness will be needed to confirm that fresh ventilation air is effectively reaching the potential leak source through visual inspection, smoke tests or other effective means.
4. Uncertainty in the model accuracy needs to be accounted for in applying this area classification methodology. This can be simply done by applying a safety factor of two to the estimated ventilation rate or by ensuring that the hole size is over-estimated.
5. The indoor release result assumes that the effects of ventilation permeate the whole room. If the release is likely to be within a sub-chamber which is largely isolated from the effects of ventilation in the main room, then V_z should be computed for the volume of the sub-chamber with a lower ventilation rate, or simply set to the volume of the sub-chamber.
6. For enclosure volumes less than $10m^3$ the criterion of $0.1m^3$ for V_z should be reduced to 1% of the enclosure volume. This constraint is taken from IEC EN 60079-10-1:2009 and is based upon the findings in Ivings et al [16].
7. The guidance in IEC EN 60079-10-1:2009 on the availability of ventilation should be followed.
8. Operating pressures exceeding 20 barg should not be modelled using the modelling software.

Tables 2 and 3 show the modelled results of area classifications for a high pressure gas release (13barg) under normal operating conditions. In the tables five different ventilation rates are considered: 4, 6, 8, 10 and 12 air changes per hour, at all times during normal operating conditions.

Tables 4 and 5 show the modelled results of area classifications for a high pressure liquid release (13barg) under normal operating conditions. Again, in the tables five different ventilation rates are considered: 4, 6, 8, 10 and 12 air changes per hour, at all times during normal operating conditions The results in the Tables 2, 3, 4 and 5 should be interpreted in the following way:

- V_z is the volume
- HR is the 'Hazard Range' and represents the distance from the point release to the point where the gas concentration has reduced to the critical concentration (in this case 50% LEL).
- LEL is the distance from the point of release to a gas concentration equal to LEL
- ERV means that the risk exceeds the 'Entire Room Volume'.

Where the results are shown in a pink cell V_z is estimated to exceed $0.1m^3$ and therefore no unprotected equipment should be located within the hazard range (HR). Alternatively, in these cases to achieve a zone of negligible extent (NE) the rate of ventilation would need to be increased.
Where the results are shown in an amber cell it is recommended that caution is observed since as can be seen from Figure 1 below the calculation of V_z is sensitive to small changes in enclosure volume. If in doubt it is recommended that a higher ventilation rate is used.
In the new guidance referred to below tables will be provided for a range of hole sizes at all typical operating conditions for ammonia refrigeration plants (both gas and liquid releases) for enclosures with volumes from $25m^3$ to $1,000m^3$.

Table 2 showing typical results from the model for a hole size of 0.25mm². (Gas Release - 13barg operating pressure, and 0.5 mixing efficiency).

Mixing efficiency = 0.5 where there is a MODERATE OBSTRUCTION(S) — Outdoors: V_z (m^3) 0.000, HR (m) 0.121, LEL (m) 0.055

Room Volume (m3)	4 air changes per hour			6 air changes per hour			8 air changes per hour			10 air changes per hour			12 air changes per hour		
	V_z (m^3)	HR (m)	LEL (m)	V_z (m^3)	HR (m)	LEL (m)	V_z (m^3)	HR (m)	LEL (m)	V_z (m^3)	HR (m)	LEL (m)	V_z (m^3)	HR (m)	LEL (m)
50	≤ 0.001	0.202	0.069	≤ 0.001	0.165	0.064	≤ 0.001	0.151	0.062	≤ 0.001	0.144	0.060	≤ 0.001	0.140	0.059
75	≤ 0.001	0.165	0.064	≤ 0.001	0.147	0.061	≤ 0.001	0.140	0.059	≤ 0.001	0.135	0.059	≤ 0.001	0.133	0.058
100	≤ 0.001	0.151	0.062	≤ 0.001	0.140	0.059	≤ 0.001	0.134	0.058	≤ 0.001	0.131	0.058	≤ 0.001	0.129	0.057
125	≤ 0.001	0.144	0.060	≤ 0.001	0.135	0.059	≤ 0.001	0.131	0.058	≤ 0.001	0.129	0.057	≤ 0.001	0.128	0.057
150	≤ 0.001	0.140	0.059	≤ 0.001	0.133	0.058	≤ 0.001	0.129	0.057	≤ 0.001	0.128	0.057	≤ 0.001	0.126	0.057
175	≤ 0.001	0.137	0.059	≤ 0.001	0.131	0.058	≤ 0.001	0.128	0.057	≤ 0.001	0.127	0.057	≤ 0.001	0.126	0.057
200	≤ 0.001	0.134	0.058	≤ 0.001	0.129	0.057	≤ 0.001	0.127	0.057	≤ 0.001	0.126	0.057	≤ 0.001	0.125	0.056
300	≤ 0.001	0.129	0.057	≤ 0.001	0.126	0.057	≤ 0.001	0.125	0.056	≤ 0.001	0.124	0.056	≤ 0.001	0.124	0.056
400	≤ 0.001	0.127	0.057	≤ 0.001	0.124	0.056	≤ 0.001	0.124	0.056	≤ 0.001	0.123	0.056	≤ 0.001	0.123	0.056
500	≤ 0.001	0.126	0.057	≤ 0.001	0.124	0.056	≤ 0.001	0.123	0.056	≤ 0.001	0.123	0.056	≤ 0.001	0.122	0.056
600	≤ 0.001	0.125	0.056	≤ 0.001	0.124	0.056	≤ 0.001	0.123	0.056	≤ 0.001	0.122	0.056	≤ 0.001	0.122	0.056

Table 3 showing typical results from the model for a hole size of 2.50mm². (Gas Release - 13barg operating pressure, and 0.5 mixing efficiency).

Mixing efficiency = 0.5 where there is a MODERATE OBSTRUCTION(S) — Outdoors: V_z (m^3) 0.002, HR (m) 0.382, LEL (m) 0.175

Room Volume (m^3)	4 air changes per hour			6 air changes per hour			8 air changes per hour			10 air changes per hour			12 air changes per hour		
	V_z (m^3)	HR (m)	LEL (m)	V_z (m^3)	HR (m)	LEL (m)	V_z (m^3)	HR (m)	LEL (m)	V_z (m^3)	HR (m)	LEL (m)	V_z (m^3)	HR (m)	LEL (m)
50	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	3.863	ERV	ERV	0.764	ERV	ERV	0.495
75	ERV	ERV	ERV	ERV	ERV	1.190	ERV	ERV	0.495	ERV	erv	0.365	1.275	3.274	0.310
100	ERV	ERV	3.863	ERV	ERV	0.495	ERV	ERV	0.342	0.245	1.877	0.289	0.057	1.142	0.261
125	ERV	ERV	0.764	ERV	ERV	0.365	0.245	1.877	0.289	0.046	1.059	0.256	0.022	0.820	0.238
150	ERV	ERV	0.495	1.275	3.274	0.310	0.057	1.142	0.261	0.022	0.820	0.238	0.013	0.689	0.225
175	ERV	ERV	0.395	0.145	1.586	0.280	0.028	0.892	0.244	0.014	0.705	0.227	0.010	0.619	0.216
200	ERV	ERV	0.342	0.057	1.142	0.261	0.018	0.765	0.233	0.011	0.638	0.219	0.008	0.574	0.210
225	1.275	3.274	0.310	0.032	0.938	0.248	0.013	0.689	0.225	0.009	0.594	0.218	0.007	0.544	0.206
250	0.245	1.877	0.289	0.022	0.820	0.238	0.011	0.638	0.219	0.007	0.563	0.208	0.006	0.522	0.202
275	0.101	1.390	0.273	0.016	0.743	0.231	0.009	0.602	0.214	0.007	0.540	0.205	0.005	0.505	0.199
300	0.057	1.142	0.261	0.013	0.689	0.225	0.008	0.574	0.210	0.006	0.522	0.202	0.005	0.492	0.197
325	0.038	0.992	0.252	0.011	0.649	0.220	0.007	0.553	0.207	0.006	0.508	0.200	0.005	0.481	0.195
350	0.028	0.892	0.244	0.010	0.619	0.216	0.006	0.536	0.204	0.005	0.496	0.198	0.005	0.473	0.194
375	0.022	0.820	0.238	0.009	0.594	0.213	0.006	0.522	0.202	0.005	0.486	0.196	0.004	0.465	0.192
400	0.018	0.765	0.233	0.008	0.574	0.210	0.006	0.510	0.200	0.005	0.478	0.195	0.004	0.459	0.191
425	0.015	0.723	0.228	0.007	0.558	0.208	0.005	0.501	0.199	0.004	0.471	0.194	0.004	0.454	0.190
450	0.013	0.689	0.225	0.007	0.544	0.206	0.005	0.492	0.197	0.004	0.465	0.192	0.004	0.449	0.189
475	0.012	0.661	0.222	0.006	0.532	0.204	0.005	0.485	0.196	0.004	0.460	0.191	0.004	0.445	0.189
500	0.011	0.638	0.219	0.006	0.522	0.202	0.005	0.478	0.195	0.004	0.455	0.191	0.004	0.441	0.188
525	0.010	0.619	0.216	0.006	0.513	0.201	0.005	0.473	0.194	0.004	0.451	0.190	0.004	0.438	0.187
550	0.009	0.602	0.214	0.005	22.000	0.199	0.004	0.468	0.193	0.004	0.448	0.189	0.004	0.435	0.187
575	0.008	0.587	0.212	0.005	0.498	0.198	0.004	0.463	0.192	0.004	0.444	0.188	0.004	0.432	0.186
600	0.008	0.574	0.210	0.005	0.492	0.197	0.004	0.459	0.191	0.004	0.441	0.188	0.004	0.430	0.186
700	0.006	0.536	0.204	0.005	0.473	0.194	0.004	0.446	0.189	0.003	0.432	0.186	0.003	0.422	0.184
800	0.006	0.510	0.200	0.004	0.459	0.191	0.004	0.437	0.187	0.003	0.425	0.185	0.003	0.417	0.183
900	0.005	0.492	0.197	0.004	0.449	0.189	0.003	0.430	0.186	0.003	0.420	0.184	0.003	0.413	0.182
1000	0.005	0.478	0.195	0.004	0.441	0.188	0.003	0.425	0.185	0.003	0.415	0.183	0.003	0.409	0.181

Tables 4 and 5 below show the modelled results of area classifications for a high pressure liquid release (13barg) under normal operating conditions. Again, in the tables five different ventilation rates are considered: 4, 6, 8, 10 and 12 air changes per hour, at all times during normal operating conditions.

Table 4 showing typical results from the model for a hole size of 0.25mm². (Liquid Release - 13barg operating pressure, and 0.5 mixing efficiency).

Mixing efficiency = 0.5 where there is a MODERATE OBSTRUCTION(S) Outdoors V_z (m³) 0.007 HR (m) 0.436 LEL (m) 0.206

Room Volume (m³)	4 air changes per hour			6 air changes per hour			8 air changes per hour			10 air changes per hour			12 air changes per hour		
	V_z (m³)	HR (m)	LEL (m)	V_z (m³)	HR (m)	LEL (m)	V_z (m³)	HR (m)	LEL (m)	V_z (m³)	HR (m)	LEL (m)	V_z (m³)	HR (m)	LEL (m)
25	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	1.345	ERV	ERV	0.638	ERV	ERV	0.471
50	ERV	ERV	1.345	ERV	ERV	0.471	2.140	3.689	0.354	0.153	1.493	0.307	0.061	1.067	0.282
75	ERV	ERV	0.471	0.368	2.032	0.326	0.061	1.067	0.282	0.031	0.829	0.261	0.022	0.721	0.259
100	2.140	3.689	0.354	0.061	1.067	0.282	0.027	0.785	0.260	0.019	0.677	0.259	0.015	0.620	0.258
125	0.153	1.495	0.307	0.031	0.829	0.261	0.019	0.677	0.259	0.015	0.610	0.258	0.013	0.572	0.257
150	0.061	1.067	0.282	0.022	0.721	0.259	0.015	0.620	0.258	0.013	0.572	0.257	0.011	0.544	0.257
175	0.036	0.881	0.266	0.018	0.680	0.259	0.013	0.585	0.258	0.011	0.548	0.257	0.010	0.525	0.256
200	0.027	0.785	0.260	0.015	0.620	0.258	0.012	0.561	0.257	0.011	0.531	0.257	0.010	0.512	0.256
225	0.022	0.721	0.259	0.014	0.593	0.258	0.011	0.544	0.257	0.100	0.518	0.256	0.009	0.502	0.256
250	0.019	0.677	0.259	0.013	0.572	0.257	0.011	0.531	0.257	0.100	0.509	0.256	0.009	0.495	0.256
275	0.017	0.645	0.258	0.012	0.556	0.257	0.010	0.520	0.256	0.009	0.501	0.256	0.009	0.489	0.256
300	0.015	0.620	0.258	0.011	0.544	0.257	0.010	0.512	0.256	0.009	0.495	0.256	0.009	0.484	0.256
325	0.014	0.601	0.258	0.011	0.534	0.257	0.010	0.505	0.256	0.009	0.490	0.256	0.008	0.480	0.255
350	0.013	0.585	0.258	0.010	0.525	0.256	0.009	0.500	0.256	0.009	0.485	0.256	0.008	0.476	0.255
375	0.013	0.572	0.257	0.010	0.518	0.256	0.009	0.495	0.256	0.008	0.482	0.255	0.008	0.473	0.255
400	0.012	0.561	0.257	0.010	0.512	0.256	0.009	0.491	0.256	0.008	0.479	0.255	0.008	0.471	0.255
425	0.012	0.552	0.257	0.010	0.507	0.256	0.009	0.487	0.256	0.008	0.476	0.255	0.008	0.469	0.255
450	0.011	0.544	0.257	0.009	0.502	0.256	0.009	0.484	0.256	0.008	0.473	0.255	0.008	0.467	0.255
475	0.011	0.537	0.257	0.009	0.498	0.256	0.009	0.481	0.255	0.008	0.471	0.255	0.008	0.465	0.255
500	0.011	0.531	0.257	0.009	0.495	0.256	0.008	0.479	0.255	0.008	0.469	0.255	0.008	0.463	0.255
600	0.010	0.512	0.256	0.009	0.484	0.256	0.008	0.471	0.255	0.008	0.463	0.255	0.008	0.458	0.206
700	0.009	0.500	0.256	0.008	0.476	0.255	0.008	0.465	0.255	0.008	0.459	0.206	0.008	0.455	0.206
800	0.009	0.491	0.256	0.008	0.471	0.255	0.008	0.461	0.255	0.008	0.456	0.206	0.007	0.453	0.206
900	0.009	0.484	0.256	0.008	0.467	0.255	0.008	0.458	0.206	0.007	0.454	0.206	0.007	0.451	0.206
1000	0.008	0.478	0.256	0.008	0.463	0.255	0.008	0.456	0.206	0.007	0.452	0.206	0.007	0.449	0.206

Table 5 showing typical results from the model for a hole size of 1.00mm². (Liquid Release - 13barg operating pressure, and 0.5 mixing efficiency).

Mixing efficiency = 0.5 where there is a MODERATE OBSTRUCTION(S) Outdoors V_z (m³) 0.055 HR (m) 0.871 LEL (m) 0.412

Room Volume (m³)	4 air changes per hour			6 air changes per hour			8 air changes per hour			10 air changes per hour			12 air changes per hour		
	V_z (m³)	HR (m)	LEL (m)	V_z (m³)	HR (m)	LEL (m)	V_z (m³)	HR (m)	LEL (m)	V_z (m³)	HR (m)	LEL (m)	V_z (m³)	HR (m)	LEL (m)
25	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV
50	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV
75	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	4.242	ERV	ERV	1.667
100	ERV	ERV	ERV	ERV	ERV	ERV	ERV	ERV	2.690	ERV	ERV	1.276	ERV	ERV	0.941
125	ERV	ERV	ERV	ERV	ERV	4.242	ERV	ERV	1.276	ERV	ERV	0.894	124.037	14.394	0.744
150	ERV	ERV	ERV	ERV	ERV	1.667	ERV	ERV	0.941	124.037	14.394	0.744	2.943	4.064	0.653
175	ERV	ERV	12.321	ERV	ERV	1.159	ERV	ERV	0.792	4.057	4.530	0.664	0.898	2.681	0.599
200	ERV	ERV	2.690	ERV	ERV	0.941	17.122	7.377	0.707	1.222	2.987	0.614	0.485	2.134	0.565
225	ERV	ERV	1.667	ERV	ERV	0.821	2.943	4.064	0.653	0.641	2.359	0.580	0.326	1.841	0.540
250	ERV	ERV	1.276	124.037	14.399	0.744	1.222	2.987	0.614	0.420	2.019	0.556	0.251	1.658	0.522
275	ERV	ERV	1.069	9.742	6.037	0.691	0.710	2.453	0.586	0.311	1.805	0.537	0.207	1.534	0.520
300	ERV	ERV	0.941	2.943	4.064	0.653	0.485	2.134	0.565	0.251	1.658	0.522	0.175	1.443	0.519
325	ERV	ERV	0.855	1.477	3.181	0.623	0.371	1.922	0.548	0.213	1.556	0.520	0.156	1.374	0.518
350	ERV	ERV	0.792	0.898	2.881	0.599	0.296	1.771	0.534	0.187	1.470	0.519	0.142	1.320	0.517
375	124.038	14.394	0.744	0.641	2.389	0.580	0.251	1.658	0.533	0.165	1.466	0.518	0.131	1.277	0.517
400	17.122	7.377	0.707	0.485	2.134	0.565	0.220	1.571	0.520	0.151	1.355	0.518	0.122	1.241	0.516
425	5.942	5.155	0.677	0.394	1.968	0.552	0.196	1.500	0.519	0.140	1.312	0.517	0.115	1.211	0.516
450	2.943	4.064	0.653	0.326	1.841	0.540	0.175	1.443	0.519	0.131	1.277	0.517	0.110	1.185	0.515
475	1.792	3.416	0.632	0.283	1.740	0.531	0.162	1.395	0.518	0.124	1.246	0.516	0.105	1.163	0.515
500	1.222	2.987	0.614	0.251	1.658	0.522	0.151	1.355	0.518	0.117	1.220	0.516	0.101	1.144	0.515
600	0.485	2.134	0.565	0.175	1.443	0.519	0.122	1.241	0.516	0.101	1.144	0.515	0.090	1.088	0.514
700	0.296	1.771	0.534	0.142	1.320	0.517	0.107	1.170	0.515	0.091	1.095	0.514	0.083	1.050	0.513
800	0.220	1.571	0.520	0.122	1.241	0.516	0.097	1.122	0.514	0.085	1.061	0.513	0.078	1.024	0.512
900	0.175	1.443	0.519	0.110	1.185	0.515	0.090	1.088	0.514	0.081	1.036	0.513	0.075	1.005	0.512
1000	0.151	1.355	0.518	0.101	1.144	0.515	0.085	1.061	0.513	0.077	1.017	0.512	0.073	0.989	0.512

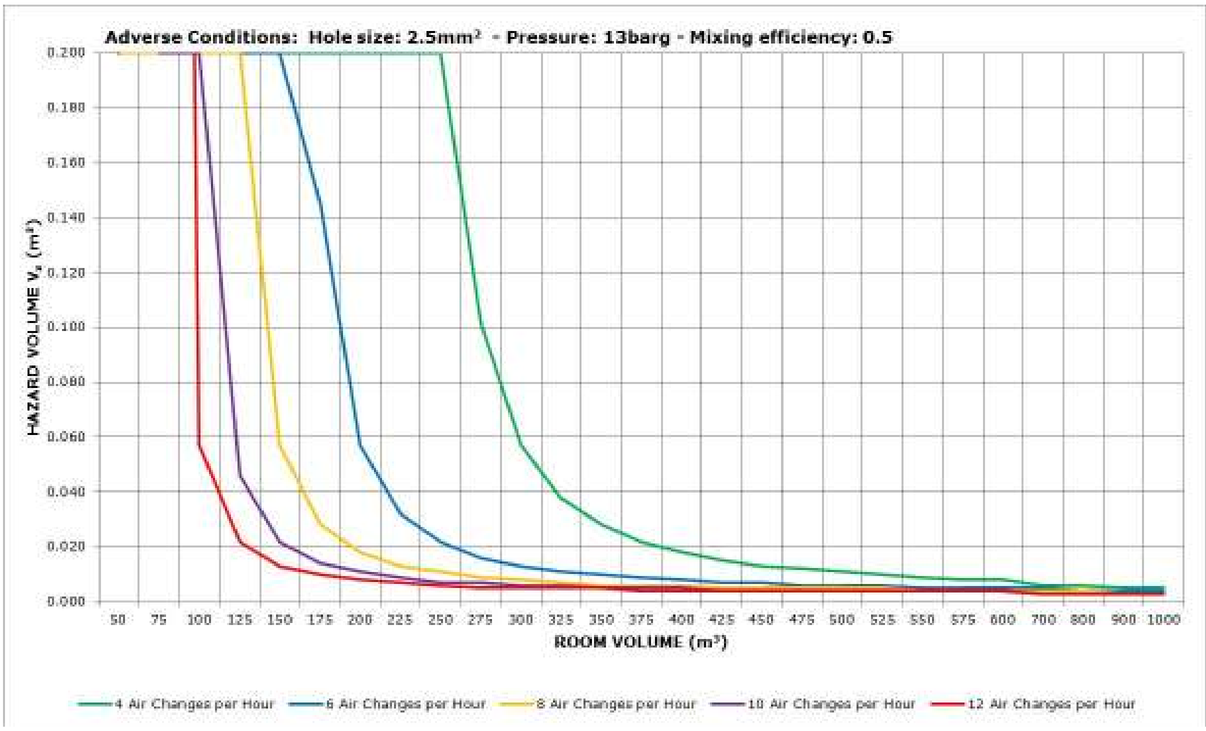

Figure 1 showing a graphical representation of the model results shown in Table 3.

6 The new guidance

Following the work with HSE and HSL the authors are developing a guidance document on behalf of the Food Storage and Distribution Federation (FSDF) and the Institute of Refrigeration (IoR). The objective of the guidance is to steer plant owners and designers through the complex array of requirements in order to ensure legal compliance without adding significant cost to a project. The guidance applies to existing plants as well as new designs, but it should be viewed as an opportunity to make a rational assessment of the fitness of an existing installation for continued operation. In the majority of cases which can be envisaged, and in light of recent experiences in applying the guidance to existing systems, we believe that most systems will not require significant capital expenditure to ensure compliance with the requirements. It is also possible that the survey required when completing the assessment, if carried out methodically and with some knowledge of refrigeration good practice, will deliver sufficient operational savings to cover the cost of any measures required, including the cost of the survey itself.

Table 6 is based upon the requirements of BS EN 60079-10-1:2009 and has been modified to make it appropriate for ammonia refrigeration systems. It gives the appropriate size of hole which should be used in assessing the magnitude of a leak for the purposes of determining the extent of a hazardous zone.

Table 6 Suggested hole cross sections for secondary grade of releases

<table>
<tr><th rowspan="2">Type of Item</th><th rowspan="2" colspan="2">Item</th><th colspan="3">Leak Considerations</th></tr>
<tr><th>Typical values for the conditions at which the release opening will not expand
S (mm²)</th><th>Typical values for the conditions at which the release opening may expand, e.g. erosion (e)
S (mm²)</th><th>Typical values for the conditions at which the release opening may expand up to a severe failure, e.g. blow out (f)
S (mm²)</th></tr>
<tr><td rowspan="3">**Sealing elements on fixed parts**</td><td colspan="2">**Flat or raised face flanges with compressed fibre gasket or similar (g)**</td><td>0,25</td><td>>0,25 up to 2,5</td><td>(sector between two bolts) × (gasket thickness) usually ≥ 1 mm</td></tr>
<tr><td colspan="2">**Flanges with spiral wound gasket, trapped joint flanges or similar**</td><td>0,025</td><td>0,25</td><td>(sector between two bolts) × (gasket thickness) usually ≥ 0,5 mm</td></tr>
<tr><td colspan="2">**Small bore connections up to 32 mm (a)**</td><td>≥0,025 up to 0,1</td><td>>0,1 up to 0,25</td><td>1,0</td></tr>
<tr><td rowspan="3">**Sealing elements on moving parts at low speed**</td><td rowspan="2">**Valve stem glands (d)**</td><td>**packed**</td><td>0,25</td><td>2,5</td><td>Not less than 2,5</td></tr>
<tr><td>**o-ring**</td><td>0,025</td><td>0,25</td><td>Not less than 0,25</td></tr>
<tr><td colspan="2">**Pressure relief valves (PRVs) (b)**</td><td>**0,1 x orifice section**</td><td>Not Applicable</td><td>Not Applicable</td></tr>
<tr><td>**Sealing elements on moving parts at high speed**</td><td colspan="2">**Pumps and compressors (c)**</td><td>≥0,25 up to 1</td><td>≥1 up to 5</td><td>Not less than 5</td></tr>
</table>

Notes:

(a) Hole cross sections suggested for flared joints, threaded connections, compression joints (e.g. metallic compression fittings) and rapid joints on small bore piping (EN378-2:2008 restricts flared joints to 20mm outside diameter, compression joints to DN32 maximum and taper threaded joints to instrument piping up to DN40).

(b) PRVs must be piped to atmosphere. At the point of discharge PRVs are normally zoned as secondary release points when fully open with a 1m Zone 1 to allow for fugitive emissions from a leaking valve seat. For further information refer to EI Model code of safe practice Part 15 [17]

(c) Compressors – These values relate to the shaft seal of an open drive compressor. The frame of compressor and the cylinder heads are usually not items that leak - various pipe connections on the compressor body may require further consideration due to high vibration.

(d) This includes motorised valves with an actuated spindle, hand-operated valves and jacking spindles on solenoid or expansion valves.

(e) In normal circumstances it is unlikely that an ammonia refrigerant leak will persist for long enough to cause erosion.

(f) A blow out is in normal circumstances highly unlikely for ammonia refrigeration systems unless there are particular circumstances which make it more probable, for example the age and condition of the plant, the particular design or method of operation or extreme adverse operating conditions.

(g) This type of joint should not normally be used in refrigeration systems.

These values are typical of the conditions found in industrial refrigeration and heat pump applications using ammonia. This table has been adapted from EN FDIS 60079-10-1:2015 Annex B Table B.1 and shaded boxes in the table represent circumstances which are considered to be not relevant to refrigeration systems.

Hazardous area classification requires detailed consideration to be given to each item of process equipment which contains flammable material (in this case ammonia), and which could therefore be the source of release.

In particular, Zone 1 areas should be minimised in number and extent by design or suitable operating procedures. In other words, ammonia refrigeration plants and installations should be designed to be mainly Zone 2 or non-hazardous. Where the potential release of ammonia is unavoidable, process equipment items should be limited to those which give secondary grade releases or, failing this (that is where a primary grade release is unavoidable), the releases should be of a very limited quantity and rate.

In carrying out area classification, these principles should receive prime consideration. Where necessary, the design and location of process equipment should ensure that, even when it is operating abnormally, the amount of ammonia released into the atmosphere is minimised, so as to reduce the extent of the hazardous area.

Once a plant has been classified and all necessary records made (IEC EN 60079-10-1 Annex C provides examples of area classifications and suggested document templates that can be used for data records), it is important that no modifications to equipment or operating procedures are made without discussion with the 'competent person' responsible for the area classification.

7 Worked Examples

The following diagram shows a typical ammonia refrigeration circuit.

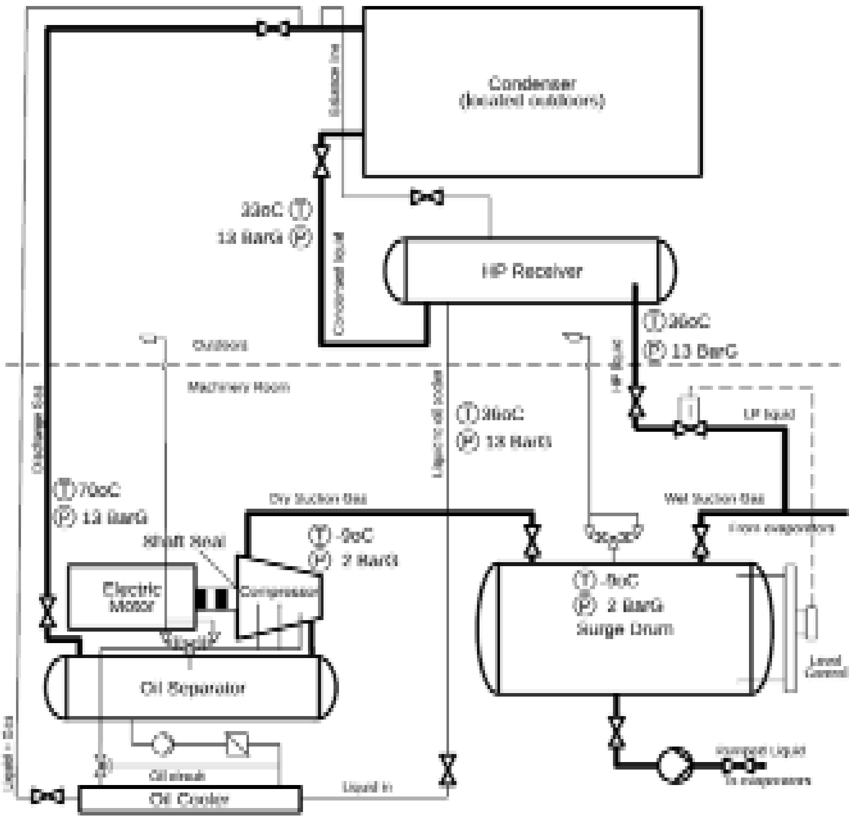

Figure 2 – Typical Ammonia Refrigeration Circuit

Assume that the assessment of the refrigeration plant has identified two 'worst case' scenarios – high pressure gas release through 1.00mm^2 hole and high pressure liquid release through a 0.25mm^2 hole. EN378-3:2008 states that ventilation of machinery rooms shall be sufficient both for normal operating conditions and emergencies. It goes on to say "Ventilation shall be in accordance with National regulations with a minimum of 4 air changes per hour when the machinery room is occupied."

In the following example 4 air changes per hour has been used as the starting point to calculate the hazardous zone based upon the above 'worst case' scenarios in three different machinery rooms with a net volume of 50, 150 and 400m^3.

Table 7 – Area classification assuming 4 air changes per hour

Gas Release	50m^3	150m^3	400m^3
V_z (m^3)	ERV	0.007	0.001
HR (m)	ERV	0.525	0.299
LEL (m)	0.519	0.149	0.121

Liquid Release	50m^3	150m^3	400m^3
V_z (m^3)	ERV	0.061	0.012
HR (m)	ERV	1.067	0.561
LEL (m)	1.345	0.282	0.257

It is evident from the above results that if the machinery room volume is 150 m^3 or more then the identified 'worst case' scenarios result in an area classification of Zone 2NE for both gas and liquid releases and in normal circumstances the zone could be treated as non-hazardous meaning no further action would be required. Caution should be exercised in the case of liquid release in the 150 m^3 enclosure to check that the assumptions are reasonable since the V_z volume is greater than 0.05 m^3.

If Zone 2NE status is to be achieved for the smallest machinery room then the minimum ventilation rate would need to be increased during normal operating conditions. Increasing ventilation rates to 10, 11, or 12 air changes per hour would result in a V_z of 0.153, 0.089 and 0.061 respectively. At least 12 air changes per hour should therefore be provided during normal operation.

Increasing the ventilation rate while the plant is running is not an issue, indeed in normal circumstances it is an advantage because it assists in keeping the machinery room at an acceptable temperature. Higher rates of ventilation can cause problems when the plant is not operational for any length of time. However, the minimum of 4 air changes per hour required by EN378 is conditional upon the room being occupied and not on the plant being operational.

It is also necessary to check the area classification for the plant when it is shut-down for periods of time such as holiday periods. However, in that event it is reasonable to use a smaller hole size as operating condition is less severe and a lower pressure because the pressure within the refrigeration system will equalise at the equivalent of the ambient temperature.

Therefore, in the case outlined provided the entire refrigeration system has been shut-down and the pressure within the plant has reduced to a maximum of 3 barg a 0.50mm^2 hole size for the gas release and a 0.025mm^2 hole size for the liquid release could be considered resulting in the following results with a lower ventilation rate of 2 air changes per hour.

Table 8 – Area classification assuming 2 air changes per hour

Gas Release	50m^3	150m^3	400m^3
V_z (m^3)	≤ 0.001	≤ 0.001	≤ 0.001
HR (m)	0.200	0.118	0.105
LEL (m)	0.060	0.049	0.047

Liquid Release	50m^3	150m^3	400m^3
V_z (m^3)	≤ 0.001	≤ 0.001	≤ 0.001
HR (m)	0.119	0.109	0.106
LEL (m)	0.065	0.064	0.064

Therefore provided the higher ventilation rate is maintained until the pressure within the refrigeration system has equalised Zone 2NE area classifications are achievable for all three enclosure sizes.

In addition to assessing the machinery room similar calculations need to be carried out in all places where refrigeration equipment is located using the same principles set out above.

Normally, outside locations are not critical but should nevertheless be assessed. Typically, high pressure gas and liquid releases outdoors result in a V_z of ≤ 0.002 and ≤ 0.060 respectively and can therefore be classified Zone 2NE. It is acknowledged in EN378 and by HSE that it is virtually impossible to ignite ammonia outdoors.

8 Technical challenges

There may be circumstances where it is necessary to consider larger holes than those indicated in Table 6, for example if the atmosphere around the plant is particularly corrosive (coastal or in an aggressive chemical environment) or if the plant is subjected to particularly heavy vibration. In such cases it may be appropriate to increase the hole area by up to a factor of 10. It does not make sense to base the calculation on much larger sizes than this because the factor of safety that this creates is excessive and will result in much more stringent precautions than necessary being taken.

As mentioned earlier the key to ensuring that hazardous zones do not exceed the limits of negligible extent is to provide sufficient background ventilation at all times. This is relatively easy when the system is in operation since the heat emitted by the compression process and the heat resulting from motor winding losses need to be removed anyway. Problems can be foreseen however if the plant is switched off for a prolonged period and the outside temperature is extremely low. A typical scenario would be during a Christmas shutdown with cold weather outside. In this case ventilating the machinery room at a high enough rate to ensure small zone volumes might cause other problems. For example the cooling effect of the air flow might exceed the capacity of the crankcase or oil separator heaters, causing ammonia to condense in the low lying parts of the system and resulting in mechanical damage when the plant is restarted. Permanent background ventilation may also bring a significant amount of dirt into the machinery room, particularly if it is located directly above the loading dock where trucks may stand for hours with their engines idling. It is appropriate in considering possible leaks during periods of downtime to base the calculation on a smaller hole size and lower pressure than would be experienced during normal running, and this may lead to a lower level of background ventilation for downtime than is required during normal operation. However it is not possible to have a zone of negligible extent if there is no ventilation at all.

It is also necessary to ensure that the ventilation as installed is effective and that the maintenance regime includes checks to ensure that it remains effective. This includes checks that the inlet and outlet louvers and ducts are not blocked and that the fans are operable. The same process is required for all parts of the site which have equipment containing ammonia. However a location which only contains permanent joints and where the equipment is adequately protected against mechanical damage, for example inside a cold store or blast freezer, would not require further consideration. Areas outside the building, where it is recognised that ammonia is extremely difficult to ignite (as noted in BS EN 60079-10-1:2009 clause 5.4.2) are considered non-hazardous with the exception of the area within 1m in all directions of the relief valve outlets which should be classed as Zone 1. Areas inside the building but not in the machinery room and not in the cold store or blast freezer, for example roof voids containing valve stations, should be assessed in the same way as the machinery room. The level of background ventilation required to ensure that the hazardous volume is of negligible extent should be calculated and extract ventilation which ensures sufficient air volume in the vicinity of the potential leak points, for example using an extract hood, should be fitted in the vicinity of each valve station. It is probably more sensible to provide small ventilation fans local to each valve station rather than attempting to ensure a sufficient air change rate throughout the entire roof void but each installation will require to be assessed for any specific considerations that may apply.

If the pipework feeding an evaporator is known to be subjected to hydraulic shock (internal knocking) during normal operation or defrost then it should be treated as being prone to mechanical damage and assessed accordingly. The most cost effective solution is likely to be finding a way to eliminate the shock, for example by using soft-acting solenoid valves or small flow bleed valves prior to applying the main hot gas pressure to the evaporator. If the shock cannot be eliminated then it will be necessary to treat the entire area surrounding the evaporator and the valve station (both inside and outside the refrigerated space) as a hazardous area. It will not be possible to manage this size of release through ventilation.

In addition to ensuring compliance with DSEAR by following the assessment procedures outlined above it is also necessary to remember the general duty of care contained in the Health and Safety at Work Act. This may require consideration of leakage scenarios that go beyond those described by BS EN 60079 and in particular it is very important to consider the effects of the toxicity of ammonia with regard to employees working on the site and neighbours.

9 Conclusions

Ammonia refrigeration systems are subject to DSEAR which require that where explosive atmospheres may occur plants are assessed, potential risks are identified, and areas of the workplace are classified. EN378 focusses on machinery rooms with regard to flammability considerations for ammonia plant and so does not fully address the parts of the system that are not in the machinery room. Conversely DSEAR only requires that hazards which could arise in normal operation are considered whereas EN378 (and indeed other health and safety legislation) also requires the effect of extreme conditions, for example the foreseeable effects of vandalism or other misuse of the equipment, to be considered.

Therefore to ensure safety it is necessary to satisfy the requirements of both the regulation and the standard. While this is a necessary response to increasing legislation, it should not be seen as a burden but rather as an opportunity to ensure compliance with sensible modern requirements based on the latest understanding of the relevant factors.

For new ammonia refrigeration systems making sure that the requirements of DSEAR are integrated at an early stage into the design phase of a project should lead to better plant layouts and machinery rooms that are cost-effective (possibly 'no-cost') and fully compliant.

For existing ammonia refrigeration systems there may be some greater obstacles to overcome particularly where machinery rooms are extremely small or poorly ventilated. However even in the majority of these cases following the guidance provides owners with a useful method of prioritising their capital spend on those improvements that are essential and will bring real benefit to the system without introducing additional difficulties.

10 Acknowledgement

The authors of this paper are the representatives of FSDF (Young) and IoR (Pearson) on the HSE's 'Joint Industry Project' on the compliance of ammonia refrigeration systems with DSEAR. This paper and the work it has described are an integral part of the JIP. In this regard the authors wish to recognise in particular the contributions and advice of Mat Ivings, Head of Fluid Dynamics Team (Mathematical Sciences Unit) at HSL and his colleagues Simon Coldrick and Roger Santon along with Margaret Gregson from HSE. The contents of this paper, including any opinions and conclusions expressed, are those of the authors alone and do not necessarily reflect the FSDF's and IoR's position, nor do they reflect the HSE's policy and enforcement strategy.

About the Authors

Maurice Young has been involved in Supply Chain and Logistics for more than 30 years. As Senior Vice President of the world's largest food service company he was responsible for the design, construction, and maintenance of the company's temperature controlled warehouses at more than 100 logistics centres throughout Europe and the United States. Maurice starting his own consultancy practice in 2000 and has contributed to the development of numerous codes of practice and technical standards. He is a Director of the Food Storage and Distribution Federation and a member of the Federation's Technical and Safety Committee.

Andy Pearson is a Past President of the Institute of Refrigeration and the Chairman of the Technical Committee. He is a Fellow of the IOR, of the Institution of Mechanical Engineers and of ASHRAE and a Member of the International Institute of Ammonia Refrigeration. He holds a BSc (Hons) in Manufacturing Science BEng (Hons) in Engineering and a PhD in Mechanical Engineering and is a Chartered Engineer. Andy is chairman of the Refrigeration Safety Technical Committees for the British Standards Institute (BSI), and a member of the European Committee for Standardisation (CEN) and the International Standards Organisation (ISO). He is currently Group Engineering Director: Star Refrigeration Ltd.

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Discussion report

David Bostock noted that this research and paper was focused on ammonia refrigerant, but asked whether the same could be applied to any A2 or A3 group refrigerant?

Andy Pearson responded that in general terms the same philosophy would apply but the lower flammability level figures are different so the tables contained in the paper would not apply and the calculations would need to be re-done for the refrigerant in question.

Andrew Gigiel asked where the authors' estimate of hole sizes came from?

Andy Pearson replied that the hole sizes were originally published in IGEM25 for gas systems and the authors considered the similarities and differences with ammonia systems. For the type of releases covered by DSEAR these sizes were felt to be conservative.

Andrew Gigiel commented that holes might be found in permanent joints but not identified by leak testing. He asked would these also be covered by the DSEAR regulation requirements?

Andy Pearson replied that this type of leak is not covered by DSEAR because such a hole would be so small, in practice, that there would be no prospect of the leakage resulting in a zone larger than $0.1m^3$ if there is any ventilation at all.