Water contamination in ammonia refrigeration plant

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Every day, Danfoss Industrial Refrigeration (DIR) has to use its knowledge and resources to help customers all over the world solve problems with industrial refrigeration plants. It is often the case that the customer’s problem has nothing to do with our products or the way in which the plant is designed, but is the result of completely different factors.

To help our customers save energy and minimise their service costs, we at DIR collated some of our knowledge and experience in a technical document which was presented to the 1998 annual conference of The International Institute of Ammonia Refrigeration (IIAR). This article is an abstract of that document and its presentation at the conference1).

The “vicious wet circle”
The actual cause of many problems in industrial ammonia refrigeration plants is water contamination of the ammonia itself. Often, the only visible signs in the plant are just the result or a symptom of the problem.

Fig. 1 Consequences of water contamination “The vicious circle”
Incorrect service and maintenance procedures
Water penetrates into the system
Chemical reactions
Problems with oil and sludge, compressor affected

If the connection between cause and effect in a refrigeration plant where the ammonia refrigerant has been contaminated by water is not known there is a risk of many resources being devoted to “curing” the symptoms rather than solving the real problem. We call this the “vicious wet circle”. (See fig. 1.)

The bottle test
To understand how large quantities of water enter an ammonia plant it is first necessary to look at the affinity that exists between water and ammonia. The easiest way to illustrate this phenomenon is by using the so-called “bottle test”.
If an empty bottle is turned upside down, filled with ammonia vapour and then taken down into water until the neck is immersed, water will begin to rise up in the bottle – at first slowly and then more quickly – until the bottle is almost full of water. The reason is the affinity between water and ammonia; it is so great that the ammonia vapour dissolves in the water. The pressure in the bottle thereby falls and water is sucked up into it.

The bottle test illustrates perfectly how water can suddenly be sucked into an ammonia refrigeration plant when the refrigerant is being evacuated, for example during service work when it is normal practice to blow the refrigerant out through a water-filled container. That is why the use of a check valve in the drain line is always recommended when ammonia is evacuated through water. The valve eliminates the risk of water suddenly being sucked into the plant (see fig. 2).

How and where does water come in?
Water can enter a refrigerating plant in many ways. Before starting up, there may already be water from pressure testing in vessels, evaporators, condensers, etc., or water condensate might appear because of temperature variations before the system is charged with refrigerant. Such water contamination can and should be avoided partly by drying out the system thoroughly, and partly by ensuring adequate vacuum in the system before the ammonia is charged and the plant started.

When a plant is in operation, water can find its way in when service work is being carried out, by accident (e.g. corrosion in chillers) or when on the low-pressure side of the plant moist air is sucked in through glands and gaskets that do not seal properly. Water ingress in this way is especially common if the normal suction pressure is lower than atmospheric pressure.

The air that enters the plant in this way and which is blown out again on the high-pressure side (either manually or by an automatic air purger) is completely dry because it has yielded all the moisture it contained to the ammonia and hence water will be accumulated. This is how water accumulates in the plant.

The aspect to be aware of here is that although automatic air purgers eliminate the problem of air in the system, they do not solve the problem of water accumulation.

The size of the problem can be illustrated with the help of simple arithmetic:
If 5 litres of air per minute is sucked into a plant and allowed out again through the automatic air separator, and assuming an air temperature of 20°C [68°F] and air humidity of 80%, in the course of 10 years the quantity of water dissolved in the system ammonia will amount to 363.5 litres.

Where is the water?
Because of the great difference between the vapour pressures of ammonia and water, an ammonia refrigeration plant can be regarded as a large distillery where only small amounts of water evaporate together with the ammonia. Water thus accumulates in the low-pressure side, i.e. in liquid separators, intermediate coolers, etc. while, practically speaking, no water appears in the high-pressure side.

The extraction of refrigerant in order to measure water content should therefore only be performed on the low-pressure side, while as much as possible of the ammonia charge is on the high-pressure side of the plant. Such measurements will reveal the largest percentage of water content.
How much water can actually be found in a plant?
In Denmark, Norway and Sweden, and with the participation of the Danish Technological Institute and other bodies, an extensive investigation into water content was conducted in 175 industrial ammonia refrigeration plants. Of these, 25 contained more than 3% water, 37 more than 2% and 77 more than 1%. In a few plants, water contents of 26%, 24% and 18.5% were found (see fig. 3).

In 65 of the plants examined a water rectifier was installed to boil off the water. The quantity of boiled-off water was then measured. In two of these plants, 250 litres of water were separated out and in one plant 199 litres. On a further 10 plants, the figures were between 100 and 150 litres (see fig. 4). In none of the plants were service personnel aware that there might be problems with water in the ammonia.

These measurements must be seen in the light of the recommended water content in ammonia refrigeration plant; i.e. max. 0.3%.

How can the water be removed?
In industrial ammonia refrigeration plant, water is removed by distillation in a water rectifier where the ammonia slowly evaporates leaving the water behind in the vessel. When this process has been repeated many times, the residue in the container is drained off. This normally consists of water with a content of about 30-40% ammonia, depending on the pressure and temperature at the time of emptying).

What about filter driers?
Danfoss has looked into the possibility of producing filter driers for ammonia refrigeration plant. The conclusion is that even though it should be technically feasible to produce such a filter, it would be very expensive and the amount of separated water very small in relation to the water quantities that exist in ammonia refrigeration plants (a few hundred grams per filter).

What happens “chemically” in the plant?
Pure ammonia or, as it might be called, “dry” ammonia is not particularly chemically reactive. In fact, if ammonia were free of water and remained in this condition, copper or copper alloys such as brass could be used in ammonia systems.

In the case of small commercial ammonia refrigeration plant with refrigerant charges of less than about 4 kg, it is cheaper to replace the whole charge several times than it is to install or replace a filter drier. Danfoss has also looked at other filters on the market without finding any of them suitable for ammonia refrigeration plant.

What happens to pressure and temperature when water enters the plant?
When water becomes mixed with the ammonia, the thermodynamic properties of the mixture are different from those of pure ammonia because changes occur in the relationship between the pressure of the respective saturated vapours and the corresponding temperatures. At the same pressure, an ammonia-water mixture has a higher evaporating temperature than pure ammonia. A refrigeration plant in which water has mixed with the ammonia must therefore operate with a lower pressure in the evaporator to maintain the same evaporating temperature than a plant with pure ammonia. This can have serious consequences on plant capacity and operating economy.

A rule of thumb says, “at low evaporating temperatures the power consumption of the plant rises about 5% for each degree Celsius the corresponding pressure drops on the suction side.” The plant capacity falls markedly at the same time.

An example:
At an absolute pressure of 3 bar [43.5 psia] the evaporating temperatures will be as follows (see fig. 5):

-9.23°C [15.39°F] with pure ammonia
-6.69°C [19.96°F] with 10% water in the ammonia
-3.16°C [26.31°F] with 20% water in the ammonia.

Such a change in the evaporating temperature because of water in the ammonia can have a significant effect on the capacity and power consumption in, for example, a chiller unit. When working with dry expansion on ammonia systems such changes in pressures and temperatures will be registered as superheat by the thermostatic expansion valve – without this being the case. In the event of too high a “false superheat” the valve will become unable to “control” the evaporator.

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Conversely, aqueous or “wet” ammonia is very chemically reactive and very aggressive towards copper, copper alloys, zinc, etc. “Wet” ammonia is highly corrosive and can lead to galvanic corrosion of the valves, which in turn might result in regulation problems. This corrosive environment together with vibration and/or pulsation can also give rise to the phenomenon known as “fretting corrosion” where surface metal fatigue, wear and corrosion becomes intensified by the presence of the other two. Under these conditions, mechanical regulators and valves can either seize up completely or malfunction because of increased friction (see fig. 6).

What about the oil?
Ammonia containing water and oxygen also reacts with the oil in the compressor and creates reaction products. Some of these are organic acids that react with the ammonia and form complex nitrogen compounds (e.g. sludge, salt and soap products) all of which are highly injurious to the plant.

Characteristic of the nitrogen compounds is that:
- they are partially soluble in ammonia (the ammonia becomes coloured),
- they do not dissolve in oil,
- they are able to pass through the oil separator together with the ammonia,
- they create sludge in the compressor and throughout the whole system (valves, regulators, evaporators),
- they act as catalysts which accelerate the on-going process by creating more damaging nitrogen compounds.

Orifice wear in an ammonia plant?
It is well known that the orifices can be subjected to wear because of the erosion and cavitation that occur in the orifice where expansion takes place. Erosion is caused by the flowing medium, which at certain points can reach a velocity almost the same as that of sound. Cavitation arises because small bubbles in the ammonia implode (collapse).

Wear in orifice elements such as floats and expansion valves becomes greater when the ammonia contains water. The water creates corrosion in the orifice, i.e. it adds corrosion to the erosion and cavitation already taking place. Furthermore, water in the ammonia might intensify the cavitation affecting the orifice (even though this has not been scientifically proved). Wear from erosion is also intensified by the larger amounts of rust and sludge particles that circulate in the system.

Conclusion
It can be concluded that ammonia refrigeration plants often contain more than the maximum recommended 0.3% water. This can be because automatic air purgers “hide” leakage and allied problems which allow water to accumulate in the system. Another cause is that personnel who service such plants are not always very acquainted with water-related problems.

The “good dry circle”
Now let us look at the “good dry circle” where the real problem is cured rather than just the symptoms (see fig. 7).

The initial step is to follow the correct procedure in starting up and servicing the plant. The better these instructions are observed the fewer the problems with oil and sludge become, and the smaller becomes the risk of corrosion. Problems with mechanical valves and regulators will thus be fewer.

Making sure that the plant runs with minimum water content means lower service and operating costs, without negatively affecting capacity and power consumption.

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Fig. 5: Thermodynamic properties NH₃ + H₂O

<table>
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<th>Saturation Bar</th>
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The real problem is solved and not just the symptoms
Investigation of water content. Use of water rectifier units
Reduced service and operating costs
Capacity and energy consumption not affected
Fewer problems with valves and regulators
Minimum risk of corrosion

Advantages of keeping systems dry - “The good circle”
Correct service and maintenance procedures
Minimum water penetration
Minimum number of chemical reactions
Fewer problems with oil and sludge. Longer service intervals

For a more detailed description of how water content is measured and how water is boiled off in ammonia systems refer to the IIAR (The International Institute of Refrigeration) technical bulletin no. 108.