Industrial Refrigeration - Refrigerants

**Ammonia Facts**
- Natural refrigerant
- GWP=0
- ODP=0
- Environmentally friendly
- High efficiency
- Low Cost
- Widely available
- Self-alarming – by odour

Ammonia is the dominant refrigerant in industrial systems.

**Specific design requirements needed**, due to ammonia’s classification as toxic and flammable fluid.
Analyses of Ammonia refrigeration accidents

The analyses is divided into 3 groups:

- ”Installed base” in Europe and USA
- ”Installed base” in Emerging Markets (China, India,.....)
- ”NEW installations” designed acc. ”state of the art”
Installed base in Europe and USA
Analyses of Ammonia refrigeration accidents in Germany 1993 - 2013

- The statistical cover installations requiring hazardous approval (threshold quantity of ≥ 50 tons of dangerous substances).
- Ammonia systems with more than 3 tons of ammonia installed in facilities with other dangerous substances are included in this statistic.

- 29 reportable events in the period from 1993 to 2013
  - NO deaths occur
    - 54 people inside the plant exposed to ammonia (15 evacuated)
    - 51 people outside the plant exposed to ammonia (12 evacuated)
    - More than 1130 people complained about odors.
  - NO explosion / fire caused by ammonia, has been reported
    - 59% of the events took place in the machinery rooms
    - 28% of incidents during maintenance and repair work
    - 28% were foreign companies involved.

Source: TRAS 110 Sicherheitstechnische Anforderungen an Ammoniak-Kältanlagen Nov. 2014
Analyses of Ammonia refrigeration accidents in Germany 1993 - 2013

Source: TRAS 110 Sicherheitstechnische Anforderungen an Ammoniak-Kälteanlagen Nov. 2014
# Reported ammonia incidents United Kingdom 1992-1998

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigeration</td>
<td>21</td>
<td>6</td>
<td>10</td>
<td>11</td>
<td>8</td>
<td>13</td>
<td>4</td>
<td>73</td>
</tr>
<tr>
<td>Process</td>
<td>6</td>
<td>3</td>
<td>7</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>Transport</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
<td>18</td>
<td>26</td>
<td>23</td>
<td>13</td>
<td>21</td>
<td>6</td>
<td>139</td>
</tr>
</tbody>
</table>

Total 139 incidents reported over 7 years
- Many resulted in injury and ammonia exposure
- **NO** explosions
- **NO** deaths occur

Ammonia Incidents Reasons for Release
Release source (1994-2013) RMP-database (US EPA)

1,253 Total Releases

Ammonia Incidents  Reasons for Release
Incident Injuries and Fatalities  (1994-2013) RMP-database (US EPA)

Incident Injuries

Worker Injuries | Responder Injuries | Public Injuries |
----------------|-------------------|-----------------|
1,369           | 11                | 84              |

Incident Fatalities

Worker Deaths* | Responder Deaths | Public Deaths |
----------------|------------------|---------------|
16              | 1                | 1             |

Installed base in Emerging Markets (China, India,..)
# Review of ammonia plant accident in China

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
<th>Casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013/06/03</td>
<td>Electricity ignite the flammable materials around. The fire cause high</td>
<td>121 died, 77 hurt</td>
</tr>
<tr>
<td></td>
<td>temperature and make physical explosion of ammonia equipment and piping.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Then ammonia leak out and burn together with the existed fire.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Fire, explosion and leakage).</td>
<td></td>
</tr>
<tr>
<td>2013/08/31</td>
<td>Manual hot gas defrost with wrong process and the welding of piping is</td>
<td>15 died, 7 serious injury and 18 hurt</td>
</tr>
<tr>
<td></td>
<td>low quality and with defect caused the piping end broken under long time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>operation in low temperature with low stress. Then ammonia leak out.</td>
<td></td>
</tr>
<tr>
<td>2013-11-28</td>
<td>Ammonia leakage in a food company</td>
<td>7 died, 6 hurt</td>
</tr>
<tr>
<td>2014-11-16</td>
<td>Fire accident in a food company (Cable in air cooler is shortcut and ignite</td>
<td>18 died, 13 hurt</td>
</tr>
<tr>
<td></td>
<td>the insulation on the wall)</td>
<td></td>
</tr>
</tbody>
</table>

Source: Analysis of Ammonia Accidents Recently Happened in China, GL2014-Hangzhou + Danfoss China
Some common root cause for major incidents on ammonia systems

Operation

- System exceed max limit (e.g. trapped liquid)
  - Due to lack competence (do not understand the system)
  - Due to incorrect procedure or procedure not followed
  - Lack of maintenance

- Hydraulic shocks ("liquid hammer")
  - Due to incorrect operation
  - Due to bad design of system
  - Lack of maintenance

- Failure of equipment
  - Due to incorrect operation
  - Due to bad design of equipment
  - Lack of maintenance
Effect of liquid hammer

Rupture in welding

Rupture of base material
## Importance of correct material properties

<table>
<thead>
<tr>
<th></th>
<th>Brittle material</th>
<th>Ductile material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure peaks due to &quot;Liquid Hammer&quot;</td>
<td><img src="pressure.png" alt="Pressure Peaks" /></td>
<td><img src="pressure.png" alt="Pressure Peaks" /></td>
</tr>
<tr>
<td>Impact Strength</td>
<td>1-5 Joule</td>
<td>≥ 27 Joule</td>
</tr>
<tr>
<td>Ability to withstand pressure peaks</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Effect of &quot;Liquid Hammer&quot; Brittle vs. Ductile materials</td>
<td><img src="rupture.png" alt="Rupture" /></td>
<td>NO Rupture</td>
</tr>
</tbody>
</table>

**International standards requires ductile materials for ammonia installations**

- Brittle material:
  - Low impact strength
  - High pressure sensitivity

- Ductile material:
  - High impact strength
  - Low pressure sensitivity

International standards require ductile materials for ammonia installations.
Some common root cause for major incidents on ammonia systems

Maintenance
- During service work on system
  - Due to lack competence (do not understand the system)
  - Due to incorrect procedure or procedure not followed
- Oil draining
  - Due to bad oil-drain method
  - Due to incorrect procedure or procedure not followed
  - Lack of maintenance

Education and training
- All people involved in operation of ammonia installation need to be trained
  - Conduct training
  - Evaluate competence level
  - Due to incorrect procedure or procedure not followed
Safe oil drain

Oil drain is often reported to be responsible for significant ammonia releases.

Safe oil drain method

- The 2 additional shutoff valve ensure that the “worst case release scenario” for draining oil are limit to be less or equal to the collector size.
- Without the shutoff valves; the “worst case release scenario” for draining oil are limit to be less or equal to the receiver size.
- The shown method is also safe when draining oil at higher pressure.
“Installed base” in Emerging Markets

Observations

- Several installations are manually controlled - Automatic control reduce risk of human error.
- Safety equipment need to be prober installed and maintained
Typical refrigerant charge

Ammonia charge in large industrial refrigeration systems

<table>
<thead>
<tr>
<th></th>
<th>Estimated Refrigerant Charge [kg ammonia / kW cooling capacity]</th>
</tr>
</thead>
<tbody>
<tr>
<td>China Ceiling coils</td>
<td>30</td>
</tr>
<tr>
<td>(Bunker coils) Installed base</td>
<td></td>
</tr>
<tr>
<td>Europe Recirculating systems Installed base</td>
<td>20</td>
</tr>
<tr>
<td>Europe Recirculating systems 2014</td>
<td>15</td>
</tr>
<tr>
<td>Ammonia DX</td>
<td>5</td>
</tr>
<tr>
<td>Ammonia / CO2</td>
<td>2</td>
</tr>
<tr>
<td>Super Low Charge Ammonia systems</td>
<td>1</td>
</tr>
</tbody>
</table>
Refrigerant charge

**Example: Cold Store 2300 kW** - (China 2014)

Ammonia Ceiling Coil system ⇔ Ammonia DX system with Aluminum Air Coolers

<table>
<thead>
<tr>
<th>Type of evaporators</th>
<th>Ammonia charge (kg)</th>
<th>Ammonia charge (kg /kW)</th>
<th>Charge reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U bend ceiling coil (OD,38mm; ID, 32mm)</td>
<td>59869</td>
<td>26</td>
<td>94%</td>
</tr>
<tr>
<td>Aluminum DX Air coolers</td>
<td>3680</td>
<td>1.6</td>
<td></td>
</tr>
</tbody>
</table>

*Capacity, 50,000 pallets with recirculation system, room temperature, -18°C*
NEW installations designed - ”state of the art”
“State of the art” ammonia refrigeration system

A Raw materials
- Castings requirements
- Welding requirements, Etc.

B Components
- Components design / requirements
- Valves
- Safety valves
- Vessels
- Compressors

C System design
- System requirements
- System design
- Safety requirements

D Management (operation)
- Instructions / training
- Maintenance
- Safety
- Risk assessment

E Off site safety
- Safety distance

Europe
- Legal requirements
- Harmon. standards
- EN 378
- EN-Product standard:
  - EN 12284
  - EN 13136
  - ...

USA
- ANSI IIAR 2
- ASTM Product standard:
  - ASME Section VIII, Division
  - ..... ...

Global Guidelines
- PSM (Process Safety Management)
- IIAR Guidelines
- ISO 5149
“State of the art” ammonia refrigeration system

**Cooperation**

Government

Individuals

Designers

Employers

**System**

- Full fills all “state of the art” ammonia guidelines
- Fully automated with performance monitoring
- Fully welded system
- Build with reliable and effective components
- Component performance based on fact based calculations
- “Low” refrigerant charge
- High COP-value
- System solution based on Total Cost of Ownership

**Operation**

- Up-to-date operation and system documentation
- Competent and trained system operators
- Risk assessment
- Preventive Maintenance
# Offsite risk assessment

<table>
<thead>
<tr>
<th>Frequency classification</th>
<th>Frequency per year</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undesired event</td>
<td></td>
<td>Minor material damage</td>
</tr>
<tr>
<td>Minor accident</td>
<td></td>
<td>Minor occupational injuries onsite</td>
</tr>
<tr>
<td>Serious accident</td>
<td></td>
<td>Serious occupational injuries onsite</td>
</tr>
<tr>
<td>Major accident</td>
<td></td>
<td>Fatalities on site, injuries to people onsite</td>
</tr>
<tr>
<td>Disaster</td>
<td></td>
<td>Fatalities on and offsite</td>
</tr>
</tbody>
</table>

- **Frequent**: Will happen several times during lifetime of installation
  - Frequency: $>1.0E-02$

- **Likely**: Will probably, but necessarily happen
  - Frequency: $1.0E-02$ to $1.0E-04$

- **Not likely**: Could possible happen
  - Frequency: $1.0E-04$ to $1.0E-06$

- **Very unlikely**: Almost unthinkable
  - Frequency: $1.0E-06$ to $1.0E-08$

- **Extremely unlikely**: Frequency below reasonable limit
  - Frequency: $<1.0E-08$

---

**High risk**

- Reduce impact
- Reduce frequency

**Low risk**
Examples of offsite risk assessment

Reduce frequency (probability)
- Ensure “State of the art” design are implemented.
- Ensure proper management of the system.
  - Education
  - Training
  - System documentation
  - Maintenance
  - Etc.
- Increase safety level of system

Reduce impact
- Reduce charge that potentially can release, in the event of a major accident (e.g. by subsegmentation of the system)
- Reduce charge that potentially can release, in the event of a major accident (e.g. installing quick closing valves)
## Offsite risk assessment

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<tr>
<td>Disaster</td>
<td></td>
<td>Fatalities on and offsite</td>
</tr>
</tbody>
</table>

### Frequency classification

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Frequency Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent</td>
<td>Will happen several times during lifetime of installation</td>
<td>&gt;1.0E-02</td>
</tr>
<tr>
<td>Likely</td>
<td>Will probably, but necessarily happen</td>
<td>1.0E-02 to 1.0E-04</td>
</tr>
<tr>
<td>Not likely</td>
<td>Could possible happen</td>
<td>1.0E-04 to 1.0E-06</td>
</tr>
<tr>
<td>Very unlikely</td>
<td>Almost unthinkable</td>
<td>1.0E-06 to 1.0E-08</td>
</tr>
<tr>
<td>Extremely unlikely</td>
<td>Frequency below reasonable limit</td>
<td>&lt;1.0E-08</td>
</tr>
</tbody>
</table>
Safety barriers in ammonia systems

Initiating event

Preventive barrier
- “Safe” system design, build-in safety barriers preventing accidents (based on documented reliability data)

Mitigation barrier
- Safety barrier minimizing the effect of possible accidents (based on documented reliability data)

Mitigated (reduced) release

"Organizational" barrier
- Operation instructions (SOP)
- Safety procedures describing safety requirements
- Maintenance procedures
- Competence & educations programs

Unmitigated release

Reduced effect (leak) of possible accidents. (unchanged failure frequency)

Failure frequency (quantified risk assessment)

Reduced failure frequency (based on documented reliability data for mitigation barrier)

Mitigation barrier

Mitigated (reduced) release

Refrigent release

Unmitigated release
Super low charged ammonia system for cold storages
New upcoming trend in USA

Mitigating risks
Though not entirely new, advancements in evaporator design and liquid feed control open the door to NH3 systems offering
- Roof-top based design
- “VLC” very low NH3 charge
- **Claimed to have up to 98% less ammonia** than regular systems (lowest charge < 100 g / kW)
- Fully automated self-contained NH3 system
- Very fast installation

Multiple self-contained “penthouse units” with very low ammonia charge
Benefits with low charge factory build systems

**Recognized Safety benefits with low charge**

- Inherently Safer Technology
- Lower Regular Burdon
- Reduced off-site consequences
- Strong Complaisance with codes and standards
- Strong Quality control and testing
- Reduce liability & exposure to fines
- Great training
- Makes training easier

**Easy documentation**

<table>
<thead>
<tr>
<th>Safety documentation</th>
<th>Unit supplier</th>
<th>System owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refrigeration system documentation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hazard Review</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation and Maintenance Procedures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td></td>
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<tr>
<td>Self audit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident investigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contractors</td>
<td></td>
<td></td>
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<tr>
<td>Emergency Action and / or Responce program</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hazard Assesment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Managing Changes</td>
<td></td>
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</tr>
</tbody>
</table>
Conclusion

• Safe and reliable ammonia systems are based on well designed systems, reliable products, up-to-date operation, competent and trained system operators including risk assessment and preventive maintenance and system documentation.

• Present International design and application standards support “state of the art” ammonia systems.

• The “installed base” of ammonia systems are however not all at high safety level, in particular not in the Emerging Markets, where accidents with severe impact underline the need for:
  - Implementation of “state of the art” design and application standards.
  - Improvement of operation and system documentation, competence and fully implemented risk assessment.