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COLD CHAIN

Volume 5 Number 2

Supplement to Air Conditioning and Refrigeration Journal

Refrigeration for Breweries

PLUS

- My Story on Opportunities for Refrigeration Specialists in Rural India
- Air Purging in Ammonia Plants
- Use of Unit Coolers & Air Cooled Condensers with Less-than-claimed Nominal Performance
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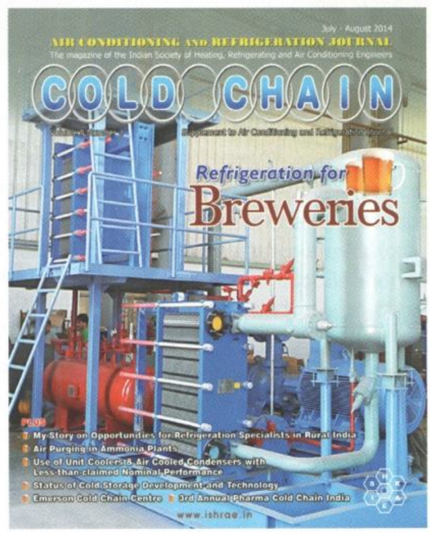
An ammonia refrigeration plant



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An ammonia refrigeration plant

Air Purging in Ammonia Refrigeration Plants

By Anand Joshi
Partner
Manik Engineers, Pune

Introduction

Air is essential to life, but when it is in a refrigeration system, it can reduce efficiency, increase energy cost and damage equipment. The secret is to prevent air from entering the system. But when it does, there is a need to remove it quickly.

Whether a system uses ammonia or any other refrigerant, the heat transfer efficiency is greatly improved when unwanted air (comprising all non-condensable gases) is removed. The process of removing colourless, odourless air is called purging. Automatic air purgers are products that are specifically designed to remove air and other non-condensable gases from an industrial or commercial refrigeration system, with minimum loss of refrigerant.

The purger is an essential component for proper and efficient operation of the refrigeration system. It gathers, separates and expels air from the system. Successful purging of non-condensable gases from a refrigeration system leads to increased refrigeration capacity, improved system efficiency and enhanced system safety.

In this article, we shall review the types of non-condensable gases that can accumulate in refrigeration systems, their consequences, various methods of purging, purger operation, application considerations and factors that influence purger performance. Our emphasis shall be on vapour compression based industrial refrigeration systems that use anhydrous ammonia as the refrigerant, because this scenario covers the majority of industrial refrigeration systems in use today.

Condensable Gases in a Refrigeration System

In the context of vapour compression ammonia refrigeration systems, we want only pure refrigerant (anhydrous ammonia) present in the system. Unfortunately, refrigeration systems accumulate 'foul substances'. The foul substances that are gaseous in nature are the non-condensable gases. They eventually accumulate in all ammonia vapor compression systems, if adequate means are not provided for their removal. Their constituents commonly include air, nitrogen, hydrogen and hydrocarbons. The term 'non-condensable' means that these gases do not liquefy at the temperatures and pressures present in condensers consistent with industrial refrigeration systems. For example, ammonia

About the Author

Anand Joshi is a graduate in Industrial Engineering from the University of Pune. He is a Partner at Manik Engineers, Pune, a manufacturer of controls and control panels for industrial refrigeration and cold chain industry for the past 35 years. He is a past president of ISHRAE Pune Chapter, member of International Institute of Ammonia Refrigeration (IIAR USA), member of ASHRAE, and Secretary of Association of Ammonia Refrigeration.

changes phase from gas to liquid if heat is removed while at a temperature of 35°C and a pressure of 12.5 kg/cm². At the same pressure, any nitrogen present would have to be cooled to -164°C in order to liquefy. As a result, any nitrogen that may accumulate in a refrigeration system always remains in a gaseous state.

Ways in which Non-condensables Accumulate

Air is the most abundant non-condensable gas impacting industrial refrigeration systems. It is important to understand how air or non-condensable gases enter the system. The air, once in the system, accumulates on the inner surface of the heat exchanger, creating an insulating barrier. Whether the suction side pressure is above or below atmospheric pressure, air can accumulate in a refrigeration system in various ways:

1. The refrigerant, when delivered, may contain non-condensable gases upto 15%.
2. Inadequate evacuation before commissioning the refrigeration plant
3. Certain parts of the refrigeration plant are frequently opened for service and maintenance, causing air to penetrate into the system.
4. Oil changing and recharging with refrigerant have the same effect.
5. Systems operating with suction pressure below atmospheric (i.e., working temperatures below -33°C for an ammonia system) can have small leaks from system piping, valves, vessels, valve stem packing, bonnet gaskets, compressor shaft seals, non-welded connections, control transducers, etc., allowing air to penetrate into the system.
6. Decomposition of the refrigerant or the lubricating oil can occur due to the catalytic action of various metals in the installation and high discharge temperatures. Ammonia, for instance, decomposes into nitrogen and hydrogen.

The Need to Purge Non-condensables

Non-condensable gases cause considerable loss of efficiency. Air and other non-condensable gases can dissolve in the refrigerant and come into circulation in the refrigeration system causing, even in small concentrations, a significant increase in condensing pressure, resulting in loss of efficiency. The non-condensable gases in the condenser raise head pressure, mainly due to their insulating properties, which are well known. Air molecules generated in the gas by the compressor accumulate on the inner heat transfer surface of the condenser. This accumulated air both insulates the transfer surface and effectively reduces the size of the condenser. (A good analogy is cholesterol and fatty deposits clogging arteries.) To offset this size reduction, the system must work harder by increasing the pressure and temperature of the refrigerant. For each 4 psi of excess head pressure caused by the air, the power cost to operate the refrigeration system compressor increases 2% and compressor capacity drops 1%.

Air in the system typically causes excessive wear and tear on bearings and drive motors and contributes to a shorter service life for seals and belts. In addition, the added head pressure increases the likelihood of premature gasket failures. Also, increased pressure leads to increased temperature, which shortens the life of compressor valves and promotes the breakdown of lubricating oil. It increases condenser scaling, raising maintenance cost and reducing condenser life.

Water content in the air leads to corrosion inside the refrigeration plant and problems with automatic controls.

Increase in discharge temperature leads to 'ammonia explosions' and breaks it down into nitrogen and hydrogen, which means further addition to non-condensable gases.

When to Purge?

As shown in *Figure 1*, in the event that air or any other non-condensable gas enters the system, it is evidenced by an increase in condensing or discharge pressure.

The effect of combining two or more different gases within one pressure vessel is governed by the law of partial pressures (*Dalton's Law of Partial Pressures*). Simply stated, the total pressure of a gas mixture equals the sum of the partial pressures that make up the mixture.

$P_{actual} = P_{refrigerant} + P_{noncond}$

If the pressure at which refrigerant is condensing is 150 psig ($P_{refrigerant}$), and there is a quantity of air in the condenser that would create 20 psig ($P_{noncond}$) with no refrigerant present, the resultant pressure would be 170 psig (P_{actual}). In other words, if the refrigerant was removed and the air left behind, the remaining pressure would be 20 psig; or if the air was removed (as with purging), the resultant pressure would be 150 psig.

A test of the need for purging is to compare the actual pressure to the saturation pressure at the temperature of liquid at a location where liquid and vapor are in equilibrium, such as in the receiver of *Figure 1*. If the actual pressure P is significantly higher than the saturation pressure corresponding to t, purging is warranted.

If $P > P_t$

Where,

P is actual pressure in receiver

Pt is saturation pressure corresponding to temperature t

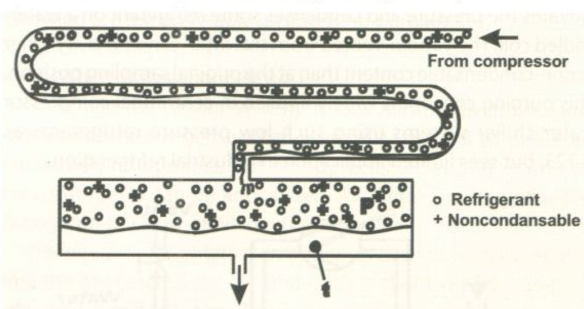

Figure 1: Liquid and vapour in equilibrium in the receiver

Methods of Ammonia Purging

Air, or any non-condensable gas, always flows to the condenser (and sometimes the receiver as well), regardless of how or where it entered. Once a non-condensable gas enters the condenser and receiver, it cannot flow out with the liquid to other parts of the system, since it cannot condense. It can only be removed by purging to the atmosphere. Purging from any point on the low pressure or intermediate pressure section of a system cannot remove non condensable gases.

The three principal concepts available for purging are:

1. Direct venting of the air-refrigerant mixture.
2. Compression of the mixture, condensing as much as possible of the refrigerant, and venting the vapor mixture that is now rich in non-condensables.
3. Condensation of refrigerant using a small evaporator, followed by venting of the air-refrigerant mixture that is now rich in non-condensables.

Figure 2 shows the first method, a primitive, manual technique. Vapour is released from a high-pressure vessel, such as the receiver; this vapor is mostly refrigerant but also contains a small amount of the non-condensables that are the target. In the case of ammonia, the discharge bubbles through a container of water to absorb the ammonia. As venting proceeds, more refrigerant liquid vapourises, so the concentration of non-condensables decreases, but never drops to zero. This method wastes considerable refrigerant to expel a small amount of non-condensables.

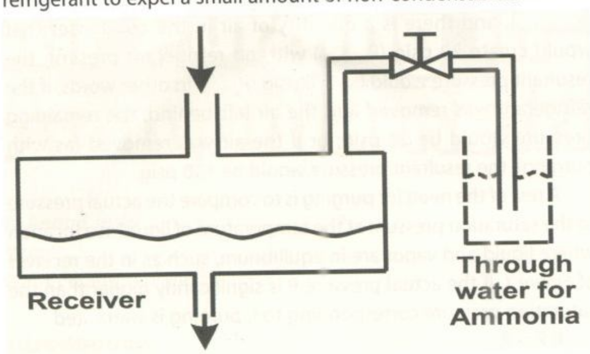

Figure 2: Direct venting of the air-refrigerant mixture

The second method of purging, shown in *Figure 3*, consists of drawing a sample from the vessel with a small compressor that elevates the pressure and condenses some refrigerant on a water-cooled coil. The vapour vented from this after-condenser is higher in non-condensable content than at the original sampling position. This purging concept is widely applied in centrifugal compressor water chiller systems using such low pressure refrigerants as R-123, but sees limited application in industrial refrigeration.

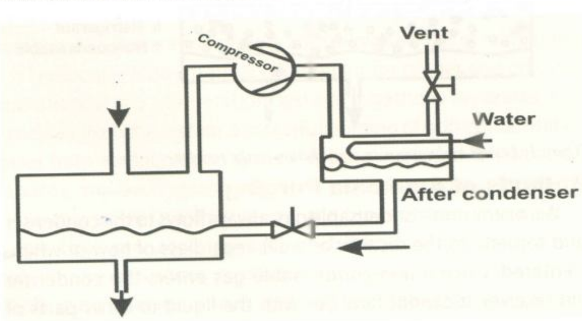

Figure 3: Venting from after-condenser

The third concept in purging, shown in *Figure 4*, which is widely used in industrial refrigeration, avoids the need for a separate compressor, and instead uses low temperature developed in a small evaporator. The air-refrigerant mixture from the condenser or receiver bubbles through cold liquid and condenses most of the refrigerant. This concept is embodied in automatic purgers that move from one purge point to another, allowing enough time at each point for a satisfactory purge. Commercial models of refrigerated purgers employ refinements in handling the vented stream leaving the after- condenser. The proper procedure is to purge one point at a time, because if one solenoid control valve serves two or more purge points, the pressure at these positions is equalized during purging.

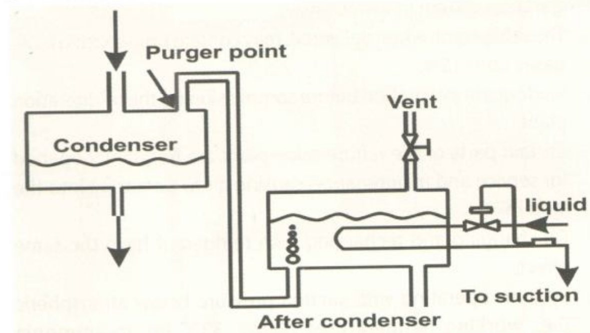

Figure 4: Purging by bubbling air-refrigerant mixture through cold liquid

Figure 5 shows the actual construction of a purger. It has a built-in heat exchanger connected to the liquid line from the receiver or the pump discharge line on the low-pressure side of the refrigeration

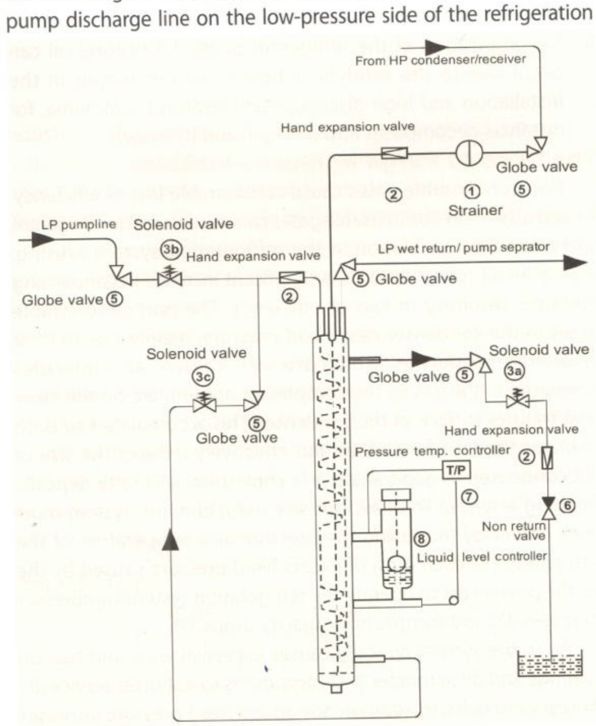

Figure 5: Construction of a purger

plant. The outlet must be connected to the low-pressure suction side of the plant. From the condenser and/or receiver, a mixture of refrigerant vapour and non-condensable gases are bleeded to the purger. The coil cools down the gas mixture, and the refrigerant part of the vapour condenses and gradually fills up the lower part of the purger. The non-condensable gases are retained and concentrated in the upper part of the purger and gradually the condensation of refrigerant stops. Consequently the temperature in the gas purger drops below the condensing temperature. The automatic control adapts deviations between the evaporation temperature of the liquid and the corresponding suction pressure to a switch that activates the solenoid valve in the outlet, by which the non-condensable gases escape. When the liquid refrigerant exceeds the level controlled by the level switch, a solenoid valve opens and leads the refrigerant into the liquid line to the cooling coil.

Do I Need Automatic Purging?

The need for purging exists in all ammonia refrigeration systems. A question often asked is: "Do I need an automatic purger?" This question has to be answered on a case to case basis. Generally speaking, systems with reciprocating compressors, or any systems operating under sub-atmospheric conditions, directly benefit from an automatic purger.

Figure 6: A fully automatic air purger

Figure 7: Site installation of automatic air purger at a sea food plant

The following example gives us a good insight to the increase in electricity bill due to the presence of air in a refrigeration plant operating below atmospheric pressure.

Design refrigeration capacity: 500kW for evaporating pressure -40°C, condensing pressure +38°C, 13.7 kg/cm^2

Power required by compressor: 281kW*

If the actual pressure is 0.5 kg/cm^2 higher, i.e. 14.2 kg/cm^2, power required would be 285kW.

The additional 4 kW per hour for 6000 hours of operation is 24,000kWhr.

If electricity costs Rs. 8/ kWhr, total increase in electricity bill is Rs. 1,92,000.

**The power data is based on Kirloskar KC-72 compressor at 700 rpm, giving 100kW refrigeration capacity; power required is 58kW for -40°C evaporating and +38°C condensing.*

Before the development of reliable automatic purgers in India, we were dependent on high priced imported purgers. Availability of spares parts and after sales service were also critical issues. Hence most of the small or medium sized plants used manual purgers. In a manual purging system, individual purger points are provided with manual globe valves. A separate purge piping is run from each valve to the purger unit location and connected to purger unit using a common header. The purger unit consists of a modified bucket steam trap with internal heat exchanger. The operator has to operate individual valves on each purge point. It requires a lot of operator work and wastes considerable refrigerant to expel a small amount of non-condensables. It also costs more to operate (compressor energy) than automatic purgers, because the only source of make-up liquid to the flooded evaporators must come from a high-pressure source.

The advantages and disadvantages of automatic air purger are listed in *Table 1*.

Table 1: Advantages and disadvantages of automatic air purger

Advantages	Disadvantages
Safety: Automatic purgers eliminate the need for refrigeration staff to manually 'open the system' frequently. ***Effectiveness:*** A properly installed and operated multipoint purger can continually function to scavenge and remove non-condensable gases from the system. ***Labour:*** Eliminates the labour associated with regularly removing non-condensable gases through manual operation.	***Capital cost:*** The cost is high because of purger unit, piping, solenoid valves and other controls. ***Maintenance cost:*** in addition to the purger unit, solenoid valves and transducers are required for purge control.

Where to Purge the Air From?

A refrigerated purger does not have magic fingers that can reach into a refrigeration system and find air. It is a device that separates air from refrigerant gas in a purge stream. Therefore, purge point connections must be at places where air collects. Following are the preferable locations for purging:

1. On the high-pressure side of the system.
2. Where only vapour exists.
3. Where the vapour velocity is low. Air at a given pressure and temperature is denser than ammonia, and not as dense as halocarbon refrigerants, but no appreciable settling of one of the constituents can be anticipated. Air diffuses quite uniformly throughout the slow-moving refrigerant.

Refrigerant gas enters the condenser at high velocity. By the time the gas reaches the far (and cool) end of the condenser, its velocity is practically zero. This is where the air accumulates and where the purge point connection should be made. Similarly, the purge point connection at the receiver should be made at a point furthest from the liquid inlet.

Purge point connection locations shown in *Figure 8.1* through *8.5* are based on thousands of successful purger installations. In these drawings, the long red arrows show high velocity gas. Arrow length decreases as gas velocity decreases approaching the low velocity zone. Air accumulation is shown by the black dots. Be prepared to purge from both the condenser and the receiver. Air would migrate from the condenser to receiver and back, depending on the load and plant conditions.

Air would remain in the condenser when the receiver liquid temperature is higher than condenser liquid temperature. This can happen when:

1. The receiver is in a warm place.
2. Cooling water temperature is falling.
3. Refrigerating load is decreasing.

Conversely, air would migrate to the receiver when the condenser liquid temperature is higher than the receiver temperature. This can happen when:

1. The receiver is in a cold place.
2. The cooling water temperature is rising.
3. The refrigeration load is increasing.

Purge Points

Evaporative Condenser

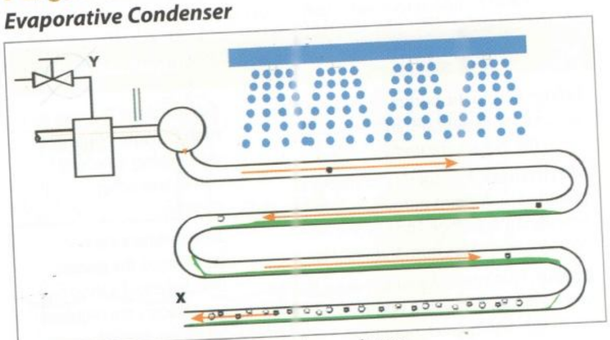

Figure 8.1: Purge point in an evaporative condenser

In *Figure 8.1* high velocity of entering refrigerant gas prevents any significant air accumulation upstream from point X. High velocity past point X is impossible because receiver pressure is substantially the same as pressure at point X. Purge from point X. Do not try to purge from point Y at the top of the oil separator because no air can accumulate here when the compressor is running.

Horizontal Shell and Tube Condenser

Side Inlet Type

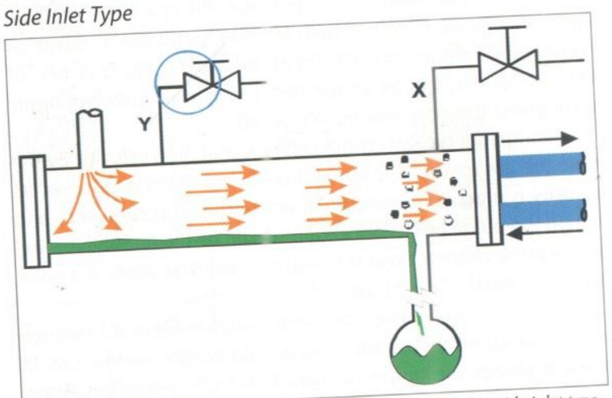

Figure 8.2: Purge point in horizontal shell and tube condenser – side inlet type

Centre Inlet Type

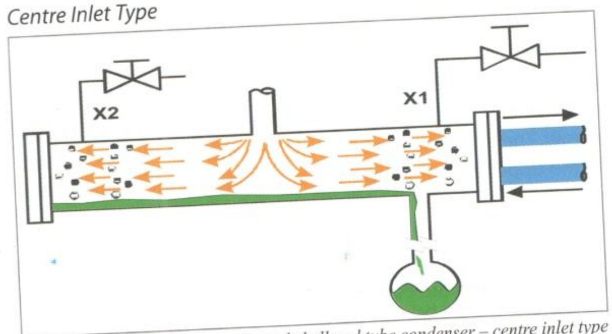

Figure 8.3: Purge point in horizontal shell and tube condenser – centre inlet type

In *Figure 8.2,* incoming gas carries air molecules to the far end of the condenser near the cooling water inlet as shown. *Purge from point X.* If purge connection is at Y, no air will reach the connection counter-current to the gas flow until the condenser is more than half full of air.

In *Figure 8.3,* incoming refrigerant blows air to each end of the condenser. Air at the left hand end cannot buck the flow of incoming gas to escape through the right hand connection at X1. Provide a purge connection at each end but never purge from both at the same time.

Vertical Shell and Tube Condenser

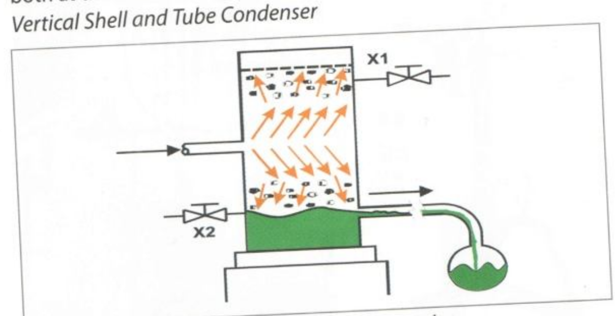

Figure 8.4: Purge point in a vertical shell and tube condenser

In *Figure 8.4,* low gas velocity will exist at both top and bottom of the condenser. Purge connections are desirable at both X1 and X2.

Receiver

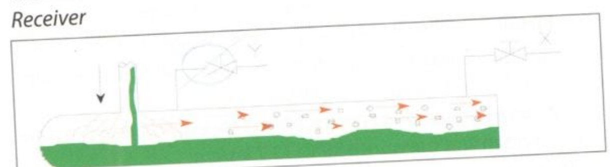

Figure 8.5: Purge connection for a receiver

In *Figure 8.5,* purge from Point X farthest away from liquid inlet. 'Cloud' of pure gas at inlet will keep air away from point Y.

Conclusion

It is important to understand why, where and how to purge the system. Once we understand the fundamentals thoroughly, we can adopt automatic purging very easily. This article will, hopefully, help refrigeration engineers and technicians better understand how air enters the system, why it is essential to remove it, and how it can be accomplished efficiently. ❖