Purging, Piping, and Safety

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PURGING, PIPING, AND SAFETY

Lesson One

Purging Air and Noncondensables

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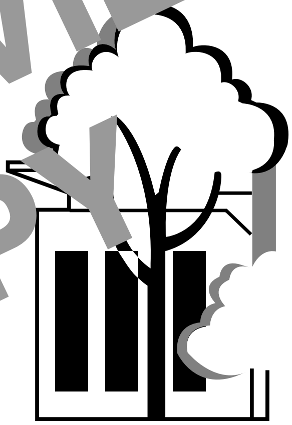

TPC Training Systems

46401

Lesson 1

Purging Air and Noncondensables

TOPICS

Materials to Be Purged
Effects of Noncondensables
Power Penalty
Determining If Noncondensables Are Present
Removing Noncondensables (Purging)
Purge Point Locations
Automatic Purging
Economics of Purging

OBJECTIVES

After studying this Lesson, you should be able to…

- List common noncondensable vapors and discuss their effects in a refrigeration system.
- Discuss the power penalty resulting from noncondensable gases in terms of compression and loss of refrigeration capacity.
- Explain how to determine the presence of noncondensables.
- Explain how to minimize the entrance of noncondensables and describe common entry points.
- Compare the features and operation of manual and automatic purging equipment and name the best connection points for the purge unit.
- Discuss the economic benefits of the purge unit in terms of typical payback times.

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KEY TECHNICAL TERMS

Purging 1.01 the process of removing noncondensable gases from a refrigeration system

Dalton's law 1.07 the physical principle that states that when two or more gases are mixed in the same volume, the total pressure exerted by the gases is equal to the sum of the partial pressures of each gas

Foul gas line 1.34 the line carrying the vapor to be purged

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Purging is a process that should be used on all industrial ammonia refrigeration systems, from the smallest to the largest, regardless of their operating conditions. Many benefits result from routine purging, and many harmful effects result from the failure to purge. One of the main harmful effects is economic.

This Lesson describes the effects of allowing air and other noncondensables to remain in the system. You may be surprised to see how expensive these unwanted contaminants can be, and also how fast the payback is with proper purge equipment. This Lesson explains how to determine if noncondensables are present. You will also read about ways to minimize the entry of noncondensables as well as various methods and connection points for removing them from the system.

Materials to Be Purged

1.01 *Purging* is the process that removes noncondensable gases from the refrigeration system. These gases do not contribute to the refrigeration capacity. Instead they reduce the capacity, increase the system power requirement, and lead to system degradation.

1.02 The noncondensable gases involved in ammonia refrigeration systems are primarily air, nitrogen, and hydrogen. Because the gases do not condense at the temperatures and pressures existing in the ammonia condenser, they remain as a gas in the condenser and receiver areas. They are also trapped in these areas because they cannot travel beyond the liquid seal in the receiver. Therefore, the noncondensable gases eventually accumulate to the point where they become a problem.

1.03 Air as a noncondensable in the system is relatively easy to account for. It enters whenever the system is opened for service or repair, when filters are changed, or when screens are cleaned. Air enters any time the sealed ammonia system is violated, especially in systems operating under vacuum conditions.

1.04 The air is about 80 percent nitrogen. However, additional nitrogen and hydrogen may also be found as noncondensables. These come directly from a breakdown of the ammonia refrigerant, which is a compound containing nitrogen and hydrogen (NH_3). The breakdown occurs mainly in systems with reciprocating compressors operating at discharge temperatures approaching 300°F. At these temperatures, a small portion of the ammonia disassociates (chemically breaks down) into the primary nitrogen and hydrogen.

1.05 This problem is almost nonexistent with screw compressor units, because the discharge temperature is controlled to less than 200°F at all times. Recall from previous Units that this cooling is provided by the large quantities of oil that are circulated through the compressor. The circulating oil effectively removes the heat of compression.

1.06 Other minor noncondensable gases include the trace gases that are part of the air that enters the compressor. In addition, some hydrocarbon gas products are generated by the breakdown of the oil. These products are most likely to be found when moisture is present in the system along with the high temperatures possible with reciprocating compressors.

Effects of Noncondensables

1.07 Over time, noncondensable gases collect in the condenser and receiver vapor spaces. A physical law applies when more than one gas fills a fixed volume. This is known as *Dalton's law*, which states that when two or more gases are mixed in the same volume, the total pressure exerted by the gases is equal to the sum of the partial pressures of each gas.

1.08 What Dalton's law means is that the total pressure of the mixture is equal to the pressure that one gas would have in that volume plus the pressure that the second gas would have if each gas were the only gas in that volume. Figure 1-1 on the following page illustrates Dalton's law, showing schematically how the total pressure is equal to the partial pressures of the refrigerant and the noncondensable gases. You can see that any additional noncondensables, whether air or hydrogen or nitrogen, will raise the condensing pressure above that of the ammonia alone without the noncondensables.

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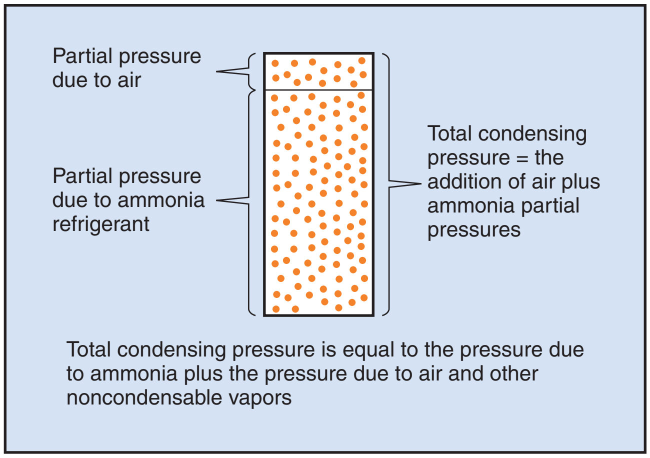
Fig. 1-1. Dalton's law illustrated



Total condensing pressure is equal to the pressure due to ammonia plus the pressure due to air and other noncondensable vapors

1.09 This increase in pressure has several harmful effects. A main problem arises because the saturated condensing temperature is equivalent to the ammonia pressure without the additional noncondensable pressure. However, the actual pressure is not at the saturation value—it is higher. The compressor has to work harder to reach the higher-than-normal condensing pressure. This requires more horsepower and results in a lower refrigeration capacity.

1.10 The higher condensing pressure caused by the noncondensables also results in higher discharge temperatures, especially in systems with reciprocating compressors. Because the screw compressor discharge temperature is controlled by the oil flow and cooling methods, its discharge temperature remains relatively stable.

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1.11 Operation against a higher condensing pressure and the resulting higher discharge temperatures leads to increased bearing loads, reduced lubrication quality, and mechanical stresses on the operating components. These together generally reduce compressor life or certainly the time periods between major maintenance requirements.

1.12 A second main disadvantage of air and noncondensables in the condenser is that the air acts as an insulating shield between the condenser tube surface and the ammonia vapor to be condensed. This occurs on the inside of the tubes of an evaporative condenser and also on the external surfaces of a shell-and-tube condenser in which the refrigerant is on the outside of the tubes. Figure 1-2 shows how the air acts as an insulator, inhibiting heat transfer and reducing the condenser capacity.

Power Penalty

1.13 It is estimated that for each 4 psi of additional condensing pressure caused by air and noncondensables, the compressor power requirement increases by two percent and the compressor capacity decreases by about one percent. However, when the air continues to accumulate, the pressure may rise to 20 psi or more above the normal condensing pressure. At 20 psi above normal operation, the increased power requirement is about 10 percent or more.

1.14 Table 1-1 shows the additional operating costs for electric power associated with a 1000-ton system operating 6500 hours per year. At a moderate

Fig. 1-2. Air insulation of condenser tubes

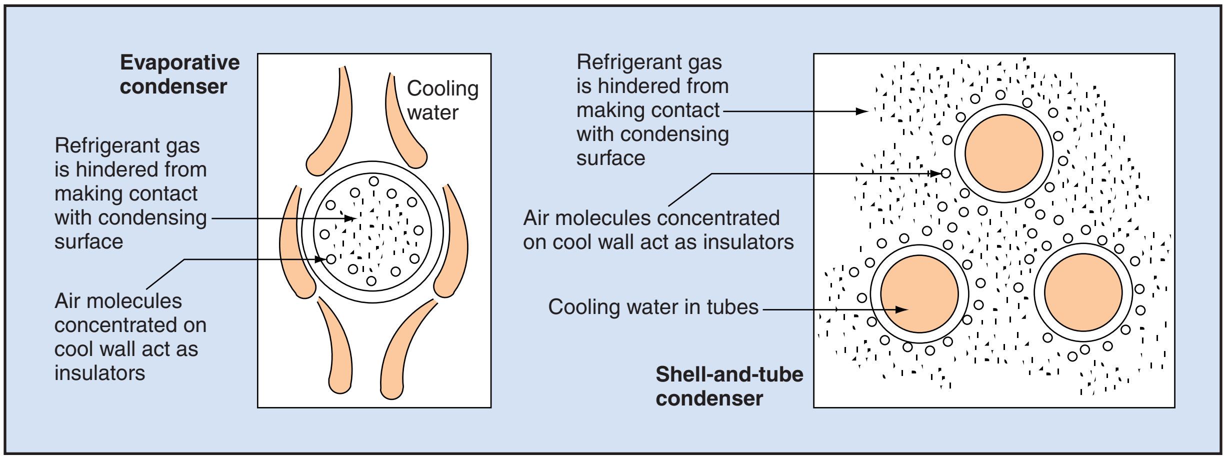

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Table 1-1. Operating costs

Excess pressure due to air (psig)	$0.05 kWh	$0.07 kWh	$0.10 kWh	$0.12 kWh
5	$8,200	$11,500	$16,500	$19,750
10	$16,400	$23,000	$33,000	$39,500
15	$24,600	$34,500	$49,500	$59,250
20	$32,800	$46,000	$66,000	$79,000

electrical rate of $0.07 kWh, excess air of only 5 psi costs an additional $11,500 per year. If the noncondensables rise to an excess of 20 psig, at the same electrical rate of $0.07 kWh, the additional cost to operate the system will be $46,000 per year. These additional costs are significant and need not be incurred.

Determining If Noncondensables Are Present

1.15 The presence of noncondensables increases the condenser pressure above the normal saturation pressure. The most convenient way to detect noncondensables is to measure the temperature of the liquid refrigerant leaving the condenser or in the receiver. It is also necessary to measure the pressure in the condenser or receiver and compare the pressure against the saturation pressure at the measured temperature. Table 1-2 shows the saturation temperatures and pressures for ammonia.

1.16 To determine if noncondensables are present, compare the measured pressure against the saturation pressure. Then analyze the situation as follows:

- If the pressures are equal, there are no noncondensables in the vapor. The temperature and pressure are at the saturated condition.
- If the measured pressure is above the saturated pressure, the pressure difference indicates that noncondensables are present in the ammonia vapor.
- The higher the difference in measured pressure above the saturated pressure, the greater is the power requirement to compress the ammonia and the greater is the loss in capacity.

1.17 Notice that, when noncondensables are present in the ammonia vapor, the measured pressure is always higher than the saturation pressure for the particular temperature. However, it is important to remember that not all high condensing pressures are the result of noncondensables in the system. If the measured pressure agrees with the saturation table, then the high pressures are caused by a problem other than noncondensables. Some possible causes for a high condensing pressure include insufficient condenser capacity, fouled condensing surfaces, clogged

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Table 1-2. Ammonia saturation temperatures and pressures

Temp. (°F)	Sat. pressure (psig)	Temp. (°F)	Sat. pressure (psig)	Temp. (°F)	Sat. pressure (psig)
72	118.7	80	138.3	88	160.1
73	121.0	81	140.9	89	163.0
74	123.4	82	143.6	90	165.9
75	125.8	83	146.3	91	168.9
76	128.3	84	149.0	92	171.9
77	130.7	85	151.7	93	174.9
78	133.2	86	154.5	94	178.0
79	135.8	87	157.3	95	181.1

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spray nozzles, or liquid backing up into the condenser due to improper condenser drain design.

Removing Noncondensables (Purging)

1.18 Additional costs due to noncondensables can be avoided in two ways. The first means of control is to minimize the amount of air entering the system. The second is to use a purge process that removes air and noncondensables from the system effectively.

1.19 To minimize air entering the refrigeration system, take special care while performing the following maintenance procedures:

- adding additional refrigerant from the ammonia supplier's tank truck
- adding oil as required to the system
- draining oil from systems in a vacuum
- changing oil filters
- cleaning strainers
- servicing compressors and components
- operating the system in a vacuum.

By simply being careful to prevent contamination while charging with oil and refrigerant, you will greatly reduce the chance of introducing noncondensables into the system.

1.20 It is surprising how much air enters a refrigeration system during service maintenance. Air that enters the system can be evacuated after the service work is completed, but before introducing ammonia to that area. A second method is to bleed some ammonia through the portion of the system that was open to flush out the air. This method, although common, does not ensure that all of the air is expelled, and it also wastes ammonia in the process. In addition, it is not generally recommended because of safety considerations.

1.21 The best method by far is to use the method routinely practiced by the air-conditioning technician—that is, to connect a vacuum pump to any area that has been opened for service. The vacuum pump should be operated long enough to pull the pressure into a high vacuum range. This ensures that all air and moisture have been expelled. Note that the vacuum pump must be made of materials suitable for use with ammonia systems.

1.22 Years ago it was common to purge air and noncondensables from ammonia systems by opening a valve on the condenser or receiver. Technicians let the system vent to the atmosphere for a period of time while they watched the condensing pressure. When the pressure returned to its normal range, they closed the valve. This method was wasteful because it released much more ammonia than air. Ammonia was cheap then, and there was little or no concern for the environmental impact in comparison with the OSHA and EPA regulations of today.

1.23 Some systems still are purged of the noncondensables by venting the ammonia vapor from the condenser and receiver areas. However, the venting is into water. The water absorbs the ammonia vapor, preventing what would otherwise be considered an ammonia release. If enough water is used, all of the ammonia is completely absorbed in the water, and only the air or noncondensables bubble up through the water. When bubbles are no longer evident, you can assume that all of the air has been removed from the system. Great care must be taken during this procedure because of safety considerations.

The Programmed Exercises on the next page will tell you how well you understand the material you have just read. Before starting the exercises, remove the Reveal Key from the back of your book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

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1-1. Noncondensable gases ________ system power needs and ________ system capacity.	1-1. INCREASE; REDUCE Ref: 1.01
1-2. The main noncondensables in ammonia refrigeration systems are ________, ________, and ________.	1-2. AIR; NITROGEN; HYDROGEN Ref: 1.02
1-3. Hydrocarbon noncondensables caused by oil breakdown are most common when there is ________ in the system along with ________ temperatures.	1-3. MOISTURE; HIGH Ref: 1.06
1-4. Noncondensables increase condensing pressures because of the principle known as ________ law.	1-4. DALTON'S Ref: 1.07
1-5. Air and noncondensables act as a(n) ________ in the condenser, inhibiting heat transfer.	1-5. INSULATOR Ref: 1.12
1-6. For each 4 psi of additional condensing pressure, system power needs increase by about ________ percent and capacity decreases by about ________ percent.	1-6. 2; 1 Ref: 1.13
1-7. To determine if noncondensables are present, first measure the ________ of the liquid refrigerant at the condenser ________ or in the ________.	1-7. TEMPERATURE; OUTLET; RECEIVER Ref: 1.15
1-8. The best way to minimize the entrance of air into the system is to use a(n) ________ after a service procedure.	1-8. VACUUM PUMP Ref: 1.21

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Purge Point Locations

1.24 Because the noncondensables travel to the condenser and receiver vapor spaces, the places from which they may be purged are all found in these areas. However, some locations within these areas contain higher accumulations of the noncondensable gases. These locations are the obvious choices for points at which to connect purging vents.

1.25 The air is always located on the vapor side of the condenser and receiver. It may also be found on the vapor areas of high pressure oil separators, demisters, and heat recovery coils. The best location for the purge connection on an evaporative condenser in service is at the top of the liquid outlet line. This point has the highest concentration of air because it is a place of low velocity and is at the coolest portion of the condenser. Manufacturers of evaporative condensers normally provide purge connections at the top of the liquid outlet header for each circuit to make it easy for customers to connect their purge units.

1.26 When the condenser is shut down, the air generally rises and is found at the top of the condenser. Purging is most effective from connections at the vapor inlet to the condenser. Manufacturers also supply purge connections at the top of the inlet header.

1.27 In shell-and-tube condensers where the vapor refrigerant is on the shell side and the cooling water runs through the tubes, the purge connection should be located at the top of the shell away from the hot gas inlet. This location has the lowest velocity and the coolest sections.

1.28 Receivers must also be fitted with purge connections, following the same basic rules of lowest velocity and coolest areas. For receivers as well as condensers, the purge connection should be in the vapor portion of the vessel and not in the liquid portion.

1.29 Horizontal receivers with the inlet at one end have a single purge point on the opposite end of the receiver at the top. Horizontal receivers with the inlet at the center have two purge connections, one at either end of the receiver, again at the top. Figure 1-3 shows purge connection locations on evaporative condensers and receivers.

Automatic Purging

1.30 In order to minimize the noncondensables in the refrigeration system at all times, it is necessary to use an automatic purge unit. The automatic purger takes a small amount of vapor from the purge point. It runs the vapor through a low-temperature heat exchanger to condense the ammonia from the vapor. The remaining vapor that is not condensed is mainly the noncondensable gas that was drawn along with the ammonia vapor. The condensed ammonia is

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Fig. 1-3. Purge connections

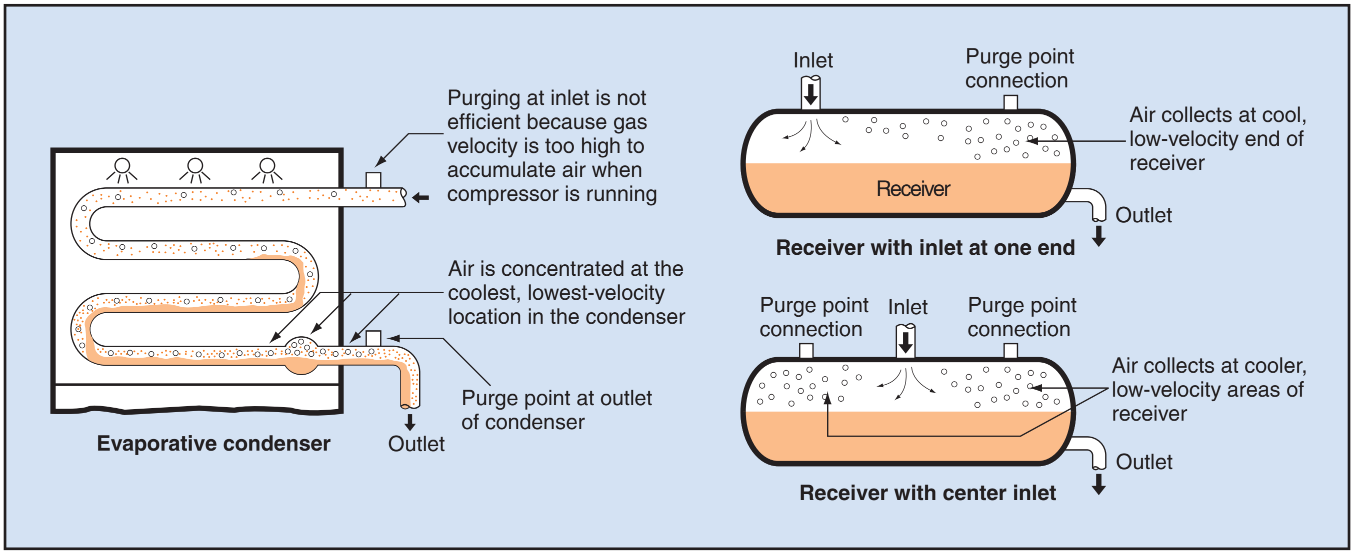

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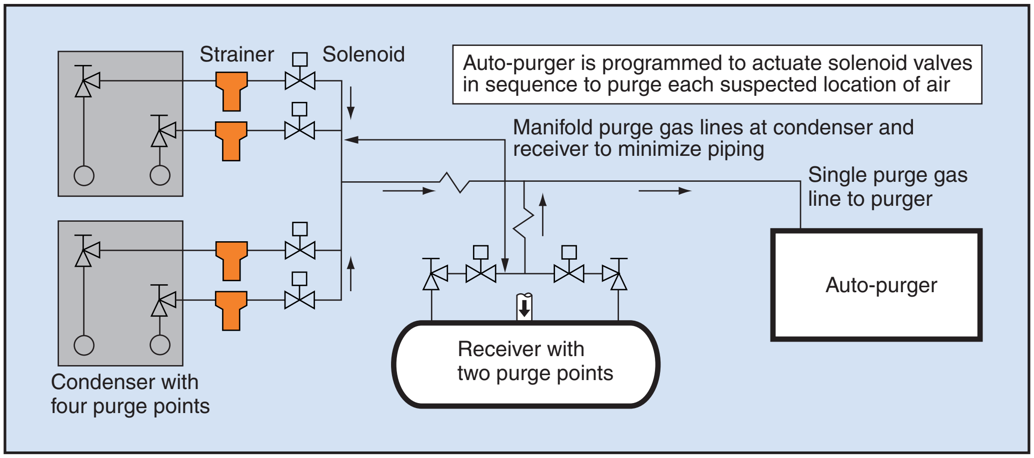
Fig. 1-4. Multipoint auto-purger schematic



returned to the refrigeration system, and the noncondensables are bubbled through water and vented to the atmosphere.

1.31 Most industrial systems are large and typically have several evaporative condensers and often more than one receiver. Thus, there are many points where the purge unit can be connected. Automatic purge units are available for either a single purge point or multiple purge points. Some units can handle up to 24 locations.

1.32 A single-point purge unit must not be connected to all of the possible connection points at once. In this case, connection to multiple points permits the vapor from only the highest pressure point to flow to the purge unit. The other connection points will not be purged. On the other hand, the multiple-point purger is connected to the numerous purge points on the condensers and receivers, using solenoid valves at each location. The purge unit opens one of the purge points to supply refrigerant vapor to be purged from that area.

1.33 Figure 1-4 shows a typical piping schematic between the auto-purger and the refrigeration system. Notice that the solenoid valves are located adjacent to the purge points and that shortly beyond these locations the purge line may be manifolded to a single $1/2$-in. pipe. This simplifies the piping between the multiple-point purger and the several locations from which the purge is taken.

1.34 A sketch of one manufacturer's purge unit is shown in Fig. 1-5 on the following page. The line carrying the vapor to be purged, called the *foul gas line*, directs the vapor through a strainer and into the air or noncondensable separator. Any liquid ammonia in the foul gas line is caught in a liquid drainer and fed into the evaporator chamber.

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1.35 A $1/2$-in. high-pressure ammonia liquid line feeds ammonia through a metering valve into the evaporator chamber. A $3/4$-in. suction line is connected to the point of lowest system suction pressure. The lower the pressure, the lower is the temperature in the evaporator chamber and the more air or noncondensables are trapped and removed from the system.

1.36 The foul gas is contained within a spiral tube wrapped around the horizontal air separator chamber, and the vapor condenses at the low temperature. The noncondensables remain in vapor form and are released through a float switch and bubbled through a water bubbler, which captures any ammonia vapors.

1.37 The purge unit is designed so that operation is automatic. A control system maintains the liquid level in the evaporator chamber. A timer in the purge unit determines from which purge point the foul gas is taken. The timer periodically changes the purge point by opening the suitable solenoid valve and keeping the remaining solenoids closed.

1.38 In normal operation, the purge unit functions continuously to prevent the buildup of noncondensables in the system. Remember that any noncondens-

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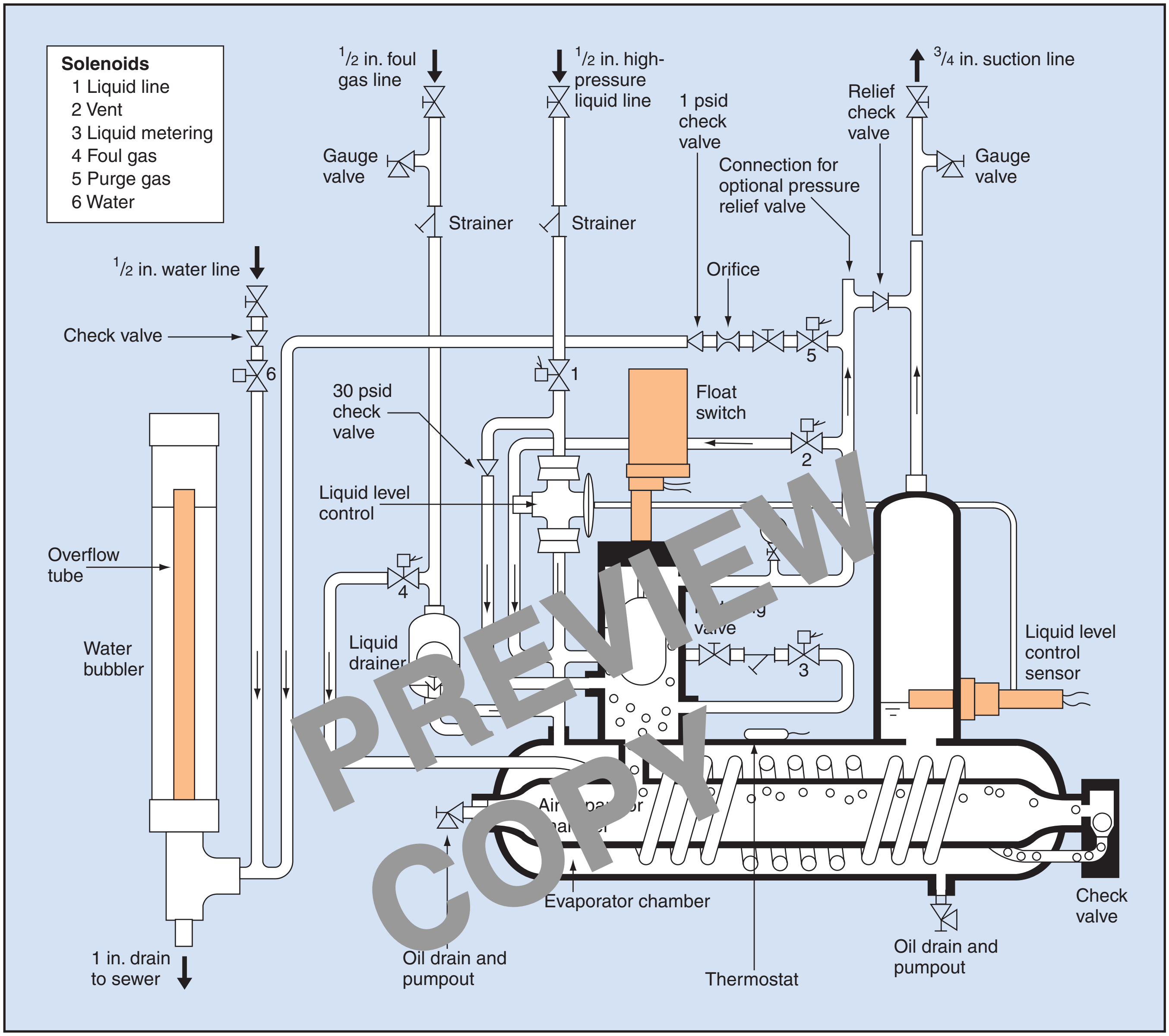
Fig. 1-5. Auto-purger



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ables will raise the condensing pressure above the normal saturation condition and will cost additional compression power.

1.39 Most industrial refrigeration purge units operate in a similar manner to that just described. Some units, however, change purge points not by a timer, but rather by the amount of air measured at the purge point. In this kind of control, the unit purges a particular location until the measured value of noncondensables is below a specified value. Then the unit closes the solenoid on that purge point and selects the next. It continues to purge the new point until the noncondensables are measured below the specified limit. It continues in this manner, going from point to point and even skipping those locations at which no substantial noncondensables are found.

1.40 Figure 1-6 shows the effectiveness of various methods and degrees of purging. Line A shows the worst case. This is for occasional manual purging with a varied time period between purgings. Line B shows the use of a single-point or undersized automatic purger, which results in incomplete removal of noncondensables. Therefore, the system always has some level of noncondensables remain-

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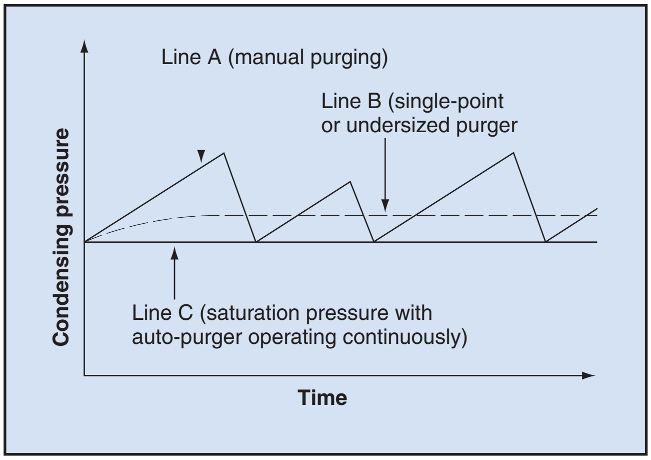
ing and operates at a pressure above the refrigerant saturation pressure.

1.41 The most efficient use of the automatic purger is with sufficient purge points and continuous purge unit operation. This is indicated by line C, which is also the saturation pressure of the refrigerant. The system will remain free of noncondensables and will operate at optimum efficiency as long as the purge unit is adequately sized, the system is free of vacuum leaks, and proper service techniques are applied.

Fig. 1-6. Purge method effectiveness



Economics of Purging

1.42 Earlier in this Lesson, you read about the high operating costs incurred by not using a purge system. Now consider the economics for a typical system. How long will it take to pay back the initial cost of the automatic purge unit? Assume that the cost and installation of a suitable eight-point automatic purger for the 1000-ton ammonia system is $10,000.

1.43 From the data in Table 1-1, for a system that normally operates 6500 hours a year with 15 psig excess pressure caused by noncondensables, the cost of electricity at $0.07 kWh is $34,500 per year. This indicates that in less than half a year, the purge unit will pay for itself. Moreover, the additional savings accrued for the first year will be $24,500 ($34,500 – $10,000 = $24,500). Figure 1-7 shows the payback period as well as the savings accrued for the first four years of operation. This graph shows these savings for both the 15-psig differential and also for a 10-psig differential caused by noncondensables.

1.44 As you can see, payback for the automatic purge unit is typically less than a year for almost any level of noncondensables or almost any electric power rate. Keep in mind that this is a simple payback. There are generally additional electrical costs to consider—for example, time-of-day rates, demand charges, and ratchet costs. All of these increase the basic electricity cost and reduce the payback time, making use of the auto-purger even more economical.

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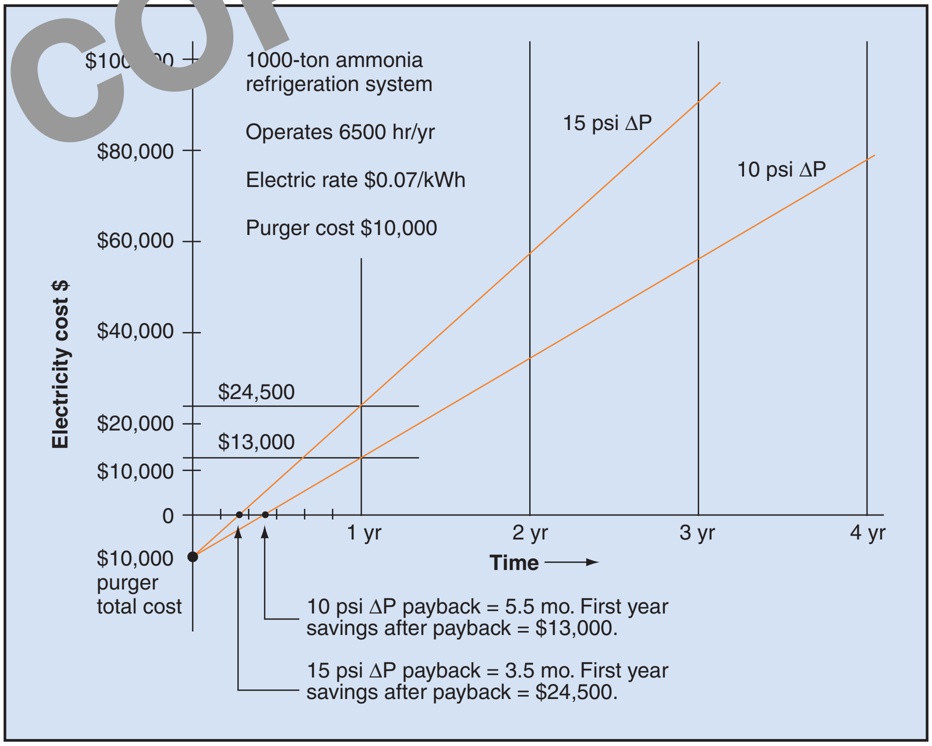
Fig. 1-7. Simple payback analysis for auto-purger



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1-9. Air is always located on the ________ side of the condenser and receiver.	1-9. VAPOR Ref: 1.25
1-10. The best purge points are at the ________ of the vessel in sections where the ________ is lowest and the vapor is ________.	1-10. TOP; VELOCITY; COOLEST Ref: 1.25
1-11. A horizontal receiver with a center inlet needs ________ purge connections, one at each ________ at the ________ of the receiver.	1-11. TWO; END; TOP Ref: 1.29
1-12. The auto-purger operates ________, passing ammonia through a(n) ________ where the ammonia condenses and leaves the noncondensables to be vented.	1-12. CONTINUOUSLY; HEAT EXCHANGER Ref: 1.30
1-13. Some multiple-point auto-purgers can handle up to ________ purge points.	1-13. 24 Ref: 1.31
1-14. The line that carries the vapor to be purged is called the ________ line.	1-14. FOUL GAS Ref: 1.34
1-15. Some purge units work by means of a(n) ________, but others work by measuring the amount of ________ at the purge point.	1-15. TIMER; AIR Ref: 1.39
1-16. The payback time for an auto-purger is usually ________ a year.	1-16. LESS THAN Ref: 1.44

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Answer the following questions by marking an "X" in the box next to the best answer.

1-1. Noncondensables caused by ammonia breakdown are a problem, especially in systems with ________ compressors operating at temperatures ________.

☐ a. reciprocating; approaching 300°F
☐ b. reciprocating; below freezing
☐ c. screw; approaching 300°F
☐ d. screw; below freezing

1-2. According to Dalton's law, the pressure in a closed vessel filled with three gases is equal to the

☐ a. average pressure of the gases
☐ b. pressure of the gas with the highest pressure
☐ c. product of the highest and lowest pressures
☐ d. sum of the partial pressures

1-3. At a condensing pressure 12 psi above normal, the increased power requirement is about

☐ a. 4%
☐ b. 6%
☐ c. 8%
☐ d. 10%

1-4. If the measured condensing pressure is higher than normal but equals the saturation pressure for the measured temperature, then noncondensables

☐ a. are not the cause of the problem
☐ b. are raising the system pressure
☐ c. are raising the system temperature
☐ d. may or may not be present

1-5. When purging by venting through water, you can assume that all air is removed when

☐ a. bubbles no longer appear
☐ b. condensing pressure returns to normal
☐ c. refrigerant temperature returns to normal
☐ d. the vacuum pump draws a high vacuum

1-6. The best purge point for an operating evaporative condenser is at the

☐ a. center of the condenser
☐ b. drain connection
☐ c. top of the liquid outlet line
☐ d. top of the vapor inlet line

1-7. The ammonia drawn from the system by an auto-purger is condensed and

☐ a. bubbled through water
☐ b. discharged to a purge receiver
☐ c. returned to the refrigeration system
☐ d. vented to atmosphere

1-8. The timer in a typical auto-purger changes the purge point by

☐ a. opening and closing solenoid valves
☐ b. repositioning three-way valves
☐ c. responding to the changing liquid level
☐ d. sensing the amount of air in the section

1-9. An undersized multiple-point auto-purger

☐ a. always leaves some noncondensables in the system
☐ b. is much more effective than a single-point auto-purger
☐ c. provides no benefits over manual purging
☐ d. removes all noncondensables in systems operating above freezing

1-10. The savings resulting from installation of an auto-purger increase as the

☐ a. electrical rates decrease
☐ b. pressure due to noncondensables increases
☐ c. saturation pressure increases
☐ d. system operating temperatures decrease

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SUMMARY

Purging is the process that removes air and other noncondensables from refrigeration systems. Air, nitrogen, and hydrogen are common in ammonia systems, especially those with high discharge temperatures. Noncondensable gases accumulate in the condenser and receiver. They raise the condensing pressure, because each noncondensable gas adds its own pressure to that of ammonia in the same space. This principle is known as Dalton's law. The higher pressure makes the compressor work harder, raising electrical costs and reducing efficiency. The power penalty is about 2% increased power for each increase of 4 psi, with decreased capacity of about 1%. The power penalty causes surprisingly high avoidable extra annual costs.

To determine if noncondensables are present in the system, measure the temperature of the liquid refrigerant leaving the condenser or in the receiver and compare the condenser or receiver pressure to the saturation pressure at the measured temperature. Noncondensables are not present if the pressures are equal, but are present if the measured pressure is higher than the saturated pressure. The greater the difference, the greater the extra power required by the compressor.

The main ways to minimize the power penalty are to reduce the entrance of noncondensables and to purge them from the system. Pulling a vacuum after repairs or service is very helpful, as is installation of a correctly sized purge unit. Sometimes the system is purged by venting ammonia vapor through water, which dissolves the ammonia and releases the noncondensables. Purge points where noncondensables are most likely to collect are those locations with the lowest velocity and the coldest temperatures.

Automatic purgers (auto-purgers) are available as single-point or multiple-point units. Single-point units must be connected to only one purge point at a time, proceeding throughout the system. Multiple-point units can be connected to as many as 24 purge points. Noncondensables are trapped and removed from the system, and any liquid ammonia caught in the foul gas line is fed to the evaporator. Some purge units work by means of a timer, and others work by measuring the amount of air at each purge point. Purge points are opened by solenoid valves regardless of the purge method. Installation of an auto-purger can remove the noncondensables very efficiently and economically, with unit payback generally in less than a year and considerable additional savings as well.

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Answers to Self-Check Quiz

1-1. a. Reciprocating; approaching 300°F.
Ref: 1.04

1-2. d. Sum of the partial pressures.
Ref: 1.07, 1.08

1-3. b. 6%. Ref: 1.13

1-4. a. Are not the cause of the problem.
Ref: 1.17

1-5. a. Bubbles no longer appear.
Ref: 1.23

1-6. c. Top of the liquid outlet line.
Ref: 1.25

1-7. c. Returned to the refrigeration system.
Ref: 1.30

1-8. a. Opening and closing solenoid valves.
Ref: 1.37

1-9. a. Always leaves some noncondensables in the system.
Ref: 1.40, Fig. 1-6

1-10. b. Pressure due to noncondensables increases. Ref: 1.43, Fig. 1-7

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Figure 1-5. Hansen Technologies Corporation

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