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Ammonia Safety by Design and Maintenance
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In recent years, awareness about safety has increased for many reasons. This led to a lot of discussions on how to increase safety. It all starts with design followed by good practice during installation followed by careful maintenance. There are obligations to be understood by the contractor but also by the user and owner of the system. Standards do not always fully meet all requirements and you can say that just fulfilling what standards and laws say is not always good enough.

I. INTRODUCTION

In some countries, the use of ammonia is more widespread than in others. Concerns about global warming and energy prices have led to a growing interest in the efficient refrigerant. In companies with no experience with ammonia there is great resistance to the use of ammonia. In some cases it is related to some kind of myth or stories about accidents with ammonia where someone has been injured. In many cases if you look deeper into the story it turns out to be made a bit more colorful and interesting than it actually was originally. It almost works like the fairytales from our childhood and the story about the feather that became 10 chickens. In fact more people have been killed by R22 than by ammonia according to an investigation made by Professor Gustav Lorentzen and Helge Lunde in Norway many years ago. What is often forgotten is that under certain conditions both R22 and HFC refrigerants can become flammable and cause accidents. The intention of this paper is not to discuss what is best but to try to show how steps can be taken to improve safety around refrigeration plants, with a focus primarily on ammonia plants. However, many of the considerations also apply to good practice when using all other types of refrigerants.

II. NEW POSSIBILITIES

In the light of the phase-out of R22, in the coming years there is an opening for greater use of ammonia.

![Figure 1. Some data for a given compressor under the same operating conditions (-10/+35°C)](image-url)
The main obstacle to use of ammonia (NH\textsubscript{3}/R717) as a retrofit refrigerant in existing R22 plants is that many components in R22 plants are not compatible with NH\textsubscript{3}. The efficiency is good, as shown in Figure 1, and the capacity is close to that of many alternatives. The same figure shows that R22 is actually a relatively good refrigerant from capacity and efficiency perspectives. The problem with R22 and other HCFC types is the ozone-depleting potential which is covered by the Montreal Protocol and the subsequent phase-out over the coming years.

**Figure 2.** Many alternatives have a higher GWP than R22. The best in this comparison are the natural refrigerants

Global warming is now focusing on the high impact of man-made greenhouse gases. It seems to be a bad idea to replace a gas with a relatively moderate impact on global warming with gases with a very high global warming impact. As shown in Figure 2, only the blend R407C and R134a look relatively good, but here also the natural refrigerants look very good.

What are the main obstacles to more widespread use of natural refrigerants when they look safe to the environment? In many cases ignorance will be the answer. Bad experience and poor knowledge of real facts is one explanation. Also, cost plays a big role. The first cost for R717 systems is in some cases higher than the alternatives and for many customers first cost forms the basis for decision, whether it is relevant or not.

New computer tools can perhaps in some cases deliver some hope for alternative solutions when cost is an issue. The increasing cost of energy should also change the way the choice of a refrigeration system has to be made. Accepted payback times are often very short. Three years tends to be a maximum for many plants with a life expectancy of 10 years.

**Figure 3.** An example comparing a R404A (system 1) with a R717 (system 2) under Mediterranean conditions. The refrigeration capacity of R717 is slightly higher than the capacity of the R404A system because the calculation is using specific compressors. Even then it uses less power.
Figure 4. Even with a higher first cost of 17% there is a payback time of just 3.1 years (R404A $Q_0 = 302.7 \text{ kW}$, R717 $Q_0 = 335.2 \text{ kW}$)

However, 10 years is very short for an industrial plant where systems are expected to stay in operation for 20+ years. Figure 4 and 5 show the output of the cost comparison for the two systems with a fictitious price and the accumulated cost over 10 and 20 years. It is not sustainable just to look at first cost. A first-cost approach can be regarded as bad management.

Figure 5. In the example given, the payback period is about 3 years and the rest of the time it is money in the bank. For many commercial type systems, the service cost increases after 10 years.

III. THE SAFETY ASPECT

Of course, the safety issue is a valid point in the respect that the persons working with the plant need training in order to work with the new refrigerant. With proper training and the right respect for the refrigerant, and provided that the design of the plant/system, the installation and the maintenance is done properly, there is no increased risk associated with the use of ammonia or any other natural refrigerants including hydrocarbon refrigerants.

The first thing to do in order to increase safety is to reduce the charge. For some types of applications this can be done by using an indirect refrigerant. This secondary refrigerant can be either a one-phase refrigerant such as glycol or it can be a two-phase refrigerant such as CO$_2$.

The most important characteristic of ammonia is the natural smell and the immediate impact it has on the body, especially parts of the body with some moisture. It provides safety in that most people will react to the smell at levels long before the toxicity even becomes a problem and most persons have run away if they can.

A good example of a large-capacity chiller installed with ammonia as refrigerant can be mentioned: the chiller in the new Terminal 5 at Heathrow International Airport. The capacity is about 26.4 MW based on large ammonia screws. Each chiller has a capacity of 6.6 MW and there are 4 units in total.

To avoid releases of large amounts of ammonia from the plant room, an air scrubber that can prevent ammonia from leaving the room can be added to the ventilation systems. One litre of water can absorb about 700 litres of ammonia gas and with the very high affinity ammonia has for water, washing the ammonia out of the exhaust air leaving the plant room is not a problem. In principle, it should be similarly easy to ensure that other refrigerants are also bound to water to some extent. CO$_2$ as an example is also absorbed by water, although not to the same extent as ammonia.

For many applications, a chiller will do. Using the newest heat exchanger technology can help reduce the installed charge to an absolute minimum. With shell and plate technology, it has been possible to reduce the charge to an...
absolute minimum. A comparison of the small-size chillers and their refrigerant charge with what has been obtained in the larger systems is shown in Figure 7. It is very clear that some reductions have become possible.

**Figure 6.** A chiller using a low ammonia charge

<table>
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<tr>
<th>Small chillers</th>
<th>Recip chiller</th>
<th>Screw chiller</th>
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| 690           | 29           |              |              |              |              |
| 715           | 30           |              |              |              |              |
| 878           | 36           |              |              |              |              |
| 921           | 37           |              |              |              |              |
| 1066          | 41           |              |              |              |              |
| 1167          | 45           |              |              |              |              |
| 1398          | 49           |              |              |              |              |

**Figure 7.** Charge compared for different systems. The small-capacity chillers are not using shell-and-plate heat exchangers

**Figure 8.** Higher capacity per kg ammonia is obtained as capacities increase
The next thing to look at when the charge has been minimized is to ensure that the valves are placed in an easily accessible manner. If the valves are too difficult to reach, this can be a source of accidents when incidents occur, because the service technician cannot get out fast enough or the refrigerator may even blow straight into his face. This is valid for all refrigerants but can cause more problems with some refrigerants than others.

Relief valves have to be placed in such a way as to make it possible to connect them to a discharge system to the ambient. It is not acceptable for any refrigeration system to have the relief valves that do not discharge outside the plant room because some refrigerants can cause a lack of oxygen and have caused the death of technicians working in the room. In the case of ammonia, the gas will be observed by most persons but they cannot see because they are blinded by water forming in the eyes and the situation can become more dangerous than need be.

Relief valves have to be checked and tested using a calibrated bench to verify that they can open and that they open at the designed pressure. Therefore, they have to be installed in a manner in which they can be safely and easily changed without danger of accidents.

Insulation has its own challenges. If the vessels and pipes are not properly treated before insulation, there is a risk that after a few years, water will start to corrode the pipes and in the end can cause a burst that in turn can cause a fatal accident. It has happened that pipes have corroded and broken suddenly after 30 years. Many people in the industry think that when vessels and pipes are insulated with foam and aluminium cladding, nothing can happen. That is not the case. Water will over time find its way through even the smallest openings and little by little come in behind the insulation and start the corrosion process. It is estimated that good insulation has a lifetime of about 20 years. It is important to ensure that the insulation is checked regularly for any damage, especially around valves and other openings as they are the main sources of breakage of the diffusion barrier.

Corrosion is one of the main reasons underlying accidents in ammonia plants and has to be taken seriously. An inspection of the surface of vessels and pipes has to be made on a regular basis. It is expensive but if it is allowed for as a part of the running cost and if the plant is inspected on a regular basis with infrared thermographic camera, this is an efficient way to see if there are changes in the insulation or the surface temperature.

Pipes and vessels must be properly coated before insulation takes place. Normally this is done by painting. There are different traditions from country to country regarding the number of layers of paint the pipes are given and how much of the pipework is actually painted. Under all circumstances the pipes also have to be treated with some grease or oil if the insulation is done by foaming with PUR or similar. The pipes have to be able to contract or elongate depending on the temperature changes. Otherwise the insulation will suffer when the pipes contract for example. The foam does not contract in the same way and in this case will cause damage to the structure of the foam. This will allow water to enter the insulation and then the process can go really fast. Some types of insulation are not always compatible with the metals insulated and care must be taken when selecting the insulation.

When designing a system you should always keep in mind to not lock up the refrigerant. The hydrostatic pressure will break any pipe if liquid between two valves and the temperature in the liquid is allowed to rise. For many low-temperature systems, the liquid in some parts can be far lower than the ambient. In some cases you are saved by the valves because solenoid valves in most cases are not tight if the pressure moves the wrong way back upstream. If the valves are shut-off valves in both ends of a line you have to use a check valve that ensures that the pressure can be relieved upstream.

Also, access to valves is important especially if they are installed for a purpose; otherwise, don’t install them. Often, valves are installed in order to make it possible to change evaporators. Consider where the valves are installed and if they can be serviced so they also work the day you really need them. Valves should preferably isolate the stem when fully open to prevent an open valve to start leaking after some years in the open position. Caps on valves should preferably be capped.

Labelling of pipes and identification of valves in accordance with P & I diagrams should always be available on site in updated versions in case something happens. This is in fact very often ignored on many sites. In some cases it is not done because no-one takes the responsibility for doing so. In other cases it is because the company that does the servicing cannot update the drawings due to a lack of competence. It is in the interests of the owner to maintain good-quality documentation in case something happens. The other advantage the owner has is if the normal servicing company should not be able to carry out servicing, a new contractor stands a better chance of getting a quick overview of the plant. In the case of expansion, it is also good to have the existing plant documentation available for documentation of the design and for completing commissioning according to the standards.

All gases except fresh air are dangerous. A survey done by Gustav Lorentzen and Helge Lunde years ago showed that more people had been killed by R22 than by ammonia. This is often due to the fact most plants using synthetic refrigerants are not properly monitored by detectors. Detectors should be used regardless of the refrigerant in all occupied areas, where the release of the charge could produce a concentration that is dangerous. In many countries, it is mandatory to have detectors in rooms cooled with ammonia while nothing is required for other refrigerants. In some countries, additional exhaust in the event of a leak from the room is required.

Pipe cleanliness or system cleanliness is a major issue. In small systems and commercial systems, historically this has been taken more seriously than in industrial installations using NH₃ as refrigerant. However, this is changing, especially after CO₂ came in to the picture, and has raised the awareness of the issue. In industrial plants, previously it was fairly common to use cutting tools such as angle cutters and angle grinders. This produces a lot of powder that is spread into the system and then carried around. These are bad habits that should be dealt with.
Pipes and fittings must fulfill the requirements given in standards and regulations covering pressurized equipment. When purchased, it must also be specified that the deliveries are to be used in refrigeration systems and therefore are expected to be clean and capped. Steel pipes must be the drawn type and if that is not possible they have to be cleaned and capped before delivery. In some cases, stainless steel is used and raises fewer problems with cleanliness. However, stainless steel equipment should be delivered capped and dry.

Welding must only be done by certified and specially qualified people. This is already required by some standards and is now coming with the implementation of new rules covering the qualifications of service personnel working with refrigeration installations. Within the EU, this topic is covered by PED and EN 378:2008 1-4. The owner/the body who specifies should claim the right in the specifications to select which welding is to be taken out for inspection. Alternatively, a third party can be appointed to do so.

IV. PUBLIC AWARENESS

Global production of ammonia is huge and contributes to about 7 to 11% of global warming through production from natural gas and coal. Ammonia is also produced by animals and is therefore considered to be a natural substance. When an accident happens with ammonia, regardless of the industry, it also affects the view people have of ammonia in all industries. Considering that production was between 127 and 154 million metric tons in 2007\(^1\) there is a lot of ammonia around. About 80% is used in the fertilizer industry but some is also used in the plastics industry and many other places. No more than 40 000 tons are used as refrigerant, so the refrigeration industry is affected when other industries have an accident. However, the number of accidents per year has been falling, although one hears about accidents from time to time. The number of accidents in the refrigeration industry has to become lower if we don’t want more stricter regulations applied to our trade.

V. CONCLUSION

By fulfilling simple rules and by reducing charges it is possible to make it safe to work with ammonia. Many rules of thumb are applicable not only for ammonia but also for other refrigerants. However, it is not enough to fulfill the requirements as described in standards and regulations. Common sense and good practice also have to be used although such practice can be hard to describe.

In order to achieve a more widespread use of ammonia, it is important to ensure that no accidents happen and that no leaks can become front page headlines in the newspapers. Therefore, it is important that the contractor and the owner remain aware of what it takes to install and maintain a safe NH\(_3\) plant. Also, the owner has a responsibility to get the servicing and maintenance done by qualified staff and not just the cheapest cowboy around the corner. This is not in the long-term interests of the refrigeration industry or the plant owner or the service technicians doing the job. Ultimately, someone can pay the highest price, and that can be innocent people.

REFERENCE

1. The International Fertilizer Industry Association (IFA), http://www.fertilizer.org