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Overcoming the High Cost of Water

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Water, the same water that we drink from those little clear plastic bottles, seems so harmless compared to the sharp-smelling ammonia we've come to know and respect. Water's not just harmless; on a hot summer day we'll pay two dollars or more for 16 ounces of the cool refreshment it gives. That's $16 a gallon. But today people are becoming more aware that, like water in a little bottle, water in an ammonia refrigeration system can be surprisingly expensive.

Some of the expense of the water is due to its destructive effects on the system. Common metals are not affected by dry (anhydrous) ammonia. But when water is added, the aqueous ammonia will react rapidly with copper, zinc, and many alloys of these metals. Ammonia mixed with water produces ammonium hydroxide ($NH_3 + H_2O \bullet NH_4^+ + OH^-$). And while iron and steel do not themselves react to aqueous ammonia, the ammonium and hydroxyl ions can cause galvanic corrosion between two different metals near each other, especially if the metal lacks a protective coating of oil.

Another part of water's expense is that if it gets into the compressor oil, it will take part in a series of chemical reactions that create nitro compounds (sludge). Some of these compounds are soluble in ammonia and can escape with ammonia vapor through the oil separator and into the system. There, they will clog strainers and filters and cause operational problems in valves.

The effects of both galvanic corrosion and sludge on the system, although definitely harmful, can be difficult to quantify and

What makes cold water so expensive?

When water is added to anhydrous ammonia, the saturation temperature, at a given pressure, increases. In other words the boiling point of the ammonia rises. This is illustrated in figure 1 below for several pressure levels.

When there's no water in the ammonia, a system with a 0°F evaporator would need a suction pressure of about 15.5 psig. But if 10% water is mixed with the ammonia inside the evaporator, the 15.5 psig suction pressure would give a coil temperature of about 3°F.

The practical implication of this is that in order to maintain the desired temperature, the suction pressure must be lowered and the compressor must work harder. This is illustrated in figure 2. Here you see that if the ammonia is contaminated with 10% water, the compressor suction pressure must drop to 13 psig to hold 0ºF in the evaporator.

For a constant condensing pressure, this means increased power consumption (higher electric bill) and a higher compressor exit temperature (increased wear).

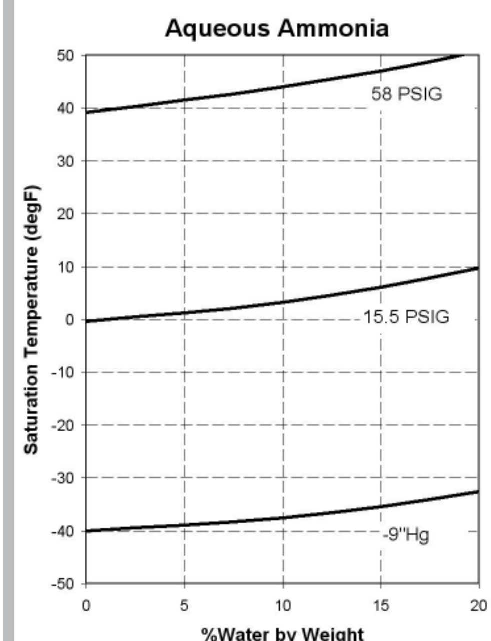

Figure 1

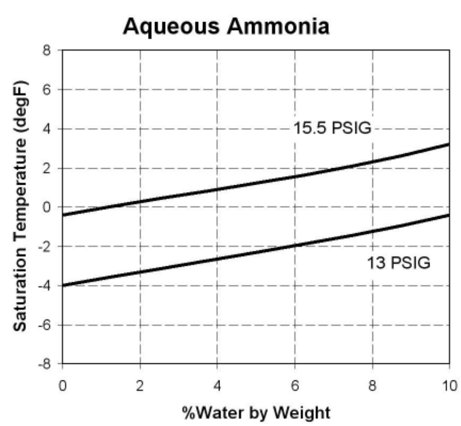

Figure 2

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trace back to water as the root cause. What is easier to quantify is the effect that water has on energy consumption. As explained in the box (right), water makes the compressors work harder in order to maintain the desired evaporating temperature. This in turn increases energy bills.

The first reaction to all of this disturbing news might be to conclude that water inside the system must be completely eliminated. After all, refrigerant grade anhydrous ammonia is supposed to be at least 99.95% pure; and it cannot have more than 33 ppm water.[i] Yet water content of up to 0.2% (2,000 ppm) in a refrigeration system may protect against stress corrosion cracking (SCC) in vessels by scavenging oxygen.[ii] However, this benefit would occur only in the low pressure vessels because, as explained at right, water collects on the cold side of the system. The high pressure vessels in the system, which may be more vulnerable to SCC, receive little if any protection from the water. The problem may not be very large: anecdotal evidence suggests SCC occurs once in every 400 to 2000 vessels.[iii] The best protection against SCC in both high- and low-side vessels is probably post-weld stress relief by heat treating. This process reduces residual stresses in welds, which is where SCC is likely to occur.

The bottom line might be that the timeless advice, *all things in moderation,* applies here. There is no need to expend large amounts of resources trying to ensure that the water content never exceeds 0.2% anywhere in the system. If you take another look at Figures 1 and 2 *(see front page)*, you'll notice that below about 1%, water actually has very little effect on system operation.

Is there any guide to tell how much water is too much? Any guidelines that are good for your system should, of course, relate to your particular equipment and operating conditions. This can lead to either simplified but over-stated claims of potential improvement on the one hand, or complicated charts and graphs giving possibly unrealistic precision on the other. There is a rule of thumb, however, that a 1ºF increase in suction temperature (about 2% water) corresponds to 2.5% to 3% of lost compressor capacity.[iv] Translating this lost capacity into wasted energy dollars is a tricky business that depends on a number of assumptions. But some fairly straight-forward calculations can show that 5% water in the ammonia

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How did water get into the system and where does it go?

Figure 3 (at right) shows that there are numerous ways water can enter a refrigeration system. It can enter in relatively small quantities at any time during construction, operation, and servicing as humidity in the air. Or a leak in a shell and tube heat exchanger will admit larger quantities more suddenly. Also, new vessels that have not been properly dried and evacuated after hydrostatic testing can contain a significant amount of water.

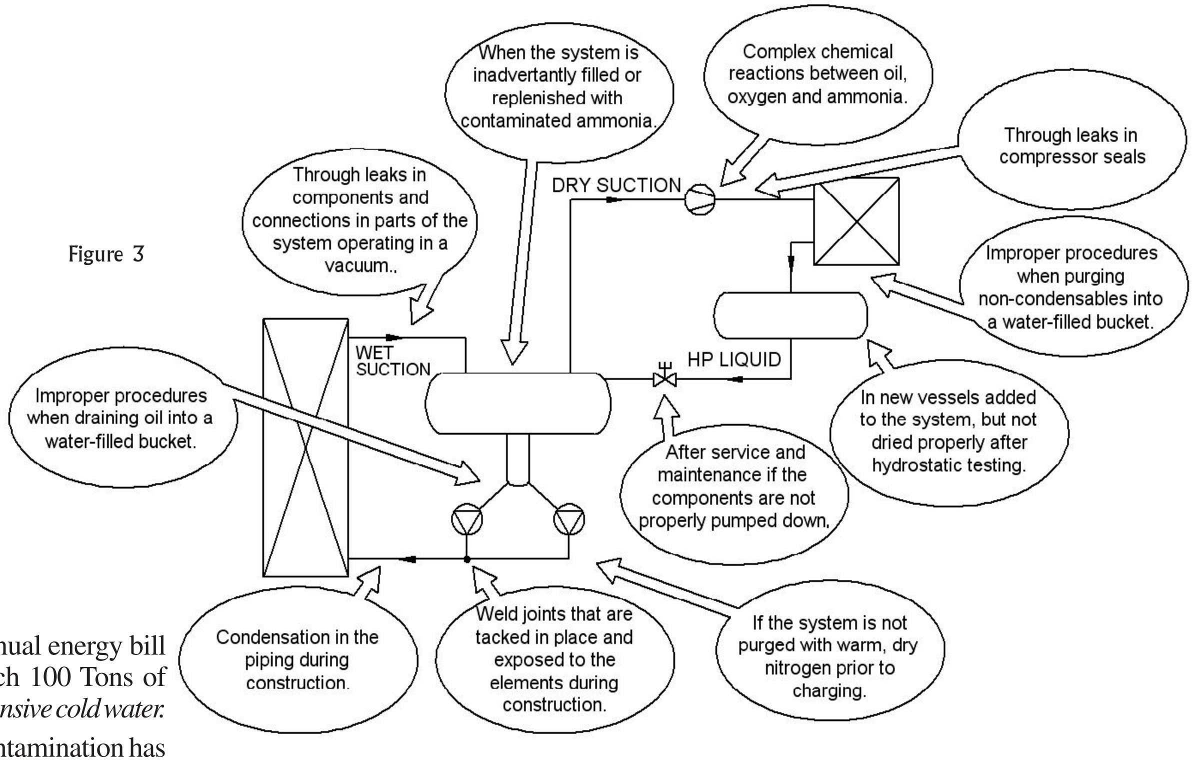
Moisture that leaks with air into the low side of the system will immediately combine with liquid ammonia and stay there (except as noted below). Meanwhile, the air will move on to the high side of the system where it can be purged. You can be sure that if there is a purger on the system, and it is been purging air, then you've got water.

Water vapor can only travel with gaseous ammonia in *extremely* minute quantities. This is why it is nearly always found on the low side of the system where the ammonia is allowed to boil away. Measurable water found on the high side of the system is usually the result of droplets carried over from an ineffective liquid separator. Water that does get to the high side of the system either combines with oil in the compressor to form sludge, or flows through the compressor with the ammonia vapor and into the condenser. There the ammonia/water mixture can liquefy, flow to the high pressure receiver and ultimately find its way to a place in the system where the ammonia boils away. This could be an evaporator, chiller, intercooler, or shell and coil economizer.

In a mechanically-pumped recirculation system, water will become concentrated in the pump accumulator. In a gas-pumped system, the water will be transferred through the dump trap (pumper drum) into the controlled pressure receiver. But ultimately it is fed back to the low pressure vessel. On a gravity flooded system, the water will accumulate in the evaporator or heat exchanger.

Once it reaches one of these locations, there is no way for the water escape. It cannot evaporate with the ammonia, so it simply accumulates, and as the amount of water increases either the temperature of the evaporator must increase or the compressor must work harder to maintain the desired temperature.

Figure 3



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can increase a system's annual energy bill as much as $2,000 for each 100 Tons of refrigeration. *Now that's expensive cold water.*

The problem of water contamination has been known for a long time. An excellent paper by J. Edmonds was presented on the topic at the RETA National Convention in 1996.[v] So if water is such a problem, you might wonder why not much attention has been paid to it. There seems to be several likely reasons. First of all, the problem is generally hidden. The 2% water mentioned earlier causes less than a 0.5 psig change in the suction pressure of a 0ºF coil. This water collects slowly over time. Such a gradual change in system performance can easily be attributed to measurement error or *normal aging*. At right is a brief discussion of how to measure water in the system.

What about air purgers? (Consider only extremely minute traces of water vapor can travel with ammonia vapor and air purgers simply cannot remove water from ammonia vapor.[1]) Conventional air purgers work by cooling and condensing the warm ammonia vapor to separate it from non-condensable gases. Water vapor is not a non-condensable gas, and therefore cannot be separated from ammonia by cooling it in a purger. However an air purger connected to the high side of the system can be a qualitative indicator of the presence of water. Remember that water can leak into a system as humidity in air. If you have a purger that has been removing air from the high side, then there's water in the low side of your system.

Instead of cooling the warm ammonia vapor, you must warm and vaporize cold contaminated liquid ammonia. This separates it from the water and any other contaminants such as oil. Essentially, this is a process of distillation.

Of course on smaller systems, it might be acceptable to shut down the system, remove the complete charge of ammonia, then recharge and restart the system. The recharge could be either new ammonia or the old ammonia, cleaned by a

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Exceptions To The Rule

Direct Expansion Systems

In a direct expansion system water will accumulate in the evaporator. During normal operation, high velocity ammonia vapor can carry water droplets out of the evaporator. If there is no suction accumulator, these droplets can move to the compressor and mix with oil. Also, as the water concentration increases inside the coil, the evaporator exit temperature will increase. This may be misinterpreted as an improperly adjusted superheat. In attempting to reduce the superheat, the expansion valve may open too much and liquid ammonia and/or water can slug the compressor.

Two Stage Systems with Hot Gas Defrost

Liquid remaining in a low temperature evaporator at the start of defrost can contain a significant amount of water. If this liquid cannot be completely drained before hot gas is applied, the defrost condensate will have water in it. This condensate may be drained to an intermediate pressure vessel, where it may be used for liquid-injection oil cooling. The water in the liquid ammonia injected into the compressor will react with the oil to form sludge.

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[1] *One relatively new purger enhancement takes liquid from the system low side as well as vapor from the system high side to separate both air and water inside the same unit. However, the water is being removed from the liquid ammonia, not the gaseous ammonia.*

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distillation unit described at right. But the combination of down-time and the quantity of ammonia that must be handled often prohibits this approach.

Larger systems are sometimes cleaned of water in batches. That is, a fraction of the ammonia charge is admitted as a liquid into a (usually portable) distillation unit, evaporated and purified. The pure ammonia is returned to the system, while the separated water and other impurities are drained and disposed of. Then another fraction of the contaminated system charge is admitted and purified. The process continues until the entire system charge reaches the desired level of purity. It can take weeks to clean out a large system by the batch method. These distillation units need to be carefully adjusted for particular operating conditions, monitored and emptied at unpredictable intervals. For these batch-type water removers, a change in the system's operating conditions can result in sudden and violent boiling inside the distillation vessel. This can cause some of the impurities to be sent back into the system.

Water removal units, sometimes called *ammonia regenerators,* can also be integrated directly into the refrigeration system. These typically use hot discharge gas or warm condensed liquid to provide an inexpensive heat source for boiling the cold contaminated liquid ammonia. These units can vary in complexity and effectiveness, but generally are capable of operating continuously. Intervention is only needed to drain the collected impurities.

There are some water removal units that use electric heaters to warm the ammonia-water mixture to temperatures above 150ºF. This is done so that as much ammonia as possible is removed from the water and other contaminants before they are drained. This approach can indeed lower the ammonia remaining in the effluent to as little as 5% (about the same as extremely strong household cleaner). Unfortunately, this approach adds the complexity of heaters and thermostats, heating the mixture generates steam – just like a pot of water warming on a stove. If the temperature is high enough and the pressure is low enough (190ºF at -10"Hg), the water will even boil. The resulting steam and water droplets are then sent with the ammonia vapor back into the system.

There are a number of solutions to the problem of water in an ammonia refrigeration system. And with each solution, the pros and cons of complexity, expense, and effectiveness must be carefully considered. In the end, getting water out of the system probably won't change the $2 price tag on those little plastic bottles. But with the proper information at hand, a system operator can select the most effective way to reduce operating costs and extend equipment life. In doing so, he really can lower the high cost of cold water.

Finding Out How Much Water Is In There

The first step in eliminating water from the ammonia is to see how much is already there. A very precise method for doing this is given in *IIAR Bulletin No. 108.* Essentially, samples of ammonia are taken from the locations in the system where water is likely to be present. The ammonia is allowed to boil away at room temperature and the remaining residue indicates the percentage of water present.

The state of the system at the time the sample Is taken should always be considered. If, for example, ammonia is taken from the pump discharge when the level in the high pressure receiver is low, the results may indicate a low level of water present. This is because there is more ammonia in the low side of the system. If the sample is taken at a different time, when the HP receiver level is high, the results would indicate a higher percentage of water. In both cases, the actual amount of water present in the accumulator is the same. But reducing the amount of ammonia on the low side of the system increases the percentage of water there. This means the evaporator or chiller temperature can vary due to the changing nature of the liquid flowing through it, even if the suction pressure and load are steady.

A *quick and dirty* test would be to simply compare the system's actual operating condition to the ammonia charts. For example, if your suction pressure is 15 psig, your evaporator coil should be operating at 0ºF (assuming, of course, that saturation conditions prevail). If, however, your coil is at 2ºF there's probably 6 or 7% water present. With this method, the more precise the pressure and temperature measurements the more reliable your conclusions will be.

Sources

[i] http://www.osha.gov/SLTC/etools/ammonia_refrigeration/ammonia/

[ii] "Stress Corrosion Cracking: Prevention", The Cold Front (Vol.5, No.2, 2005), Industrial Refrigeration Consortium, University of Wisconsin, Madison, WI

[iii] "Stress Corrosion Cracking: Defining and Diagnosing", The Cold Front (Vol.5, No.1, 2005), Industrial Refrigeration Consortium, University of Wisconsin, Madison, WI

[iv] Bulletin No. 108, Water Contamination in Ammonia Refrigeration Systems, International Institute of Ammonia Refrigeration

[v] "Ammonia System Water Contamination", Edmonds, JM. Presented at the Refrigerating Engineers and Technicians Association National Convention, Valley Forge, PA, Oct. 1996

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