# REVIEW ARTICLE

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## Extending the Life of Ammonia Refrigeration Systems: Part II

by

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### BACKGROUND

This article is based on a paper presented at an IIR conference, Ammonia Refrigeration Technology for Today and Tomorrow, held in Ohrid, Macedonia, on April 19-21, 2007. It addresses issues related to the useful working life of ammonia refrigeration equipment. It considers the economic case for extending the life of equipment and reviews the factors which affect the condition of equipment. Key issues in the design, operation and maintenance of plants are explained, with examples to illustrate the effect of earlier decisions on later life. Some recommendations are given as guides to good practice when equipment is being modified or reconfigured, with the objective of finding ways in which existing systems can be brought into line with current international safety standards without incurring an excessive investment cost.

Part I dealt with economic aspects, factors affecting system life and design considerations.

### V. OPERATING ISSUES

#### V.1. Condition of lubricant

Most refrigeration compressor types require lubricant to ensure correct operation. This reduces friction in bearings, slide valves and piston wrist pins, but it also provides a cooling and cleaning function, creates a pressure seal between the low- and high-pressure parts and can also be used for auxiliary functions such as hydraulic operation of the capacity-control system. The lubricant also provides an excellent measure of the general health of the compressor system, and for that reason it should be regularly monitored, with test results recorded so that trends can be identified. The key considerations are the general appearance, the colour, the viscosity, the water content and the presence of metal fragments. If the condition observed through regular checks is worsening, then the oil should be changed in order to protect the compressor, but there is probably also a fault in the system causing the degradation. This should be investigated before more expensive damage occurs.

A full oil analysis requires sophisticated laboratory equipment to measure water content and viscosity and to identify particles, but several simpler tests can be done on site without difficulty. For example, if an oil sample is taken every week, the colour and appearance can be noted, the presence of particulates recorded and a qualitative estimate of the viscosity can be made. It is essential that oil is drawn from the same place each time, and the ammonia is driven off before assessing viscosity. A normal sample should occasionally be sent for more detailed analysis.

Mineral oil will tend to degrade in use and its viscosity may reduce over time as longer chain molecules are broken down, or it may increase through contamination with water. It may be appropriate to change from mineral oil to a modern synthetic, for example a hydrocracked oil or a polyalphaolefine. Although the initial charge of oil may be more expensive, it is less likely to require to be changed as frequently and so there will be a saving in the long term. Oil carryover from the compressor is likely to be reduced, and if the oil condition remains good, it is possible to arrange an automatic oil return system to the compressor, even on an existing plant. However, when changing oil type there are some factors to bear in mind. The change might cause some elastomer materials in o-rings and seals to shrink, causing oil or ammonia leaks. To avoid this, an oil with a seal additive to reduce shrinkage should be used. In some cases, it is possible to buy the seal additive separately, or a pre-mixture of oil and additive can be used. The change of oil type might also cause a lot of dirt from the system to be returned to the compressor in the suction line. This can have a disastrous effect on the compressor and can also greatly increase the use of oil filters on the compressor packs over a surprisingly long period. For this reason, a commissioning sock should be fitted to the compressor suction strainer and changed regularly until the level of contamination has been reduced. This is a messy and awkward procedure, but it is important to follow it carefully because running costs will be reduced in the long run, and the system will be much more reliable.

If automatic oil return is already in use, or is fitted at the same time as the oil type is changed, then it should not be used until the old oil and dirt have been flushed out of the system. This change should be done before there are any serious operational issues with compressor performance or evaporator fouling — if the system is already in a poor condition, then the oil change and remedial work will be much more expensive and serious damage may already have occurred.

## V.2. Variations in operation

It may be necessary to take a compressor that was intended for low-temperature operation and use it for chill duty, or vice versa. While the compressor suction swept volume remains much the same, and hence the suction pipe velocities will not change much, the suction gas becomes more dense as the pressure is increased, and so the refrigerating effect is greatly increased. This results in a much higher power consumption for a given compressor size on chill duty, even though the system COP is better. Reciprocating compressors can operate over a wide range of pressure ratios, but care must be taken when running at lower than design suction conditions to ensure that the machine does not overheat. It may be necessary to add water-cooled cylinder heads or some other form of external cooling if this operation is required in the long term. On screw compressors, the oil cooling circuit will probably provide sufficient cooling, but it may be necessary to adjust the compressor's built-in volume ratio to ensure efficient operation. In extreme cases, operation at the wrong volume ratio has been known to cause significant bearing or rotor damage due to excessive internal pressure.

The sizing of vessels also needs to be checked to ensure that a change of operating conditions does not cause droplets of liquid to be carried back to the compressor. It may be necessary to change compressor speed if the suction pressure is raised, slowing the compressor down to compensate for the increased capacity. This is easy with belt-drive reciprocating compressors, but is more difficult with a screw compressor, where the options are to fit a four-pole motor or fit an inverter. This may be expensive and may require a new motor matched to the inverter.

Where a chill system is run at low temperature, there may be insufficient insulation on pipework or vessels to prevent condensation on the colder surface. If this is the case, then additional insulation can be applied over the existing, provided the surface is clean and dry. There may also be a tendency towards accelerated corrosion where a low-temperature system is modified to run at chill conditions. Steel which is permanently under ice is unlikely to corrode, but if the surface is regularly thawed and refrozen the corrosion will be quite rapid. Care should also be taken to ensure that precautions against frost heave are adequate when storage temperatures are lowered.

## V.3. Minimizing wear and tear

A regular walk through the plant room and around the condensers will identify early symptoms of problems long before they turn into expensive repairs. The site mechanic should listen for unusual noises, for example where a gauge pipe is touching a pipe or vessel. If this is not corrected, it may cause fretting, leading to a leak of refrigerant or oil. Early indications of bearing wear on motors or rotor wear on compressors can be detected by a change in the running noise. In the case of belt drives, the specified design belt tension includes an allowance for belt stretch. If the drive is regularly adjusted to return the tension to the set-up condition, then the bearings on the driven shaft will be overloaded and their operating life will be shortened. In one case, a customer had a very expensive bearing condition monitoring regime on an axial fan evaporative condenser. The motor mounting arrangement was flexible to cope with movement of the fan, and high vibration velocities were recorded at the feet of the motor. This high velocity was incorrectly diagnosed as the result of belt slackening, and so the tension was regularly checked. It was always found to be less than the design figure and so the belt was frequently tightened. This overloaded the bearings, but when they failed, this was said to be the result of the high vibration measured. When the client commissioned a second identical system and delayed the implementation of the condition monitoring system, the root cause of the bearing failure became clear. The system with no monitoring had no bearing failures, even though the motor foot vibration velocities were extremely high when measured. Once the belt retensioning on the original system was stopped, the bearing failures also ceased.

### V.4. Defrost considerations

If frost covers the fins of an air cooler in a cold store, then the performance will be impaired. In less severe cases, airflow will be reduced and the temperature difference in the evaporator will increase. If the frosting is more severe, then parts of the cooler face area may be completely blocked. If this is not removed then after some time the frost will turn into solid ice. In addition to blocking airflow and reducing system efficiency, the expansion of the ice may be sufficient to crush the tubes of the cooler and the extra weight might overload the cooler support system. If a cold store system is defrosted too frequently, then there will be a significant waste of energy and it may be difficult to maintain the required air temperature. It is therefore important to defrost sufficiently often to avoid the accumulation of frost and snow, without incurring additional running cost by overdoing it.

A typical hot gas defrost should function without any intense banging sounds. These are caused by one form or another of “liquid hammer”, of which there are three distinct types. The most familiar is the knocking sound often heard in water pipes when a valve is quickly opened or closed. This is often called water hammer, and is caused by a pressure wave travelling through liquid in the pipe. It is in fact very uncommon in refrigeration pipework, because the pressure wave has a minimum value which is likely to vaporize the liquid and destroy the wave. A second form of liquid hammer is also called “liquid slugging”. In this occurrence, if high-pressure gas is introduced to a pipe which is partially filled with liquid, then the liquid may be propelled at high velocity along the pipe until it meets a restriction such as a solenoid valve or the end of a header. The momentum created by the high velocity of the liquid can be sufficient to create a large force when the flow is stopped, and this can cause damage to valve components, although it is unlikely to fracture a pipe. The third form of liquid hammer is also called “condensation-induced shock”. If part of a system is filled with liquid which contains small bubbles of gas and the pressure is suddenly increased then the bubbles will collapse and very large forces will be transmitted through the liquid. Water hammer and liquid slugs are easy to visualize and so are quite well understood. Condensation-induced shock is not so easy to imagine, but is far more common and is also far more damaging and dangerous. Condensation-induced shock can occur in defrost systems if the hot gas header is not pressurized and liquid has collected in part of the pipe. At the start of defrost, bubbles in the liquid will collapse and may exert high forces on all the liquid-filled parts of the pipe. The stresses created are far higher than normal, and are likely to cause pipe failure even if there are no obvious defects in the welds. These failures might not be close to the evaporator being defrosted at the time of failure.

## VI. MAINTENANCE PRIORITIES

It used to be common for cars to require a service visit to the garage every 20 000 km or after 12 months. Most manufacturers now work on a service interval of 60 000 km or 36 months, and a few even work on 100 000 km or 60 months. This seems very impressive until it is compared with typical refrigeration compressor service intervals. If the average speed for a car is 50 km per hour then a 100 000 km service interval equates to 2000 hours of operation. The typical interval between reciprocating compressor minor overhauls is between 5000 and 10 000 hours depending on compressor type, and the typical interval between screw compressor overhauls is between 25 000 and 50 000 hours run. For a car the 5000 hour service would be the equivalent of 250 000 km.

### VI.1. Compressor overhauls

Manufacturers provide guidelines on the overhaul work required, generally divided into minor and major overhauls. While it is not necessary to comply exactly with the manufacturer’s guidelines, maintenance intervals should not be extended too far beyond the prescribed periods.

For reciprocating compressors, the minor overhaul is called a top-end overhaul. The cylinder head covers will be removed and valve plates and unloading springs replaced: as these operate every cycle a compressor that has run for 10 000 hours at 1450 rpm will have flexed the valves and springs 870 million times. The springs are very small and cheap components, but if one breaks in operation it could destroy the whole compressor. For a reciprocating compressor major overhaul, the pistons will be removed and bearings replaced at both the top end and bottom end of the connecting rod. Axial movement of the crankshaft must also be checked as any float here imposes side load forces on the connecting rods and pistons and will cause accelerated wear. Reciprocating compressors do not lose efficiency between overhauls: either they keep running well or there will be clear signs of a problem. For example, leaking valves cause high temperature in the affected cylinder. This will be obvious from a check of head temperatures. It should be repaired quickly to avoid further damage.

Screw compressors require less frequent attention, but when an overhaul is required, it is more difficult to do on site, and in many cases the compressor should be moved to a workshop before it is opened up. There are also many ways in which compressor performance can be impaired without failing completely, and where external oil cooling is fitted, the usual inefficiency symptom of high discharge pressure will be masked by a subtle increase in oil cooling capacity. High oil temperature is not a sure indicator of inefficient operation; it might also be due to a fault in the oil cooling circuit. If the inefficiency is the result of rotor wear caused by regular liquid carryover, then the liquid ammonia in the compressor suction will also prevent temperature rise. There is no easy way to measure the refrigeration effect, so it is important to pay close attention to secondary indicators such as full load current and discharge temperature. For freezers, the time taken to pull down in temperature is also a good indicator of compressor condition. In some screw compressors it is possible to inspect the rotor tips through the economizer port connection, although this only gives access to a small segment of the tip seal. If the seal is worn at any point along the length of the rotors, then the compressor will pump a reduced volume of gas, and the capacity will be reduced. In this case, because the power consumption remains the same, it is economic to get the compressor repaired as soon as possible in order to re-establish the expected efficiency.

## VI.2. Condenser conditions

Condensers are subject to extreme environmental conditions and it is not unusual for them to corrode faster than the rest of the system, but there are several things that can be done to prolong their life. For evaporative condensers, it is essential that the zinc coating on the condenser tubes remains intact so great care must be taken in cleaning the coil, particularly if scale-removing chemicals are used. If water softeners are installed in the plant to reduce scaling, then they may create a more corrosive chemical balance. Copper pipework should not be used in the feed to the condenser, as copper ions are very corrosive to zinc. Corrosion inhibitor should be used in the condenser sump, as this will help to preserve the galvanized coating on the coil. It is essential that the water treatment chemist is aware that the condenser contains a galvanized coil, as the water treatment regimes used for cooling towers are often more acidic than is suitable for zinc.

## VI.3. Evaporators

Evaporators should be checked regularly for signs of inadequate defrosting. If frost is allowed to build up and turn to solid ice, then it may distort fins and casework, reducing the evaporator's performance even after the ice has been removed. If defrosts are not progressing sufficiently quickly, then fan socks and cowls may be fitted to improve heat retention. The accumulation of ice should be removed with a steam lance, not by mechanical means which might cause additional damage to the coil. The operation of electric heaters should also be checked regularly as the consequences of a failure of these small components are very expensive.

## VI.4. Control systems

It is likely that the control system on an ammonia refrigeration plant will be obsolete long before the mechanical equipment is worn out. Where control systems are replaced, it is important to ensure that the required function from the original system is faithfully replicated in the upgrade. Often it is cheaper and easier to specify and install a more basic control which does not contain all the safety features of the original system, and it is possible that the life of the mechanical equipment is then shortened by its more arduous running conditions. In one example, an upgrade to a brewery plant software system inadvertently removed the start restriction timers from the compressor control, resulting in 11 kV, 400 kW motors starting several times in quick succession. Fortunately, this error was noticed before any damage was done to the motors or the mechanical equipment.

The control system should also provide meaningful data to the plant operators and service technicians to enable them to detect maloperation. In many cases, the software can be self-checking, for example in confirming that the pressure drop across a filter is zero when the plant is not running the relative calibration of the sensors will be confirmed each time the plant stops. Pressure and temperature sensors should include end-of-range checks for both open-circuit and closed-circuit conditions, or if these are not flagged automatically by the control system then they should be checked manually as part of the daily routine. If the control system provides meaningful data about the plant operation then early warning of potentially damaging conditions, such as damaged compressor valves, or faulty level switches can be corrected before the equipment comes to any harm. It is more difficult to detect when a temperature probe is not properly located in its pocket. In one case on a chilled water plant the compressor tripped on low suction pressure, although the temperature probe in the water outlet was reading a high temperature. On closer investigation, the probe was found to be out of the pocket, and was reading plant room ambient temperature. This caused the chiller to load up to full capacity, with no evident reduction in water temperature. In fact the chiller was very close to freezing up, and was only saved by the low suction pressure trip which had been correctly set. This example also emphasizes the importance of using available sensors to provide auxiliary fault signals and the need to have these set to realistic, useful values.

### VI.5. Insulation and vapour barrier

Insulation provides several useful functions on a refrigeration system. It keeps the plantroom dry and clean, reduces heat gains and protects steel from corrosion. As the insulation is colder than the ambient temperature, it will tend to attract moisture and it must therefore be protected by an impermeable membrane, called a vapour barrier. This often takes the form of plastic sheeting or overlapping tape on the outer surface of the insulation. In some cases the insulation itself forms the barrier, perhaps with an outer layer of metal foil or a closed cell structure. Where insulation is foamed in place within an outer plastic or metal casing the outer casing forms the vapour barrier.

If the vapour barrier is damaged, moisture will penetrate the insulation and saturate the insulation. It will freeze, destroying the protective layer. The ice continues to attract moisture and grows until the surface is warm enough to run wet rather than freezing. If the ice remains in place, there will be no corrosion, but points where pipework emerges from the ice will be particularly susceptible. This includes not only the main pipe runs but also any branch pipes, or small diameter gauge connections which are tapped into the main pipe. A small break in the vapour barrier can therefore lead to a great deal of damage. The system needs to be turned off, warmed up and dried out to make effective repairs to the damaged insulation. This can be extremely inconvenient and expensive.

Damage to vapour barriers can be detected using a thermographic scan of the insulation, as any water penetration will show up as a cold spot, even if ice has not broken the surface of the insulation. These damaged spots should be cut out and repaired, ensuring that a good vapour seal is achieved between the repair and the original insulation so that the problem is not repeated.

## VII. MODIFICATION OF EXISTING SYSTEMS

Requirements for the design, installation and maintenance of refrigeration systems in Europe are detailed in the European Standard EN378:2000. National health and safety legislation differs in the way in which these are mandated, and usually they are not law. The requirements do not apply retrospectively, although where a plant is modified or extended the standard covers the modification or extension. This is rather short-sighted. A major refurbishment provides an opportunity to introduce safety measures to the whole plant so that workers in future will know the standards that apply to different parts of their system. It would be nonsense, for example, if one compressor were added to a machinery room to install a gas detection system in accordance with EN378, but to isolate the supply only to the new compressor. If an oil recovery pot is added to a system it would not be sensible to install self-closing valves on the new pot but not fit them to the existing oil drain points. Before the design of any modification or extension a full plant survey should be completed with a “gap analysis” highlighting areas where the plant falls short of the safety and environmental requirements detailed in the current version of EN378. The cost of upgrade will probably not add significantly to the project cost for the extension and will provide a common base for future work.

### VII.1. Design changes

For a small increase in capacity it might be possible to add condenser or evaporator surface and get the benefit of more efficient operation, or to determine by a detailed audit which of the existing loads can be trimmed or even eliminated to offset the effect of the increase. If the increase is more than 10% of the baseload then it is unlikely that the capacity can be achieved by these means alone. It is not feasible to add compressors to an existing system without considering the effect on other parts of the system. Heat rejection is the most obvious requirement, but great care must be taken when adding condensers and high pressure receivers to an existing installation because there is a real chance that the liquid and vapour flow will be restricted when two condensers are connected in parallel and the full advantage of the additional surface area will not be realized.

If the additional capacity cannot be achieved by shedding other loads then consideration should first be given to the installation of a separate additional plant with no cross connections to the existing system. This might seem like a poor choice, but if additional compressors, condensers, evaporators, controls and pipework are required, and the existing system is not well located to serve the new load then there may be some economies in installing the new plant next to the new load. Where the refrigeration system is chilling water or brine, additional care must be taken to ensure that any increase in flowrate to match the new duty does not have an adverse effect on chiller tubes (through erosion due to increased velocity) or pump power (through higher power input due to increased flowrate and pipe-work pressure losses). It is sometimes possible to avoid increasing pipe header sizes round chillers and pumps by feeding the header from both ends rather than from the centre.

The design change may be to introduce operation at a lower temperature, for example adding freezers to a cold storage plant. Rather than add large ammonia compressors, it may be feasible to install a carbon dioxide system with much smaller compressors discharging to $CO_2$ condensers operating at the ammonia suction temperature or intermediate temperature. The existing ammonia boosters can be used as high stage compressors for the carbon dioxide cascade, increasing their capacity while minimizing the additional equipment required, however it is likely that larger electric motors will be required, unless the boosters were capable of operating as swing compressors.

### *VII.2. System complexity*

Modification and extension work often adds complexity to existing systems. The designer must always bear in mind that excess system complexity is likely to shorten the life of the plant as it will undoubtedly make the plant more difficult to understand and will therefore increase the risk of operation under adverse or damaging conditions. When the system is being reconfigured for the additional loads every opportunity to reduce system complexity should be taken – even to the extent of considering division of the equipment into two or more separate systems.

### *VII.3. Dealing with redundant equipment*

Where the modification work renders some equipment redundant it should, wherever possible, be removed from the plant. This applies particularly to evaporators in process areas, but it should also be applied to roof voids and machinery rooms. It is particularly important that pipe stubs left where equipment has been removed are correctly capped. If they are not likely to be used in the future, then a suitable weld prep of the end of the stub should be made and an end cap welded to the pipe. If the stub may be used in future then a shut-off valve should be welded in the line and an end cap fitted with a 6-mm vent valve should be welded to the outlet side of the valve. The end cap should be sufficiently far from the valve (a minimum of 150 mm) to allow welding of the stub with the valve closed in future. The shut-off valve should be open and the vent valve closed. When the stub is connected to new equipment then the shut-off valve should be closed and refrigerant vented through water from the vent valve. The end cap can then be cut off, the pipe end prepared for welding and the new pipe welded in place. The system operation should be observed during and after pressure testing of the new stub to guard against nitrogen at high pressure leaking past the shut-off valve when the new section is at test pressure. If there is a nitrogen leak into the ammonia system the gas can be removed through a non-condensible gas purger in the usual way. Carbon dioxide should not be used for pressure testing against a closed ammonia valve.

Removal of redundant equipment adds to project cost, but also frees up valuable space in the process area, roof void or machinery room. It makes further future work easier and cheaper. The equipment may have some value that will contribute to the cost of its removal. Ultimately the most important reason for taking care to remove redundant equipment is to ensure staff safety.

## *VIII. RECOMMENDATIONS AND CONCLUSIONS*

Industrial refrigeration equipment is constructed from rugged, hard-wearing components that have life measured in decades, not years. Paying attention to maintenance schedules will avoid expensive breakdowns and can be justified financially in terms of reduced operating costs. Parts of the system such as compressors and controls should be evaluated regularly to see whether replacement of one component can extend the life of the rest of the system. Every opportunity should be taken to simplify the system design and make the operation safer and more reliable. An understanding of current safety codes and legislation is essential in this respect.